PROCEEDINGS OF THE SEMINAR ON CIRCULAR ECONOMY IN BIOPRODUCT INDUSTRY

(HELD AT KOTKA, FINLAND, 13th MARCH 2018)

Merja Mäkelä (ed.)

XAMK
Kaakkois-Suomen ammattikorkeakoulu

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FOREWORD

Circular economy and sustainable development are permanently asked for, both in industrial and consumer activities. The challenges with the sufficiency of energy and food supply, harmful and toxic emissions and global warming touch us all, and these challenges still exist in the future. It was a pleasure to welcome our Russian guest again to our energy seminar, this time with the title "Circular Economy in Bioproduct Industry". This event took place at the South-Eastern Finland University of Applied Sciences (Xamk), in Kotka Finland, on March 13th, 2018. Six interesting topics concerning circular economy in industrial activities were presented. The scientific articles of this publication are based on the presentations, held at the seminar and written by the related expert teams.

Development of renewable energy production in Russia and globally deals with the conditions, main driving forces and development trends of global and Russian renewable energy. It discusses the regional, economic and technological aspects in the development of renewable energy sources, functional features and government support for non-traditional energy sources in Russia, and digitalization of energy systems with renewable energy sources.

Condition assessment and diagnostics in asset management of critical infrastructure facilities discusses the condition assessment of power production machinery and devices, which is a crucial part of asset management and one of the main challenges concerning critical infrastructure facilities (CIF). The applied condition assessment approach is a way to improve the quality of maintenance and repair procedures of power production machinery and devices based on their real-time diagnostics data and related technical condition. Diagnostic procedures for CIF are divided into integrated parts according to the type of installed machinery and devices.

Digitalization in cost calculations for the construction of power and industrial facilities deals with digital cost calculation methods and applications for power industries. Several challenges with calculation methods and software applications are highlighted. The active usage of digitalization by modern, efficient Russian enterprises such as JSC Gazprom, JSC Concern Rosenergoatom, JSC Transneft, JSC Russian grids improves the accuracy of the cost calculations and creates a possibility to choose the most qualified winner for the procurement of power and industrial construction.

Circular economy in the Finnish bioproduct industry studies the product concepts of Finnish pulp mills and bioproduct mills. Besides the production of pulp and energy in pulp mills, new innovative ways to use sub-products such as bio-ash, softwood bark and carbon dioxide are discussed in the article. South-Eastern Finland University of Applied

Sciences is working with the development of bio-ash, softwood bark and carbon dioxide utilization to create new process technologies and possibilities for value added products from bioproduct industries.

Renewable energy from chemical recovery of biorefineries discusses the role of pulp mills in producing renewable energy in Finland, and current statistics are also presented. Besides chemical pulp, biorefineries also produce plenty of energy in their manufacturing processes. This energy as heat and electricity comes from the combustion of black liquor and process gases in a recovery boiler. The black liquor results in the separation of fibres and cooking chemicals using washing, and chemicals need to be recovered, also enabling interesting sub-products.

Technical visit to Biosampo research facilities at Anjala focuses on the development aspects of the Finnish bioeconomy by improving the education and research strategy. One goal of the Finnish government program for 2025 is to make Finland a top country in modern learning using digitalization. South-Eastern Finland University of Applied Sciences has research centres and laboratories, and it operates and constantly develops novel and relevant research infrastructure and laboratories. BioSampo, the bio and circular economy research centre, is one of Xamk's research units currently expanding.

We wish readers an interesting and pleasant time with the articles dealing with the progress of methods and technologies promoting circular economy and sustainable development.

Editor
Kotka, Finland August 2nd, 2019
Merja Mäkelä
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DEVELOPMENT OF RENEWABLE ENERGY PRODUCTION IN RUSSIA AND GLOBALLY

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ABSTRACT

This article is focused on the current state, main drivers and development trends in global and Russian renewable energy sector. Regional, economic and technological aspects of the development of renewable energy sources, as well as the functional features of and government support for non-traditional energy sources in Russia and the digitalization of systems using renewable energy sources are considered.

1 INTRODUCTION

In 2017, the use of renewable energy in the world once more surpassed the capacity of new conventional power plants. The total installed capacity of renewable energy production exceeded that of the last year by 178 GW. Thus, in 2017, the share of renewable energy amounted to 70% of all new power generating capacity [1].

According to the International Organization for the Support of Renewable Energy, in 2017, the share of renewable energy resources in electricity production in the world increased in comparison with 2016 and amounted to 26.5% of all electricity production, excluding large hydropower plants, the other renewable energy sources accounted for 10.1% of the total production. The shares of various renewable sources in the total output were as follows: wind power 5.6%, biomass 2.2%, solar energy 1.9%, and other renewable sources (geothermal, ocean energy, etc.) 0.4%. In China, renewables produced more than 1 trillion kWh of electricity.

The capacity of all power plants using renewable energy sources is constantly growing. At the beginning of 2018 it was 2,195 GWh including large hydro power plants and 1,081 GWh without them. In 2017, wind farms reached a capacity of 539 GW and for the first time surpassed the capacity of existing nuclear power plants (363,4 GWh). The leaders in installed capacity of non-conventional sources are China with 334 GW, USA with 161 GW and Germany with 104 GW.

Table 1

The share of renewable energy sources in electricity production (including hydropower), 2017

State	% of production of electrical power
Norway	97.9
New Zealand	80.0
Brazil	73.5
Venezuela	68.9
Colombia	67.9
Sweden	64.3
Canada	62.7
Portugal	49.3
Romania	42.6
Chile	41.6

Power demand is growing, and the power plants using renewable sources are becoming larger. The world's largest solar power plant with a capacity of 648 MW was built in Camuti, India. The power plant consists of 2.5 million solar modules and its construction costs amounted to 679 million dollars.

The largest wind farm, Alta Wind Energy Center (Tehachapi pass, California, USA) has a capacity of 1320 MW. On this farm, 390 Vestas V-90 turbines with a 3 MW capacity each and 100 turbines manufactured by General Electric with a unit capacity of 1.5 MW were installed.

2. STATUS OF THE RENEWABLE ENERGY SECTOR IN RUSSIA

In 2017, the total installed capacity of power generating facilities and power plants in the Russian Federation using renewable energy (excluding hydropower plants with an installed capacity of over 25 MW) stood at approximately 2.4 GW [5]. The power outputs of various sources were as follows: solar plants 950 MW, wind farms 113 MW, geothermal power plants 87 MW, biogas 3 MW, and power plants using biomass 1.4 GW.

Nowadays, the alternative energy sector as a whole in Russia generates approximately 2.3 billion kWh per year, which is less than 0.4% of Russia's total output. At the same time, the potential of renewable energy exceeds 20 times the annual primary energy consumption in the country.

The largest power plants using renewable energy sources in Russia are:

- SES Perovo, power capacity 105.56 MW;
- SES “Okhotnykove”, power capacity 82.65 MW;
- SES “mykolaivka”, power capacity 69.7 MW;
- Ostaninskaya wind farm, power capacity 25 MW;
- Saki wind power, power capacity 20.83 MW;
- Boiler CTC G. Narimanov, power capacity 30 MW.

There is a specific application of RES in Russia caused by territorial characteristics and the current state of the economy and society, which creates preconditions for using renewable energy sources.

- Ensuring power supply to remote areas not connected to the networks of power.
- Prevention or reduction of limitations on the consumers connected to the networks of power.
- Development of private industry, increase in the export share of machinery and equipment, creation of additional jobs, implementation of existing high scientific and technical potential in Russia.
- Reduction of environmental stress in a number of cities, including recreational areas, by reducing harmful emissions from traditional power plants.
- Ensuring energy security of some regions of Russia, including Kamchatka, Chukotka and Primorye.
- Increased tariffs for the generation and transport of electrical energy, high costs, long timelines and the complexity of the procedure of technological connection to electric networks.
- High regulatory risks in the energy industry
- Reduced cost of installed capacity of wind turbines.

With regards to a full development in the sphere of alternative energy, regulatory framework was long insufficiently developed in Russia. By 2017, the basic documents regulating and stimulating the development of renewable energy in Russia were finally developed and adopted.

In accordance with 35-FZ on the electric power industry in the Russian Federation, the following mechanisms were established to support renewable energy:

Measures to support the development of renewable energy sources:

1. The mechanism of capacity sales for capacity supply contracts on the wholesale market (DPM RES) for the generation of over 5 MW of power;
2. Compulsory purchasing by grid companies of the electric energy losses in networks, primarily due to the energy produced by generating facilities based on RES;
3. The provision of Federal budget subsidies to compensate the cost of technological connection of generating facilities based on RES with a capacity of up to 25 MW;

4. Establishing long-term tariffs (the price formula) for the purchase of electricity from renewable energy facilities in the payback period.

The Federal law N 250-FZ from November 4, 2007, “On amendments to certain legislative acts of the Russian Federation in connection with implementation of measures on reforming of the Uniform power system of Russia” and the No. 1-R decree of the RF Government of 8 January 2009 “About the main directions of state policy in the sphere of energy efficiency through the use of renewable energy sources for the period up to 2020” defined the main directions of the state policy in the field of development of power industry based on renewable energy for the period until 2020 and set targets for renewable energy in the electricity sector, including the scheme of building power generating industry objects through the use of renewable energy sources on the territory of the Russian Federation, which is in accordance with the No607 order concerning energy in the Russian Federation from 17 Dec 2010 “About the organization of the Ministry of energy of the Russian Federation of work on formation of the scheme of accommodation of generating facilities of electric power industry based on renewable energy sources on the territory of the Russian Federation”.

The No. 1-p decree of the RF Government of 8 January 2009 for the period of up to 2024 is set as a description of target values of output and consumption of electric energy using renewable energy sources (excluding hydropower plants with installed capacities of over 25 MW): in 2010, 1.5 per cent; in 2015, 2.5 per cent; in 2024 4.5%.

5,871 MW of the total input amounts of installed capacity is expected by 2024.

In the period 2014-2018 JSC “ATS” conducted a competitive selection of projects for the construction of power generating facilities operating on renewable energy sources for the next 4 years.

Within a single selection of renewable energy projects, selections were held each year with respect to each type of renewable energy facilities (hydro, wind and solar stations). The winners of the selections were the cheapest (with a minimum stated capital cost) projects.

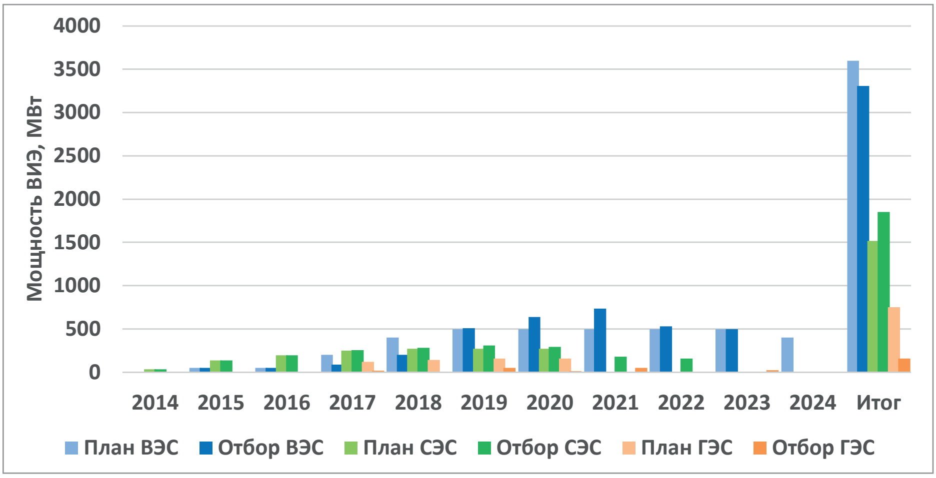

Figure 1. The volume of installed generating capacity of renewable energy sources based on the results of the project selections of the CDA RES, carried out in 2013–2016.

The data (Figure 1) indicate that the targeted inputs for power generating facilities using renewable energy sources were attained for all types facilities in 2014–2016, and the capacities of SES and WPPs seem to be higher than planned for the period of 2019-2023. The targets for small hydropower plants are currently not being met for the period of up to 2020. In 2017, the targets for wind energy and small hydropower plants were not met due to insufficient investor interest in the data objects which was associated with a high level of localization of equipment in case of insufficient production volume in Russia and the low marginal value of capital costs for the output of of 1 kW of installed capacity from the generating facility.

3. ECONOMY OF RENEWABLE ENERGY USE

Another aspect of renewable energy development in the world is the growth of investment. Globally, the total investment in clean energy in 2017 was $279.8 billion. Investments in developing countries fell by 19% in 2017, while in developed countries they grew by 20% to $177 billion [6]. If investments in renewable energy sources across sectors are considered, the only increase in investment was in solar energy sector, which grew by 18% compared to 2016, and reached $161 billion.

According to the report “Global trends in investment in renewable sources of energy” made by the UN environment programme (UNEP), the largest investments in renewable energy were made in in China, $126.6 billion, in United States, $40.5 billion, in Japan, $13.4 billion, in India, $10.9 billion, and in UK, $7.6 billion.

According to forecasts of the European Council for renewable energy by 2040, renewables will account for 50% of all energy production in the world. In accordance with the decision of the European Parliament, the share of renewable sources in the energy mix of EU in 2020 should be 20 %, and in 2040–40 %.

In many countries, increased investments are associated with the state support for developing the use of renewable sources to reduce the cost of energy generation.

According to the National Laboratory of Renewable Energy (NREL), U.S. Department of energy, over the last ten years the cost of 1 kWh of electricity on a modern wind farm has decreased from 15-20 cents to 4 to 7 cents, compared with the cost of electricity generation at traditional power plants: 5-9 cents/kWh at nuclear power plants, 4-5 cents at thermal power plants burning coal and gas, and 5-20 cents at hydro plants of various capacities (Table 2). This is confirmed by the figures for the cost per installed kW of power, which at present are as follows: HPS 1000 – $2500/kW; CHP 800 – $1400/kW; VES 800 – $3000/kW; and nuclear power plants 2000 – $3000/kW.

Table 2

The production cost of electricity, $/kWh

Type of a power plant	Min	Mid	Max
Photovoltaic plant	0.14	0.25	0.48
Thermal solar ES	0.17	0.19	0.2
Marine wind turbines	0.09	0.12	0.17
Geothermal ES	0.04	0.06	0.12
Large hydro plant	0.03	0.06	0.11
Coal ES with pulverized coal boiler	0.04	0.05	0.11
Nuclear power plant	0.01	0.06	0.11
Onshore wind turbine	0.03	0.06	0.09
Steam and gas ES	0.02	0.05	0.07

Since 2015, solar energy has become the cheapest renewable energy source. The Spanish Corporation “Solarpack” won the contract for the sale of electricity from a 120-megawatt solar power plant for $29.10/MWh, which is comparable with the cost of energy from combined-cycle plants [8].

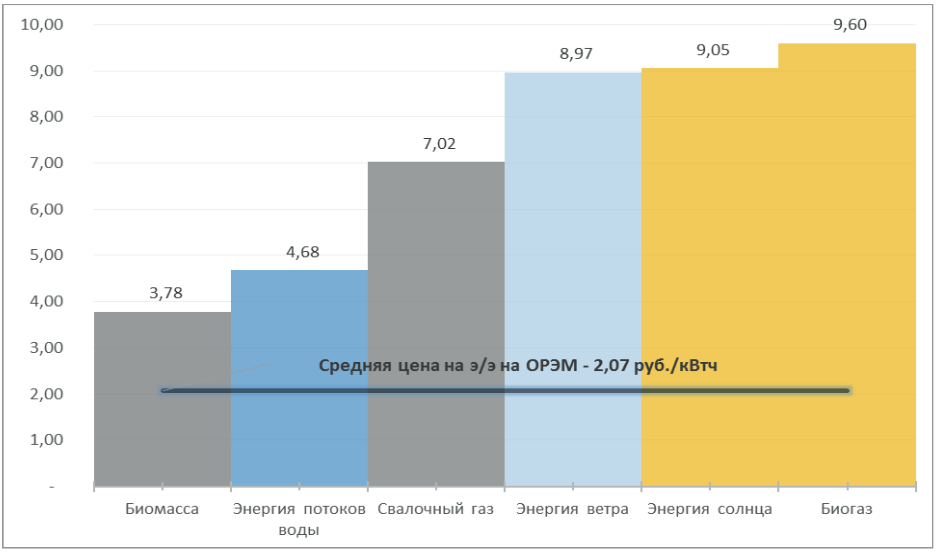

Figure 2. Average single-rate energy tariffs generated by renewable energy facilities.

In Russia, the cheapest electricity generated by renewable sources (Figure 2) is produced by biomass-based facilities ($0.054/kWh), while the most expensive is generated by biogas stations - $ 0.137/kWh [5]. At the same time, the cost of electricity generated by renewable energy sources is 1.8 times higher than the average price of electricity on the wholesale energy and power market (WECM). However, if we consider that renewable energy can be an autonomous source of energy for the consumer, the cost will be comparable to the cost of energy (taking into account the cost of transportation through electric networks) generated by traditional sources.

4. MANAGEMENT OF POWER PLANTS BASED ON RES

The effective functioning of power plants based on RES independently or as part of the energy system is impossible without a specialized control system. The automation of such a system is necessary due to the high dynamics concerning the change of plant parameters and probabilistic nature of these changes for wind and solar plants. The automatic control system must ensure a reliable operation of the plants in the production and delivery of electricity without the participation of station personnel based on the signals of the respective sensors and the solution of tasks of operational dispatch management with generation and transmission of electric energy.

Nowadays, there is a trend in the digitization of economic and technological processes, and making changes in management models based on digital technologies in fuel and energy complex of Russia.

The modern systems of automatic control on power plants using renewable energy sources are based on digital controllers that collect information, monitor the condition of equipment and control the operation.

The control system should ensure energy production by power plants with all necessary parameters of reliability and quality in all operating modes of the facility with levels of efficacy.

Among the main areas of using digital technologies in energy production using renewable energy sources are as follows:

- distributed energy producers can act technologically and economically as one entity of the market (virtual power plant);
- "smart contracts" based on the blockchain technology and the "Internet of things" technology can be used to manage the balance of supply and demand, monitor the activities of power plants and energy storage devices using smart metering systems that conduct transactions in automatic mode;
- managing and optimizing the functioning of the power systems using renewable energy sources on the basis of digital real-time models.

CONCLUSIONS

In conclusion, there are economic and organizational barriers associated with the significant capacities of cheap traditional energy sources in Russia. Today, however, the technological development has created conditions for the use of renewable energy sources, including the sources of autonomous power supply.

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CONDITION ASSESSMENT AND DIAGNOSTICS IN ASSET MANAGEMENT OF CRITICAL INFRASTRUCTURE FACILITIES

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ABSTRACT

In case of critical infrastructure facilities (CIF) the application of traditional methods for improving power equipment reliability is limited. Condition assessment of power equipment is a crucial part of asset management and one of the main challenges facing CIF. Moreover, asset management practices around the world vary significantly in their approach. This causes similar variation in the quality of asset management (as condition assessment) practices and the benefits these practices bring to the utilities which are responsible for the reliable maintenance and operation of CIF.

In this paper, the applied condition assessment approach is described as a way to improve the quality of maintenance and repair procedures of electrical equipment on the basis of actual diagnostic data and its technical condition. The needs to develop automated monitoring systems in scale of smart grid concept are proven. Diagnostic procedure for CIF is divided into integrated parts according to the type of installed power equipment. The conditions of reliable operation of power equipment are highlighted. Operation factors affecting the power equipment condition are divided into the related groups according to the current period of equipment lifetime.

1 INTRODUCTION

Many of the assets in developed countries remain quite old, and have not been upgraded or refurbished, as shown in Figure 1.

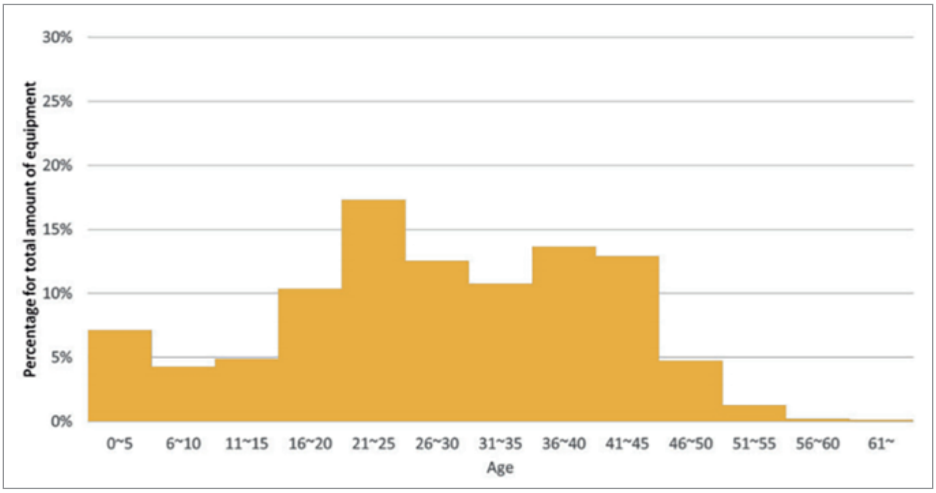

Figure 1. Typical electricity network asset age distribution

At the same time in many countries the pace of equipment upgrades significantly lags behind the amount of aging equipment that is approaching end of life. At the current rate of replacement, it would take several hundred years to replace all the aged equipment, as shown in Table 1.

Table 1. Estimated years to replace aged assets from different electric utilities

	OHL wire	Tower	Cable	Transformer	Switchgear
Utility A	47	399	112	110	80
Utility B	68	178	278	93	45
Utility C	758	179	63	124	172
Utility D	276	327	n/a	59	41
Utility E	96	174	42	49	47

Table 2 shows the results of a questionnaire on the service life of various types of electricity network equipment, collected in CIGRE TB 176 [1].

Table 2. Asset life estimation

Plant type	System voltage (kV)	Mean and range of asset life estimates (years)	Standard deviation (years)	Reason for asset life variances
Circuit breakers				
Air	110-199 200-275 ≥345	**41** (30 to 50) **41** (30 to 50) **40** (30 to 50)	6 6 6	Rating requirements, fault duty changes, maintenance costs, spares obsolescence, mechanical wear, safety, seal problems
Oil	110-199 200-275 ≥345	**42** (30 to 50) **41** (30 to 50) **38** (30 to 45)	6 6 5	Rating requirements, fault duty changes, maintenance costs, spares obsolescence, mechanical wear, safety, seal problems
Gas	110-199 200-275 ≥345	**43** (30 to 50) **42** (30 to 50) **42** (30 to 50)	6 6 6	Rating requirements, fault duty changes, maintenance costs, spares obsolescence, mechanical wear, safety, seal problems, seen as "less robust", environmental concern re SF6
Bay assets				
Earth switches and disconnectors	≥110	**42** (30 to 50)	8	Rating requirements, maintenance costs, corrosion, mechanical wear
CTs-Oil	≥110	**39** (30 to 50)	7	Design weaknesses, seals
CVT's	≥110	**39** (30 to 50)	7	Moisture ingress, PCB contamination of oil
Transformers	≥110	**42** (32 to 55)	8	Design, loading, insulating paper and oil degradation, system faults, spares, rating requirements, high temperature, moisture levels
Indoor GIS	≥110	**42** (30 to 50)	8	Rating requirements, fault duty changes, maintenance costs, spares obsolescence, mechanical wear, safety, seal problems, environmental concern re SF6
Electro-mechanical protection	–	**32** (20 to 45)	9	Wear, contact erosion, reliability, verdigris, temperature extremes, skilled labour, spares, functionality, system design changes
ACSR-OHL				
"Normal" environment	≥110	**54** (40 to 80)	14	Climate, environment, corrosion, conductor grease levels, creep, mechanical fatigue, insulator failures, wind, precipitation, ice loading, pollution levels, material quality, high temperatures due to loading, joint, design
"Heavily polluted"	≥110	**46** (30 to 70)	15	
Towers				
Steel lattice	≥110	**63** (35 to 100)	21	Climate, environment, corrosion, maintenance, poor galvanizing, ground conditions, concrete spalling, grillage corrosion, steel/concrete junction
Wood poles		**44** (40 to 50)	4	Preservation treatment, rot, woodpeckers, insects, wind, precipitation
Cables				
Oil filled	≥110	**51** (30 to 85)	20	Environmental concerns (oil leaks), backfill, sheath (oil reinforcing tape) corrosion, electrical/thermomechanical stress, loading, crystalline lead sheath

At service the continuously ageing equipment leads to its failure and serious blackout accidents. In the Russian city of Saint-Petersburg, with a population of more than 5 million people, there was a technological fault at the biggest city substation 330/220/110 kV with installed capacity of 2100 MWA. The result was that 4 biggest thermal power plants had to be shut down; more than 2.2 million people were out of electricity during several hours; there was no electricity in 19 city hospitals and 3 main railroad stations; the water supply was cut off; there was an underground railway malfunction; and more than 70 trains were stopped. In principle, such heavy blackouts had never been seen in Russia. The cause of the blackout was damage of a control cable with further false operation of the busbar protection relay system. The lifetime of the control cable was 46 years to the date of failure. It had been working since 1964 when the substation was constructed. There were plans to replace the control cable with a new one in 2011 but its failure came faster than the maintenance and reconstruction programs. According to statistical data in Russia serious power outages happen due to the high ageing degree of electric equipment of CIF. Because of the large amount of old equipment, there is a significant risk of multiple failures occurring simultaneously; more than many electricity companies would be equipped to handle. Ageing of CIF power equipment is faster than the inspection and service procedures. These challenges pose significant risks when it comes to power quality and reliability of supply. It leads to high economic and social costs. Therefore, the actual way to ensure the reliability and safety of CIF is to improve its maintenance and repair techniques and programs based on results of diagnostics and tests with consequent determination of actual technical condition.

2 MAIN AIMS OF CONDITION ASSESSMENT AND DIAGNOSTICS WITHIN ASSET MANAGEMENT SYSTEMS

The condition for reliable operation of power equipment is periodic or continuous assessment of its technical condition by inspection, measurement, control, monitoring and diagnostics as well as the prediction of changes in technical condition due to different loads, maintenance and repairs procedures. Therefore, early diagnostics is a necessary and very important part of critical infrastructure power equipment operation. Consideration of multiple adjacent assets, and scheduling work based on reducing later planned outages, are practices that are not always implemented in electricity network companies, often leading assets to be considered only in isolation, which results in unnecessary planned outages and inefficient maintenance practices. Given this structural complexity of CIF, efficient asset management practices should consider CIF as a whole (fig. 2).

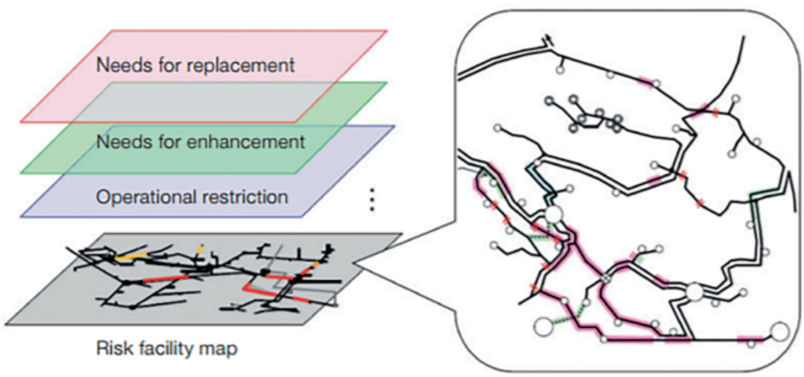

Figure 2. Map of various CIF and their risk impacts

Using different means and methods of testing and fault detection it is possible to significantly reduce the number of failures of CIF, avoid serious consequences in case of accidents, reduce the downtime of power equipment during repair, and improve the reliability and quality of power supply. During the procedures it is important to find answers to the following questions:

1) Is the available information on power equipment technical condition reliable for evaluating its current status?
2) Is it possible to compare the information on technical condition of power equipment installed on adjacent CIF (fig. 2)?
3) When should it be necessary to provide maintenance and repair of power equipment in terms of optimal relation between service costs and possible risks of outage (fig. 3)?

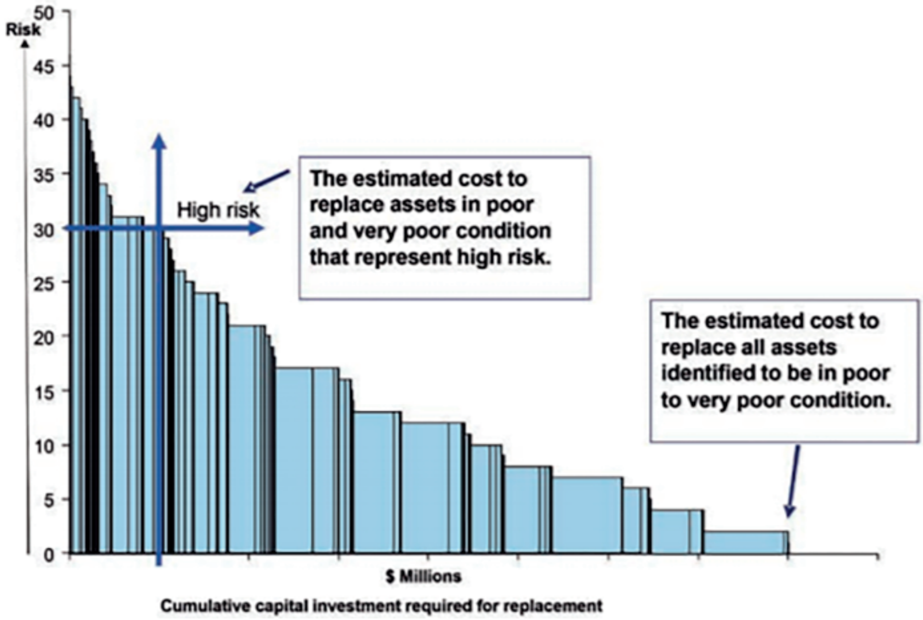

Figure 3. Long term planning and prioritization [ComEd 2015, from IEC MSB workshop]

4) When should it be necessary to replace power equipment in terms of its complete lifetime achievement as well as relation between service costs of aged equipment and costs of new ones?
5) How to define the consequences of making or failure of power equipment replacement/repair?
6) Should we spend more (or less) money on repairs and replacement of power equipment to provide the required level of reliability and security of CIF?
7) How to justify the cost of repairs or replacement of power equipment to the management and shareholders of the company?
8) How to solve the problem of power equipment service life limit and priority of its maintenance?

The latest tendency in technical diagnostics regarding smart grid concept implementation is associated with the development and integration of automated monitoring systems which allow controlling power equipment online with the help of various diagnostic methods and expert systems. It enables changing the maintenance and repair policy with regard to actual technical condition of CIF's power equipment.

The aims of diagnostic systems implementation at CIF are:

- providing support to management decision-making on the basis of reliable online information on technical condition of CIF within asset management strategy [2] (fig. 4);

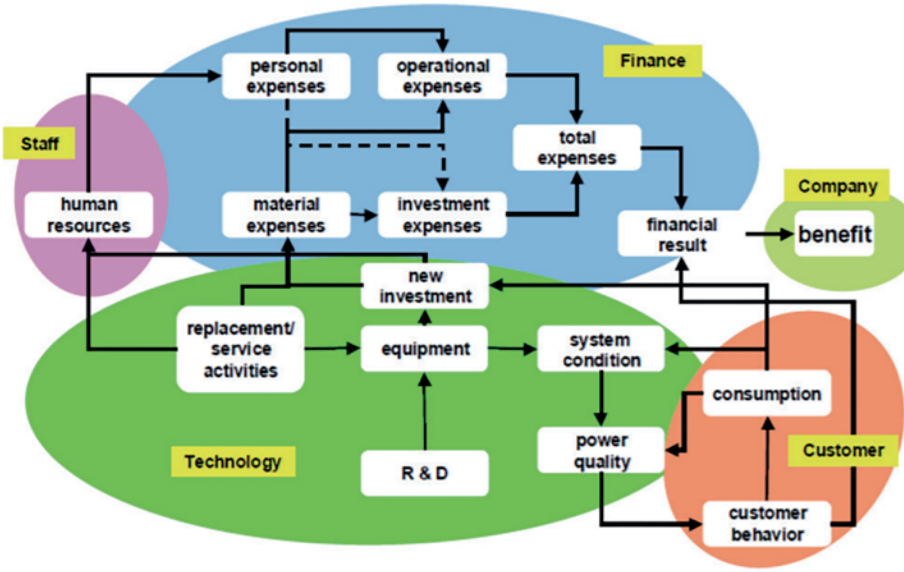

Figure 4. Overall asset management strategy

- providing the ability to forecast defects growing in power equipment on the basis of a database consisting diagnostic information about dynamic properties of ageing processes;
- data acquisition, processing and analysis of diagnostic information which is necessary for the implementation of a new maintenance and repair strategy based on the actual technical condition of CIF's power equipment (fig. 5);

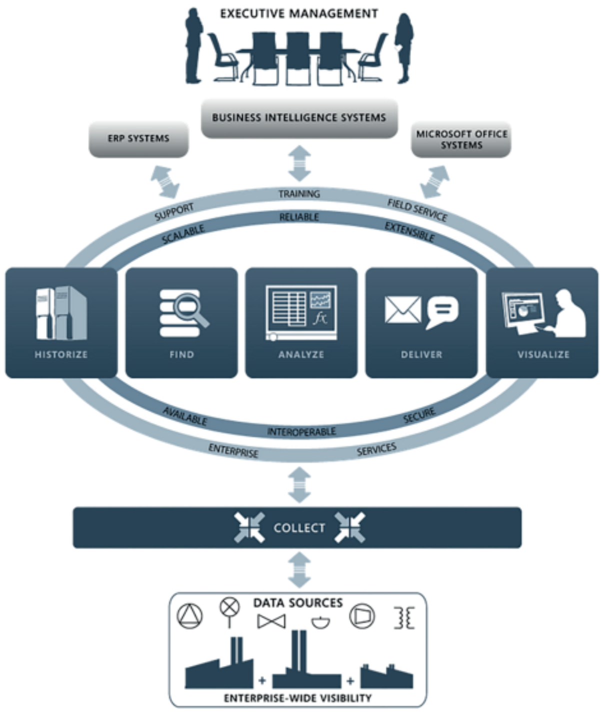

Figure 5. Structural scheme of diagnostic data collecting and its processing

– improving the reliability of electricity supply through downtime detection of defects and taking measures to prevent failures of power equipment,
– cost reduction by eliminating unreasoned repairs of power equipment,
– improving the quality of power equipment repairs based on an actual diagnostic database.

The main diagnostic tasks in terms of smart grid concept are [4]:

1) identifying the type, location and severity of defects in power equipment,
2) recognizing the causes of defects and ageing factors. As an example, ageing factors of extruded cables and accessories [3] are presented in fig. 6;

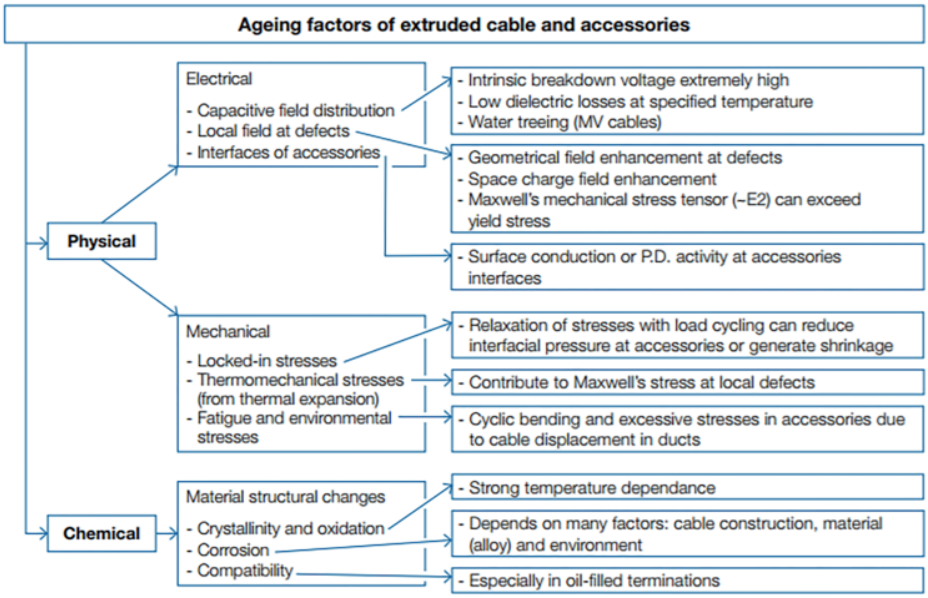

Figure 6. Ageing factors of extruded cables

3) developing the model of defect formation and growing inside power equipment,
4) creating instruments for the control of defect growing,
5) evaluating the integral index of technical condition considering service impacts, conditions and operation modes of power equipment,
6) determining the type of defects in power equipment units should be primarily removed for providing the required level of performance capability,
7) predicting technical condition of CIF's power equipment.

Russian and foreign companies have developed a large number of methods and means of power equipment diagnostics. Generally, the application of diagnostic procedures at CIFs can be divided into groups according to the types of installed power equipment: generators, power transformers, high voltage breakers and switchgear, cables and overhead lines, line and post insulators, busbars and current systems, electric contact systems and electrical connections, measuring current and voltage transformers, arresters, relay protection, and operating DC voltage systems. As an example, diagnostic tools and methods for extruded cables are shown in Table 3.

Effective and long-life operation of power equipment is based on the following statements:
– unconditional fulfillment of the requirements of standards, instructions for operation and maintenance published by manufactures,
– continuous and complex evaluation of the technical condition of power equipment in service on the basis of diagnostics procedure implementation,

– forecasting of technical condition changes by monitoring operation conditions and loads,
– preventing failures by means of back-up systems, structural and temporal redundancy, availability of reserves of equipment strength, material and technical resources,

Table 3. Diagnostic tools and methods for extruded cables

Tool	Description of method	Events/ cause detected	Comments	On-line/Off-line
1) Cable route inspection (for third party activities)	Visual inspection of the cable route to observe any third party activities near the cable route	Prevention of damage by third party	Well established	On-line
2) Serving test	Measurement of the oversheath insulation resistance by HV testing Location of any defects and repair	Damaged outer sheath	Well established	Off-line
3) Tan δ measurement	Measurements of increased power factor	Ingress of water in insulation area	Under development. The methods have only been developed for medium voltage cables, and are at the moment not possible to use on HV cables	Off-line
4) Temperature measurement	Measurement of temperature along the route by optical fibre (DTS)	Increased temperature causing thermal ageing Failure of cooling system	Well established technique, but requires fibre to be installed on the system	On-line
5) Partial discharge measurement	Measurement of discharges within the cable system	Defects and degradation of insulation Assembly errors in accessories	Well established for accessories. Increased partial discharges are only detectable in cables during a short time before failure	On-line/Off-line
6) Chemical and physical analysis of insulating fluid of terminations	Fluid samples taken from the cable system and tested for: - DGA - Tan delta - Water content - Particles - etc.	Thermal ageing of insulation (caused by different events)	Well established technique, relies on regular testing regime since interpretation of individual DGA results not clearly understood	Off-line
7) X-ray of accessories	Use of X-ray on accessories	Movement of cable causing ferrule unplugging Incorrect assembly of joint connector	Well established but significant health and safety issues and practical application limitations	Off-line
8) Inspection of cable system	Visual inspection of all components of the cable system for damage, leaks, corrosion, etc.	Visual damage, leaks, corrosion, etc.	Well established	On-line
9) Inspection of termination for ferrule retraction	Internal inspection and measurement of ferrule movement	Movement of cable causing ferrule unplugging	Well established	Off-line
10) Sheath voltage limiter test	Measurement of increased sheath standing voltage	Failure of SVL	Basic test on integrity only	Off-line
11) Bonding systems test	Checking the integrity of specially bonded systems by measurement of insulation resistance and/or circulating current in the screen	Loss of cross-bonding function	Well established	Off-line

– timely maintenance and repair on the required date with sufficient and appropriate quality,
– acquisition and analysis of real cases of power equipment failures enable making timely decisions for preventing similar failure events in other power equipment as well as identifying the conditions and patterns of defect formation and growing.

3 FACTORS AFFECTING TECHNICAL CONDITION OF CIF'S POWER EQIPMENT. TYPES OF APPLICABLE DIAGNOSTICS

Structure factors affecting power equipment reliability are divided into design mistakes, inadequate design and poor production quality. Operation factors can be divided into industrial (operation technology disruption, inefficient maintenance and repair programs as well as monitoring and diagnostics procedures), installation (installation technology disruption, low qualification of personnel), maintenance and repair (maintenance personnel qualification, logistics, timely reconstruction of facilities). These factors are primarily related to the physical conditions of power equipment operation in service, such as weighted long time modes and starting duty, voltage and current overloads, power frequency deviation, shock and vibration loads, mechanical overloads, and climatic impacts (temperature, humidity, contamination, hostile environment). Analysis of the causes of unreliable power equipment operation indicates that the above factors are interrelated. At the same time failures of power equipment are caused by the integrated effect of these factors. Complex physical and chemical processes of power equipment deterioration are the sources of failures which lead to service life decrease. The ageing processes involve heating and cooling, moisture penetration in electric insulation, overvoltages, electrical discharges, electrochemical and electromagnetic phenomena, and shock and mechanical vibrations. During operation of power equipment its ageing processes become more intensive under the influence of friction, current, voltage and contamination. The ageing behavior is heavier due to additional impacts of power arc, high temperature and dynamic mechanical loads. The overloads enhance thermal aging of transformer, generator, motor drive, and cable insulation as well as contact connections.

For reliable operation of CIF's power equipment it is necessary:

- to comply with the established rules and regulations during manufacture, design, installation, commissioning, testing, operation, maintenance and repair, in case of failures of power equipment;
- to take measures eliminating or warning harmful manifestations of operation factors;
- to monitor power equipment operational modes and conditions with the aim to develop suitable maintenance and repair procedures corresponding to the actual technical condition;
- to identify power equipment faults and defects at early stages using modern diagnostics tools.

At CIFs in Russia experience is obtained of solving the above tasks. The experience would be interesting from the perspective of widespread usage. Power equipment diagnostics can be realized in the following forms:

- periodic inspection of technical condition parameters during maintenance outage,
- periodic inspection of technical condition parameters under operating voltage,
- periodic inspection of technical condition parameters under overvoltage,
- continuous automatic control (monitoring),
- overall diagnostic inspection.

Periodic inspection of power equipment during its maintenance outage enables using a set of different nondestructive diagnostic tools and means for detecting defects and faults. It provides wide opportunities for safe inspection, but stops power supply and changes the mode of power equipment.

Periodic inspection under operating voltage provides the opportunity to make express assessment of power equipment technical condition with the detection of damages due to operation factor impacts. The disadvantage of this type of diagnostics is the absence of information about defects in the early stages of its growing.

Periodic inspection under overvoltage is regulated by a guidance document RD 34.45-51.300-97 "The volume and rate of electrical equipment testing". The document contains only lists and guidelines of testing procedures for separate parameters but it does not include instructions for overall analysis of test data. According to the type of diagnostic a defect is mainly detected by comparing the test data with standard values, it does not take into account the dynamic properties of controlled parameters. The analysis of correlations between test results for parameters with a common physical nature is not specified using this type of diagnostics.

Principally different diagnostic methods and tools should be used for overall diagnostic inspections. In this case decision making about the technical condition of power equipment is the most adequate. At the same time the durability of overall inspection is large enough. As a result, it is impossible to timely respond to the dynamic changes in the technical condition.

It should be noted that now all type of diagnostics require its further development and improvement. It enables determining the technical condition of power equipment in the most reliable way. It also gives the opportunity to detect defects at the early stages and predict their dynamic properties. Moreover, it is possible to oversee the overall impact of operation factors on the technical condition of each type of power equipment individually and plan the counter measures on reliability improvement.

Power equipment diagnostics should be performed during commissioning. After that power equipment should be inspected periodically during its operation, maintenance and repair works. Diagnostics of power equipment should be performed after the standard service life of the equipment is over or when its extreme limit condition will be achieved with high probability. At critical infrastructure facilities where especially high reliability of power equipment should be provided, it is useful to implement a monitoring system highlighting the parameters which characterize the technical condition of power equipment. Therefore, development of such automated diagnostic systems based on the latest information technologies is in progress now. This type of diagnostics is the most preferable because it actually provides online monitoring of dynamic changes of controlled parameters. In addition, it eliminates the influence of judgmental factors on results of monitoring and helps to analyze a number of diagnostic parameters. Using modified math algorithms provides the prediction of dynamic properties of growing defects and evaluation of technical condition of power equipment structural units.

The main tasks which should be solved on the way of building such monitoring system are:
1) integration of developed automated diagnostic systems in the existing SCADA systems installed on critical infrastructure facilities,
2) development of the math model describing technical condition changes and providing the opportunity to detect defects and identify their causes,
3) development of a power equipment functional model which helps to evaluate durability and reliability indicators based on overall impacts of operation factors and existing diagnostic parameters,
4) diagnostics algorithm design allowing to determine and classify power equipment technical conditions as well as to differentiate between types of defects and to predict their dynamic properties,
5) information and software algorithms designed to execute diagnostics algorithms, data processing and indication.

The frequency and terms of diagnostic works should be indicated in technical rules and regulations on maintenance and repair of power equipment. The scope of diagnostic works is determined for each type of power equipment or a group of the same type equipment with regard to its design specialties, type of identified defects, and terms and operation conditions by means of making a diagnostic schedule. Depending on the specific conditions and operation modes as well as the importance and general technical condition of power equipment, the scope and terms of diagnostic works can be corrected by a technical manager. Depending on hardware and controlled diagnostic parameters it is possible to create the following list of diagnostic methods that are most commonly used to control the power equipment of critical infrastructure facility: acoustic control; heat monitoring; optical inspection; vibration control; ultrasound testing; chromatographic analysis of gases dissolved in oil; electric parameters control and analysis of current and voltage harmonics; oil physicochemical analysis; emission control; radar control; impulse control; and control of partial discharge intensity. Diagnostic works generally include the following steps:

- analysis of design, background, expertise, operational, regulations and other documentation concerning the technical condition and quality of installed power equipment,
- development of diagnostic schedule with the list of tools,
- operational (functional) diagnostics,
- instrumental inspection of power equipment,
- analysis of identified defects and mechanisms of its growing,
- computer processing of diagnostic data,

- identification of patterns of technical condition parameters changes with forecasting of limit values,
- current life time assessment and residual life time forecasting,
- grounds for a decision concerning the further power equipment operation,
- definition of limit terms of excessive power equipment operation,
- making conclusions about technical condition and recommendations for further operation or repair of power equipment.

CONDITIONS OF DIAGNOSTICS EFFECTIVENESS

Professional engineering companies with highly skilled specialists and experts with wide practical experience should be involved in the execution of diagnostic works. The companies should be equipped with a set of instruments and tools for measuring and non-destructive testing. Measures to ensure the reliability and security of power objects installed in critical infrastructure facilities are based on controlling the technical condition and should include immediate, medium and long-term objectives [5].

The following results define the effectiveness of diagnostics:

- significant reduction of injuries of staff working on objects of critical infrastructure facilities due to reducing the number of equipment failures,
- increased reliability through timely preventive measures,
- reduced costs on unjustified reconstruction of power equipment,
- reduced labor costs by implementing the system of power equipment technical condition monitoring,
- reduced operating costs by establishing optimal schedule of maintenance and repair,
- reduced maintenance and repair costs on the basis of determining optimal scope of works with allowance for diagnostic data,
- ensuring the optimal level of operating quality of power equipment installed in critical infrastructure facilities by eliminating the defects that cause performance degradation,
- reduced insurance costs,
- increased level of safety by preventing unexpected failures and related emergencies,
- reduced number of power supply outages and quantity of penalties from consumers because of damages.

At the same time costs for using automated monitoring systems, non-destructive testing and diagnostic tools should be justified by application effect.

CONCLUSIONS

The results of latest studies can be considered as a comprehensive solution for the control of technical condition of power equipment of critical infrastructure facilities in the energy sector. Solved tasks are essential for making a transition to explore maintenance and repair system according to the technical condition of power equipment as well as its operation control depending on the obtained values of reliability indicators based on diagnostic data. It enables implementing an approach providing high reliability indexes of power equipment of critical infrastructure facilities. It is achieved by improving maintenance and repair procedures as well as operation procedures by taking into account the actual technical condition determined by means of a diagnostic system. The priority way to improve the diagnostic system of power equipment is to monitor and control its technical condition by using automated diagnostic tools. All newly built and reconstructed electric stations and substations shall be equipped with automated monitoring systems for evaluating the technical condition of main power equipment.

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DIGITALIZATION IN COST CALCULATIONS FOR THE CONSTRUCTION OF POWER AND INDUSTRIAL FACILITIES

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ABSTRACT

Digitalization is the translation of information into digital form. Digital transmission of data encoded in discrete signal impulses is widely used in the modern information society, particularly in the construction of energy facilities.

1 INTRODUCTION

In the course of carrying out research by leading foreign and Russian universities and business schools, it was concluded that the most pressing concerns among directors of modern companies are still related to determining the price of the subject of a contract. Also, the forecasts of the authors of the research are interesting: everything indicates that the pressure caused by the price factor on the management of companies will increase.

Domestic experience of energy and industrial construction shows that only carefully designed project and work documentation, performed in accordance with regulatory and methodological documents, allows the commissioning of facilities on time, with a subject to the contract price.

Because of this, the participants in an investment-building process, investors, customers, contractors and subcontractors, should require from the designer full development documentation related to the project in sufficient detail in accordance with the regulatory and methodical documents and task instructions. Only strict adherence to this will increase the accuracy of cost calculations in the design of energy and industrial-civilian objects.

2 APPLICATION OF PROGAMS IN COST CALCULATIONS

The completion of cost calculations (budgeting) is a time-consuming process. When determining the estimated cost of the construction of an object, a large number of options are applied such as calculation methods, options for elements of the direct costs and their indexation. In order to improve the efficiency of the implementation cost (estimated) calculations, the programs performing estimates are actively being developed in the energy sector. Their development is only possible with a thorough digitalization of the budgeting processes. The most commonly used budgeting programs:

1. Grand estimate.
2. Wizard.
3. Bagira.
4. Leopard.
5. A 0.
6. Estimate calculator
7. Aros.
8. Hector-Construction Cost Estimator.
9. ABC-4C.
10. Gosstroysmeta.
11. Winсмета NEO.
12. Baby – смета.
13. Atom – смета.
14. Смета.ru.
15. Смета 2000/ Ресурсная смета.
16. WinАверс.
17. Смета+.
18. Адепт.
19. Estimate.
20. Система ПИР.
21. 1 C: estimate and others

In order to maintain a competitive environment in the field of digitalization of cost calculations, the selection of the necessary budgeting program is carried out by a user enterprise which makes calculations to determine the cost of building an energy facility.

When analyzing programs, it is necessary to evaluate the composition of the regulatory framework, the functionality of the cost estimate documentation, the convenience of the program interface, the cost of the program and the after-sales service.

When using a program, it is important to compile local budgets, object estimate, summary estimate, resource estimate, acceptance certificates for completed work, resource records, material requirements sheets, labor costs, cumulative records, and various forms. Most of the programs support all of these modes. It is possible to modify standard forms to suit the user's needs.

An important factor in the functionality of the budgeting program is the possibility of applying various coefficients and corrections when calculating the estimate. When forming the budget documentation, it should be possible to support different methods of calculation - basic, index, resource and mixed methods. The support of these means of calculation is stated by the developers of programs.

Within the functions of a particular program, the use of the digitalization unit in cost calculations allows:

- the possibility of combining settlement methods in one document and comparing the results
- automatic formation of estimates on the basis of the work performed under the acts
- automatic creation of object estimate calculation on the basis of local calculations, compiled in the program.
- automatic creation of a summary resource list for selected acts of work performed.
- the formation of a statement of resources for the balance of work performed
- updating cumulative KC-6 and KS-6a statements
- automatic generation of a report on the consumption of basic materials (form M-29)
- automatic creation of a consolidated estimate calculation, with the possibility of automatic creation based on local object calculations, compiled in the program
- automatic distribution of costs by chapters and synchronization of data as they change
- calculation of the unit value indicator
- automatic creation of a resource sheet based on local estimate data
- formation of a summary resource list
- automatic calculation of the total cost by sections and by estimate
- Creation and use of customized cost templates when creating new calculations
- review of local estimates for compliance of quotations in the estimate-normative base
- comparison of different editions of local estimates, acts of completed work
- calculation of aggregated cost indicators for certain types of work and the elements for the preparation of tender documents
- use of additional details in the budget documentation and certificates of work performed: inventory number, edition number, archive number, title item.
- analytical reports on the executed work for different periods by executors of work, for individual objects and for construction in general, both in the structure of the budget documentation and in the structure of contracts
- in the hierarchical structure of the estimate data, a “complex project” can be created that contains “standard” projects - summary estimates. A complex estimate calculation can also be calculated for the complex.
- budgeting of construction on the basis of estimated data
- making of a production plan by months and by work assignments. Making a calculation of a project in terms of materials and other necessities by months.

- Conducting of a plan-fact analysis of costs.
- Planning, management and analysis of a cost price for a construction project.
- Preparation and submission of estimated data for the calendar-network plan, created in Primavera. Processing of a document in the form in which it will be printed. Creation of one's own document templates.
- Making a package of functionally related documents, related to one project.
- Automatically receiving a total value of unaccountables with reference to materials, equipment, and returned materials.
- Implementation of a monitoring system and accuracy of estimates.
- A possibility to connect additional modules (ПИР, ПНР, CadWIZARD, Energyaudit).

IN THE METHODS OF CALCULATING ESTIMATES:

- Mechanism of price storage enables to centrally type prices of resources simultaneously in all estimates of the object in network mode.
- Recalculation of the estimate documentation by an object and by resource method into prices of any region and any date in one operation.
- Customizable automated pricing formulas.
- Parametric estimates allow the use of flexible standard fragments, enlargement of an estimate, and also accuracy in the volumes in operative estimates.
- Introduction to the calculation of any taxes, duties, contractual and tendering ratios, including ratios characteristic for the specific activities;
- An automatic binding of the unit price standards for overhead and profit estimated and correction factors, indexes of recalculation referring to the current level of prices;
- Automatic storage of base and current prices. Indexes and ratios are applied to any element of a line of a local estimate, a separate row, an arbitrary group of rows, full estimates, sections of an estimate, and also the resource prices.
- Calculation of a planned and actual resource volume, both at the level of individual local budgets, and at the level of the object or a construction in general.
- Forecast assessment of the value of the construction at the stages of pre-project preparation and feasibility studies.
- The total value and volume figures for all types of work for the individual structural elements of objects and the construction site in general.

IN THE FUNCTIONALITY OF THE INTERFACE:

- A possibility to download estimate templates from the implementator's site .
- Group operations with document;
- Estimation parameters are applied on-line;
- Automatic calculation of normal overhead costs and estimated profit on the rates and types of work.

- Search by code or by context. Resource-based search;
- The possibility of transfer and acceptance of cost estimates in an open XML format, and also ARPS 1.10 for data exchange with other programs;
- The embedded plugins provide a rapid increase in program functionality for users or with reference to applications.
- Organization of archives into folders by type allows a structured storage of estimates.
- On-line archives provide shared access to estimates of the user working groups.
- There is a possibility to deduce the estimates in Excel with formulas, creating stand-alone documents with the possibility of changes in prices and volumes in the finished file.
- The scalability of the system allows to simultaneously work on 1, 2-3, and 100 or more work places.
- Shared access to a single database in vast corporate networks within the organization (local and volumetric estimates, projects, certificates of completion, reference resources, price estimate-normative base).
- Possibility of setting access rights to the estimated data and reports to the employees of various departments in accordance with their duties and their assigned role in a specific project.
- Creation and processing of archives of estimate data.
- Data synchronization between the databases of different organizations: the Designer - Client – Contractor.
- Remote access to the DB, the estimated data of each of the work places included in corporate network.
- Integration with related software products is interaction with systems such as Navision, 1C - Предприятие 8.0, Global.
- Panel (customizable) and ribbon interface.
- Search for quotations and resources by code and name.
- Transfer of the estimate documentation between users of the program in the form of files.

THE SHORTCOMINGS OF THE APPLICATION OF THE ESTIMATE PROGRAMS ARE:

- High performance requirements for the computer
- the estimates created in a newer version can only be opened in the previous version through xml or ARPS,
- When printing multiple versions of a quote, unnecessary items must be manually hidden. This is a very complicated procedure of a settings.
- When exporting to Word or Excel, problems may occur with forms
- Reviewing the estimate is difficult because of the additional windows
- The performance of the program decreases as more data is fed
- Some operations require the user to perform various actions.
- It is impossible to print the technical part

CONCLUSIONS

The active use of means of digitalization by modern, efficient enterprises such as JSC Gazprom, JSC Concern Rosenergoatom, JSC Transneft, and JSC Russian grids improves the accuracy of the cost calculations and creates a possibility to choose the most qualified operator for constructing the object of power and industrial building.

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CIRCULAR ECONOMY IN THE FINNISH BIOPRODUCT INDUSTRY

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ABSTRACT

There are major changes in bioproduct and pulp manufacturing industry in Finland. The main product is and will be cellulose and wood fiber. Because of the continuously increasing energy efficiency, the surplus power production is a more important side product of bioproduct mills. This article discusses the concept of bioproduct manufacturing for efficient and innovative use of side products of pulpmill biorefineries. Besides energy (power and biofuels), new innovative way to use bio-ash, softwood bark and carbon dioxide are discussed in the article. South-Eastern Finland University of Applied sciences is working with bio-ash, softwood bark and carbon dioxide conversion to create new process technologies and possibilities for value added products. Circular economy policies and cascade use of raw materials create the need for new process and product concepts for the bioproduct industry.

1 INTRODUCTION

Wood products are typically considered to have lower environmental impacts than equivalent products made out of non-renewable raw materials. Woody biomass is presently used in various industrial sectors and in many different value chains, such as wood-based products and materials, bio-chemicals, and bioenergy (e.g. power, heat and biofuels). Targets for greenhouse gas emission reduction and more resource efficient society are expected to further increase the demand for wood raw material in Europe during the next decades (Sokka et. al 2015). In Finland the research, innovation and investment activities for bio-circular economical concepts have increased during the past few years. The concept of chemical pulp mill is developing towards a holistic bioproduct mill including optimal production of green heat and power, biofuels and bio-based materials. Some more specific circular economy products and industrial ecosystems are also under development. From the viewpoint of South-Eastern Finland University of Applied Sciences (Xamk), important examples include the reuse of side products as sludges and ashes for fertilizers and other circular economy products, chemical product options (for example sustainable binders for wood industry) from softwood bark and reuse of carbon dioxide from industrial flue gases for new renewable and sustainable products.

2 BIOPRODUCT MILL CONCEPT

The development of chemical forest industry towards more diversified and more intensive use of side products for energy and materials has accelerated during the past few years in Finland. The best known concept in Finland is the *bioproduct mill concept* launched by MetsäFibre (Figure 1). The best known and still developing concept of circular economy based bioproduct mill is located in Äänekoski in Finland. The new bioproduct mill is using 100 per cent of the raw materials and side streams to produce bioproducts and bioenergy.

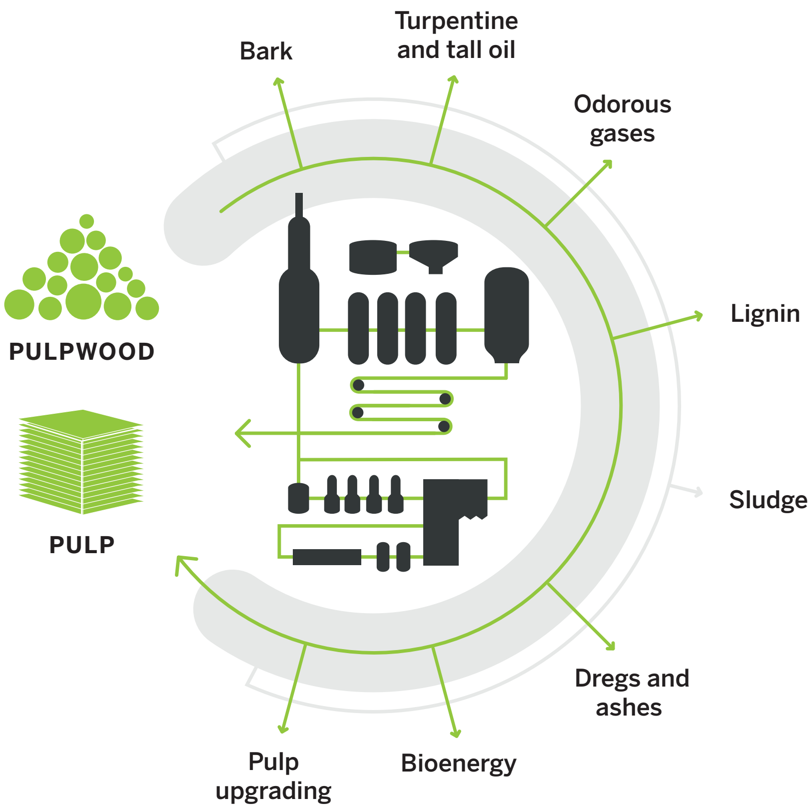

Figure 1. Bioproduct mill concept. Figure source: Metsä Group.

2.1 ENERGY PRODUCTS IN BIOPRODUCT MILL

Pulp and paper mills are logical sites for increased biomass use. They have access to biomass feedstock, and a possibility to utilize process residues (Vakkilainen 2018: 5). A pulp mill utilizes large amounts of wood. It therefore generates a large amount of biofuels; black liquor, bark and other side streams. Biofuels like pellets have become tradeable goods. Biomass gasification is a well-known process, and it has been previously used in pulp mills to fire lime kilns, for example in Finland at the beginning of the 1980s.

The target of the new process concept and optimized energy efficiency is that a bioproduct mill is not using any fossil fuels whatsoever. All of the energy needed by the mill will be produced from wood. Increased use of bioenergy and biofuels can reduce greenhouse gas emissions. Also, some new concepts for bioenergy (cf. biogas from sludge gasification) will be demonstrated.

One modern bioproduct mill is helping Finland in a remarkable way to achieve its renewable energy targets. The mill is producing 1.8 TWh of electricity per year, which represents 2.5 per cent of all electricity production in Finland. It is increasing the share of renewable energy in Finland by more than 2 percentage points (MetsäFibre 2018).

In a nutshell total energy production at the modern bioproduct mill can be summarised as follows (Metsäfibre 2018):

- Electricity self-sufficiency: 240%
- Total electricity production: 1,800 GWh per year
- District heat and steam: 640 GWh per year
- Solid fuels, or wood energy, for sale: 550 GWh per year (around 750 GWh per year of the energy created by bark generated at the bioproduct mill is used to produce product gas at the mill)

Besides energy (heat, power and electricity and biofuels), fertilizers and chemicals are going to be more and more interesting end products from side streams.

2.2 FERTILIZERS FROM WASTE

In its communication on "Circular Economy" (COM(2014) 398), the European Commission statesthat it will encourage the cascading principle in the sustainable use of biomass, taking into account all biomass using sectors so that biomass can be utilized in a most resource efficient way (Sokka et. al. 2015: 5). In the circular economy, raw materials and products are reused or recycled and their value endures for as long as possible. This requires companies to develop new value chains, in which the familiar "use, discard, and destroy" chain no longer works. Recycled fertilisers are an excellent example of industry's resource efficiency and the forest industry's ability to transform as a frontrunner in the bioeconomy (Finnish Forest industry 2017). Main raw material sources from bioproduct industry for fertilizers as circular economy products can be bio-based flyash, water treatment sludge and fiber sludge.

Strategies for fertilizers (by using waste and production side streams) are diversified in the Finnish forest industries. In addition, different kind of industrial alliances have been established for these side product and business concept purposes. For example, the co-operation project between UPM and Yara as part of the Finnish fertilizer reuse program RAKI is an interesting example of new joint development action under this topic (Viitikko et. al 2018).

3 EXPERIENCES IN XAMK FOR NEW BIO-CIRCULAR ECONOMY CONCEPTS

Xamk is co-operating with the bioproduct industry for new circular economy concepts. The main interest areas are, besides bio-ash, softwood bark and carbon dioxide capture and reuse. Development work needs expertise from the fields of chemical engineering, energy, process engineering and material technology.

3.1 BARK FROM BIOPRODUCT INTEGRATES FOR NEW BIO-BASED MATERIALS

Around 3 million tonnes of softwood bark is available as a side stream from the Finnish forest industry each year. Most of this bark is burned for energy in pulp mills, for instance. More efficient use of the bark would generate added value from Finnish forest biomass and create new business. Water-based extraction processes are employed in the production of tannin from tropical trees such as acacias. Currently the major application of these tannins is in dying (tanning) of leather. In the future, tannins could also be applied in adhesives, more specifically as a phenolic component in resins for wood gluing. This would open access to a large market, since phenol-based adhesive resins have a global market of approximately 4 million tonnes per year and a value of EUR 10 billion. Phenolic resins are mainly used as binding agents in the production of plywood and laminates. Xamk is co-operating with the Technology Research Center of Finland VTT, Natural Research Center of Finland LUKE and the industrial network with the aim of developing a process and business concept for a softwood bark biorefinery (VTT 2018). The softwood tannins are a new, less utilized type of tannins with different properties than the currently available commercial tannins.

3.2 CARBON DIOXIDE

There has been interest in Finland in developing clean physical water-absorption based CO_2 separation methods. In the Savonlinna FiberLaboratory, which is a research unit of the South-Eastern Finland University of Applied Sciences, researchers are studying a novel water-based CO_2 separation method which is being tentatively calculated and experimentally tested. The Technical Research Centre of Finland has also verified these calculations and has given a second opinion on the performance of this method (Mamk 2016). However, there is no single winning technology in terms of costs (Vakkilainen 2018). The process has been patented in Europe, China and the United States.

The main CO_2 sources in pulp mills are the recovery boiler, the biomass boiler, and the lime kiln. Xamk has studied carbon dioxide capture and reuse since 2008. Carbon dioxide utilization employs heterogeneous reaction to convert CO_2 to products. Impurities present in the reacting stream can affect any of these steps and may result in low reactant conversion and/or low selectivity. CCU from various CO_2 sources may contain a host of impurities, and these will purified before further processing. Carbon dioxide conversion for renewable fuels or chemicals can be done through different routes. However, these new circular economy options are only in lab-scale and simulations and piloting and demonstration projects will need good co-operation between bio-circular economy industry, research organizations and financers.

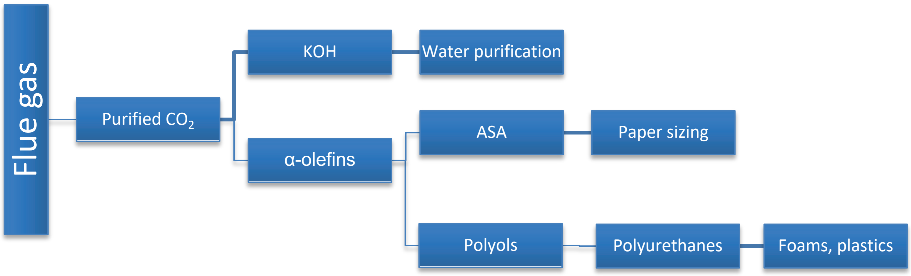

Figure 2. CO_2 from flue gases to possible value-added products can be done through different routes.

4 CONCLUSIONS

A modern chemical pulp mill can be defined as a forest biorefinery and bioproduct mill. Surplus of energy – heat and power – by using lignin, bark and other fuels is still increasing through better energy efficiency in the production. The concept of bioproduct mill and biorefinery also leads some new conversions and production possibilities in these complexes. Fertilizers by using circulated materials is under strong development in the Finnish forest industry. Softwood bark and carbon dioxide reuse routes and new possible value chains are identified in Finland.

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RENEWABLE ENERGY FROM CHEMICAL RECOVERY OF BIOREFINERIES

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ABSTRACT

Pulp mills, today also called biorefineries, mainly produce chemical pulp which can be used in the manufacturing of paper and board products, and dissolved pulp which is increasingly used as a raw material for textile industries. Besides chemical pulp, biorefineries also produce plenty of energy in their manufacturing processes. This energy comes from the combustion of black liquor and process gases in a recovery boiler in the form of heat and electricity. Black liquor is collected in the separation of fibres and cooking chemicals by means of washing. In addition, some other energy-related products, such as biodiesel and lignin can be extracted as sub-products. This article discusses the role of pulp mills in producing renewable energy in Finland.

1 INTRODUCTION

The trend of total energy consumption in Finland has been decreasing a little during the last ten years (Figure 1). Recently, the total energy consumption makes annually almost 1400 petajoules, while the final energy consumption of end users is approximately 1100 petajoules. Renewable sources accounted for 31.9% of the total energy consumption in 2017, representing 38.7% of the final energy consumption which stands for the reference EU value. (Statistics Finland a 2019)

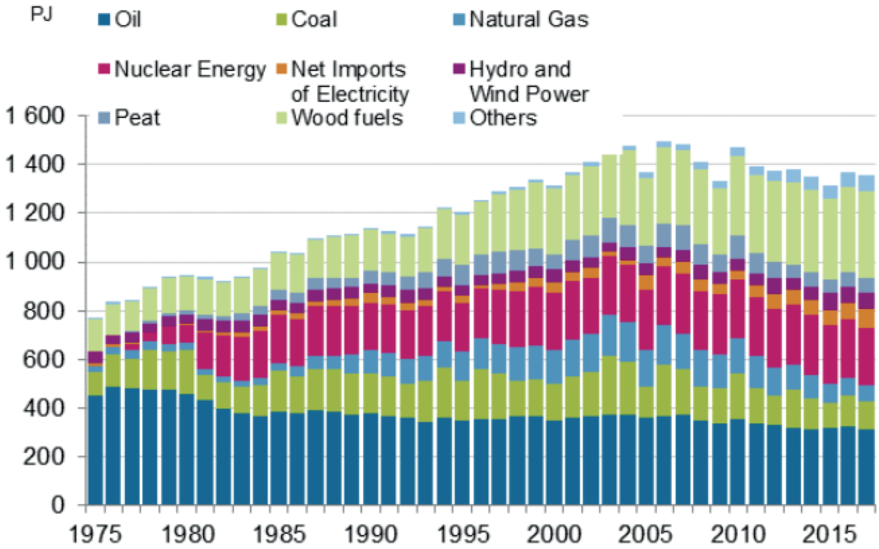

Figure 1. Total energy consumption in Finland, presented by individual energy sources, in 1975-2017 (Statistics Finland a 2019).

In Finland, renewable energy sources mainly comprise different wood-based sources, such as wood fuels in industries and energy production (29%), black liquor and other concentrated liquors (32%) and wood in small-scale combustion (13 %), and make up for 74% of the total renewable sources (Figure 2). This implies that a significant part of renewable energy comes from pulp mills and related industries.

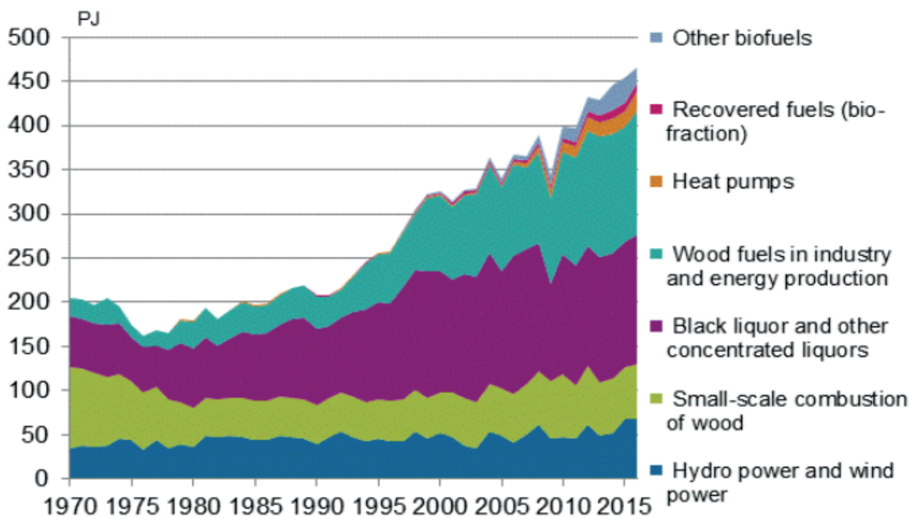

Figure 2. Renewable energy sources in Finland, in 1970-2017, by individual sources (Statistics Finland b 2018).

The major challenges in using wood-based energy sources are in the reduction of emissions during the combustion process. The combustion of wood produces carbon dioxide (CO_2), nitrogen oxides (NO_x) and particular matter, while in the combustion of black liquor, also sulphur dioxide (SO_2) is emitted. The EU directive 2010/75/EU presents the general framework for the management of emissions. The best available techniques for the reduction of emissions in large combustion plants are introduced in European recommendations (BAT 2017).

2 CHEMICAL RECOVERY IN PULP MILLS

Traditionally, the main products of pulp mills are hardwood pulp (HW), softwood pulp (SW) and dissolved pulp grades. Nordic long-fibre pulps from pine and spruce belong to SW pulps, while eucalyptus and birch pulps, for example, are HW pulps. Dissolved pulps come from hardwood, mainly from northern birch and southern eucalyptus, to be used mainly as raw material in textile industries. Dissolved pulp contains less hemicellulose than other pulp grades. In textile industries, viscose is developed from dissolved pulp and it partly replaces the increasing demand of cotton. In addition, pulp mills produce energy in the form of heat and electricity, more than they need themselves. The largest pulping companies in Finland are StoraEnso, United Paper Mills (UPM) and MetsäFibre, and all of them also have operations abroad.

The fibre line is the core of the pulp mill producing pulp grades, as presented in Figure 3. The fibre line comprises the cooking, oxygen delignification, bleaching and drying stages.

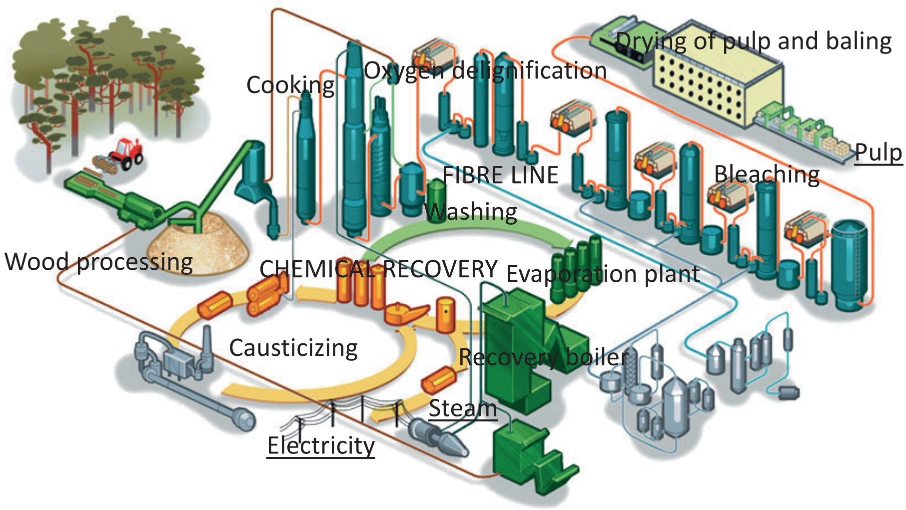

Figure 3. Main pulp mill processes and products (KnowPulp 2017).

Chemical recovery, also presented in Figure 3, is an essential process in the pulp mill aiming at the recovery of cooking chemicals. In chemical recovery, black liquor formed in the separation of fibres and chemicals by washing is first concentrated in an evaporation plant and then combusted in a recovery boiler producing green liquor and energy in the form of steam and electricity. Further, the important chemical compounds of green liquor are recovered from the recovery boiler by means of causticizing to generate white liquor for the cooking process.

3 ENERGY-RELATED PRODUCTS FROM CHEMICAL RECOVERY

Besides the main products of a pulp mill i.e. pulp and energy, several sub-products can be produced during the chemical recovery. Traditionally, tall oil and turpentine have been extracted. Turpentine is formed at the cooking stage of the fibre line and tall oil is separated in the chemical recovery evaporation plant. Tall oil may be used in many different ways, for example in the manufacturing of food additives, industrial chemicals and fuels. Globally, the pulp industries produce and combust approximately 200 million tons of strong black liquor annually, which accounts for a significant part in the generation and use of renewable energy sources (KnowPulp 2017).

3.1 HEAT AND ELECTRICITY FROM A RECOVERY BOILER

Black liquor is produced during washing in the separation of fibres and cooking chemicals in the fibre line. During cooking, the affecting cooking chemicals sodium hydroxide ($NaOH$) and sodium sulphide (Na_2S) have an impact on wood resulting in the dissolving of lignin and other organic compounds in the residue liquid known as weak black liquor. The amount of the produced lean black liquor is 7-12 m^3 per one ton of pulp. This weak black liquor with a dry content of 15-18% has to be concentrated in the evaporation station into strong black liquor with the dry content of 75-85%. Black liquor contains several sulphur compounds, and the sulphur and sodium have to be recovered. The high heating value (HHV) of strong black liquor is approximately 13 MJ/kg dry content (KnowPulp 2017).

The combustion of black liquor takes place in the furnace of the recovery boiler plant (Figure 4). Black liquor and combustion air are injected into the furnace. The heat from the combustion boils the water in the boiler and high-pressure steam of approximately 11 MPa is produced. The steam turbine runs the generator, effectively producing electricity. The outcoming smelt from the furnace together with white liquor makes green liquor. The green liquor is mostly sodium carbonate (Na_2CO_3), sodium sulphide (Na_2S) and sodium sulphate (Na_2SO_4), and it is converted to white liquor in the causticizing process. The flue gases generated in the combustion mainly contain carbon dioxide (CO_2), nitrogen oxides (NO_X), sulphur dioxide (SO_2) and particulate matter, and these emissions have to be treated.

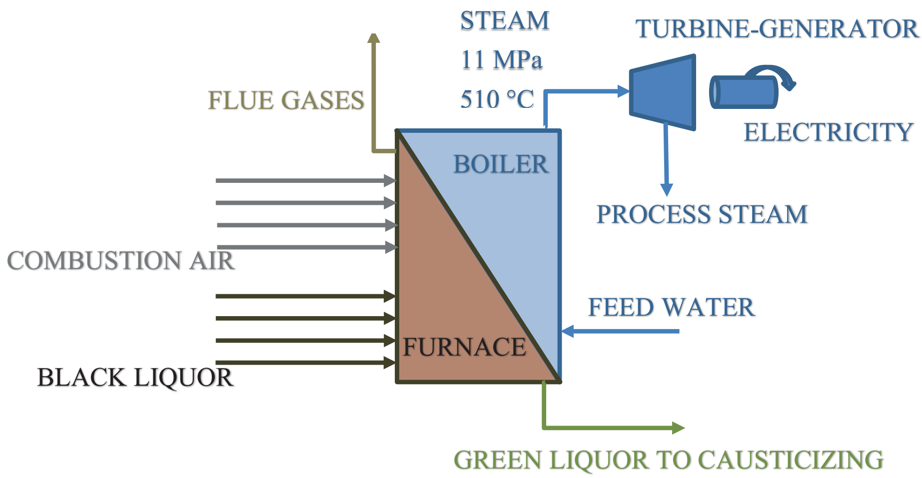

Figure 4. Main input and output flows of a recovery boiler plant.

In large capacity biorefineries with an annual production of 1.3 million tons of pulp, approximately 45,000 tons of black liquor is combusted daily, adding up to 16 million tons annually (MetsäFibre a 2014, p. 46).

3.2 BIODIESEL FROM TALL OIL IN THE EVAPORATION STATION

Crude tall oil is a residue that can be extracted from black liquor in the evaporation phase of chemical pulping. If black liquor is concentrated, soap-like ingredients rise onto the top of the liquid and can be collected as raw soap. This extraction takes place in special tanks, separation boxes and cones. In raw soap, approximately 50% of the total mass is tall oil. If the raw soap is treated with sulphur acid (H_2SO_4), washed and concentrated, the result is crude tall oil.

The most common biodiesel in Europe is an ester made of rapeseed oil or methanol. In Finland, Neste Oil has been manufacturing its renewable diesel NExBTL since 2007, based on an alcane obtained from vegetable and animal fats. In 2015, United Paper Mills (UPM) started producing biodiesel from tall oil in Kaukas Biorefinery in Lappeenranta. This kind of biodiesel can only be produced using tall oil from Nordic softwood. The tall oil needed in the production comes from UPM Lappeenranta and Kuusankoski mills.

In the pretreatment stage, there are evaporation units (Figure 4). The hydrotreatment comprises several reactors, and a modified Fischer-Tropsch process is utilized. In the rather complicated process, tall oil is gasified and circulated together with hydrogen. The process is controlled by hydrogen flow and the temperature and pressure in the reactor. The needed hydrogen (H2) comes from the adjacent hydrogen plant. The fractionation of hydrocarbons takes place in distillation reactors. Biodiesel is one of the fractions produced in this process. The production of biodiesel as a whole is an extensive process involving 5,000 automation engineering tags. The annual production is 100,000 tons, and the investment costs were 175 million euros. Biodiesel is used as a 5-20 percentage mixture with fossil diesel. (United Paper Mills 2019) (Chemicals Technology 2019) (Mäkelä 2017, pp. 10-11)

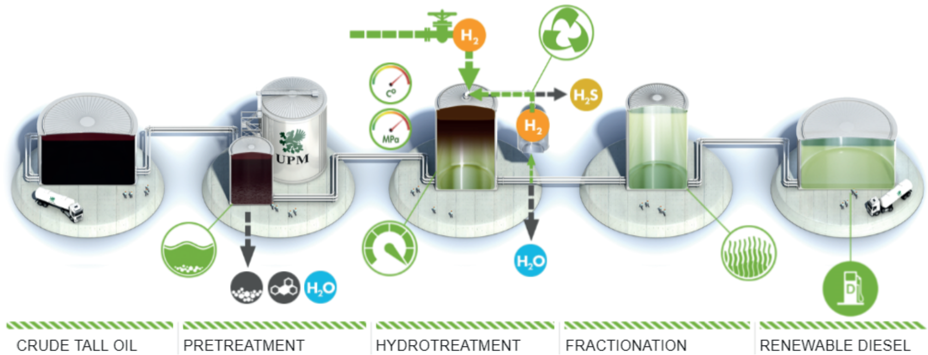

Figure 4. Main process stages in the production of biodiesel (United Paper Mills, 2019).

3.3 LIGNIN FROM THE EVAPORATION STATION

The production capacity of a pulp mill can be raised if the combustion capacity of the recovery boiler is increased. This may take place without cost-intensive investments in the recovery boiler if the combustion load can be reduced by extracting lignin from black liquor in the evaporation station. If one fourth of the lignin is extracted, the pulp production capacity can be increased by as much as 20-25% (KnowPulp 2017). The HHV of dry lignin varies between 25-27 MJ/kg, thus it can be used as a rather efficient fuel. However, biorefinery companies are more interested in its diverse and higher value usage.

In the commercial LignoBoost extraction process of Valmet, lignin is precipitated with carbon dioxide to reduce the pH of black liquor from approximately 13 to 10 in the first stage (Figure 5). After the dewatering stage, the precipitated cake is dissolved again with sulphuric acid (H_2SO_4) and washing waters with a pH of 2 in the conditioning stage, and finally washed and once more dewatered.

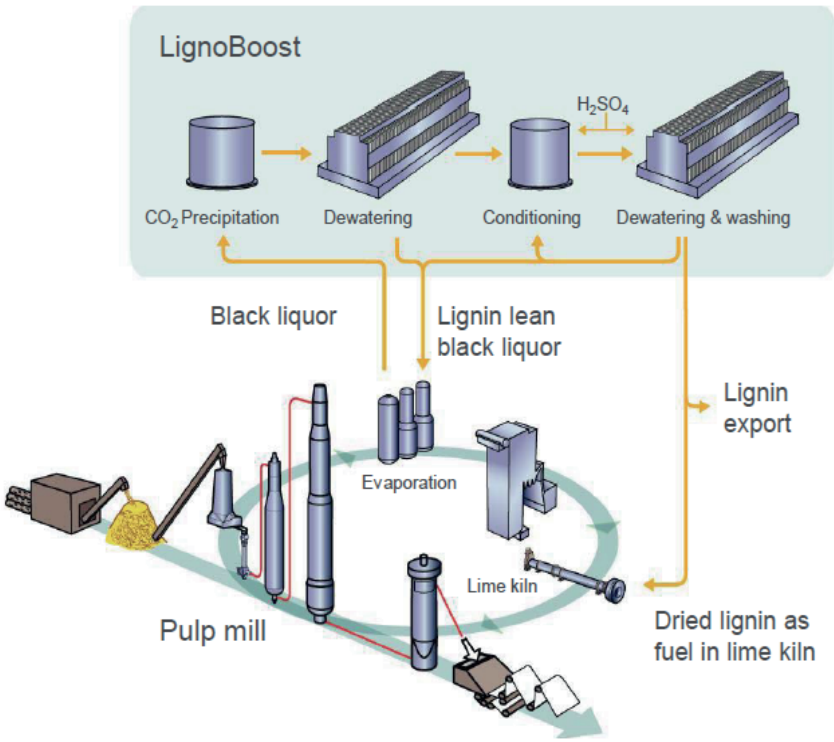

Figure 5. Lignin extraction connected to the evaporation plant (Mäntyniemi 2016).

StoraEnso's pulp mill in Kotka has been extracting lignin using the LignoBoost process since 2015 producing 50,000 tons of lignin annually. The production facility comprises lignin extraction, storage of moist lignin, drying of lignin, and storage of dry lignin. In the beginning, the produced lignin was used mainly as a fuel in the mill's lime kiln to replace natural gas in the combustion, thus reducing carbon dioxide emissions from the mill. Currently, also other potential usage for lignin is being examined.

4 SEVERAL MAIN PRODUCTS AND SUB-PRODUCTS FROM A MODERN BIOREFINERY

In modern biorefineries, the share of sub-products in the net sales may reach 20% and is increasing. In Figure 6, the product catalogue of a major modern biorefinery is presented. The MetsäFibre Biorefinery in Äänekoski started operation in 2017, and the production specifics are as follows:

- The main products are SW and HW pulp with an annual production of 1.3 tons in the fibre line.
- 640 GWh of bio-based heat and 1800 GWh of electricity is produced annually from the combustion of black liquor and process gases in the recovery boiler, and 550 GWh of bio-based energy can be sold to other users.

- Approximately 60,000 tons of tall oil and 2,000 tons of turpentine is produced.
- Bark is gasified and sludges fermented to serve as product gases and they are combusted in the lime kiln of the chemical recovery plant.
- Biopellets and biogas are produced during the treatment of wood-based and wastewater sludges. They are sold as fuels or used in the mill.
- Sulphuric acid (H_2SO_4) and methanol (CH_3OH) are extracted from the odorous gases in the fibre line and are used in the processes of the biorefinery.

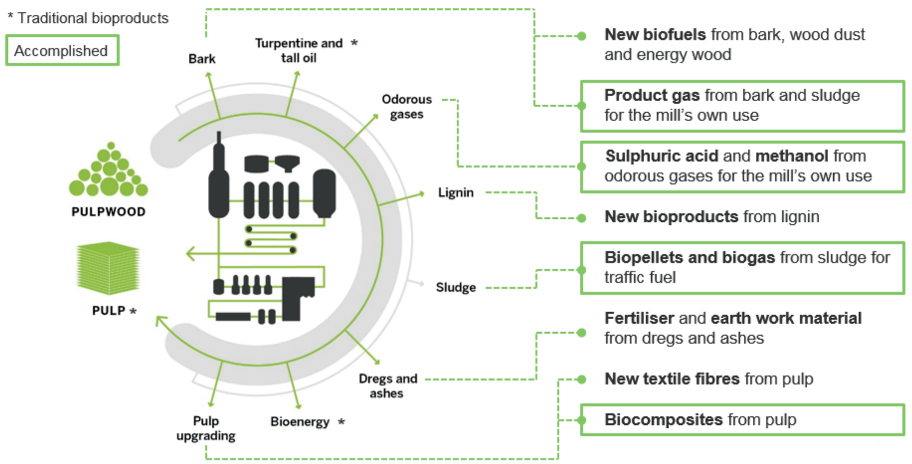

Figure 6. Main products and sub-products of a biorefinery (MetsäFibre b 2019).

MetsäFibre biorefinery company is looking to further improve the efficiency in the recycling of fibres and waters and in the recovery of chemicals and heat. The biorefinery is upgrading pulp to dissolved or similar grades to be used in new textile fibres. Also, the potential of lignin for new bioproducts is studied. (b 2019).

4 CONCLUSIONS

The circular economy in biorefineries is aiming at higher efficiency in the production processes and less emissions from these processes. Fibres and waters are recirculated, and chemicals and heat are recovered. Modern biorefineries focus on the usage of renewable energy sources, thus minimizing the impact of carbon dioxide emissions on nature. Interesting main products such as SW, HW and dissolved pulp grades and renewable energy are produced, and new sub-products from side streams are developed. Besides the efficient production of heat and electricity from the recovery boiler, the mill-scale manufacturing of energy-related products from the chemical recovery, such as biodiesel from tall oil and lignin extracted from black liquor in the evaporation station, are significant steps in the progress of upgrading traditional pulp mills to multi-product biorefineries.

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TECHNICAL VISIT TO BIOSAMPO RESEARCH FACILITIES AT ANJALA

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Mr. Juha Solio, Manager of BioSampo Research Centre, Forest, Environment and Energy, South-Eastern Finland University of Applied Sciences, Finland juha.solio@xamk.fi

ABSTRACT

The priorities of the Finnish bioeconomy strategy include creating a competitive environment for bioeconomy growth. This will be done by developing education and research. The goal of the government program for 2025 is to make Finland a top country for education, skills and modern learning. The importance of digitalisation is also increasing.

South-Eastern Finland University of Applied Sciences (Xamk) has research centres and laboratories and it operates and constantly develops novel and relevant research infrastructure and laboratories in order to support the national targets. Xamk also has a significant role in Kymenlaakso's regional development as a part leader of the implementation of the bioeconomy research and innovation strategy in smart specialisation (RIS3). BioSampo, bio and circular economy research centre, is one of Xamk's research units that is expanded towards development needs.

1 INTRODUCTION

South-Eastern Finland University of Applied Sciences (Xamk) is an innovative higher education institution that aims to prosper by being a strong, student-oriented international expert of applied research. Xamk has over 160 ongoing projects annually and a combined RDI budget of approximately EUR 48 million (5/2018). Based on external financing, South-Eastern Finland University of Applied Sciences is Finland's largest University of Applied Sciences in the field of RDI.

Xamk's RDI activities produce research data, new methods, products and services according to the needs of the region. The aim is to promote the sustainable wellbeing, business, expertise and competitiveness of the region by improving the conditions for regeneration, growth and entrepreneurship, as well as national and international innovations. Activities are guided by the EU, national and regional strategies and are carried out mainly through projects which are implemented in cooperation with different companies, organizations, universities, universities of applied sciences and research institutes both nationally and internationally.

The four RDI focus areas in Xamk are: digital economy; forest, the environment and energy; sustainable wellbeing and logistics; marine technology and transport. These are more specifically shown in the chart below (figure 1).

Forest, the Environment and Energy	Digital Economy	Sustainable Wellbeing	Logistics and Seafaring
New fibre products and processes	Digital information management and archiving	Data-based wellbeing services	Maritime safety
Environmental safety	User-orientation, visualisation gamification	Equality and empowerment of youth	Oil spill prevention and response
Renewable and efficient energy systems	Entrepreneurship and entrepreneurship education	Smart, user-centred food services	Port logistics and environments
Forestry and wood construction	Cyber security	Responsible tourism	Railway logistics
Material and circular economy			Transport systems

Figure 1. Xamk's focus areas in RDI.

Xamk also has research centres and laboratories and it operates and constantly develops novel and relevant research infrastructure and laboratories in order to support its RDI activities and projects, and to enable competence building. Educational, as well as test and measurement laboratories are important facilitators and sources for RDI activities. Research laboratories and centres also sell their services to external parties. The centres are located in or close to Xamk's campuses in Kotka, Kouvola, Mikkeli and Savonlinna.

Forest, the environment and energy focus area researches and develops new products, production processes as well as measurement and monitoring solutions for the fields of bio-economy, circular economy and technology industry. The focus area expertise and laboratories excel in the fields of bio-product and fibre technology, wastewater purification, environmental safety, wood modification and energy technology. Annually, the focus area cooperates with nearly 400 companies in research and development projects and commissioned projects as well as through piloting and analysis services. **BioSampo** is located in Kouvola, at a village called Anjala, and is one of Xamk's Research Centres, focusing on bio and circular economy.

2 XAMK'S BIO AND CIRCULAR ECONOMY RESEARCH CENTER BIOSAMPO

The Research Centre BioSampo moved to the South-Eastern Finland University of Applied Sciences from Kouvola Region Vocational College (KSAO) in August 2017. A new research unit strengthens the development of polytechnic education in the fields of forest, environment and energy in RDI activities.

BioSampo's activities have been developed from a learning environment into that of applied research. Laboratory exercises are also provided for the students of the University of Applied Sciences, without forgetting collaboration with the students of the vocational college. BioSampo is located in the area of Kouvola, but it is halfway between Xamk's campuses Kotka and Kouvola (figure 2).

Figure 2. BioSampo's location (marked as a red dot).

2.1 TRAINING AND APPLIED RESEARCH IN THE FIELD OF ENERGY, BIO AND CIRCULAR ECONOMY

Digital learning environment and expanding field of RDI activities

BioSampo's operations are increasingly focused on the circular economy and finegrained wood materials and processes needed in their utilization, for instance. Slow pyrolysis plays a major role in BioSampo.

Smart grids and "Iot" remote access systems are the new operating environments. Decentralised electricity energy production and the development of CHP energy units and laboratory operations, together with the use of electricity control and storage methods, will enable the digital learning environment, and the enlargement of RDI activities in BioSampo.

The main building of BioSampo features a class room and space for equipment and research(ers). The biogas plan and patchtype slow pyrolysis process equipment are located close by the main building.

Figure 3. BioSampo main building (photo by Eveliina Kuokkanen, 2017).

Fraction technology research centre as part of BioSampo

Xamk RDI activities are strongly expanding in South-Eastern Finland and the activities of circular economy and energy are concentrating on the vicinity of BioSampo. An example of this is that the fraction technology research centre became a part of BioSampo, when the technology from Kotka was moved to the charcoal hall of BioSampo. In the fraction technology research centre, ashes from industry and power plants are treated. One of the upcoming objectives is to micronize ash and charcoal.

The charcoal hall is located about 200 meters from main building of BioSampo. There is plenty of space for equipment, and it provides the opportunity to expand actions at BioSampo without additional buildings.

Figure 4. Charcoal hall (photo by Eveliina Kuokkanen, 2017).

Activities are being developed mostly with external funding, therefore, funding for development is sought e.g. from the EU as well as from national and international sources. Partner networks are extended all the time.

4 CONCLUSIONS

The objective of the Finnish Bioeconomy Strategy is to generate new economic growth and new jobs from e.g. high added value products and services. The leading idea of the strategy is that competitive and sustainable bioeconomy solutions for global problems will be created in Finland, and that new business will be generated both in the Finnish and international market, thus boosting the welfare of the whole of Finland. (Sustainable growth from bioeconomy 2014, 17.)

At BioSampo Research Centre there is an ambitious target to develop new methods and processes to exploit various wastes and side streams and turn them into more valuable materials, for example by separating elements and materials or processing thermally to give materials added value and/or enable reuse.

Nevertheless, the most valuable fact is to systemically and continuously develop the chosen activities and methods together with different coalitions to achieve sustainable solutions to resolve problems of today and the future.

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Technical visit to BioSampo research facilities at Anjala. Kirsi Tallinen and Juha Solio. Slides shown in seminar: Circular Economy in Bioproduct Industry in 13.3.2018 at Xamk BioSampo.

APPENDIX 1

Circular Economy in Bioproduct Industry

March 13th, 2018 Xamk in Kotka, Auditorium A1004

7.53	Arrival of our Russian guests at Kouvola and transfer to Kotka, Ms. Merja Mäkelä St. Petersburg Power Engineering Institute of Professional Development (PEIPK)
9.15-9.30	**Opening of the seminar** Seminaarin avaus Ms. Merja Mäkelä, Principal Lecturer, Automation of Energy Technology
9.30-10.00	**Circular Economy in the Finnish Bioproduct Industry** Kiertotalous suomalaisessa biotuoteteollisuudessa Dr. Lasse Pulkkinen, Research Director, Forest, Environment and Energy, Xamk
10.00-10.30	**New Start-up and Maintenance Technologies of Energy Industry Machinery in Russia** Energiateollisuuden laitteistojen uudet käyttöönotto- ja kunnossapitoteknologiat Venäjällä Prof. Dr. Aleksandr Nikolaevits Nazarytsev, Rector, Peipk Institute
10.30-11.00	Coffee break and networking
11.00-11.30	**Development of Renewable Energy Production in Russia and Globally** Uusiutuvan energiatuotannon kehitys Venäjällä ja maailmassa Mr. Sergei Jurevits Tsekmarev, Faculty Director, Peipk Institute
11.30-12.00	**Digitally Estimated Costs of Energy Production** Digitaalisesti arvioidut energiantuotannon kulut Mr. Aleksandr Matjevits Bondar, Faculty Director, Peipk Institute
12.00-12.30	**Renewable Energy from Chemical Recovery of Biorefineries** Uusiutuvaa energiaa sellutehtaiden kemikaalikierrosta Ms. Merja Mäkelä, Principal Lecturer, Automation of Energy Technology, Xamk
12.30-14.00	Lunch at the university restaurant in Kotka
14.30-16.00	**Technical visit to Biosampo research facilities at Anjala** Vierailu Biosampo-tutkimusyksikköön Anjalassa Ms. Kirsi Tallinen, Research Manager, Forest, Environment and Energy, Xamk Mr. Juha Solio, Research Manager, Forest, Environment and Energy, Xamk

XAMK
DEVELOPMENT