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POTENTIAL OF BIOMASS IN NARVA REGION REGARDING OIL SHALE AND BIOMASS CO-FIRING

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Estonia had obligation to EU to use 5.1% of renewable power (from the total consumption) by the end of 2010. This obligation could be reached mainly by introduction of new co-generation power plants on the basis of biomass (Tallinn, Tartu, Pärnu), with expanding power production from the wind, but also by co-firing Estonian oil shale (OS) and biomass (BM) at large oil shale power plants in Narva region. The essential precondition of co-firing of BM and OS in boilers of Baltic and Estonian power station is availability of sufficient quantities of bio fuels in the neighbourhood. In Estonian conditions the most promising biomass for co-firing is wood fuel, but due to availability of abandoned agricultural lands in the North-Eastern part of Estonia short-rotation forestry (willow, grey alder etc.) or plantations of energy crops and wetland plants may play considerable role, too. During 2009/2010 about 200000 tons of wood chips and about 10 million tons of OS were used for power production in Narva power plants already [1]. In the context of OS and BM co-firing at large OS boilers two aspects should be analysed. The first question is related to possible technical problems of co-firing, and the second one concerns BM resources available in the North-East region of Estonia. These two problems are analysed in the paper. It was concluded that co-firing of pulverized OS and BM (up to BM content in the blend of 15% by mass) does not have any considerable negative effect on the normal operation of boiler while reducing environmental emissions. Wood and other BM resources will cover relevant need for BM at the distance of 100 km from the power plants.

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Introduction

Existing domestic sources of energy offer a considerable strategic independence as for electricity supply (the share of imported energy sources in Estonia accounts for approximately a third, in the EU Member States on average for two thirds). The main positive sides of the large-scale use of oil shale are the reliability of national energy supply and independence from the world market. Large-scale environmental damage caused by oil shale mining as well as the use thereof, and also low calorific value of oil shale can be pointed out as the drawbacks. The share of oil shale in the balance sheet of primary energy production is significantly affected by the export volume of electricity – the bigger the export of electricity, the bigger the share of oil shale in the primary energy balance sheet. Estonian electricity market has been oriented to one type of fuel – almost 94% of all electricity is produced from oil shale and the share of other fuels is modest. The structure of fuel consumption for the electricity and heat production at power plants has been relatively the same since 2003 [2]. From 2009 the share of wood fuels in power production is on the upgrade.

The calculation was carried out concerning theoretical potential of woody biomass from forests (traditional fuel wood, harvesting residues and stumps), non-forest lands (traces of drainage and power lines), short rotation forestry (as an alternative for utilization of abandoned agricultural lands), semi-natural grasslands and wetlands. Also other scenarios of utilization of abandoned agricultural lands were estimated. Finally the present consumption of biomass by other consumers (boiler houses, farms and single family houses) were taken into account to present the available biomass resources by zones (zone I up to 50 km from Narva, zone II 50–100 km and zone III more than 100 km) in the reasonable distance from Narva.

In this paper the attention has been paid to common reed from wetlands and hay plants from semi-natural grasslands, most perspective natural energy crops in Estonia. Determination of sustainable resources, fundamental characteristics of combustion and estimation of energetic potential of reed and other grasses available in a given territorial context are presented. In Estonia the harvestable amount of reed is 90.2 thousand tons per year with energy content of 0.36 TWh/y. Average productivity of reed as received is 8 t/ha in Estonian wetlands. The area of semi-natural grasslands is estimated to be 50 000 ha with total primary energy content 0.9 TWh/y of several hay species.

The easiest way of BM co-firing is to add crushed BM to the main fuel (fossil fuel, wood, etc.) as additive. For instance, in Finland crushed *reed canary grass* is feeded to the furnace of wood or peat boilers in amount of up to 10-15% from primary energy, but only to fludized bed boilers. There is limited data available about BM co-firing at pulverized fossil fuel boilers.

At Narva Power Plants only two large CFB power units (2×215 MW_{el}) are operating, which warranty terms have limited co-firing OS with other fuels. Because of that co-firing BM with OS at PF boilers is actual as well.

Usual problems arising with BM co-firing are related to fuel mixing, preparation and feeding, behavior and handling of the ash – deposit formation, clogging due to lower melting temperature of ash and to the need of additional cleaning of heating surfaces. Co-firing of OS and BM presumes competence in firing low-grade fuels of complicated composition and forseeing/unterstanding of potential technological problems [3, 4].

Potential of biomass in the neighborhood of Narva

Woody biomass from the forests

For estimation of the potential resources of forest biomass the forest inventory data from the State Registry of Forest Data and data about soil quality were used. The layers of Estonian Base Map, Estonian Basic Map, Estonian Digital Soil Map, digital forest maps from the State Registry of Forest Data and area maps of rural municipalities were exploited for spatial analysis.

At first the map layers were analysed to determine the areas described by the reliable forest inventory data in the State Registry of Forest Data. For the rest of the areas the necessary forestry data had to be created via modelling by using the databases of State Registry of Forest Data and Digital Soil Maps. Combining this data gave the specific forestry data in correlation with the soil type. For the areas which were not covered by the polygons of soil map, the average forest data was used. The traditional forest inventory in Estonia is focused on industrial wood and does not include information about forest residues. In the present study these residues were also included [5].

In order to estimate the total energy potential of wood fuels, the woody biomass from non-forest areas (traces of power lines, drainage traces, roads, etc., parks, orchards, etc.) should also be taken into account in addition to the resources from forests. Electric power lines and drainage traces, protection zones of which should be cleared periodically are additional sources of woody biomass. Though these residues are dispersed and therefore collection and processing of them is not feasible today, it may become attractive in the future. Therefore in the present study the energy potential of these areas was added to the energy potential of forest lands. The calculated annual yield of biomass from the forests regarding the regimes of protection is presented in Table 1.

Table 1. **Long-term average annual yield of forests in the neighborhood of Narva, GWh**

	Zone I up to 50 km from Narva	Zone II 50–100 km from Narva
Pulpwood	174.3	550.9
Firewood	79.0	230.7
Harvesting residues	95.7	299.1
Stumps of coniferous trees from final felling	28.3	92.5
Total production of woody biomass	377.3	1173.2
Total production of wood fuel*	202.9	622.3

* fire wood, harvesting residues, stumps of coniferous trees from final felling

Biomass from the abandoned agricultural lands

Since the restoration of independence in 1991 a rapid decline in agricultural land use has occurred in Estonia [6], and now these areas are available for bio-energy production. As the decline in arable land use was regionally variable, precise location-specific analysis is needed to determine the bio-energy production capacity on abandoned areas.

The study identified abandoned field parcels using the Estonian Basic Map (1:10,000) and field layer of Agricultural Registers and Information Board (ARIB) and databases of Common Agriculture Policy (CAP) payments in 2007. The field parcels without any applications for single area payments were considered entirely abandoned, and parcels where area payments covered 50–99% of the total area – partially abandoned. Agricultural areas outside of ARIBs fields were estimated also as entirely abandoned and determined from Estonian Basic Map. For that field layer of ARIB fields was cut out from Estonian Basic Map. Remaining agricultural areas were thereafter cleaned topologically – eliminated were areas less than 0.3 ha and areas with perimeter-area ratio over 5, visual assessment and manual correction of area boundaries based on ortho-photos was carried out. These approaches enabled to eliminate small unsuitable areas for bioenergy crops for further analysis. The total agricultural land in zone I up to 50 km from Narva included for analysis was 10,037 ha (5,467 ha ARIB fields and 4,570 ha from basic map) and 35,999 ha (24,514 ha ARIB fields and 11,485 ha from basic map) in zone II 50-100 km from Narva. The abandoned areas for potential bio-energy production were evaluated using willow (*Salix* ssp), grey alder (*Alnus incana* (L.) Moench), hybrid aspen (*Populus tremuloides* Michx. x *Populus tremula* L.), reed canary grass (*Phalaris arundinacea* L.), and Caucasian goat's-rue (*Galega orientalis* Lam.).

The estimated abandoned land was further planned depending from soil suitability analysis to potential energy crop production for combined land use strategy. The combined land use strategy for the re-use of the abandoned land was considered as follows – 1/3 remains in natural conditions (biomass yield for natural grassland 2.0 t DM/ha), 1/3 energy grasses (50% reed canary grass and 50% Caucasian goat's-rue) and 1/3 short rotation forestry (1/3 for each plantation). For analysis the annual dry matter productivity was considered to be 5.9 t ha^{-1}, 6.4 t ha^{-1} for grey alder, 6 t ha^{-1} for hybrid aspen, 8 t ha^{-1} for reed canary grass and 7 t ha^{-1} for Caucasian goat's-rue. Conversion of the abandoned land potential to a bio-energy potential was based on the methodology presented by Kukk *et al.* [7]. The results of the calculation are presented in the following Table 2.

Table 2. **Potential biomass from abandoned agricultural lands in the reasonable distance from Narva**

Parameters	Zone I up to 50 km from Narva	Zone II 50–100 km from Narva
Agricultural areas excluded from the ARIB's fields, ha*	4 570.0	11 484.9
Abandoned agricultural areas, ha	5 467.0	24 514.2
Potential biomass production from natural grasslands, GWh	31.6	99.7
Potential biomass production from abandoned agricultural lands, GWh**	135.2	651.2
Total biomass production, GWh	166.8	750.9

* ARIB – the Agricultural Registers and Information Board

** 1/3 natural grassland, 1/3 energy grasses and 1/3 short rotation forestry

Results and discussion

Biomass resources

According to the calculations the total annual yield of merchantable wood and different assortments of wood fuel in zone I up to 50 km from Narva is 337.4 thousand m^3 and 1 079.4 thousand m^3 in zone II 50-100 km from Narva. As a potential wood fuel the traditional firewood, harvesting residues (mainly tops and branches) and the stumps from the final felling were taken into account, and the total yield of wood fuel from zone I was estimated to be 202.9 GWh and 622.3 GWh from zone II (Table 1). In the situation of the decline of utilization of pulpwood by the wood processing industry, this resource can now be considered an addition to the wood fuel potential. Therefore the total potential of woody biomass including pulpwood is also presented in Table 1. Utilization of this potential depends on the wood market and probably is not sustainable in the long run.

Balance of supply and consumption of biomass

Finally the present consumption of biomass by other consumers (boiler houses, farms and single family houses) and the potential consumption by new designed Ahtme and existing Sillamäe and Narva co-generation blocks were taken into account to analyze the supply-demand balance of biomass in the neighbourhood of Narva. As an initial data it was assumed that the consumption of wood fuel by the new designed Ahtme co-generation plant (total capacity 74 MW) will be 515 thousand m^3_{loose}/a and 300 thousand m^3_{loose}/a by the co-generation block of Narva power station (calculated by wood and oil shale ratio 1:10 on the basis of mass percentage approximately the same like persentages by net calorific value). The results of the calculation (Table 5, Fig. 1) indicate that the resources of wood fuel in the zone up to 100 km from Narva are sufficient to cover the present need for biomass.

But to cover the needs of new co-generation stations of Ahtme and Narva, also the bio-energy potential of abandoned agricultural lands and natural grasslands should be implemented.

Table 5. **Potential balance of supply and consumption in the neighbourhood of Narva, GWh**

Parameters	Zone I up to 50 km from Narva	Zone II 50–100 km from Narva
Potential biomass production from natural grasslands and abandoned agricultural lands	166.8	750.9
Potential yield of wood fuel	202.9	622.3
Present consumption of wood fuel	6.8	290.8
Potential consumption of wood fuel in co-generation stations of Ahtme, Sillamäe and Narva	659.0	–
Balance	–296.1	1082.4

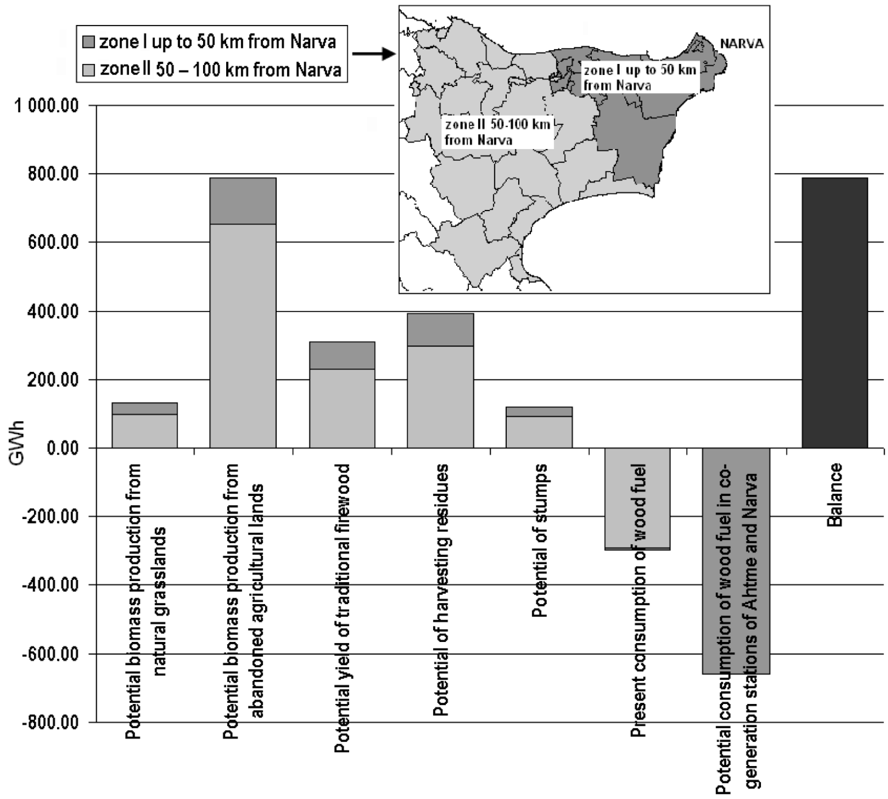

Fig. 1. Supply-demand balance of biomass in the neighbourhood of Narva.

The results of the spatial analysis of the location of biomass resources are presented in Fig. 2. The data indicates that most of the resources are located further than 50 km from Narva. Due to the considerable transport distance the price of biomass is expected to be high in this case.

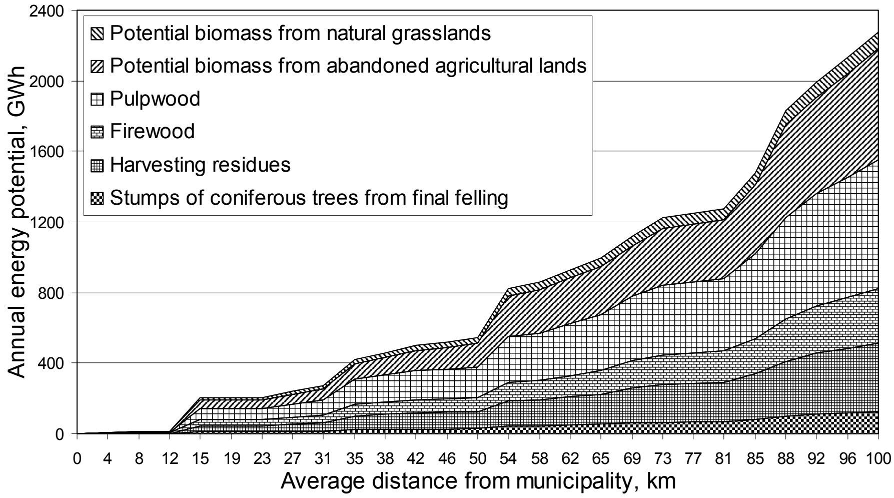

Fig. 2. Theoretical potential of biomass within the 100-km radius from Narva.

Oil shale and biomass co-firing tests at Sillamäe PP

Following the interest of reduction of air emissions and getting the state support for the power production from the renewables, Sillamäe PP initiated a relevant research project of testing OS and BM co-firing in spring 2009. Co-firing tests with OS and BM as sawdust and wood wastes were carried out at pulverized-fired (PF) boilers TP 35 of Soviet origin. Pure OS and three different fuel mixtures (by mass %) were fired – 95% OS + 5%BM, 90% OS + 10% BM, 85% OS + 15% BM. Fuel blends were prepared beforehand by mechanical mixing of fuel components at the storage area. The boilers were operated at maximum possible load of about 30 MW_{th}. The aim of the tests was to determine the influence of BM addition on the operation of boiler equipment, ash behavior and air emissions.

One test run lasted about 4–6 hours and during that time boiler operation parameters were registered periodically, fuel and bottom ash sampling was provided. Flue gas composition and parameters were determined after the three field electrostatic precipitator (ESP) before the flue gas fans. Online analyses of gaseous components with FTIR spectrometer (O_2, CO, CO_2, H_2O, NO_x, SO_2,), periodical measurements of other flue gas parameters (temperature, velocity, pressure) and sampling of fly ash (TSP, PM2.5/10) were made.

Addition of BM with higher moisture content (52.6%) and lower LHV (7.38 MJ/kg) resulted in the change of LHV of fired fuels from 9.64 MJ/kg for pure OS to 9.30 MJ/kg for the blend with 15% of BM (Fig. 3). With more BM in the blend, boiler thermal capacity dropped because of lower bulk density of BM, therefore higher fuel volumes and fuel feeders limited the operating capacity. Higher moisture content of the mixed fuels was also the reason why flue gas flow rate and temperature after the ESP almost did not change.

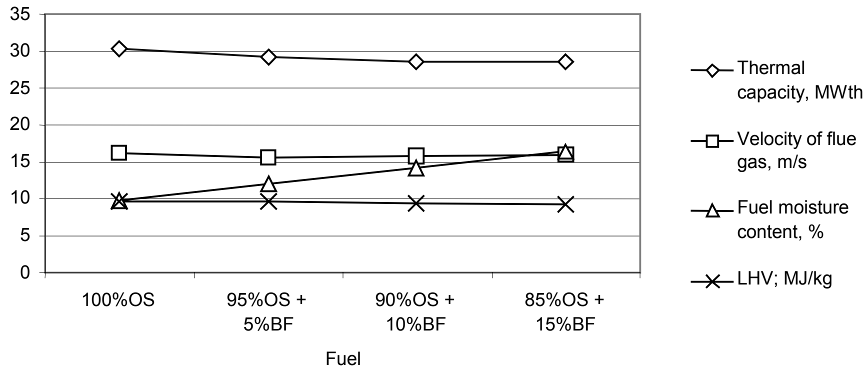

Fig. 3. Characteristic parameters of the tests.

According to the PP personnel observations, no deviations from ordinary behavior of boilers at firing OS and BM mixtures were noticed. The only important observation concerned bottom ash, where some unburned BM particles were found and little slagging of the particles was noticed. Since problems of slagging are wellknown problem at firing of different biomasses [3, 4, 8], melting properties of the ash of fuel blends were investigated. Ashing of tested fuels in laboratory conditions was provided and melting behavior of obtained ashes was studied. A high-temperature microscope with temperature raising rates in the most critical region of about 3 deg/min in oxidizing atmosphere was used.

Results of the laboratory study supported the observation about slight slagging tendency of BM added blend ashes (Fig. 4). For OS ash flow temperature (FT) up to 1400 °C was not reached and the respective hemisphere temperature (HT) value was 1300 °C. Beginning from 10% content of BM in the blend relevant HT and FT values of 1280 and 1290 °C were registered. It is important to mention that conventional furnace temperatures of pulverized-fired OS reach 1400–1450 °C. It is quite possible that slagging of BM-OS fuel blends ash was not revealed in full scale during this relatively short time of tests and it should be checked additionally during a longer period.

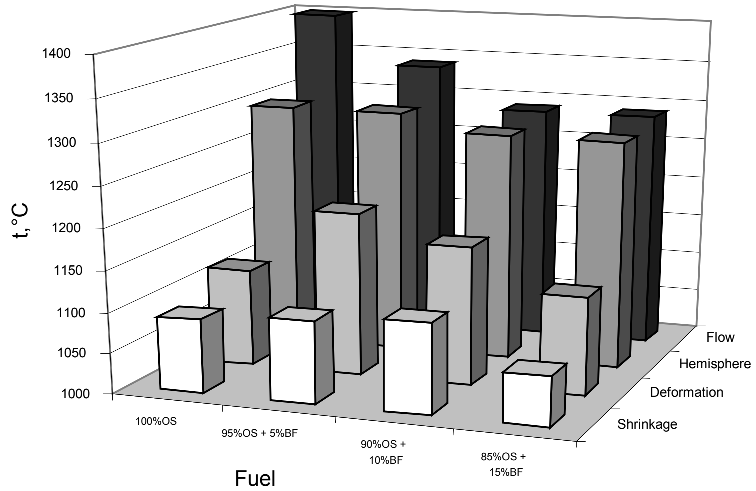

Fig. 4. Melting properties of the ashes of fired fuels.

Main flue gas emissions (SO_2, NO_x, CO, TSP) remain at the same level with data known from former studies of firing Estonian OS (Fig. 5) [9]. Smooth maximum of SO_2 curve can be explained with changes in the sulphur and mineral matter content of blends (CaO and MgO) which have an effect on ash sulphation process. The raise of NO_x is not significant and is propably caused by higher N content of BM. Fly ash content of flue gas (TSP) decreases almost correspondingly to the changes in overall ash content of the blends. Taking into account almost 100% calcination of carbonates contained in OS at pulverized firing [10] and zero CO_2 emission at firing BM decrease in CO_2 emissions in firing blend with 15% BM is about 14.5%.

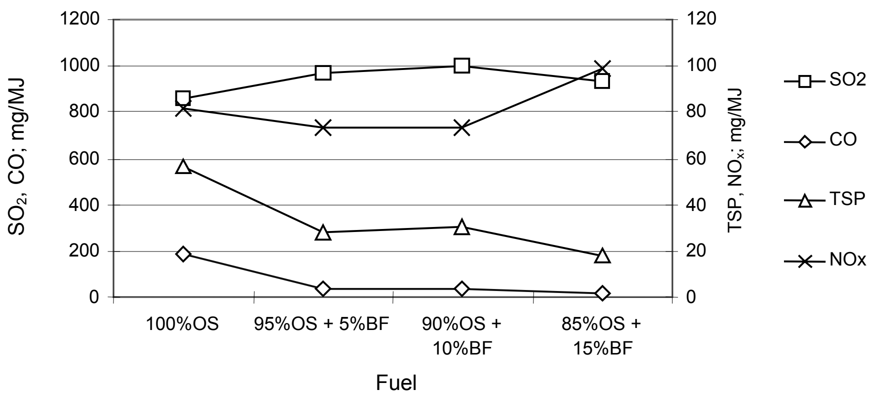

Fig. 5. Emission factors of main air pollutants for tested fuels.

Short term tests of OS and BM firing at Sillamäe PP revealed that moderate addition of BM (e.g. up to 15%) has no negative effect on boiler equipment operation even in relatively high temperature conditions of pulverized firing (1400–1450 °C). If the existing fuel preparation and feeding system without suitable upgrading is used, some capacity loss from BM lower bulk density and higher moisture content must be considered.

At co-firing of OS and BM emissions of solid particles and CO_2 are lower and respective economical benefit from lower environmental taxes and CO_2 quota plus state support for renewables-based power production can be achieved. Total feasibility of BM co-firing depends also from BM availability and price in the region.

Based on the melting characteristics of the tested OS and BM blend ashes, no harm from additional deposit forming or clogging should happen in the case of woody BM blends combustion at CFB boilers, in which furnace temperatures are much lower (750-850 °C) and burning conditions of relatively wet BM are much better thanks to longer residence time of fuel particles in the combustion zone.

Behavior of some biomass ashes in combustion processes

In the case of co-firing of other than wood-based BM additional risks of deposit formation and clogging should be taken into account [3, 4, 8].

The main chemical component of reed ash is SiO_2, whose average content is 77.8%. The minimum and maximum content of sulfur and chlorine of reed as the most well-known corrosion promoters can differ depending from growing places approximately four times. The content of sulfur and chlorine of hay plants from semi-natural grasslands is considerably higher and suggestions to avoid corrosion problems are given.

Essential chemical components of reed ash affecting ash-fusibility temperatures are CaO, K_2O and Na_2O. It is important to mark that the summer reed ash fuses at temperature lower than 1200 °C, the initial deformation takes place at temperatures below 800 °C. On the other hand, ash of the winter reed does not fuse even at 1350 °C. We are able to state that average ash-fusibility temperatures for summer and winter reed ashes differ by 200 K. This points out that reed as fuel for boilers must be to harvested in winter certainly, when the nutrients and minerals have left to the roots and leaves have fallen. Fusibility characteristics of the ash of reed and wood fuels mixtures may differ substantially (up to 200 K), according to the share of each component.

Conclusions

- Majority of forest and agricultural lands belong to private owners and serious efforts should be made to involve these owners in production of biomass to supply the potential new consumers in the region.

- The most of the resources is located more than 50 km from Narva. Due to the considerable transport distance the price of biomass is expected to be high in this case.
- The total yield of wood fuel from zone I (up to 50 km from Narva) was estimated to be 202.9 GWh and 622.3 GWh from zone II (50–100 km from Narva). Utilization of this potential depends on the wood market and probably is not sustainable in the long run.
- Properties of biomass-based fuel and combustion tests showed that these are promising renewable energy sources, and their adding as surplus fuel to oil shale could make the combustion of fossil oil shale more environmental-friendly and reduce the CO_2 emission.
- Up to 15% (by mass) addition of BM to OS had no negative effect on the PF combustion process and boiler operation during short-term tests. Reduction of emissions of CO_2 (~14.5%) and solid particles (~3 times) took place.
- The best choice for the large scale co-firing of OS and BM are the CFB boilers of Narva Power Plants, because of much lower furnace temperatures compared with PF firing.

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