Oil Shale, 2005, Vol. 22, No. 4 Special
pp. 369-379
ISSN 0208-189X

https://doi.org/10.3176/oil.2005.4S.01

POTENTIAL OF BIOMASS FUELS TO SUBSTITUTE FOR OIL SHALE IN ENERGY BALANCE IN ESTONIAN ENERGY SECTOR

A. PAIST[(a)], Ü. KASK[*(a)], L. KASK[(a)]
A. VRAGER[(a)], P. MUISTE[(b)]
A. PADARI[(b)], L. PÄRN[(b)]

[(a)] Department of Thermal Engineering
Tallinn University of Technology
116 Kopli St., 11217 Tallinn, Estonia
[(b)] Estonian Agricultural University
5 Kreutzwaldi St., 51014 Tartu, Estonia

Oil shale gained its leading role in the energy balance of Estonia already before the Second World War – in 1934 the share of oil shale in total industrial consumption was 56.8%. Though the total energy consumption has grown since that time remarkably, the share of oil shale has remained the same – in 2003 it was 60%. In the modern world environmental protection issues substantially influence the energy sector. Estonia has also ratified several international conventions – United Nations Framework Convention on Climate Change in 1994, Kyoto Protocol to the United Nations Framework Convention on Climate Change in 2002 and Convention on Long-range Transboundary Air Pollution and the Protocol to the Convention in 2000. In accordance with these agreements Estonia has declared the commitment to increase the share of renewables in electricity production up to 5.1% by the year 2012. More extensive utilization of biofuels for energy production has been pointed out also by the Long-term Development Plan for the Estonian Fuel and Energy Sector and the Estonian Forestry Development Programme 2001–2010. Successful implementation of these programmes will decrease the consumption of oil shale and the level of pollution. Based on the presented data it was concluded that though there is the huge unutilized potential of biofuels and peat, these resources are limited and can cover probably less than 20% of the energy need which is today covered by oil shale based fuels. It means that for the coming decades oil shale will remain the main fuel for electricity production, and the renewable biofuels only will support the decentralization of electricity production in rural areas.

[*] Corresponding author: e-mail *ykask@staff.ttu.ee*

Introduction

The fuel and energy sector is a strategic infrastructure of the state which must ensure that Estonia has an uninterrupted supply of high-quality fuel, electric energy and heat at optimal prices. At the same time the fuel and energy sector must be as efficient as possible and comply with the safety and environmental requirements. The sustainable fuel and energy sector is one of the bases for national security [1].

Oil shale gained its leading role in the energy balance of Estonia already before the Second World War and though the total energy consumption has grown remarkably since that time, oil shale has remained the dominating fuel. Today Estonia has also ratified several international conventions – United Nations Framework Convention on Climate Change in 1994, Kyoto Protocol to the United Nations Framework Convention on Climate Change in 2002 and Convention on Long-range Transboundary Air Pollution and the Protocol to the Convention in 2000.

In accordance with these agreements Estonia has declared the commitment to increase the share of renewables in electricity production up to 5.1% by the year 2010. More extensive utilization of biofuels for energy production has been pointed out also by the Long-term Development Plan for the Estonian Fuel and Energy Sector and the Estonian Forestry Development Programme 2001–2010 and Long-Term Public Fuel and Energy Sector Development Plan until 2015. Successful implementation of these programmes would decrease the consumption of oil shale and the level of pollution caused by burning of oil shale for energy production.

Recently Estonia has started to look an alternative for oil shale, which is the most important source of energy nowadays. Biomass will be one of the most essential renewable sources of energy in the future like it will be in many other countries. The aim of the paper is to analyze the potential of different biomass fuels to substitute oil shale in energy balance of Estonia. Fulfillment of the Estonian strategic objectives in energy [1] is based, among other things, on the following principle: Formation of the state fuel policy is based on the need to increase the importance of domestic renewable fuels in the energy balance, at the same time taking account of the principle of economic rationality and security of supply.

The Role of Oil Shale in the Energy Balance of Estonia before the Second World War

In the beginning of the 1920's, when Estonia had just gained the independence, the industry was based on wood fuel as it was the cheapest and widely available one. For example, 87.9% of the consumed fuels were wood in 1920 (Table 1). During the next few years the structure of fuel consumption changed dramatically. The consumption of wood started to

decrease, both the share and the total quantities, and the importance of oil shale increased (Fig. 1). In 1920 the share of oil shale and shale oil in total industrial consumption was only 3.3%, but by the year 1934 it had reached 56.8%.

Table 1. **Relative Importance of Different Fuels in Total Industrial Fuel Consumption [2]**

Fuel	1920	1924	1928	1934
	Share, %			
Firewood	87.9	32.3	22.3	18.9
Peat	4.6	13	8.9	10.6
Coal	2.3	25	23	11.2
Oil shale and shale oil	3.3	26	42.6	56.8
Other fuels	1.9	2.8	3.2	2.5
Total	100	100	100	100

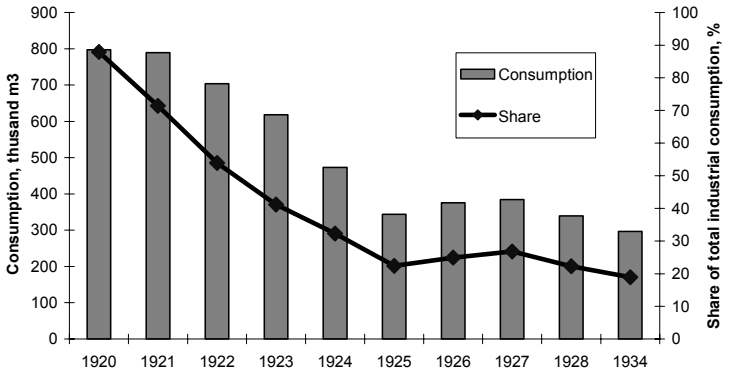

Fig. 1. Quantity of wood fuel used by industry [2]

Similar changes took place also in railway transport. In the beginning of the 1920's about 90% of the consumed fuels was wood, and it dropped to the level of 3.6% by the year 1935/36 (Table 2). Oil shale (48.9%) and shale oil (46.7%) had become prevailing fuels.

Table 2. **Fuels Consumed by Railway Engines in 1935/36 [2]**

Fuel	Volume	Share by primary energy content, %
Firewood, m^3	14,127	3.6
Oil shale, t	76,829	48.9
Shale oil, t	18,341	46.7
Gasoline, t	252	0.6
Light fuel oil, t	63	0.2

Differently from the industrial sector the supply of individual heating systems remained conservative – any changes took place. By the year 1934 wood was still the prevailing fuel, and only 4% of the total energy need was covered by peat and oil shale (Table 3). We can draw the conclusion that oil shale achieved an important

position in total energy supply because of the changes in industry sector, and it was not influenced by the behavior of private consumers.

Table 3. **Estimated Consumption of Firewood for Household Purposes in 1934 [2]**

Administrative unit	Number of inhabitants	Number of dwellings	Number of flats	Share of fuels in total fuel requirement, %		
				Logs and shrub	Wood waste	Peat and oil shale
Towns	323,007	30,935	102,376	80	15	5
Boroughs	26,819	4,693	8,492			
Rural communes	776,587	156,392	179,388	80	17	3
Total	1,126,413	192,020	290,256	80	16	4

Resources of Oil Shale

The proportion of domestic energy resources in the Estonian energy resources and in the balance of primary energy is high and mostly based on oil shale. It offers a considerable independence as regards electricity supply (the proportion on domestic energy sources is 2/3 in Estonia but on average 1/3 in EU Member States). The main positive sides of the large-scale use of oil shale are the security of supply for the state energy sector and the relative price independence from the world market [1].

In 2003, the supplies of primary energy were 210.8 PJ, oil shale formed 64.7% and wood and peat together 10.8%. The share of renewable energy sources was approximately 11%, of which wood fuels formed the main part.

Estonian oil shale resources were classified in 1997 basing on cut-off-grade (principal values are presented in Table 4). These classification principles were developed basing on combustion techniques used in oil shale power stations, taking into account Estonia's and world's energy economy trends.

Tabel. 4. **Resources of Estonian Oil Shale Deposit on 01.01.2002, billion t [13]**

Source category	Amount	Share, %
Active, economic mineable reserve, bed operating ratio of energy over 35 GJ/m^2, sufficiently explored	1.167	23
Active reserve, over 35 GJ/m^2, insufficiently explored	0.299	6
Passive reserve, 25–35 GJ/m^2	3.509	71
Totally in register	4.975	100
Content of passive reserve:		
on account of environmental restrictions	1.3	26
in protective pillars	0.2	4

The reserves estimated in 1997 were allocated into nine mining fields and fourteen exploration fields basing on cut-off-grade (limiting conditions) and environmental restrictions. Estonian field contains 4.975 billion tons of oil shale in the beginning of this year basing on the information from State Register of Mineral Resources (Table 4).

Estimation of the Potential of Oil Shale for the Future

As oil shale is the strategic energy source of Estonia, economic and environmental and also social policy and security aspects must be taken into account when its use (power industry and chemical industry) and volumes are planned. During the period under review (until 2015), the proportion of oil shale in the balance of the primary energy of Estonia decreases yet remaining, the main energy resource. At the moment, the conclusions of the oil shale resource adequacy assessment are the following [13].

- At the current volume of consumption (12 mln t/y), the active supplies of the operating mines and quarries will last until 2025. If the volume of consumption does not decrease, in approximately twenty years new mines must be opened and, if the volume of consumption increases, new mines must be opened already sooner.
- At the current volume of consumption, the total active supplies of oil shale will last for sixty years calculated on the basis of the technical-economic conditions of power stations [3].

Utilization of Biomass Fuels

After re-establishment of political independence of Estonia in 1991 it became essential to gain also the economical independence. At that time the substantial part of fuels was imported, and one of the priorities was the reduction in imports of fuels. The most natural solution was the substitution of imported fuels by domestic biofuels, and then the program of conversion of boilers was started.

The success was obvious only a few years later (Fig. 2), and now the share of wood fuels in total primary energy supply has stabilized on the level of 11% and peat on 2% [4, 5]. The role of renewables (biomass, biogas, hydro, wind, etc.) is not considerable in electricity production (about 0.4–0.5%), but is important in heat generation in boiler houses (wood fuels and biogas 29%, peat 4% on 2003 [6]). The presented data indicates that oil shale is still the main fuel.

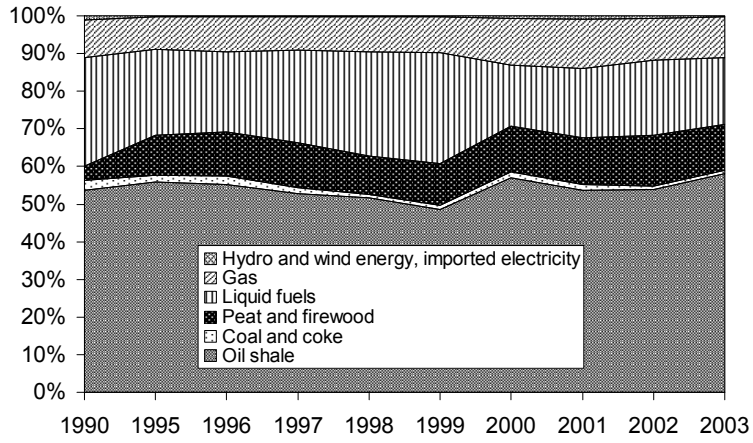

Fig. 2. The share of different fuels in the energy balance of Estonia [4, 5]

Accessibility of Biomass Fuels in the Future

Wood

According to the latest forest surveys [7], the area of woodland in Estonia is 2.27 Mha (51.5% of land area), and the calculated growing stock is 449 Mm^3. The allowable level of utilization of forest resources fixed by the Forestry Development Programme 2001–2010 is relatively high, 13.1 Mm^3, due to the overbalance of middle-aged and mature stands in private forests. The available resources of wood fuel are estimated to be about 5 Mm^3 today [8], and according to the official statistics [9] during the last years the consumption of firewood has been about 3.2 Mm^3. It is obvious that there are remarkable resources of wood fuel, not used at the present moment.

To estimate the potential of wood fuel to substitute oil shale in the energy balance of Estonia we have to know the yield of the fuel wood in long-run, at least for the coming period of 20–30 years. The calculation was carried out basing on the Estonian forest inventory data, functions of growth, algorithms of assortments and economical decisions [8].

The analysis of the age structure showed that the biggest areas of forest will reach maturity during the coming 11–20 years, quite a lot during the next ten years, and after twenty years the areas will start to decrease. The age structure of state forests is quite even, and therefore big changes in harvesting volumes will not take place.

Due to the big share of mature aspen and grey alder stands, in private forests the dominating assortment is fuel wood. If the private forest owners start to harvest besides merchantable assortments the low- quality wood, the available quantities of wood fuel will decrease step by step (Fig. 3). These figures show the theoretical potential, the real utilized quantities depend on

the wood market and the behavior of the forest owners. It should be underlined that the trend of decline, describing the wood fuel supply from the private forests, is temporary. After 35–40 years the harvesting volumes are expected to stabilize, and then a slight increase will follow.

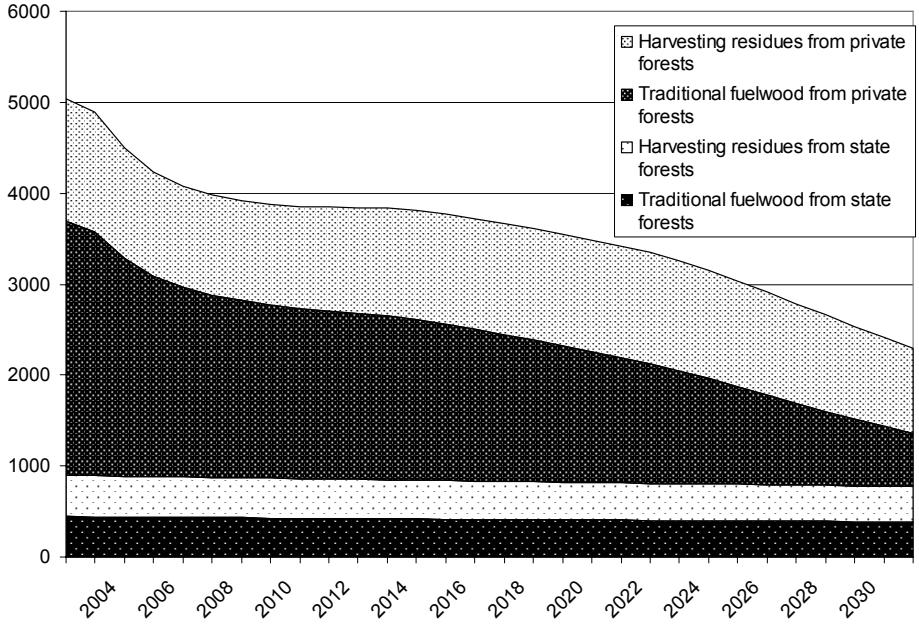

Fig. 3. Forecast of the wood fuel supply for the coming 30 years

The general data about the expected changes in wood fuel supply are presented in Table 5. The data indicates that today we can use for energy production about 5 Mm^3 of fuel wood and forest residues, after thirty years about 2.3 Mm^3.

We can draw the conclusion that though there are remarkable resources of wood fuel not used at the present moment, the potential supply of wood fuel in longrun will be decreasing. It means that in the future the possibility to substitute oil shale by wood fuel will be limited. Harvesting residues, which are seldom used today, have the biggest potential to be used as fuel.

Table 5. **Expected Changes in Wood Fuel Supply, Mm^3**

Ownership	Fuel wood	Branches and tops	Total	Primary energy content, TWh
Potential yield today				
Private	2.79	1.35	4.14	8.29
State	0.44	0.45	0.89	1.79
Total	3.24	1.80	5.04	10.08
Prognosis for the year 2030				
Private	0.58	0.94	1.52	3.04
State	0.38	0.38	0.76	1.52
Total	0.96	1.32	2.28	4.56

Energy Forests

Soil quality on one-third of arable lands in Estonia is extremely low, ≤32 points. On these soils development of traditional farming is unprofitable in the present-day economic situation, and one of the most promising alternatives for farmers can be cultivation of energy forests. In Estonia the productive tree species for energy forest are willow, black alder, birch, aspen and particularly grey alder, which may be also suitable species for cultivation. The growth of Energy plantations depends largely on the soil, meteorological conditions and agrotechnology, and the sustainable high yield can be achieved with the use of intensive technology. If to use arable lands with low-fertility soils for willow plantations, the theoretical energy potential can be up to 9.8 TWh [10].

Agricultural Residues

Considering the present situation in cereal production, the use of 25% of total straw production for fuel would make 100–150 thousand tons. In the future, with more intensive cereal production, the amount of fuel straw could be as much as 200–250 thousand tons [10]. Basing on calorific value of straw at present, it would be possible to produce 0.4–0.6 TWh of energy at the expense of straw, while in the future the corresponding amount could be 0.8–1.0 TWh.

Wetland Plants

There are plenty of wetlands in Estonia that have reasonably high productivity of biomass. Reed beds as well as natural bush are the most suitable for energetic raw material. The total area of Estonian wetlands is approximately 24 thd hectares. The research data show that approx. 1–1.5 kg dry substance per 1 m^2 is growing in the natural wetlands. The net calorific value of reed in spring is 4.2 MWh/t, which corresponds to energy content 42 MWh/y per hectare. The total primary energy potential of reed is 474 GWh/y [11].

Biogas

Basing on the data of Statistical Office of Estonia, the number of poultry is 2.26 million, cows and cattle 0.41 million, sows and fatling pigs 0.33 million. Taking into consideration that 60% of the total animal manure amount could be handling at biogas stations, the theoretically available primary energy content of biogas would be 0.4 TWh/y.

Landfill gas garnered up at Pääsküla landfill (Tallinn) today is *ca* 3 Mm^3/y, but after closing and covering it would increase to 5–6 Mm^3/y with primary energy content up to 30 GWh/y. In Tallinn Sewage Treatment Plant the yearly sewage gas production is 2.8 Mm^3/y and it primary energy content

exceeds to 13 GWh/y. Food waste gathering from the largest towns of Estonia and their anaerobic digestion can give up to 0.1 TWh/y.

Municipal Solid Waste

The total amount of the municipal solid waste formed 510,655 t/y (2003). The amount of municipal solid waste per person and per annum was 328 kg. Total primary energy resources of municipal solid waste are estimated to be 1.77 TWh/y [14].

Peat

In general peat is not considered a biofuel. However, as it is among the most important natural resources of Estonia, it has a high potential to substitute for oil shale. Of the total resources 2.37 billion tons, 1.1 billion tons are accounted in the State Register of Mineral Reserves [12]. The State Register of Mineral Reserves of Estonia includes 281 peat deposits with reserves of fuel peat 0.94 billion tons, and it is extracted from 80 deposits. The area of production fields is about 21,000 hectares, and the annual production ranges from 0.34 to 0.56 million tons depending on the weather conditions during the season [9].

The reserves of a renewable natural resource are divided into critical and applicable (active) reserves. The volume of active reserves as well as its annual quotas are established by the Government of the Estonian Republic, taking into consideration the natural increase of peat. Annual quotas for peat extraction in Estonia are following: permissible extraction limits – 2.78 million tons, amounts established by permits – 2.32 million tons. As usual, less peat is extracted. Most of the fuel peat will be produced as milled peat. The technical capacity of machinery used by Estonian companies enables to harvest up to 0.56 million tons of peat. Primary energy content of this amount of peat is approximately 1.7 TWh.

Potential of Biofuels

The consolidated data about the Estonian resources of biofuels and peat in longrun in 2030 are as follows, TWh:

Fuel wood and harvesting residues	4.6
Wood pellets and briquettes	1.2
Straw	0.8–1.0
Energy plants	9.8
Reed	0.6
Biogas	0.4
Food waste	0.1
Black liquor	0.2
Peat fuels	8.3
Total	25.8–26.0

According to official statistics [6], the consumption of fuels for electricity and heat generation in Estonia in 2003 were 145.9 PJ (40.6 TWh), including oil shale 104.5 PJ (29.1 TWh) and shale oil 4.6 PJ (1.3 TWh). So, the theoretical potential of primary energy content of non-conventional biofuels and peat may cover up to 24% of the energy need which was today covered by oil shale based fuels.

This is the theoretical potential, but the real potential depends on several factors and will be lower. One of the most important preconditions is the suitable legislation and tax system, which makes the utilization of biofuels economically competitive and turns the theoretical potential into reality. As the Estonian government is preparing the "green" tax-reform, the situation seems to be promising.

At the same time, the share of the energy plants among different energy sources is a big guess. The implementation of this potential depends on the export of agricultural products. If there will be the possibility to export more to EU countries, Russia and other countries, less free land will be available and less energy crops will be grown. Correspondingly, the general potential of biofuels will be lower. Also the pressure to decrease the utilization of peat due to environmental reasons becomes stronger, and probably in the future the full potential of peat cannot be used.

Basing on the presented data we can draw the conclusion that though there is the huge unutilized potential of biofuels and peat, these resources are limited and can cover probably less than 20% of the energy need which is today covered by oil shale based fuels. It means that for the coming decades oil shale will remain the main fuel for electricity production, and the renewable biofuels will support only decentralization of electricity production in rural areas.

REFERENCES

1. Long-Term Public Fuel and Energy Sector Development Plan until 2015. RTI, 23.12.2004, 88, 601. – Tallinn, 2004.
2. *Reim, P*. Forest Economy in Estonia. – Tallinn, 1937 [in Estonian].
3. Long-Term Public Fuel and Energy Sector Development Plan until 2015 (with vision to 2030) / Tallinn University of Technology. – Tallinn, 2003.
4. Environment 2003. Statistical Office of Estonia. – Tallinn, 2004.
5. Energy Balance 2002. Statistical Office of Estonia. – Tallinn, 2003.
6. Energy Balance 2003. Statistical Office of Estonia. – Tallinn, 2004.
7. http//: www.metsad.ee
8. *Muiste, P., Padari, A*. Long-term planning of Estonian energy sector and the sustainable wood fuel supply // Proc. Intern. Nordic Bioenergy Conf., Jyväskylä, Finland. 2003. P. 184–187.
9. http//: www.stat.ee

10. *Muiste, P., Roostalu, H., Padari, A., Paist, A., Kask, Ü., Orru, M*. Sustainable balance of biofuels supply-demand in Estonia // Proc. 2nd World Conf. and Technology Exhibition on Biomass for Energy, Industry and Climate Protection, Rome, Italy, 2004. Vol. 1. P. 568–571.
11. *Kask, Ü., Kask, L*. Biomass energy potential of wetlands at Saare County // Proc. 3rd Conf. on Investigation and Usage of Renewable Energy Sources, Tartu, Estonia. 2002. P. 118–123.
12. National Mineral Resources Registry, www.riik.ee/arr/register/maavarad.html
13. *Reinsalu, E*. Oil Shale Mining // Estonian Energy 2002. P. 25–31. http://www.mkm.ee/doc.php?9743.
14. *Paist, A., Kask, Ü., Ots, A., Poobus, A.* Technical - Economical Assessment of Waste Incineration in Estonia / Tallinn University of Technology. – Tallinn, 2005 [in Estonian].

Received May 16, 2005