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ESTONIAN OIL SHALE – RESOURCES AND USAGE

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The reserves of oil shale (OS) in the world are estimated in the amount of 10^{13} t, i.e. they exceed the resources of other solid fuels (coal, lignite, brown coal) all taken together. The OS (kukersite) resources in Estonia form a tiny part of the world reserves. However, Estonia is the only country where OS studies and technologies have been continuously developed during more than 80 years. The only special OS periodical – the journal *OIL SHALE* – has been published in Estonia for eighteen years already.

The OS deposits and OS industry are located in the North-East Estonia. Two deposits – the Estonia deposit and Tapa deposit (Fig. 1) – have been explored. The reserves of the Estonian deposit lying in the area of about 2000 km^2 make nearly $5 \cdot 10^9$ t, including $1.5 \cdot 10^9$ t of active reserves (in the areas with no environmental restrictions where energy rating is at least 35 GJ/m^2 and the calorific value of commercial bed OS is at least 8 MJ/kg). Southward and westward the depth of OS bed increases, its thickness decreases and quality becomes lower (Figs 2 and 3). The reserves located between the 35 and 25 GJ/m^2 lines form passive reserves (in the amount of $2 \cdot 10^9$ t). The OS seams in the bed (indexed from A up to F) alternate with limestone interbeds. The latter form also the main part of the overburden. The characteristics of the Tapa deposit are pitiable, and its reserves are not accounted in the balance. In Estonia we have also another type of shale – black Dictyonema argillite. Efforts have been made to extract uranium and some other metals from this shale, but it is not the subject of this paper.

The Estonian OS forms a peculiar class among the world OS resources. The organic matter of OS (kerogen) represents a mixture of high-molecular polyfunctional organic compounds, the real structure of which is yet a subject of studies.

The composition, calorific value and oil yield (by Fischer) of pure kerogen as well as crude shale oil are presented in Table 1. The relatively high content of oxygen and chlorine in kerogen strikes the eye. Usually the content of kerogen in the OS bedrock is 30–40 %. The mineral part of OS consists of carbonates, sandy-clayey minerals, pyrites, and others.

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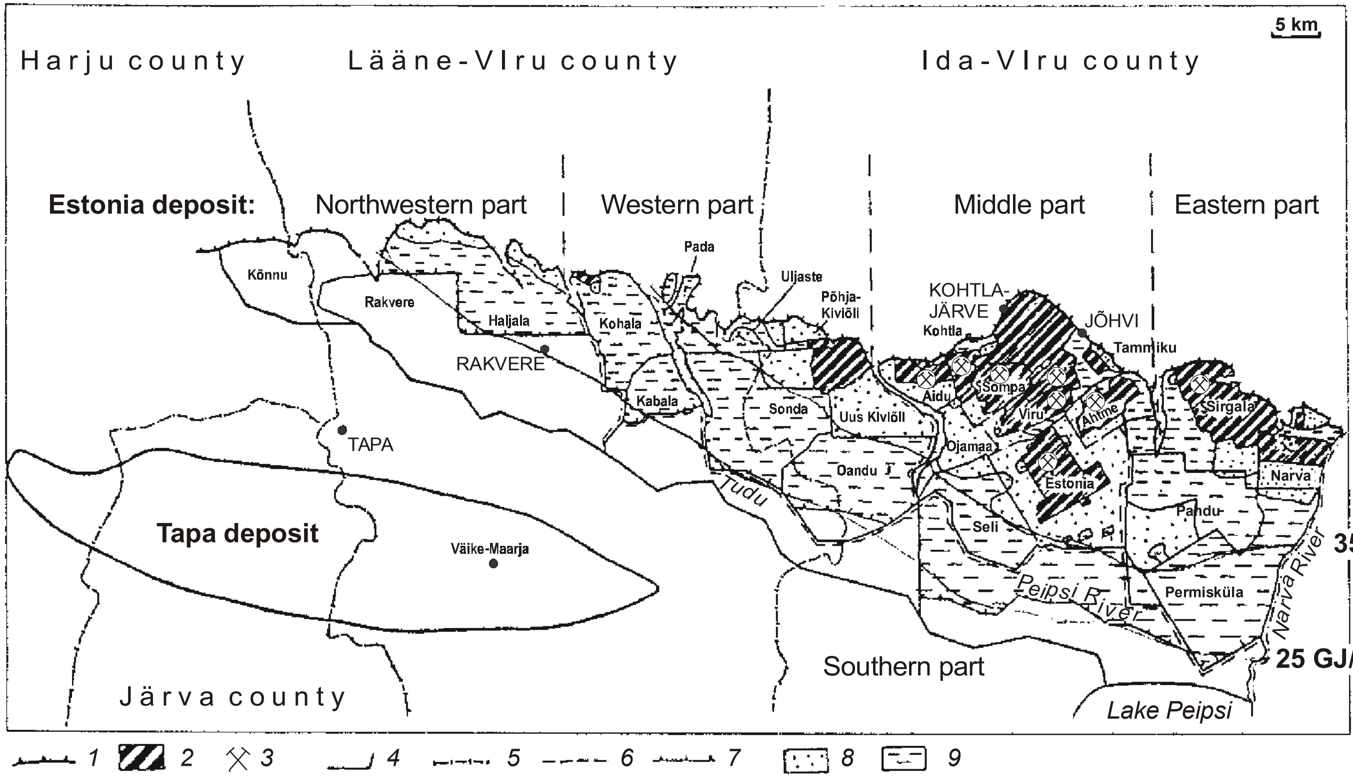
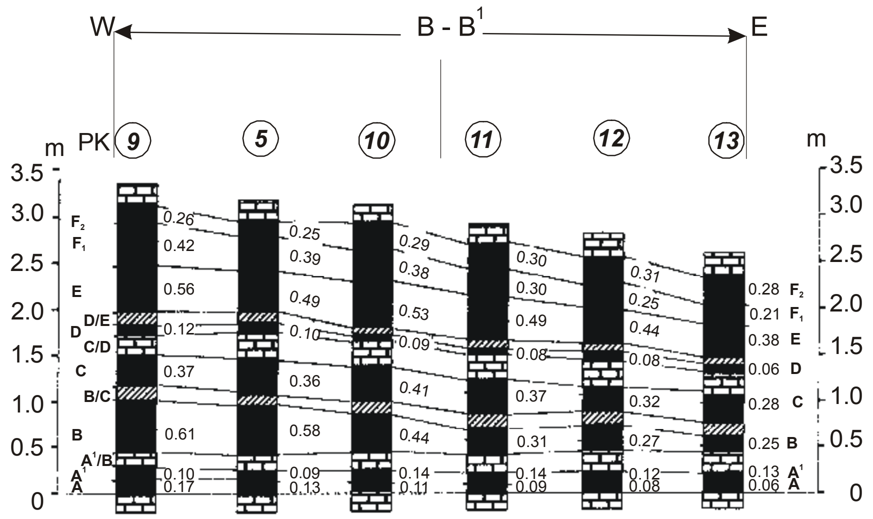


Fig. 1. Oil shale reserves by fields: *1* – outcrop line of the shale bed; *2* – exhausted areas; *3* – operating mines and opencasts; *4* – mine field boundary; *5* – county boundary; *6* – boundaries of parts of Estonia deposit; *7* – southern boundary of Estonia deposit; *8* – active reserve; *9* – passive reserve. Source: Vello Kattai *et. al*., ***Eesti Põlevkivi*** (Estonian Oil Shale), 2000



Thickness of commercial bed, m

Summary	2.93	2.73	2.68	2.49	2.26	2.05
Oil shale	2.35	2.14	2.10	1.78	1.56	1.37
Limestone	0.58	0.59	0.58	0.71	0.70	0.68

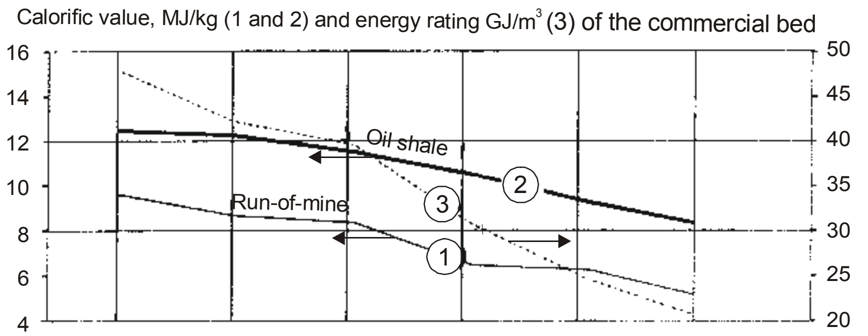
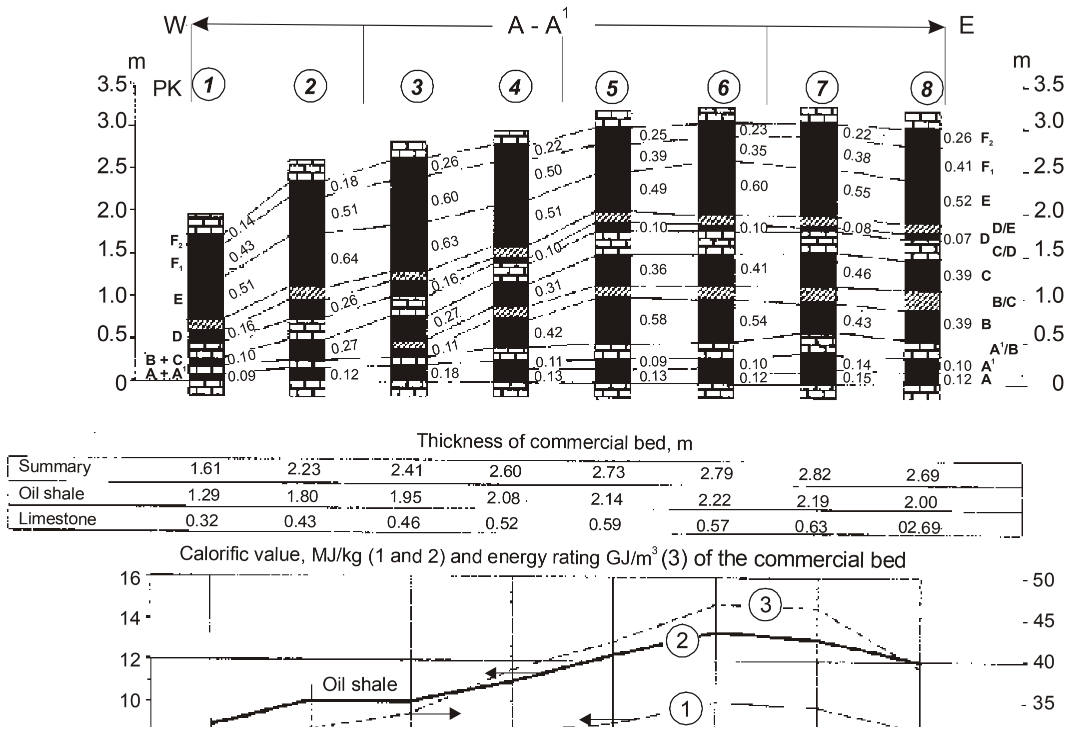


Fig. 2. Estonia deposit. Changes in the structure and oil shale quality on north-south profile. Source: Vello Kattai *et al*., ***Eesti Põlevkivi*** (Estonian Oil Shale), 2000



	1	2	3	4	5	6	7	8
Summary	1.61	2.23	2.41	2.60	2.73	2.79	2.82	2.69
Oil shale	1.29	1.80	1.95	2.08	2.14	2.22	2.19	2.00
Limestone	0.32	0.43	0.46	0.52	0.59	0.57	0.63	02.69

Fig. 3. Estonia deposit. Changes in the structure and oil shale quality on west-east profile. Source: Vello Kattai *et. al.*, ***Eesti Põlevkivi*** (Estonian Oil Shale), 2000

Table 1. **Characteristics of Estonian Oil Shale**

	Oil shale kerogen		Shale oil
C, %	76.5–77.5		81.7
O, %	9.0–11.5		6.8
H, %	9.4–9.9		10.5
S, %	1.2–2.0		0.7
N, %	0.2–0.5		0.3
Cl, %	0.5–0.9		
Calorific value , MJ/kg	37.2		36–40
Oil yield, %	67.8		
Commercial oil shale			
Kerogen, % dry basis	30–50		
Mineral part, % dry basis	50–70		
Moisture, %	10–15		
	Calorific value, mJ/kg	Oil yield, %	Size, mm
Power generation	8.7	–	< 25
Retorting:			
Galoter	8.7	11.5–13	< 25
Kiviter	> 11	15–17	25–125

The quality characteristics of commercial OS depend on the composition of OS bed, mining technology (bed as whole or selective mining, impoverishment by rock of neighboring layers, etc.), results of enrichment and the purpose of OS use. The quality of Estonian OS may be rated as one of the best OSs in the world, but preserving the quality level in the longer perspective will become still more difficult due to the mining activities advancing towards the peripheral part of the deposit.

To the present time, OS has been mined in Estonia in the amount of 10^9 t. The mining activities reached maximum ($30 \cdot 10^6$ t per year) in the early 80s and have been stabilizing during the last years at the level of $12–13 \cdot 10^6$ t. More than 80 % of mined OS is used in the power production complex (fine-grained OS with the average calorific value of 8.7 MJ/kg), the rest for processing by the use of *Kiviter* retorts (lumpy OS with calorific value >11 MJ/kg), heat and cement production. The ratio of OS mined in underground mines and opencasts (at the depth < 25 m) is about 50 : 50 with a decreasing tendency towards opencasts in the future conditioned by the increase of the OS bed depth.

When the quality of mined OS does not correspond to the requirements of consumers, OS is enriched by either jigging or benefication in heavy suspensions. Lately some old mines have been closed, new mining equipment put to use, a direct rail communication for OS transport to power plant constructed, and as a result the price of OS has dropped.

Recultivation and reforestation of exhausted opencast areas is progressing. The problems and difficulties in the mining complex are connected with big losses of OS at mining and enrichment (more than 30 %), big seasonal wavering of production, voluminous dewatering (25 m^3 water per ton of OS) and changes in the hydrogeological condition of surroundings, later setting of the surface above closed mines, and also complicated social situation because of personnel reduction. In the course of restructuring the Estonian energy system, the *Estonian Oil Shale Company* and the Narva Power Plants have merged to form a unified state-owned value chain.

Before and in the first years after the World War II, electricity production was a side-branch in the OS use as the preference was given to its processing into oil products and fuel gas. Still in the 1950s two plants were constructed for heat and power supply to the OS region. Electricity generation increased rapidly in the 1960–1970s when two big power plants (with the total capacity of 3100 MW) based on burning pulverized OS were commissioned (Table 2).

Table 2. **The Development of Power and Heat Production from Oil Shale**

Construction time	Plant	MW_e	MW_{th}
1930s	Tallinn	11	
1949–1967	Kohtla-Järve	39	534
1952–1957	Ahtme	20	338
1959–1971	Balti (BSEJ)	1624	686
1969–1973	Eesti (EEJ)	1610	84

BSEJ	4 blocks *á* 200 MW 8 blocks *á* 100 MW	Pulverized firing boilers, max 1400 ºC, efficiency 28 %
EEJ	8 blocks *á* 200 MW	

1995 –	renovation of turbines extrarepairs of boilers new electrostatic precipitators demolition of old blocks etc.
2001 –	installation of 2 blocks CFB boilers *á* 215 MW, *ca* 900 ºC, efficiency 32–34%

The aim of the Soviet authorities was to meet the electricity demand of the Northwest region of the former SU as possible on the basis of the local fuel. The electricity production reached its peak in 1980 (18.9 TWh) and from that time on has been gradually decreasing. In 2001, the OS-based electricity production was about 7.5 TWh (including auxiliary power consumption of plants which forms about 10 % of production).

After Estonia regained independence, the OS complex has guaranteed self-sufficient electricity supply at a temperate price for Estonia. OS covers 60 % of the country's primary energy demand and 90 % of electricity production. Today the generating capacity of OS power plants exceeds much the maximum demand of Estonia, but at the same time the working resource of the power plants is nearing the end, they are extremely obsolete, which results in increased expenses for repairs and high specific consumption of fuel. In the flue gas 80 % of SO_2 formed by firing OS is bound by CaO in the ash. However, in 2000 the SO_2 emission to the atmosphere was about $80 \cdot 10^3$ t (still twice less than in 1990). The emission of fly ash was reduced even more as a result of installation new electrostatic precipitators. Implementation of fluidized-bed combustion units (beginning with two blocks, 215 MW each) should improve the production efficiency and reduce SO_2 emissions essentially.

However, extremely large investments are required for the major reconstruction of power plants, which in turn would bring along pressure on the electricity price. Besides the problems with high CO_2 emission (for OS 0.106 kt CO_2/TJ, the highest among primary fuels), those related to storing and making harmless huge amounts of alkaline ash and also to increased environmental and resource taxes will remain. Utilization of ash (for the production of cement, autoclaved concrete elements, neutralizing of acid soils, etc.) has decreased and makes now a small part of the ash output, mainly for the efficiency and quality reasons. The use of the joint implementation and quota trade, foreseen by the Kyoto protocol, is of interest for Estonia, too.

Taking into account the big changes in the daily and seasonal loads in power supply in Estonia, in the future the OS power plants should cover the basic or continuous (possibly also intermediate) power supply. For the sup-

Table 3. **The Development of Thermal Processing of Oil Shale**

Low-temperature (500–550 °C) thermal processing	
The use of lumpy oil shale (25–125 mm)	
1924 – up to now	Internally heated vertical retorts (*Pintsch* retorts →*Kiviter* process) 10 → 40 →100 →200 →1000 (→ 1500, designed) t OS per day
1928–1960s	Tunnel ovens (horizontal, internally heated) 400 t OS per day
1931–1961	The *Davidson* rotary retorts (horizontal, externally heated) 25 t OS per day
The use of fine-grained oil shale (<25 mm)	
1980– up to now	*Galoter* process with solid heat carrier 3000 t OS per day
High-temperature (> 700 °C) thermal processing of lumpy oil shale (25–125 mm)	
1948–1970	Chamber ovens for gasification of oil shale 400 million m^3 gas per year

ply in peak-hours more flexible and efficient units based on natural gas and in the future probably also on shale oil have to be put in operation.* Resigning from the monopolistic energy concern that holds in our days the whole chain from power generation up to local grids and opening of electricity market should contribute to the efficiency improvement of the power complex and transition to contemporary energy regulation in Estonia.

In the world stock OS is usually taken as a resource for oil and oil products. The Estonian experience in producing shale oil, fuel gas and some chemicals as by-products is quite long-term and rather diverse, both by the way and amount of production and implemented technologies (Table 3). From 1948 to the 1970s the production of town gas for Leningrad and Tallinn was the main direction of OS processing, later, in connection with the growing use of natural gas, it was reoriented again to the production of oil and chemicals.

The composition of crude shale oil is distinguished by the high content of oxygen compounds (phenols, neutral oxygen compounds, etc.) in addition to aliphatic and aromatic hydrocarbons. In the middle 1990s, the production of shale oil reached nearly 400,000 t. Also oil coke, phenols, resins, glues, impregnates, tanning agents, mastic, and other products were produced. After that time the shale oil output came down due to the price changes both of OS and crude oil in the world market. Now the production is about 250,000 t per year, including almost 60 % for export – probably for the purposes where its lower viscosity and thickening temperature are of importance.

During the last decades, two methods were used for OS processing. The *Kiviter* process (vertical retorts with internal heating, 1000 t OS per day) with the use of enriched OS ensures the oil yield of 15–17 %. However, the efficiency of the process is low (almost 30 % of organic matter gets lost with semicoke) and harmful semicoke accumulates in large waste piles. The *Galoter* process (of solid heat carrier, 3000 t OS per day) with the use of poorer pulverized OS gives the oil yield of 11.5–13 %. Although the energy efficiency of this process is higher and environmental impact lower, it requires bulky and less reliable equipment. At the same time, connectedness of OS retorting by *Galoter* process with the power plant is an essential advantage in both ways.

The future of OS processing depends on the elaboration of new efficient technologies and prospects of enhancing the commercial value of products. The latter is the main goal of the studies, which are carried out in the framework of the US – Estonian joint programme of oil shale research or supported by the EU and Estonian funds. More profound OS studies with the implementation of positive results in industry and attracting young people to the sustainable development of the OS complex are important for Estonia.

The present changes in the Estonian energy system remind much about the period of restructuring coal and metal industries in the West Europe

* Ilmar Öpik. Oil Shale, 2002, Vol. 19, No. 2 Special, p. 197–210.

some decades ago and are similar to the processes going on in the countries of Central and Eastern Europe where solid fuel is dominating in the energy production. As a result of the unification negotiations with the EU, the European Commission agreed to give OS temporarily a specific status and postponed implementation of some requirements in Estonia otherwise foreseen by EU directives.

International co-operation in the OS research and development, exchange of experience between research institutions, companies and people may accelerate the progress in the field of OS utilization. I hope that the present international symposium will give an impulse for that co-operation.