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SCENARIOS FOR SHALE OIL, SYNCRUDE AND ELECTRICITY PRODUCTION IN ESTONIA IN THE INTERIM 1995—2025

The paper is based on the author's pre-feasibility studies of oil shale utilization in oil production, electricity generation and cement industry.

The Finnish Ministry of Trade and Industry published a prognosis of Finnish energy development up to the year 2025 in 1990 [1], to some extent it seems to be inspired by the UNIPEDE assessment presented XXI UNIPEDE Congress [2].

The energy prices in the Finnish prognosis are given in the 1988 currency and include also fiscal and excise taxes. The average value of one US $ in 1988 was FIM 4.191. The prices in US $ for 1988 have been transferred to the prices of 1990 by the coefficient 1.1. The Finnish Energy Statistics has been used for deduction of taxes from energy prices [3]. We assume that the rate of taxes will remain unchanged in the years 1990—2025.

Deducted energy prices have been used for forecasting local energy value in Estonia. Derived tax-free fuel prices in Finland in 1988 were the following:

— heavy fuel oil 554 FIM/t = 132 $/t = 11.7 $/MWh;
— hard coal 160 FIM/t = 38 $/t = 5.4 $/MWh;
— natural gas 390 FIM/1000 m^3 = 39 FIM/MWh = 9.3 $/MWh.

By subtracting the cost of transmission in distribution networks (approx 20 %) from the electricity price of large scale consumers FIM 157 per MWh we got the basic price for electricity FIM 130 per MWh or US $ (1988) 31 per MWh for 1988.

Table 1 presents the prognosis of energy prices used as basis for Tables 2 and 3. The price of shale oil has been equalized with the prognostic price of heavy fuel oil and the price of syncrude has been taken 15 % higher than the world-market price of crude. The price of oil shale has been calculated as an equivalent to the price of hard coal: for the

Table 1. **Prognosis of energy prices in the US $ 1990 with no inflation adjustment**

Year	1988	1991	1995	2000	2005	2010	2015	2020	2025
Crude oil, $/bbl	17.6	—	—	23	—	30	—	—	33
Syncrude, $/bbl	20	—	—	26	30	34	36	37	38
Heavy fuel oil, %	100	—	—	122	—	148	—	—	161
Shale oil with the price of heavy fuel oil, $/t	145	153	164	177	196	215	222	228	234
The same, UNIPEDE assessment 1988, low scenario [2], $/t	—	—	179	194	214	240	279	324	375
Hard coal, %	100	—	—	113	—	128	—	—	135
Oil shale (11,3 GJ/t) in the same relation, $/t	—	9.7*	10.1	10.6	11.3	12.0	12.3	12.5	12.7
Natural gas, %	100	—	—	117	—	137	—	—	147
The same, $/MWh	10.2	—	—	12.0	13.0	14.0	14.5	14.8	15.1
Basic electricity, %	100	—	—	106	—	114	—	—	118
The same, $/MWh	—	35	36	37	39	40	40.5	41	41.5

* 9.7 $/t = 0.86 $/GJ = 3.1 $/MWh.

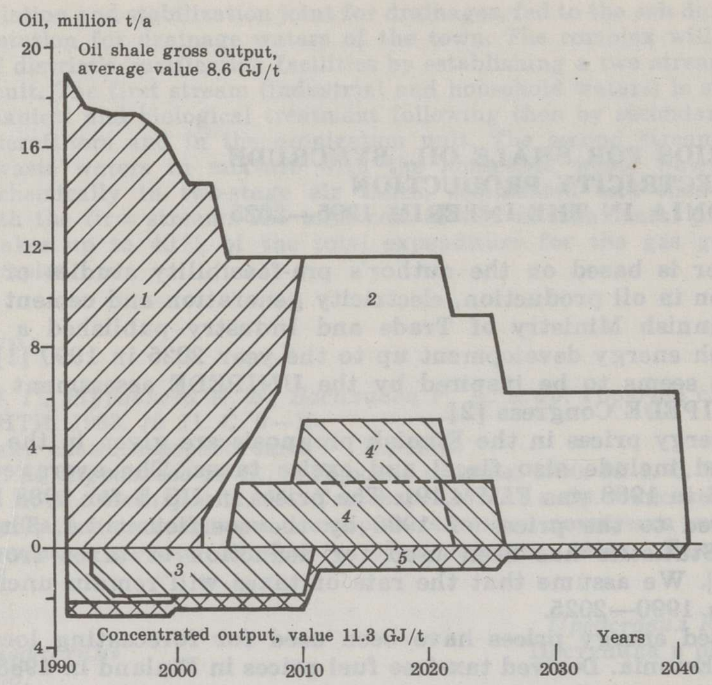

Fig. 1. Annual output and utilization of oil shale from the existing Estonian mines (resources of 0.6 billion tonnes), scenario OILMAX: *1* — pulverized oil shale fired 84—200 MW blocks; *2* — reconstructed 200 MW blocks for the combined combustion of oil shale and coal in the CFB boilers; *3* — concentrated oil shale (11.3 GJ/t) for shale oil production; *4—4′* — oil shale fines (8.6 GJ/t) for syncrude production; *5* — concentrated oil shale (11.3 GJ/t) as fuel for cement rotary klins

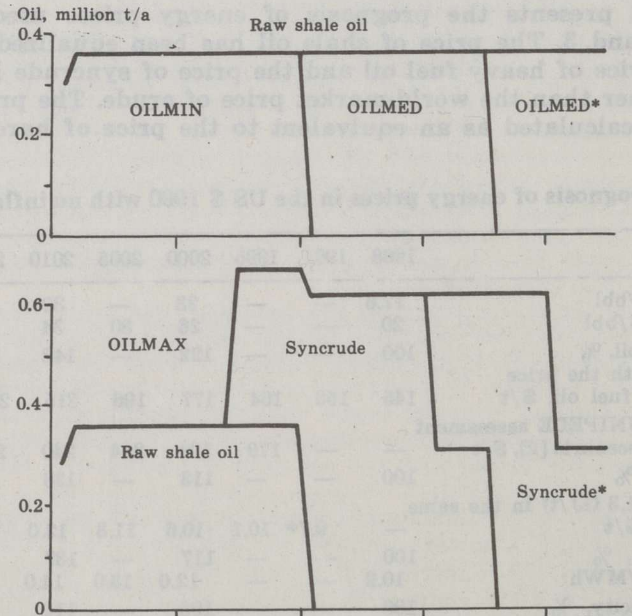

Fig. 2. Scenarios of oil production.
* — produced from additional oil shale resources

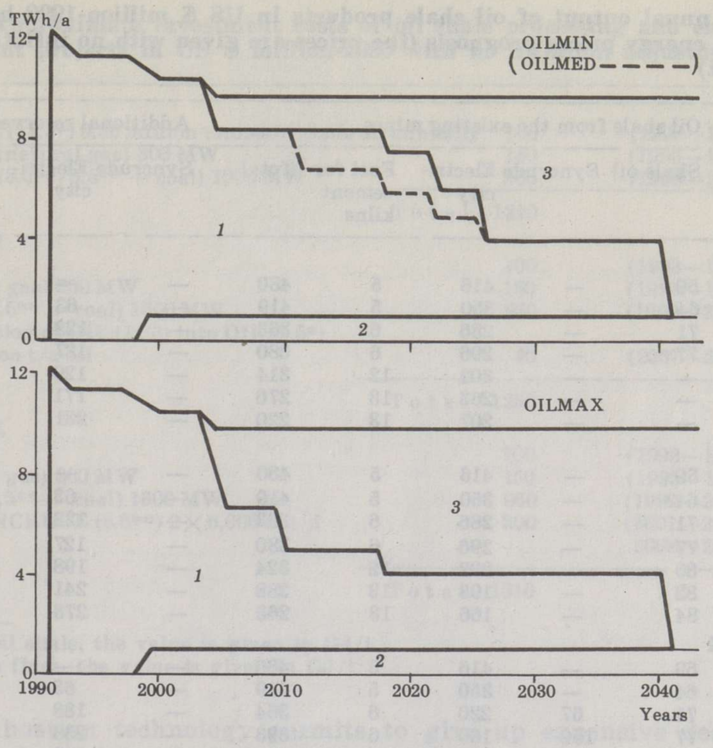

Fig. 3. Annual electricity output in TWh of the Baltic and Estonian Power Plants: *1* — electricity generated on the basis of the energy of oil shale from existing mines; *2* — electricity generated on natural gas; *3* — electricity generated on the basis of the energy of additional resources: new oil shale mines, import coal

value of an energy unit (GJ, MWh, cal) in oil shale a half of that in hard coal was taken.

The annual oil and syncrude production has been calculated on the basis of Figs. 1 and 2. Annual electricity production is given in Fig. 3.

The three scenarios OILMIN, OILMED and OILMAX differ by annual oil production (Fig. 2) and different investment costs (Table 4).

The scenarios OILMIN and OILMED foresee one oil shale processing plant with Kiviter retorts developed step by step from J. Pintsch (Berlin) gas generators of the 1920-s [4]. Providing annual shale oil output — 0.36 million tonnes. By OILMIN this plant will be closed due to the amortiziation of enrichment plants at oil shale producing mines to the end of the first decade of the next century. By OILMED the processing plant will continue processing of nonconcentrated lumpy oil shale (approx 9.5 GJ/t instead of 11.3 by concentrated shale) after some reconstructions.

The OILMAX scenario foresees addition to the OILMIN two oil shale fines (about 8.6 GJ/t) processing and shale oil upgrading plants producing synthetic crude 12,000 barrels per calendar day total.

The electricity generation has been calculated on the basis of 1.4 and 1.6 GW oil shale power plants near Narva with pulverizied fuel combustion today. Reconstruction of the plants is foreseen in the years 1995—2010 with the reduction of thier total capacity to 1.9 GW, including 300 MW based (for peak load) on natural gas combustion and 1.6 GW on the combined oil shale and coal combustion in CFB boiler units (CFB — circulating fluidizied bed combustion). The low temperature

Table 2. **Annual output of oil shale products in US $ million-1990 based on Finnish energy prices prognosis (the prices are given with no inflation adjustment)**

Year	Oil shale from the existing mines					Additional reserves		Total
	Shale oil	Syncrude	Electricity	Fuel for cement kilns	Total	Syncrude	Electricity	
OILMIN								
1995	59	—	416	5	480	—	—	480
2000	64	—	350	5	419	—	63	482
5	71	—	286	6	363	—	122	485
10	77	—	296	6	380	—	127	507
15	—	—	302	12	314	—	129	442
20	—	—	263	13	276	—	171	447
2025	—	—	207	13	220	—	231	451
OILMED								
1995	59	—	416	5	480	—	—	480
2000	64	—	350	5	419	—	63	482
5	71	—	286	6	363	—	122	485
10	77	—	296	6	380	—	127	507
15	80	—	232	12	324	—	198	522
20	82	—	193	13	288	—	241	529
2025	84	—	166	13	263	—	273	536
OILMAX								
1995	59	—	416	5	480	—	—	480
2000	64	—	350	5	419	—	63	482
5	71	67	220	6	364	—	188	552
10	77	150	160	6	393	—	263	656
15	—	156	162	12	330	—	268	598
20	—	161	123	13	297	—	311	608
2025	—	83	124	13	220	83	314	617

Table 3. **Annual output of oil shale products in the US $ million-1990 based on UNIPEDE oil price prognosis (the prices are given with no inflation adjustment)**

Year	Oil shale from the existing mines				Additional resources		Total
	Oil	Electicity	Fuel for cement kilns	Total	Oil	Electricity	Total
OILMIN							
1995	64	416	5	485	—	—	485
2000	71	350	5	426	—	63	489
5	77	286	6	369	—	122	491
10	86	296	6	389	—	127	516
15	—	302	12	314	—	129	442
20	—	263	13	276	—	171	447
2025	—	207	13	220	—	231	451
OILMED							
1995	64	416	5	485	—	—	485
2000	71	350	5	426	—	63	489
5	77	286	6	369	—	122	491
10	86	296	6	389	—	127	516
15	101	232	12	345	—	198	543
20	117	193	13	323	—	241	564
2025	135	166	13	314	—	273	587
OILMAX							
1995	64	416	5	485	—	—	485
2000	71	350	5	426	—	63	489
5	133	220	6	370	—	188	558
10	235	160	6	401	—	263	664
15	178	162	12	334	—	268	602
20	200	123	13	336	—	311	650
2025	116	124	13	253	116	314	683

Table 4. **Approximate investment costs of oil shale processing and electric power plant projects in US $ million-1990 with no inflation adjustment**

OILMIN		
Project OIL (11.3*) 0.36 million tonnes of shale oil annually	100	(1993—1994)
Project EL (natural gas) 300 MW	150	(1995—1998)
Project EL (8.6**/6.5** + coal) 1600 MW	960	(1999—2010)
Total	1210	
OILMED		
OIL (11.3*)	100	(1993—1994)
EL (natural gas) 300 MW	150	(1995—1998)
EL (8.6**/6.5** + coal) 1600 MW	960	(1999—2010)
Reconstruction of OIL (11.3) into OIL (9.5*) 0.36 million t/a oil	40	(2007—2009)
Total	1250	
OILMAX		
OIL (11,3*)	100	(1993—1994)
EL (natural gas) 300 MW	150	(1995—1998)
EL (8.6**/6.5** + coal) 1600 MW	960	(1999—2010)
Project SYNCRUDE (8.6**) 2×6,000 bbl/d	300	(2001—2003 and 2008—2010)
Total	1510	

* Lumpy oil shale, the value is given in GJ/t.
** Oil shale fines, the value is given in GJ/t.

CBF combustion technology permits to give up expensive desulphurization equipment for fuel gas cleaning [5].

The reconstruction of power plants must be planned with the maximum utilization of buildings, technological, electrical and cooling systems, communications and non-depreciated equipment of these plants. The exceptional for thermal power plant use of overhead travelling cranes in the boiler rooms of the both plants (Fig. 4) cuts down the costs and time needed for replacing of the boilers as well as for installing gas turbine equipment in the former boiler room.

The annual electricity output of the reconstructed plants has been calculated approx 10 TWh total.

Investment costs of the scenarios have been calculated in the 1990 US $ without taking into consideration the inflation as the following (Table 4):
— OILMIN approx US $ 1.2 billion;
— OILMED approx US $ 1.25 billion;
— OILMAX US $ 1.5 billion or more, because of the investment costs of oil shale fines processing units and shale oil upgrading plants may rise due to the undetermined financial scaleup risk [4].

The total value of the production of the three scenarios based on the oil shale reserves in the existing Estonian mines (0.6 billion tonnes total) in the years 1995—2025 will be US $ 10.5—10.8 billion (Finnish prognosis, Table 2) or US $ 10.7—11.4 billion (UNIPEDE assessment, Table 3).

On the basis of additional resources of oil shale and other energy supply (natural gas, coal), the value of supplementary production between 1995—2025 will be by:
— OILMIN US $ 3.6 billion;
— OILMED US $ 4.4 billion;
— OILMAX US $ 6.5 billion.

The electricity export to Scandinavia by undersea direct current links costs today approx US $ 10 per MWh (investment, electricity losses, maintenance), therefore the export value of electricity from Estonia

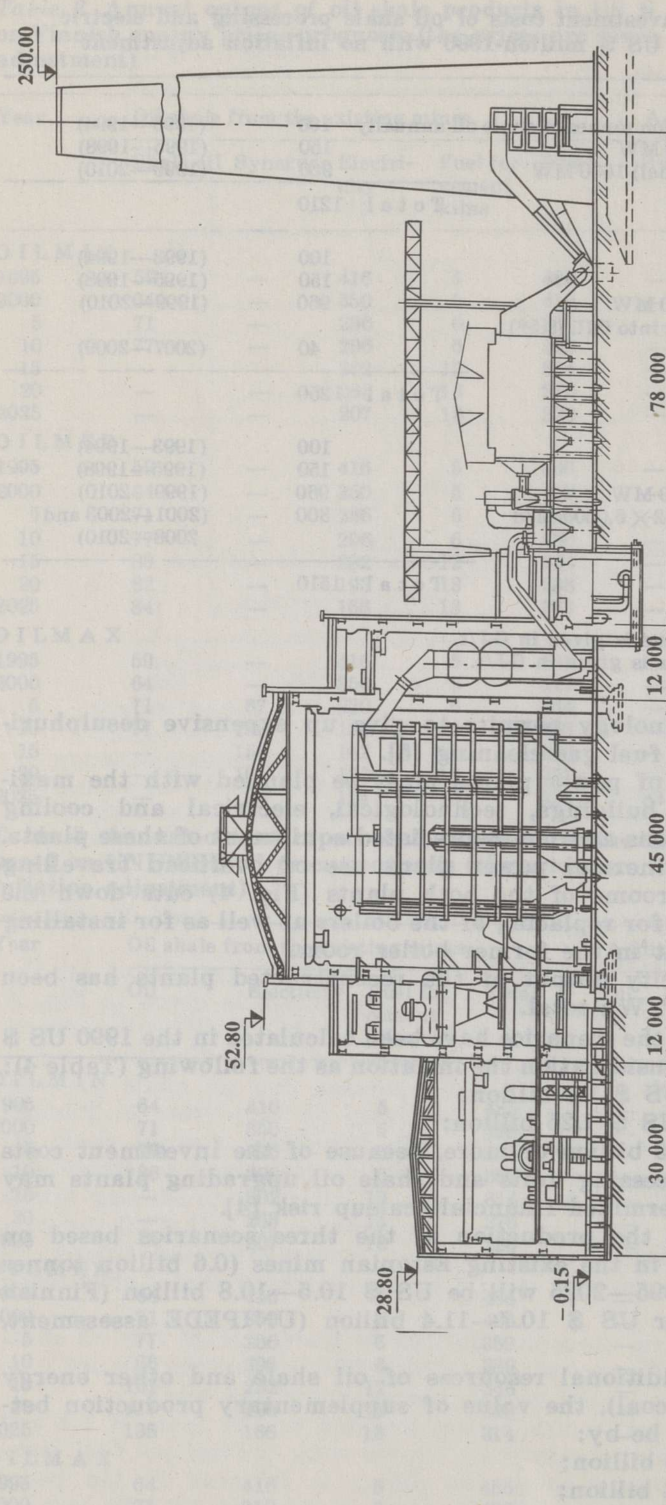

Fig. 4. Cross section of the main building of the pulverized oil shale fired 1.6 GW Estonian Power Station. The carrying capacity of the boiler room overhead travelling crane (three cranes) is 50/10 tonnes

must be lower than that given in Tables 2 and 3. The export value of one MWh (1991) will be in this case US \$ 35 — 10 = 25 MWh or 71 % from the value calculated in Table 1.

Taking into account the lower export value of the electricity, the export value according to the scenarios will be the following between 1995—2025 approx in US \$ billion:

— OILMIN 1 oil + 6.5 electricity = 7.5;
— OILMED 2—3 oil + 6 electricity = 8—9;
— OILMAX 4—5 oil + 4—5 electrycity = 8—10.

It follows that the investments in the oil shale processing industry seem to be more profitable than those in electricity generation (collate Table 5 — investment costs).

The optimum alternative seems to be the OILMED scenario (or if reduced by 6000 barrels per day per one processing unit, the OILMAX scenario?). A drawback of the OILMAX scenario is the lack of successfull tested technology for processing Estonian oil shale fines: an enterprise with two 3000 tonnes per stream day solid heat carrier (Galoter) retorts from 1980—1982 failured in Estonia. Although the average throughput per stream day of the retorts in 1989 was 2,880 tonnes, the maximum annual capacity of a single retort made only 25 % of the planned annual capacity [4].

It is also important to take into account that the very high sensitivity of oil market to geopolitical aspects of resources and to sudden crises, makes the crude price a stochastic parameter, which loses its indicative character for long term economic choices [6]. Therefore it will be very important to have the electric power plants with flexible combined oil shale and coal combustion.

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