

**GLOBAL OIL SHALE ISSUES AND PERSPECTIVES**  
**SYNTHESIS OF THE SYMPOSIUM ON OIL SHALE**  
**HELD IN TALLINN (ESTONIA) ON 18 AND 19 NOVEMBER 2002**

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**Summary**

Despite its huge resources, oil shale is an under-utilised energy resource. The reasons comprise competition from cheaper energy sources, heavy front-end investments in mining, electricity generation and refining, and an unfavourable environmental record. Oil shale has, though, a definite potential for meeting energy demand in an environmentally acceptable manner, enhancing security of supply and supporting the local labour market in a number of countries.

Accordingly, after a decline of production since 1980, oil shale's perspectives are seen more positively now: there will be a definite increase of production in the short term, probably in the medium term and eventually after 2020, when conventional oil resources become scarce. This perspective is prompted by reduced manpower costs, rising demand for electricity, new shale oil products, less polluting and more efficient technologies and an expected change of price relationships between oil shale and conventional hydrocarbons.

Already now experience in Estonia, Brazil, China, Israel and Germany demonstrates that electricity, heat, shale oil, cement, chemicals, construction materials and soil improvers could be produced from oil shale at reasonable, if not competitive, cost. New technologies such as fluidized beds for electricity generation or the ATP process for shale oil production raise efficiencies and reduce air and water pollution to sustainable levels. Innovative approaches are applied to waste remediation. Multi-purpose utilisation of the energy and mineral content of oil shale improves its competitiveness. Small-scale applications in cogeneration, cement manufacture and niche markets complement mega-uses in electricity generation and shale oil production.

However, these opportunities require efforts

- to enhance the industry's competitiveness in liberalized, global markets
- to eliminate the ecological heritage of the past (hazardous waste, water pollution)

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- to reduce emissions from combustion and processing to internationally agreed levels
- to raise efficiencies including through multi-purpose uses of oil shale
- to cater also for smaller deposits, boilers and markets (small-scale co-generation, extraction of industrial minerals and metals, use of ash in cement, construction materials and binders, niche applications)
- to strengthen international cooperative research
- to monitor and participate in international research on CO<sub>2</sub> while heralding the potential of oil shale ash for permanent carbon sequestration
- and to set up a common consulting and marketing association promoting the use of oil shale in countries, which have resources but do not use them at present.

## The Symposium

These are the main conclusions resulting from the international “Oil Shale Symposium”, held in Tallinn (Estonia) on 18 and 19 November 2002. The Symposium was held under the auspices of the Tallinn Technical University and, among others, the Member Committee of the World Energy Council for Estonia.

The Symposium was the second worldwide event on this energy source since 1968. 230 participants attended it from 13 countries. 41 papers were presented and 35 poster sessions held<sup>2</sup>. Abstracts of the papers can be obtained from Ms. Marit Seepold at [marit.seepold@ttu.ee](mailto:marit.seepold@ttu.ee).

A special issue of the Journal “Oil Shale” will be devoted to the event ([aali@kirj.ee](mailto:aali@kirj.ee)).

After the Symposium, study tours were organised to the power generation, oil shale mining and shale oil processing facilities.

In the following, a synthesis of the Symposium will be attempted along its three sections on

- Oil shale resources, geology and mining
- Power generation from oil shale
- Oil shale chemistry and technology

The names and numbers in square brackets refer to the authors of papers and poster sessions and to the page number of their contribution in the “Abstracts”. Other sources used are referred to in the footnotes.

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<sup>2</sup> the contribution of the WEC consisted of a paper on “Restructuring Estonia’s Oil Shale Industry: What Lessons Do We Learn from the Restructuring of the Coal Industries in Central and Eastern Europe” (K. Brendow) and a presentation of the WEC Survey of Energy Resources (Judy Trinnaman, Alan W. Clarke).

## I. Oil Shale Resources, Geology and Mining

### a) A Simple Definition for a Complex Mineral

Rocks which contain a high proportion of organic matter (kerogen) are categorized as oil shale<sup>3</sup>. Oil shale is characterized by a low calorific value and high ash and mineral content. This description covers a variety of deposits, encapsulated in various depositional environments [Dyini, 7; Sener *et al.*, 15, 64; Streltsova, 16; Moh'di *et al.*, 15; Lille, 26; Vorobyov *et al.*, 36; Geological Survey of Israel, 61]. In Estonia, the resource base has been mapped in geological, chemical, technical and environmental terms [Valgma, 20, 57, 58; Vanhally, 31]. X-rays have been used to determine the composition of oil shale [Paat *et al.*, 80]. In view of the variability of the properties of Estonian oil shale, an index is proposed to classify the various deposits [Aruküla, 60].

### b) A Huge, But Poorly Defined Resource

Oil shale “resources” (whether economically recoverable or not) are estimated at  $10^{13}$  or 10 trillion metric tons [Veiderma, 8]. This number depends *inter alia* on the threshold as of when an oil-bearing rock is considered an “oil shale”. It is not surprising that estimates differ according to countries, extent and time of exploration, and methodology used. The WEC’s triennial “Survey of Energy Resources” attempts at quantifying worldwide resources, reserves and shale oil production and provides country notes [Trinnaman, Clarke, 67]. But oil shale can also be genetically classified [Veski, 68]. Whatever the methodological options and caveats, the resource base is huge, exceeding coal “resources”<sup>4</sup>, at 7 trill. t<sup>5</sup>, by 1.5 times.

The oil content of this oil shale resource is estimated at 411 bill. t or 2.9 trill. barrels [Dyini, 7]. This exceeds conventional oil “resources” of 271 bill. t or 1.9 trill. barrels<sup>6</sup> by more than 50 %.

### c) Large Distributed Occurrences, Rising Production

**i. Resources.** Oil shale resources occur in many countries, of which 33 possess deposits worth recording. Among those, three countries (USA, Russia, Brazil) account for 86 % of the resource in terms of shale oil content. This seems to indicate that as in the case of conventional oil, oil shale resources are concentrated in a few countries. However, while this is true geologically, economically it is not: due to the size of the occurrences, even “small” deposits can be huge related to the energy needs of the country concerned. They may also offer more favourable conditions [Dyini, 7]. Estonia is a case

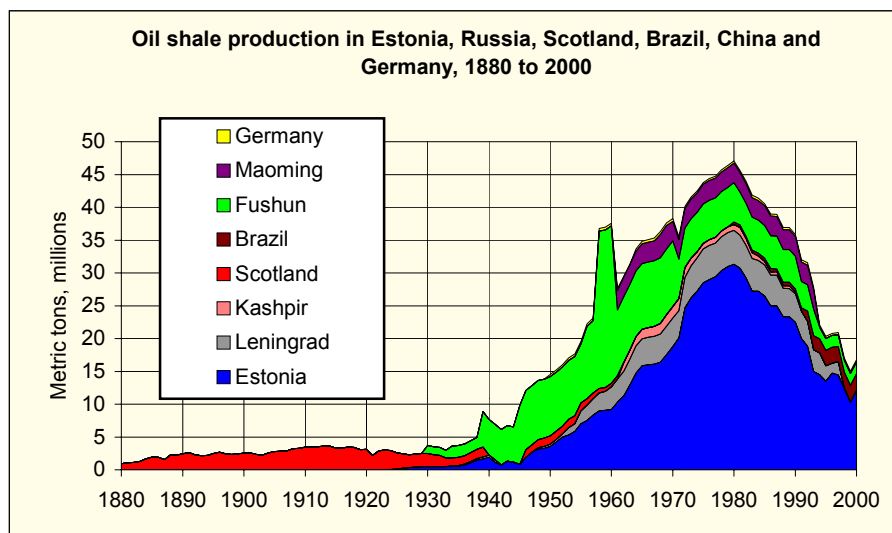
<sup>3</sup> World Energy Council, Survey of Energy Resources 1998 and 2001.

<sup>4</sup> proved amount in place and estimated additional amount in place according to [5].

<sup>5</sup> WEC, Survey of Energy Resources 1998, table 1.1 and 1.2 i, ii, iii.

<sup>6</sup> IEA, World Energy Outlook 2002, p. 97.

in point: while its deposits (at  $5 \times 10^9$  t) are insignificant related to world resources ( $10^{13}$  t) [Veiderma, 8], oil shale covers 60 % of Estonia's primary energy needs and 90 % of its electricity production.



source: Illustration #21 from paper: Origin and Resources of Some World Oil Shale Deposits, by John R. Dyni, U.S. Geological Survey, Denver, CO, USA, presented at the Estonian Oil Shale Symposium, Tallinn, Nov. 18-20, 2002.

**ii. Production so far.** Yet, only few countries utilise this resource. Under the pressure of competition, oil shale production has ceased in Canada, Scotland, Sweden, France, Australia (where it restarted in 1999), Romania<sup>7</sup> and South Africa, and has not taken off in the USA, Belarus, Jordan and Morocco. World production fell from its peak in 1980 (46 mill. t) to about 16 mill. t in 2000. At present, the major producer is Estonia with 12.3 mill. t (2002) (electricity generation and shale oil production), followed by Brazil (transportation fuels), Germany (cement and construction materials), China (fuels), Australia (fuels), Russia and Israel (electricity) [Dyni, 7].

**iii. Production perspectives:** In the short-term, till **2006**, world oil shale production may well increase under the impact of developments in Estonia, the major producer. After a significant rise during 1993–1999<sup>8</sup>, prices for oil shale have recently fallen [Adamson *et al.*, 11] due to mine closures and mergers, new mining equipment such as continuous miners [Nikitin, 32, 58],

<sup>7</sup> In Anina, in the Carpathian Mountains, a 330-MW oil shale power plant became operational in 1984. It needed 18–20 % of start-up fuel oil. The planned capacity was  $3 \times 330$  MW. In 1989 the plant was shut down (Communication by Prof. Calin Mihaileanu, Bucharest).

<sup>8</sup> Ministry of Economic Affairs, Estonian Energy 1991-2000, p. 74.

and staff reductions. Costs are likely to fall further due to early retirement and voluntary departure programmes (2000–2004: – 32 %<sup>9</sup>). According to a baseline scenario quoted by the Government’s “Restructuring Plan of Estonian Oil-Shale Sector”, production is expected to increase by 46 %, from 11.6 mill. t in 2000 to 16.99 mill. t in 2006. This is due to increased electricity demand, the coming on stream of a further shale oil plant and the possible opening of a new opencast mine [Kattel, 59]. In 2006, power plants would absorb 9.94 mill. t and shale oil plants 6.44 mill. t of oil shale. Other uses would remain stable at 0.74 mill. t.

The payback of related investments in power generation needed to be financially secured. In its negotiations with the EU concerning accession, Estonia was granted a transition period till 2010 for liberalising its electricity market; thereafter, if required, state aids could be granted to indigenous oil shale production and power generation [Kisel, 21].

Alternative scenarios to **2010** [Tenno *et al.*, 69] and **2015** [Vares, 38] suggest that policies aimed at environmental protection (and internalisation of environmental cost), energy sector liberalisation, promotion of distributed heat generation and power generation based on natural gas imports would affect the expected competitiveness of oil shale. Its use would decline not only relatively but also absolutely, despite cost reductions due to the introduction of new energy technologies and reduction of manpower. By contrast, the expected electricity deficit of the Baltic States as of 2008–2009 (closure of *Ignalina* Nuclear Power Plant) offers a growth opportunity for Estonian oil shale, if burnt in fluidized beds [Sürde *et al.*, 38].

As to the longer-term, especially **after 2020**, the IEA “World Energy Outlook 2002” (p. 97) foresees a growing importance of non-conventional sources of oil. By 2030, they are expected to cover 8 % of World oil demand. (p. 101). The greater part of that increase would come from Canadian oil sands and Venezuelan extra-heavy bituminous crude, and would be driven primarily by demand in the nearby US market.

#### **d) Repairing the Environmental Impact of Mining**

Oil shale is mined both by underground and opencast methods. In Estonia the share of underground production rose from 50 % in 1991 to 55 % in 2001<sup>10</sup>.

**i. Subsidence** prompted the closure of two mines in Estonia using long-wall shearer mining, while two underground mines with roof-and-pillar mining maintain operations as this method ensures the stability of the surface [Nikitin, 59]. Subsidence-prone areas and pillar stability are surveyed for potential risks [Reinsalu, 58; Pastarus, 65].

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<sup>9</sup> Restructuring Plan of Estonian Oil Sector, p. 12.

<sup>10</sup> *Eesti Energia*, Environmental Report 2001, p. 14.

**ii. Hydrology:** In Estonia, underground and opencast mining requires the lowering of ground water levels below the level of the oil shale strata, with harmful effects on the surrounding arable land and forest. For each m<sup>3</sup> of oil shale mined, 25 m<sup>3</sup> of water must be pumped. The pumped water is discharged into rivers, after solids are removed in sedimentation ponds. A monitoring system has been introduced to control the level and composition of the ground water and the properties of effluents. It showed that mining waters (and airborne pollution) increased the concentration of sulphate in surface and groundwater and in lakes considerably; these concentrations would remain high even after closure of the mine; models of the hydro-chemical processes allow assessing the influence of various land uses with a view to reducing the sulphate content of ground water [Erg, 33].

In Brazil, the level and composition of ground water have been disturbed by mining for a long time: levels fell from 8 m before mining to 35 m after mining; and ground water is charged with a high content of dissolved salt and minerals, despite prior sedimentation in ponds [Krahenbuhl, 19].

**iii. Recultivation:** In Estonia, mined-out areas are recultivated and reforested with proceeds coming partly from a pollution charge paid by the Estonian Oil-Shale Company (2001: EEK 79.1 mill., about \$ 4.9 mill.)<sup>11</sup>. Planned investments in land reclamation and water processing for 2001–2003 amount to EEK mill. 80 (US\$ mill. 4.9). Opencast mines have uncovered up to now 120 km<sup>2</sup>, of which 95 km<sup>2</sup> have been re-forested and 1.5 km<sup>2</sup> recultivated for agricultural purposes<sup>12</sup>.

In Brazil, 3.7 mill. m<sup>2</sup> out of 4.6 mill. m<sup>2</sup> have been reclaimed and are under continuous environmental evaluation [Krahenbuhl, 19].

**iv. Monitoring:** In 2000-2001, the Estonian Oil-Shale Company implemented an ISO 14001-compliant environmental management system [Adamson *et al.*, 11].

## II. Power and Heat Generation from Oil Shale

At present, about 69 % (or 11 mill. t) of world oil shale production is used for the generation of electricity and heat, about 6 % (or 1 mill. t) for cement production and other uses, and 25 %, principally of higher yield, for obtaining shale oil (see **Section III**).

### a) Electricity: a Premium Product, a Co-Product and a By-Product

**i. Electricity and co-generation:** Most of the world's oil shale-based electricity capacities of nearly 3000 MW is located in Estonia, where electrical capacities in four plants stand at 2967 MW. Three power plants are co-

<sup>11</sup> Environmental report 2001, *op. cit.*, p. 14 and 15.

<sup>12</sup> N. N., Oil shale reserves to the beginning of the 21st century.

generation plants [Ots *et al.*, 12]. In 2001/2002, heat supplied to residential and industrial customers contributed 14 % to the total revenues of the national holding, *Eesti Energia*, compared with 76 % from electricity<sup>13</sup>. Besides these major plants, there are privately owned small co-generation and cement plants using oil shale<sup>14</sup>.

Production and transmission facilities are outdated. Despite co-generation, the net efficiency of the two major power plants (*Eesti* and *Balti*) is 27 to 29 %. Transmission losses, at 20.5 % in 1998/99 have fallen to 13.8 % in 2001/02<sup>15</sup>, but are still above international standards (EU 10 %). Accordingly, investments are and will be high: the renovation of two 215 MW boilers in the two main power plants will require approximately EEK 4 bill. (\$ mill. 250); EEK 340 mill. (\$ mill. 21) were already invested in the national network<sup>16</sup>.

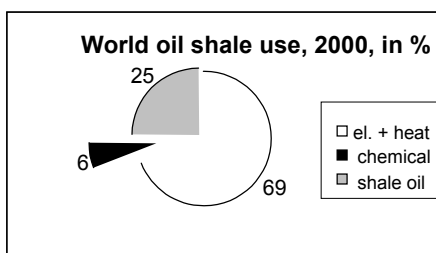
As already indicated (see **I c ii**), in Estonia, oil shale-based electricity generation is expected to rise significantly till 2006. There are prospects for further growth in the medium and long-term depending on the impact of policies in Estonia and the other Baltic States, on the competitiveness of oil shale, and on the development of hydrocarbon prices.

Besides Estonia, electricity is generated from oil shale in Israel (12.5MW) [Geological Survey of Israel, 61] and Germany (9.9 MW) [Hilger, 54].

#### **ii. Cement, chemicals production:**

In Estonia, the chemical industry and other users purchased 274,000 t of oil shale in 1999<sup>17</sup>. In Germany, 300,000 t went into cement production. Germany is a case in point for electricity output as a revenue-raising by-product. In the Dotternhausen Rohrbach Zement factory,

oil shale is used for three purposes: as a fuel for clinkering (covering 20 % of the energy and 10 % of the raw material needs); as hydraulic burnt oil shale for the production of cement, soil/rock stabilisers and filling and sealing material; and as a fuel for electricity generation: excess output is sold to the public grid. This multiple use secures the competitive use of a resource with poor quality [Hilger, 54].



<sup>13</sup> *Eesti Energia*, Annual Report 2001-2002, p. 10.

<sup>14</sup> Restructuring Plan, *op. cit.*, p. 9.

<sup>15</sup> Annual Report 2001/2002, *op. cit.*, p. 11.

<sup>16</sup> Annual Report 2001/2002, *op. cit.*, p. 6 and 22.

<sup>17</sup> Restructuring Plan, *op. cit.*, p. 5.

## b) The “Greening” of Oil Shale

**i. Combustion:** Except for Germany’s Dotternhausen cement factory [Hilger, 54] and Israel’s oil shale power plant [Geological Survey of Israel, 61], which use fluidized beds, the traditional way of burning oil shale is through pulverized firing, with high inefficiency, pollution and health hazards: indeed, the fine, respirable fraction of fly ash particles contains toxic and mutagenically active elements, which represent a health risk not only locally but also far from oil shale emission sources [Kirso *et al.*, 42]. More effective and less hazardous technologies exist, however, and are being applied in Estonia, at a total cost of EEK 5.1 bill. (\$ 320 mill.):

- renovation of electrostatic precipitators,
- replacement of two 215 MW boilers by atmospheric circulating fluidized bed technology,
- and installation of an environmental monitoring system.

These short-term measures are expected to increase plant efficiency from presently 27-29 to 36 %, to reduce CO<sub>2</sub> emissions by 7 %, SO<sub>2</sub> emissions by 37 %, fly ash emissions by 80 % and NO<sub>x</sub> emissions by 9 %. Retrofitted units would comply with EU standards<sup>18</sup>, if the boilers, as designed, successfully handle problems arising from the complexity and variability of the oil shale feed [Kinnunen, 22; Ots *et al.*, 23; Klevtsov *et al.*, 25] such as attrition of the fuel and ash during combustion, fouling of convection heat surfaces, ever-lower shale quality and chlorine-based corrosion. A solution could consist of adapting the share, quality and properties of the mineral residues in the fuel to be burnt [Dushenko *et al.*, 24, 75]. Problems of SO<sub>2</sub> and CO<sub>2</sub> could be relieved by using oil shale ash as a dry sorbent for the additional cleaning of flue gases [Kuusik *et al.*, 71].

Small-scale fluidized boilers for district heating [Shemyakin *et al.*, 69] offer an environmentally acceptable solution for the decentralized use of oil shale.

Remain as long-term issues

- **the deployment of new technologies:** In Estonia, further large-scale boilers need to be renovated. A comparative analysis of the performance of circulating or bubbling fluidized bed will be undertaken [Dushenko *et al.*, 67]; in the meantime, boiler management could be adapted in such a way that more than 90 % of the sulphur contained in the oil shale is bound in the ash [Jegorov, 43]. No studies are reported on the possible use of advanced pulverized combustion techniques for the replacement of existing boilers.
- **the sequestration of CO<sub>2</sub>;** in pulverised combustion, carbon emissions are high: 29.1 tC/TJ [Roos, 41], as CO<sub>2</sub> is not only formed as a combustion product but also during decomposition of the mineral part of the oil shale. Fluidized beds reduce CO<sub>2</sub> emissions, but only by 7 %. Thus, the

<sup>18</sup> Restructuring Plan, *op. cit.*, p. 13.



issue of carbon sequestration remains important. CO<sub>2</sub> sequestration through optimum use of land and carbon sequestration technologies offers some relief [Randla *et al.*, 63]. So does mineral carbonisation of oil shale ash [Kuusik *et al.*, 71].

- **cooperative research:** it is important for the oil shale community to monitor international research on CO<sub>2</sub> sequestration from coal-based power stations for possible application to oil shale operations: it is even more important to participate in the IEA Greenhouse Gas R & D Programme<sup>19</sup> and the EU Sixth Framework Programme<sup>20</sup> and to herald the adsorptive capacity of oil shale ash (Brendow).

**ii. Management of waste and effluents:** In 2001 alone, 4.7 mill. t of ash were deposited in Estonia, which corresponds to 46 % of the oil shale burnt<sup>21</sup>. As this ash is transported hydraulically, the water becomes alkaline upon contact with the ash. Semi-dry ash transportation was expected to reduce this risk but did not [Arro *et al.*, 44]. In order to comply with the forthcoming EU Waste Dump Directive, certain ash fields and waste dumps will be closed, a new storage facility will be opened and hazardous substances, including asbestos, will be removed. The total cost till 2009 is estimated at EEK 700 mill. (\$ mill. 44)<sup>22</sup>.

In parallel and with a view to prepare for the implementation of the EU Waste Dump Directive, an environmental risk assessment of waste sites from power generation and shale oil distillation is under way. Its purpose: to evaluate the hydrogeological and geochemical processes in landfills, quantify possible toxic hazards and propose remedial action [Sørli *et al.*, 34].

In China (Maoming City, Guangdong Province), the planting of fast-growing trees has had benign effects on the ecology of waste dumps [Jialin *et al.*, 64]

On the impact of airborne pollutants from combustion (and mine waters) on sulphate concentrations in ground and surface water and lakes, see section **I d ii** above. For the impact on bogs, see [Kaasik *et al.*, 73].

<sup>19</sup> including a project on “Sequestration of carbon dioxide in oil sands tailings streams”; contact: Randy Mikula; mikula@nrca.gc.ca

<sup>20</sup> UNECE Carbon Sequestration Workshop, Geneva, 19. 11. 2002; in particular Alain Bill, Overview of techniques and approaches to CO<sub>2</sub> capture; (IEA GHG Programme); Charles E. Schmidt, Carbon sequestration – the path forward (EU FP 2002-2006); contact UNECE: charlotte.griffiths@ece.org

<sup>21</sup> Environmental Report 2001, *op. cit.*, p. 7.

<sup>22</sup> Restructuring Plan, *op. cit.*, p. 13.

### III. Oil Shale Chemistry and Technology

#### a) Shale Oil Production: Small, Locally Important, with Some Growth Prospects

About 25 % of World oil shale production (or 4 mill. t) are processed into shale oil and combustible gas, and upgraded into jet fuel, gasoline, light fuel oil, bitumen, coke, phenols, liquefied shale gas, wax, lubricating oil and other products. At present, some 500,000 t of shale oil are produced, in Brazil (1999: 195,000 t), Estonia (2000: 238,000 t), China (2001: 80,000 t) and Australia (2001: 28,000 t; 2002: 60,000 t)<sup>23</sup>. This is insignificant compared with the resource base containing 411 bill. t of shale oil and with yearly conventional oil supplies (3.6 bill t). But shale oil can be locally important: in Estonia, shale oil production equals half the imports of heavy and light fuel oil<sup>24</sup>.

Near-term growth prospects, which depend on the prices of conventional hydrocarbons and environmental constraints, appear limited to Australia [Schmidt, 28], while in Estonia production is expected to be stable<sup>25</sup>. As to the longer-term, the IEA World Energy Outlook 2002 (p. 41) foresees a tripling of unconventional oil production during 1997–2020.

#### b) Technologies: Evolution Meets Revolution

Shale oil is obtained by mining oil shale and heating it, while adding hydrogen and removing compounds which are undesirable in petroleum substitutes. As the properties of oil shales vary, a number of technologies with different characteristics are in use [Qian, 79]. These systems replicate naturally occurring processes (like partial melting of the Earth's crust, or the formation of hydrocarbons), which suggest that the observation of these processes may be useful for shale oil extraction [Bons, 35].

Emphasis in research and industrial application is on the improvement of existing approaches as well as on the development of genuinely new ones. Four orientations can be distinguished:

- enhancing the competitiveness of shale oil production
- reducing the environmental impact
- increasing yield and product spread
- niche applications

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<sup>23</sup> for Brazil: World Energy Council, Survey of Energy Resources 1998 and 2001; for Estonia: Estonian Energy 1991-2000, p. 42; for China, Wang *et al.* p. 50; for Australia, J. Schmidt.

<sup>24</sup> Ministry of Economic Affairs, Estonian Energy 1991-2000, p. 30.

<sup>25</sup> Restructuring Plan, *op. cit.*, p. 6.

### c) Enhanced Competitiveness of Shale Oil Products

Despite 50 and more years of research, the competitiveness of shale oil versus petroleum and coal remains elusive [Dyini, 7]. Rising costs of oil shale production and falling prices for oil on the world market prompted shale oil production in Estonia to fall from 400,000 t in 1997 to 238,000 t in 2000 [Veiderma, 8].

Economic enhancement requires capacities of a certain scale (10,000 bbl/d) and the production of additional value-added products. Extraction techniques may prove superior to synthesis techniques [Bunger, 10; Blyakhina *et al.*, 77].

Yet, also the latter offer prospects for improved competitiveness through new technology – the Alberta Taciuk Process [Taciuk, 27]. Its commercialisation would raise Australia's shale oil production to ultimately 200,000 bbl/d, equivalent to one quarter of the country's crude demand [Schmidt, 28] and could lead to the construction of a new 4 mill. t oil shale plant in Estonia [Purga, 29].

Two solid-heat-carrier units operated at the Oil Factory of the *Narva Power Plants Company* for 22 years already can process up to 3,000 t of oil shale per day each [Golubev, 45].

Competitors will not remain idle, though. For dispersed uses, "bio-oil" from the liquefaction of cheap Estonian biomass is proposed as a substitute for shale oil [Venendaal *et al.*, p. 88].

### d) Reduced Environmental Impact

Distillation of oil shale generates wastes and effluents, which may contain trace metals, semi-volatiles, polycyclic aromatic hydrocarbons, oil fractions, phenolic compounds, sulphides and others. Those need to be surveyed for potential risks and remedial action [Sørlie, 34; Zirjakov, 51; Xialin *et al.*, 64], bearing in mind the possible analytical bias introduced by "aggressive" chemical analysis of single samples [Kahru *et al.*, 90].

Semi-coke, effluents and heat discharges from shale oil processing may cause environmental problems.

Semi-coke, or coke ash residue, is a harmful waste resulting from oil shale retorting if its organic content is not burnt during the process<sup>26</sup>. But semi-coke can be partly recycled and burnt in fluidized bed boilers [Martins *et al.*, 49]. The organic content in the remaining coke ash residue must be reduced via improving the technological scheme [Zirjakov, 51]. Semi-coke could also be used for construction products like cement and rock wool. The – recommended – use of semi-coke as a component in fertilizers is impaired by its high concentration of hazardous organic compounds [Teinemaa *et al.*,

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<sup>26</sup> according to *Eesti Energia*, Environmental Report 2001, p. 11, "practically all the organic content (of the Narva Oil Plant) is burnt away in the course of the process".

73]. Polluted water (1.2 m<sup>3</sup>/t of Estonian oil shale processed) needs to be treated [Munter *et al.*, 53]. The physical and chemical heat of waste and products from oil shale processing ought to be recycled [Zirjakov, 51; Kaljuvee *et al.*, 83]. Fast growing trees [Jialin *et al.*, 64] have a favourable impact on waste dumps. Laboratory and field tests suggest a similar impact of microbial biodegradation and bioaugmentation on the remediation of semi-coke deposits [Heinaru *et al.*, 87].

But shale oil production is not only a source of environmental hazard, it also removes some of it: in solid heat carrier processes, applied in Estonia, products can be burnt which otherwise cannot be regenerated, such as oil waste, sludge, rubber chips, used oils [Golubev, 45; Zirjakov, 51, 52] and waste plastics [Tiikma *et al.*, 76].

#### e) Higher Yield, More Products

At temperatures of 500 to 520 °C, shale oil is obtained while the mineral matter of the oil shale is not decomposed. The yield and quality of the products depend on a number of factors, whose impact has been identified and quantified for over thirty oil shale deposits [Soone *et al.*, 14]. Thermogravimetric analysis helps to understand oil shale pyrolysis without costly experimental plant processing [Pimental *et al.*, 82]. Sub- and supercritical extraction techniques prove particularly effective in maximising yield and developing additional products [Bunger, 10; Luik, 48]; by contrast, the retorting technology with semi-coking in use in Estonia implies losses or ineffective use of more than one third of the kerogen content [Blyakhina, 77]. Valuable hydrocarbon solvents, chemical reagents and sulphur-organic products could be obtained from processing the light fractions of high sulphur oil shale pyrolysis tar [Blokhin *et al.*, 83]. Those tars could also produce high quality benzene by catalytic hydrotreatment [Vyacheslav *et al.*, 84].

#### f) Niche Applications

Low-temperature carbonisation of oil shale could produce a generator gas to drive an internal combustion engine for the production of electricity [Muoni, 80].

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The Symposium demonstrated that a variety of options exist or are in promising stages of development to carry oil shale further, both for the generation of electricity and the production of shale oil products. What matters now is “to spread the message” **in business terms** through the creation of an international association of operators, researchers, technologists and equipment manufacturers promoting the use of oil shale resources, including and particularly in countries which have such resources but do not use them.