Oil Shale Mining Developments in Estonia as the bases for sustainable power industry

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Introduction

Estonias power industry bases on its Oil shale mining. Compared to other countries the amount of reserves and production capacity in total is not high but it is high per area or per number of habitants. Today the most difficult task is to find compromise between needs of economy and fears of mining influence.

Mineral resources

In addition to the main mineral resource Oil Shale there are sufficient reserves of limestone & dolostone, peat, sand, gravel and clay. Phosphorite and granite are occurrences in today’s economical situation in spite of the fact that phosphorite has been extracted for 70 years in former times.

Timeline

The main milestones in Estonia’s relatively short mining history are:

1916- Oil shale mining began
1960- Eastern technology was applied
1991- Western technology was introduced
2002- Environmental restrictions became limiting factors for continuing with new mining areas
2004- Estonia joined EU
2006- Tests and planned test of high-selective mechanical mining

Technology

Most of Estonia’s minerals are mined in surface mines. Still half of oil shale is mined underground showing future trends of increasing underground mining capacities.

The main used mining technologies are:

- Open cast (strip) mining
- Room and pillar mining (longwall mining is finished, shortwall continuous mining is potential)
- Truck and excavator operations
- Milling in peat fields
Lately new technologies have been introduced and tested. These are:
- Surface miner tests in dolostone, limestone and oil shale
- Hydraulic equipment in many applications
- Mobile technology in cutting, loading and hauling
- Long boreholes tests and high roof (3.5m instead of 2.8m) in underground oil shale mining (4m instead of 1.5m)
- Inclined shaft for mobile equipment for underground mining
- Mechanised roofbolting
- Railway removal, underground buses for service
- Loading with LHD-s replacing armloaders

Introducing high productive machinery has resulted in less number of equipment and higher availability.

In surface oil shale mining the main change has been:
- Using rippers (100t class) instead of drill and blast breaking
- Loading with LHD-s instead of mechanical shovel
- Blasting with modern blasting technology (Emulsion BM, Dynamit Nobel, Orica) resulting less vibration, even size, safe operations.
- Draglines have been renovated with engines changes, renewing electrical system

In Limestone mining the main changes have been:
- Using mobile crushing and screening
- Hydraulic hammers
- LHDs, hydraulic excavators
- Service and maintenance have been changed in direction of direct dealers service resulting higher availability and less employees

Technology and its developments in Estonia (limestone; oil shale) are described in more details in other articles in this book.

**Capacity**

Capacity of Estonia’s mineral production is currently depended on domestic need. Most of the export potential is related to peat, oil shale oil and limestone production.

The most important capacity is oil shale-stabilised on 13 Mt/year level. Others are highly dependent on increase in construction industry and limited by environmental and legislative restrictions.

Estonia’s power industry bases on oil shale as seen on next figure. Practically all electricity (95%) is produced from oil shale.

![Fig. 2. Annual mineral production, t/year](image-url)
Oil shale in Estonia

The basic criterion determining Estonia’s resources of kukersite oil shale is the energy rating of the bed in GJ m\(^{-2}\), implying the sum of the products of thicknesses, calorific values and densities of all oil shale layers and limestone interlayers in all A-F beds.

Estonian mining fields have the energy rating from 36.5 to 46.3 GJ per m\(^2\), with an average of 42.2 GJ per m\(^2\). Auxiliary criteria include total thickness without limestone interlayers of selectively mineable oil shale layers and the average estimated calorific value between these layers; selectively mineable oil shale layers could incorporate all the oil shale layers, including those outside the A-F bed. If the energy rating of a bed is below 35 GJ m\(^{-2}\) (about 10 MWh per m\(^2\)) at the time suitable for surface mining, then auxiliary criteria are used. The average energy rating of the bed in the oil shale exploration block registered as passive resource should be at least 25 GJ m\(^{-2}\). Based on energetic point of view, Estonian oil shale minefields have approximately one billion tons of proved reserves and exploration fields have double of these reserves. The Estonian oil shale resources are twice as large as the oil shale that has been mined up to the present time.

The second oil shale in Baltic oil shale basin is Dictyonema shale from Cambrian age; analogous mineral in Sweden and Norway is named alum shale. The peculiarity of the shale is low content of organic matter and high content of metals and sulphur. In Estonia and in Sweden, these shales have been raw materials for uranium production.

Development of oil shale underground continuous mining technology

Strategic aim of the development of oil shale underground continuous mining technology is development of Coal mining technology by testing continuous mining system in difficult conditions in Estonian Oil Shale deposit improving coal mining possibilities due to enhancing cutting, supporting and face transport form high productive short-wall face. Currently many coal fields in Europe face difficult mining conditions. The main problems in addition to deep bedding are unstable roof, dilution of side rock and content of abrasive and hard parts of side rock inside or between coal seams.

Aim of the research is to introduce oil shale underground continuous mining technology on example of Estonian oil shale deposit in areas with arduous conditions. The results of in-situ testing can be used to improve existing situation in EU coal/oil-shale mining fields with complicated geological conditions and in densely populated regions.

Currently Estonia is independent energy producer thanks to existing of Oil Shale deposit and favourable mining and processing conditions. Due to environmental restrictions, social pressure and deeper bedding of oil shale in potential mining fields, testing of high-productive, environmentally friendly, mechanical mining is needed for successful continuation of independent energy supply (oil shale) for EU state country, Estonia. Situation in energy market of EU will be change in the nearest future. Decreasing need for energy import to Estonia will be very helpful for European energy market. New flexible and powerful mining technology will
guarantee securing independence of Estonian energy sector.

Development of mining machinery and mining technology by the way of selective mining will improve environmental situation in Europe and Baltic Sea region. Effect can be achieved in decreasing CO₂ pollution, ash pollution and water pollution. To avoid a potential problem of non-utilizable waste in stockpiles of mine areas selective mining provides leaving non-conditional rock mass in mined-out underground areas.

It is intended to develop research program to develop design of cutting tools/drums with a minimum cutting tools consumption and machine down time. New design of cutting drums will lead to improved tool cutting (pick) loading efficiency with less fine rock and dust production. It is important factor in safety of mining operations. The results of this work will be taken into account for the design of continuous miner. Easy maintainability of machine equipment is just as important factor for reducing maintenance time/costs and enhancing reliability.

The project stages include selective mining research for mining machinery development also for:

- oil shale losses
- Avoiding vibration caused by blasting
- Increasing oil yield
- Decreasing CO₂ pollution ca. 1,2 times
- Decreasing ash amount
- Decreasing Avoiding ground surface subsidence (in case of longwall mining)
- Increasing drifting and extracting productivity compared with current room and pillar mining (1,7 times)
- Increasing safety of mining operations (dust explosion for oil shale and methane gas explosions for coal)

The final aim of the research is to use BAT (Best available Technology) for underground mining in with arduous conditions of coal and oil-shale deposits.

The main problems to be solved:

- Cutting selectively oil shale (15MPa) and hard limestone (up to 100MPa). The oil shale seam consists up to 50% of limestone layers and peaces.
- Roof support at the face
- Stability of the main roof, roof bolting, pillar parameters
- Backfilling with rock or residues (ash) from oil production
- Water stopping and pumping in problematic environment (30m³/t expected)

Fig. 4. The productivity of the manshift in underground mining unit has increased up to 90% with renewing of technology
Currently room and pillar mining with drill and blast technology is used. Supporting is done with bolts. Mining production is in total 14Mt/y, including 7Mt/y underground. Total raw material amount is 12Mt/y underground. Tests are made for opening two new mines, with total production 15Mt/y. Room dimensions in oil shale mines could be up to 15m in opposite to conventional coal mining with 5m dimensions.

The planned research project is based on the Sustainable Development Act (RT1 1995, 31, 384; 1997, 48, 772; 1999, 29, 398; 2000, 54, 348) and directs the development of the Estonian fuel and energy sector until 2015. The document defines the current situation in the sector, presents issues set out in the EU accession treaty, prognoses developments in the energy consumption, states the strategic development objectives for the energy sector, the development principles and the extent of the necessary investments. The plan describes the problems that require further analysis and the functions of the state relating to supervision and regulation. The strategic environmental assessment of the document is presented in the strategic environmental assessment statement of the long-term public fuel and energy sector development plan, which has been prepared at the same time as the development plan. The development plan and the statement are both disclosed on the website of the Ministry of Economic Affairs and Communications (http://www.mkm.ee/).

The specified plan helped to direct the development of the power engineering the main objective of which is to attain a level in the Estonian energy sector which is required to join the EU. At the same time, the plan does not provide sufficiently specific guidelines, e.g. regarding the objectives of renewable energy, combined heat and power production and energy conservation, and is too non-specific in directing the development of the energy sector.

The visions and needs relating to the future of power engineering have now changed to a significant extent - in connection with accession to the EU; a number of requirements and objectives have arisen, the energy technology has developed and implementation of the Kyoto Protocol provides new possibilities etc. In order to comply with the specified criteria, it is necessary to specify the public power engineering development plan.

**Previous situation**

Continuous miner operations keep playing a major role in the underground industry in over fourteen countries worldwide. Estonia’s oil-shale industry is at the beginning of introducing modern fully mechanized continuous miner systems, which will dramatically increase productivity and safety in the underground mines.

A longitudinal cutting head type was first introduced in the former Soviet Union by modifying the Hungarian F2 road headers and in 1970s in Estonia by modifying the Russian coal road header 4PP-3. Evaluation of breakability was performed by a method developed by A. A. Skotchinsky Institute of Mining Engineering (St Petersburg, Russia). For this purpose over a hundred samples produced by cutting of oil shale and limestone, as well as taken in mines by mechanical cutting of oil shale were analysed. Evaluations were made for using coal-mining equipment for mining oil shale. Comparative evaluations were made by the experimental cutting of oil shale in both directions – along and across the bedding, including also mining scale experiments with cutting heads rotating round horizontal (transverse heads) and vertical axes (longitudinal heads). In both cases the efficiency was estimated by power requirement for cutting. The feasibility was shown of breaking oil shale by direction of cutting across the bedding by using cutting drums on horizontal axis of rotation. The research also evidenced that the existing coal shearsers proved low endurance for mining oil shale. Therefore, the problem arose of developing special types of shearsers for mining oil shale or modifying the existing coal shearsers.
It was further stated that the better pick penetration of the longitudinal machines allows excavation of a harder strata and at higher rates with lower pick consumption for an equivalent sized transverse machine. It was reported that with the longitudinal cutting heads the dust forming per unit of time decreases due to smaller peripheral speed. The change in the magnitude of the resultant boom force reaction during a transition from arcing to lifting is relatively high for the transverse heads, depending on cutting head design. Specific energy for cutting across the bedding with longitudinal heads is 1.3–1.35 times lower which practically corresponds to the change of the factor of stratification.

The results of these tests were used in large body of fundamental research into rock and coal cutting in the UK during the 1970’s and early 1980’s at the UK Mining Research and Development Establishment.

About three decades ago a progressive mining method with continuous miner, which is most suitable for the case of high-strength limestone layers in oil-shale bed, did not exist in oil-shale mines of the former USSR and in Estonia. Therefore, up to now oil shale mining with blasting is used as a basic mining method in Estonia minefields while continuous miner was tested for roadway driving only. With regard to cutting, the installed power of coal shearers and continuous miners has increased enormously since the original work. Actual state of the market has changed and a wide range of powerful mining equipment from well-known manufacturers like DOSCO, EIMCO, EICKHOFF, etc. is available now.

Estonia has 30 years of experience in cutting with longwall shearers which were not capable of cutting hardest limestone layer inside of the seam. Tests with road headers have been carried out in 1970ties.

We have tested Wirtgen surface miner SM2100 and SM2600 for two years and SM22000 and Man Tackraf surface miner, and are currently testing Wirtgen surface miner SM2500 for high selective mining in an open cast mine.

Fig. 7. Cutting with longwall shearers

Testing criteria of continuous miners are:
- Decreasing CO$_2$ pollution ca. 1.2 times
- Decreasing ash amount
- Decreasing oil shale losses
- Avoiding vibration caused by blasting
- Avoiding ground surface subsidence
- Increasing oil yield
- Increasing drifting and extracting productivity
- Increasing safety of mining operations

Fig. 9. Testing Wirtgen surface miner SM2500 for high selective mining in an open cast mine

Fig. 10. Waste rock from separation plants could be one of the sources for backfilling material

European measure

Currently many coal fields in Europe face difficult mining conditions. The main problems in addition to deep bedding are unstable roof, dilution of side rock and content of abrasive and hard parts of side rock inside or between coal seams.
Development of Coal mining technology by testing continuous mining systems in difficult conditions in Estonian Oil Shale deposit improves coal mining possibilities due to enhancing cutting, supporting and face transport form high productive shortwall face.

Bases for hard rock mechanical breaking have been tested in Estonia in 1970es. The results of these tests were used in continuous miners producing in UK. Currently Estonia is independent energy producer thanks to existing of Oil Shale deposit and favourable mining and processing conditions. Due to environmental restrictions, social pressure and deeper bedding of oil shale in potential mining fields, testing of high-productive, environmentally friendly, mechanical mining is needed for successful continuation of independent energy supply (oil shale) for EU state country, Estonia. The main results of successful test are:

- Decreasing need for energy import. Oil shale, shale oil (0.5% S, -15 freezing temp.)
- Improving environmental situation in Europe and Baltic Sea region.
- Decreasing CO₂ pollution, ash pollution and water pollution.
- Improving safety (dust explosion for oil shale and methane gas explosions for coal).

Surface mining

Almost half of mined oil shale in Estonia is exploited in surface mines with open cast mining technology. Economical indexes of open cast mining surpass underground ones from 1.5 to 2.5 times.

Oil shale mining in open casts has been mostly done by drilling and blasting method and transportation with shovel and truck method. Since recent years, caused by economical reasons there are trend for using rippers, surface miner, mechanical shovels and hydraulic excavator as well as hydraulic hammers for braking oil shale layer instead of drilling and blasting.

Walking draglines with buckets of 10 and 15 m³ and booms of 70 and 90 m are the main stripping equipment. Stripping shovels with 35 m³ bucket and 65 m boom have been in exploitation but they have all stopped working for now. The overburden thickness limit is evaluated for 27 to 30 meters. The main economic marginal stripping ratio in Estonian open casts is from 6 to 8 m³ t⁻¹.

Small auxiliary surface mines at the boundaries of old mine fields and the main production units intend to change for high selective mechanical mining for achieving required oil shale quality.

Underground mining

In spite of low depth of oil shale bedding the underground mining have spread instead of surface mining. The main underground mining method is room and pillar mining. The field of oil shale mine is divided into panels by the panel drifts. The panels are from 600 to 800 m wide and a number of kilometres long. The panel is divided into 350 m wide mining blocs. The main operations carried out in rooms include bottom cutting, drilling of blast holes, blasting, loading of blasted rock on the chain conveyor and supporting by bolts. The height of the rooms is correspondent to the thickness of the commercial oil shale bed. The width of the workings is varying from 6 to 10 m.

The main losses are in the pillars which area is 30 to 40 m², depended from the depth of oil shale bed. Losses vary from 23 to 26 per cent in average 25 per cent. In three mines the longwall mining method by shearer loaders with hydraulic roof support system has been used until 2001. This caused sinking of the surface after mining activities.

Separation

Oil-shale layers of the Estonian deposit are marked by letters A, B, C, etc. Layers from A to F are commercially exploited. The mined rock is as analogue to coal separation subjected to separation in magnetite suspension at separation plants. Approximately half of mined rock is separated (see Figure 5). Separated limestone could be used as aggregate in some applications for road construction industry.

Acknowledges

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Fig. 11. Strip mining technology in Estonian oil shale surface mines
Fig. 12. Underground oil shale mining layout

References


9. Taiex Workshop on EU Legislation as it Affects Mining. Department of Mining of Tallinn University of Technology in co-operation with Society of Mining Professors and TU Bergakademie Freiberg

Fig. 13. Balance of oil shale by Heavy Media Separation

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