

Technologies for Decreasing Mining Losses

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Abstract - In case of stratified deposits like oil shale deposit in Estonia, mining losses depend on mining technologies. Current research focuses on extraction and separation possibilities of mineral resources. Selective mining, selective crushing and separation tests have been performed, showing possibilities of decreasing mining losses. Rock crushing and screening process simulations were used for optimizing rock fractions. In addition mine backfilling, fine separation, and optimized drilling and blasting have been analyzed. All tested methods show potential and depend on mineral usage. Usage in addition depends on the utilization technology. The questions like stability of the material flow and influences of the quality fluctuations to the final yield are raised.

Keywords – oil shale, losses, mining, extraction.

I. INTRODUCTION

In case of stratified deposits like oil shale deposit in Estonia, mining losses depend on mining technologies. Stratified deposits are being developed from lower bedding depth to deeper and more complicated conditions [23]. Continuously the environmental or social restrictions require increasing coefficients that increase mineral losses [20]. This could be limited with the help of technological development [34,13, 36]. During the period starting from 1916 many technologies have been used and tested [31]. Currently the market economy is the main driving force for choosing technologies. This causes short term choices and works against sustainability.

Current research focuses on extraction and separation possibilities of oil shale. Selective mining, selective crushing and separation tests have been performed, showing possibilities of decreasing mining losses. Rock crushing and screening process simulations were used for optimizing fractions. In addition mine backfilling, fine separation of oil shale, and optimized drilling and blasting have been analyzed. All tested methods show potential and depend on mineral usage [37]. Usage also depends on the utilization technology. Questions like stability of the material flow and influences of the quality fluctuations to the final yield are raised. Tonnage, calorific value and size distribution of the product form the quality indicators [43]. Avoiding losses in any of these processes decreases mining losses and has a positive effect on resource usage and sustainability. In addition, decreasing losses increases the amount of resource and sustainability of energy supply for the country [30, 32]. If optimized technology allows maintaining required productivity, it could be applied, even if fitting into the existing technological structure is taking longer than technically available [33, 35, 8].

The aim of the current study is to clarify what technical solutions could be applied for decreasing oil shale mining related losses.

II. ANALYSES AND TESTS

A. Selective mining

Selective extraction of oil shale seam was analyzed to understand following methods:

1. Cutting with bulldozer and excavator rippers
2. Cutting with surface miners
3. Cutting with longwall miners
4. Cutting with shortwall miners.

a) Cutting with rippers

Selective extraction of the oil shale seam can be done by a bulldozer ripper or hydraulic excavator ripper. Ripping is a low-selective technology [42]. In deeper surface mining areas, 100 tonnes class bulldozers were used and in more weathered areas or partial ripping zones, the 60 tonne class was used. One disadvantage of bulldozer ripping is excessive crushing of oil shale by heavy bulldozers with crawlers [18].

b) Cutting with surface miners

Tests with surface miners Vermeer T1255 and Wirtgen 2500 SM were carried out. The tests were followed after longer period tests with smaller class surface miners during the last 25 years. Tests have been performed with different oil shale and limestone layers. Surface miners are considered as BAT (Best Available Technology) for surface oil shale mining extraction [12, 42, 18, 15, 5].

c) Cutting with longwall miners

The planning and testing has been done for longwall mining possibilities. Shearers were used and tested for 30 years in five oil shale mines in Estonia [1]. Longwall technology has also been chosen as one of the alternatives for phosphate rock mining [41]. Technologically, this technological solution has improved compared with initial possibilities. Since the hydraulic support system was limiting the height of the longwall face (1,5 m) and the power of the shearers was relatively low (210 kW) the losses have been 50% in longwall section. Today's shearers utilize power in the range of 2200 kW, which is 10 times higher than in the tested units. Since the productivity (equal to income) could be increased, longwall technology is one of the possibilities for lowering losses. In case of removing protective side pillars between longwall section, rough estimation shows, that losses could be lowered down to 5% taking into account the geological dislocations and disfollowing the exact horizontal plane of the oil shale seam. The main obstacle of longwall shearing

technology is solving environmental and social questions, regarding subsiding the ground and accepting certain areas where such subsiding could be allowed. In comparison to the surface mining stripping in the open cast mining areas, longwall mining could be considered as a technology which causes less impact to the landscape. The ground would be lowered by up to 70% of the created space. That makes 2 meters. In open casts, even the fluctuations in the leveled overburden spoil could be 5 meters. In trench or ditches areas, the level fluctuations are up to 40 meters. This makes longwall mining the most sustainable mining method for oil shale.

d) Cutting with shortwall miners

Evaluations of breakability have been made with roadheaders F2 and 4PP-3. As a recommendation, a double-drum road header was proposed. Currently the power of the machines has increased and pick properties allow cutting harder rock. It is proposed, that both longitudinal or transverse head continuous miners (roadheaders) could be used for cutting oil shale [12]. The selectivity option is directly related to the waste material handling and should be tested in the mine [11].

Shortwall miner utilization could be the solution for making development entrances, drifts and rooms for mining. In case of satisfactory cutting performance, it could be used for extracting oil shale in production sections as well. The tests have shown, that shortwall mining is a promising technology and requires, as with longwall mining, surface miner mining and axle bucket crushing changes in some operations and processes in mining technology. Shortwall mining requires fast roof supporting technology. The supporting could be in addition in some extent easier because of lower possible fragmentation of rock caused by absence of blasting in the mine.

B. Selective crushing

For selective crushing, the following methods were tested:

1. crushing in a drum (Bradford drum) with help of rock falling impact and hammer crusher inside the drum;
2. impact crusher in underground sections as first stage crusher or impact crusher for aggregate production from oil shale waste rock;
3. axle crusher buckets with cutting and skimming process.

An impact crusher has been used in underground sections as a first stage crusher and for aggregate production from oil shale waste rock that is limestone [27].

The purpose of underground crushing is to reduce ROM (run of mine) size to the required size of up to 300 mm for transporting it on belt conveyors to the surface.

C. Separation

Separation tests have been performed by jigging and cycloning. The purpose was to find out the percentage of the fine material that could be separated. Jigging tests have shown relatively good results allowing separating initially mixed material into five different fractions. The calorific value of best fraction is highest and the limestone fraction in opposition

should be considered as the ready selected material for limestone aggregate. Up to now the main focus has been mechanical experimenting with jig. The main obstacle of the technology could be achieving required productivity. It is similar to the filter press technology where the productivity of the single unit could be low. On the other hand, if the production line could be completed with different stages, the required productivity could also be to some extent lower. To decrease required machine productivity for the same output, drum crushing or axle crushing could be used prior to the jigging.

Cycloning has shown that the calorific value of cycloned and non-cycloned fine material has no remarkable difference. Since cycloning could be done on many variations, the initial test could be considered as failed because of short time and no variations. These tests should be continued, preferably with a pilot unit or laboratory units at first.

D. Rock crushing

For crushing, the following options have been analysed:

1. Crushing with sizers
2. Crushing with impact crushers
3. Crushing with double drum crushers
4. Crushing with drum crusher
5. Crushing with jaw crusher.

Crushing process simulations were used to evaluate the distribution curves of the final product. The necessary data for this purpose is bulk density of material and the maximum size of the particles going for crushing. In order to get optimal results on certain cases, crushing units, crushers and mobile crushers can be added to the scheme. This gives extra value in lowering engineering costs, on experimenting with different devices and on further changes [19, 45].

As an example, material data for the simulation program has been:

- Input material < 1000 mm
- Solid density 1,84 t/m³
- Crushability 85% - which is the maximum
- Productivity 1000 t/h
- Gravel 31% - does not influence the results (Fig. 1.).

The value of abrasiveness has been between 0,1...1500 g/t, calculations show that this does not affect the simulation results. Neither does moisture. The crusher output cavity is set on 180mm which means that the maximum size of the outgoing particle is 200mm.

The workload of the impactor crusher is 97% of the maximum capacity. After crushing, the feed moves to the roller screen, where the feed flows into three classes:

- 0...25 mm 22,8%
- 12...107 mm 55,2% - which include 11% 12...25 mm (Fig.2.)
- 107...200 mm 22% .

It can be detected that the fines part is 28,9%.

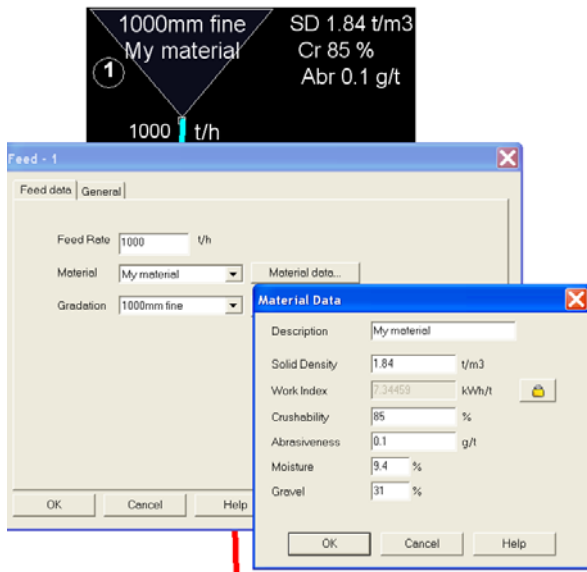


Fig. 1. Material data insertion window

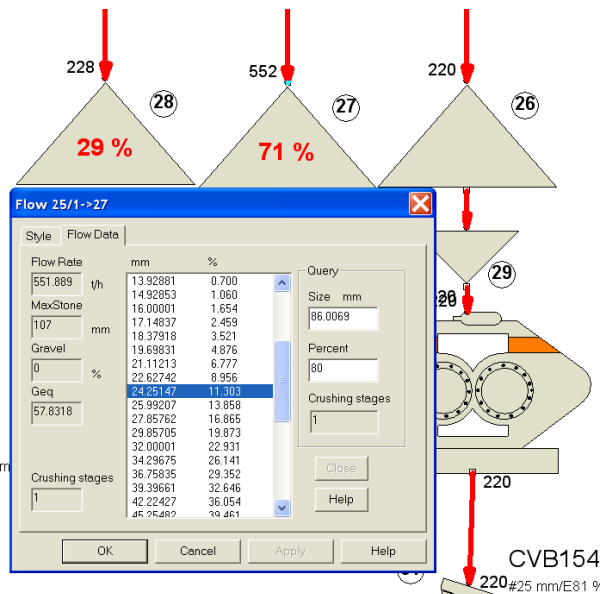


Fig. 2. Flow data

Fines are added on the secondary crushing/particle size is 107...200 mm. Calculations have shown that in this way 5% of fines are added. At the present moment the best crushing option in making the minimum fines is crushing with the sizer.

Experiments show that the minimum in generating fines is achieved when the rotating speed of sizer was 175 rpm. In slow rotation the generation was 11,8% and fast rotation gave 6,5% of fines (Fig.3).

As experiments show, it is possible to decrease the fines generation which mostly is considered to be waste.

Each simulation manufacturer focuses on separation methods or some part in the separation process. When it comes to crushers, then simulations are also manufacturer based and reflect types and models, what the company offers [7, 4]. Newer products are introduced in the simulation programmes later. In case of the roll crusher for example, the characteristics and behaviours are still added to the

programme. Sizers are even more complex, because they have been used only a few years and therefore are relatively new products among crushers. In Estonia there are a lot of questions concerning the fines in the crushing process.

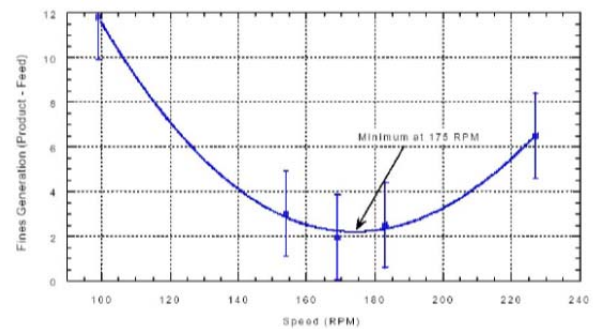


Fig. 1. Experiments resulted in fines generation of 2,2% [10]

E. screening

Two basic screening solutions have been analysed in addition to the traditional vibration screening:

1. Screening in drum screen
2. Screening on rotary screen
3. Screening on roller screen.

F. Mine backfilling

The tests contained testing of mixes properties of the backfill material, testing of backfilling technology and analyzing backfilling material flows. The main hypotheses are that backfilling reduces mining losses and the amount of waste on the ground surface [27]. In addition it increases land stability [12]. Stability issues have been developed in sense of information availability. Mapping, special information systems and seismological methods allow one to detect any collapses which have occurred [21, 25].

G. Fine separation

Fine separation tests were carried out with CDE equipment and with jigging equipment. The aim of the fine separation test is to separate fines from pulp before they reach sedimentation pond and to take it into use as a product.

III. RESULTS AND DISCUSSION

A. Selective mining

a) Cutting with rippers

In Ubja oil shale open cast, the productivity of oil shale hydraulic ripping was nearly 600 m³/h. At the Ubja open cast, overall oil shale losses are 0% based on the Environmental Register. Bulldozer ripping is considered as semi-selective ripping where seam losses make 12% in comparison to 5% with surface miners [42]. The first problem of ripping technology has been power of ripping machines. Before 100 tonnes class bulldozers were applied, the low ripping power was one of the main concerns. Excavator ripping is in similar stage like bulldozer ripping has been in its beginning stage. The power of the excavator ripper is not satisfactory to reach required productivity. Excavator ripping does not solve the losses question because of the principle of vertical movement.

Excavator ripping could be considered in low bedding areas, where drilling and blasting is prohibited, the oil shale seam is weathered meaning weaker bonds between layers. A bulldozer ripper, therefore could be used as low selective miner, but it is limited by availability of keeping losses down. The main problem is limestone and oil shale pieces and lumps that contain both material and could not be separated by the ripper. If needed, one of the solutions could be skimming with axle crushers.

b) Cutting with surface miners

It was found that extracting with a high selective surface miner is the main possibility of decreasing losses in case of surface mining. The main obstacle for using such technology is the partly unsolved overburden stripping technology. In the future, combined methods should be considered like high selective cutting plus selective axle crushing for aggregate separation.

Mining with surface miner Wirtgen 2500 SM helps to reduce losses and improve calorific value of oil shale. It is possible to mine limestone and oil shale seams separately with higher accuracy than rippers (2-7 cm) with deviations about one centimetre [42]. Losses can be decreased from 12 percent to 5 percent compared to ripping [18]. Based on practical data, the surface miner enables to increase the output of oil shale up to 1 tonne per square meter. The oil yield increases 30%, reaching up to 1 barrel per tonne of oil shale during the oil shale retorting, because of better quality, meaning higher calorific value of the material that is sent to the retorts [42].

c) Cutting with longwall miners

It was found that distribution of required large particles of oil shale is possible with longwall shearers.

The practice with longwall shearers shows that the subject for cutting is oil shale and the larger size is distributed to the limestone fraction [1]. This is due to the hardness difference of the rocks. Longwall mining could decrease horizontal losses by 20 to 40%.

d) Cutting with shortwall miners

One of the main advantages that a shortwall miner could present are the possibility of avoiding weakening pillars in the mine by blasting [20].

This in addition could give the possibility to decrease pillar size and to decrease losses left to the pillars. Pillar losses that are caused by pillars with cross section area of 16 to 49 square meters could be decreased therefore by 16 to 28% with avoidance of the 0,3 zone by sides of the pillars.

The pillars strength and stability of the ground are directly related but have the opposite influence on sustainability. In case of backfilling this dilemma could be solved [22]. In some areas also smooth and directed subsidence could be solution.

B. Selective crushing

The underground crushing process where ROM (run of mine) size is reduced to the required size up to 300 mm has no direct influence on the percentage of losses. Nevertheless,

ROM size distribution is influenced by impact crushing and fines are produced. In case of oil production with vertical generators, fines and small classes of oil shale are considered as waste, if no other uses are found, like cement, electricity or oil production with SHC technology.

Selective crushing is important both for cleaning and sizing oil shale and cleaning and sizing limestone. Therefore selective crushing or selective mining methods are recommended [27].

C. Rock crushing

a) Crushing with sizers

One of the options could be using slow rotating or optimized rotating sizer for oil shale ROM crushing. According to the recommendations of crusher producers, all crusher types are suitable for crushing oil shale [25]. In relation to the moisture content, jaw crusher and gyratory crushers are unsuitable, requiring relatively dry material (<5%). A roll sizer should be able to crush up to 175 MPa material and up to 15% moisturised material. In comparison to the other types of crushers, a sizer should give the smallest percentage of fines [24, 17, 10, 2, 9, 6]. The productivity of the sizer could reach 10000 tonnes per hour (Table 1)

TABLE I
SIZER PRODUCERS

Producer	Sizer or feeder breaker	Model	Productivity, t/h
Sandvik [24]	Sizer	CR610	8000
MMD [17]	Sizer	MMD 1500	10000
FLSmidth [6]	Sizer	ABON	10000
Williams Patent Crusher and Pulverizer Company [44]	Feeder breaker	Williams Feeder Breakers	5000
Thyssenkrupp [25]	Sizer	Thyssenkrupp 1500	10000
McLanahan [16]	Sizer/Feeder breaker		
Joy [10]	Sizer/Feeder breaker		
Caterpillar [3]	Feeder breaker		1800

Fines share could be reduced down to 2,2 % from 6 to 12% with low and fast rotation in addition with Matched Velocity Technology (MTV) [9].

D. Fine separation

The possibility of using fine oil shale that is flushed away by the HMS (Heavy Media Separation) process could increase energy of used oil shale and avoid the need for settling ponds or filter presses [38]. The main idea could be the separation of fine oil shale from fine clay and limestone particles.

Fine separation tests were carried out with cyclones and fine screens and with jigging. The amount of fines that were separated from the separation pulp was in the range of 0,2-5,1 %. The average amount of fine that was separated was 2,7 % of inflow (TABLE II). 2,7 % of fine was divided into two classes with size 0-8mm and 0-5mm. The calorific value of inflow was in the range of 10,3-10,8 MJ/kg with an average of

10,5 MJ/kg and outflow was in the range 1,2-2,4 MJ/kg with an average 1,8 MJ/kg.

TABLE II
TEST RESULTS OF FINE SEPERATION

	Sediment %	Water %
Average concentrate Inflow	21	79
Average concentrate Outflow	18	82
Average concentrate	2,7	

E. Optimised drilling and blasting

Drilling and blasting as the main method for extracting oil shale has been used and in some extent optimized.

CONCLUSIONS

Losses vary from mine to mine considerably depending on different factors. The main factor is geological bedding, the second is legal framework and the third -- mining technology. Mining technology is the main factor that could be changed realistically by miners. Currently surface mines leave less losses and advanced technologies create less losses. Up to now the technical ultimate yield has not been reached. In the future,

the percentage of losses will increase because mining is moving in deeper zones (Fig. 2, Fig. 3, Fig. 4). The largest mine "Estonia" alone accounts for most of the losses if it takes into account only tonnes. In practice, logistics quality and availability are also factors that have to be considered. On the other hand, requirements for the continuous flow of good quality oil shale will be required and environmental costs will increase. A technological solution should be analyzed and tested for implementing. Currently the oil shale mining industry is missing broad and objective analyze for technological development.

In addition in case of surface mining, stripping technologies should be evaluated. In many cases fragmented overburden placement and usage of overburden bridges could also give positive results for decreasing mining losses [39, 12]. In case of smooth stripping technology, influence to the landscape could also be decreased [29, 28].

Using continuous technologies for decreasing mining losses could give positive effects on the even distribution of fuel oil shale [14]. In the future, rapid development, computerized directing, and virtual analyzing could be applied [40, 37].

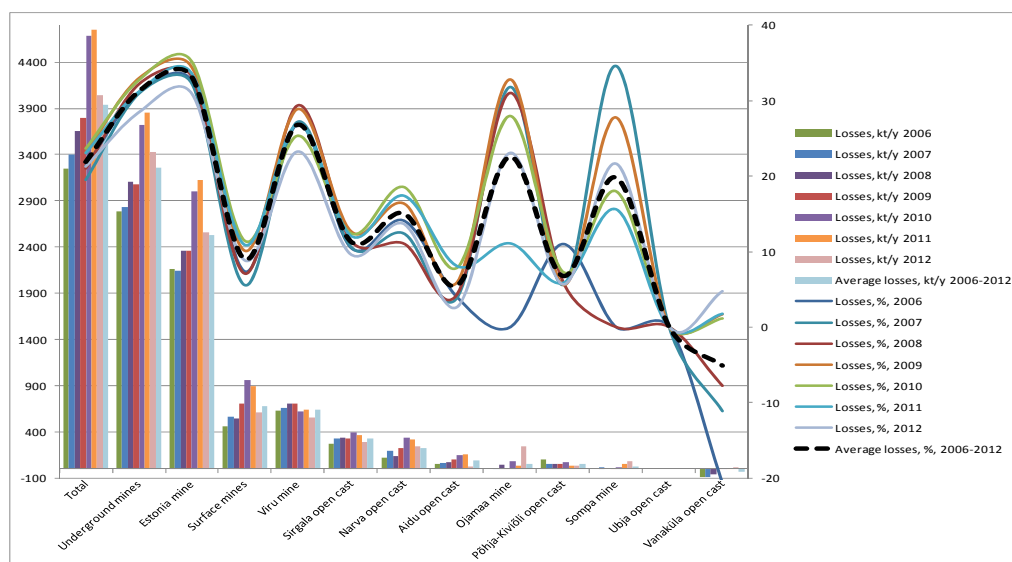


Fig. 2 Tonnage and percentage of oil shale mining losses in Estonian mines from 2006 to 2012

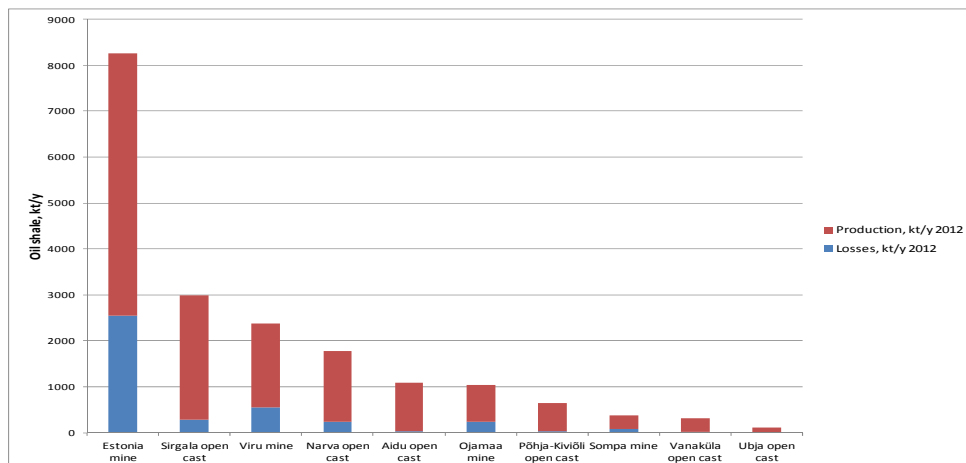
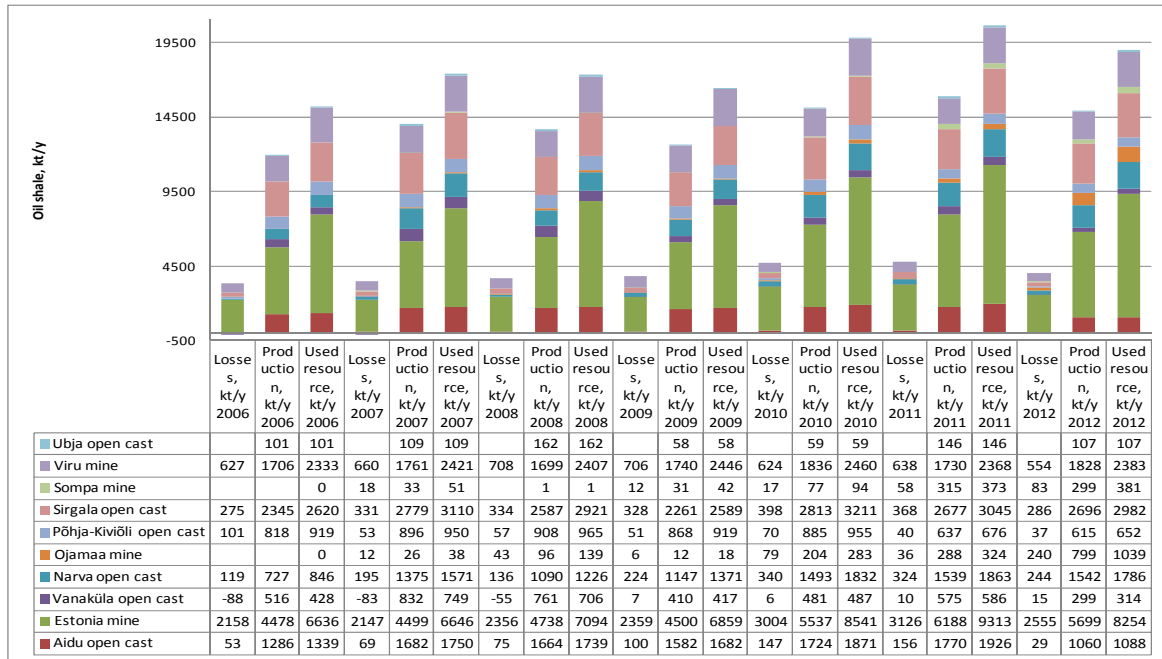


Fig. 3. Tonnage of oil shale mining production and losses in Estonian mines in 2012



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