Abstract – Oil shale mining is an important cornerstone of Estonian economy. Oil shale can be used to produce cement, oil, different chemicals products and electricity. Over 80% electricity in Estonia is produced by using oil shale. There is almost 100 years of oil shale mining experience. Despite know-how on oil shale mining and treatment, oil shale mining still suffers from remarkable resource losses and environment impact. Crushing buckets are quite novel and innovative machinery in the mining sector. This study is carried out to find out the potential of such new technology usage in oil shale industry.

I. INTRODUCTION

Oil shale has been mined in Estonia almost 100 years. At the moment, the yearly amount of mined resource is somewhat over 15 million tonnes. Maximal yearly amount has been defined as 20 million tonnes. The maximum amounts were during the 1980’s when the yearly production of oil shale was over 30 million tonnes. Oil shale is a non-renewable resource and of great national importance. Thus it has to be mined in as sustainable manner as possible.

Estonian oil shale mining technology has developed through the years, but the mining process has still several problems requiring solutions. Some main issues are resource losses and large amount of waste in processing and use. Pressure in regard with environmental protection increases steadily, and requirements for sustainable mining become tighter. Possible new technologies require critical evaluation and practical testing. Production processes needs to be planned well ahead, but on the other hand modern developments need to be followed. We describe shortly the current oil shale mining technology in Estonia, clarifying the demand for changing the technology. We also describe a promising solution for mining technology update, i.e. a crushing bucket. Initial experiments show that a crushing bucket may solve several problems in oil shale mining. This technology is somewhat more expensive. Although more waste rock would be stored on the surface, this technology is considered wasteful. It would be possible to decrease the losses considerably, if refilling of the rooms would be performed. This means that artificial supporting pillars would be constructed. With the use of backfilling technology it would be possible to increase ground stability and decrease the impact on the water system. In the case of an oil shale mine, it is possible to use waste created in heavy media separation (HMS) process, together with a mixture of oil shale ash and cement. The impact on landscape will also be diminished with room filling, as the waste of oil shale industry could be exploited as useful filling material. Thus, oil shale combustion ashes and separated waste rock would no more be stored on the surface. This would decrease environmental fees on waste storage. The drawback of such technology is that it is complicated compared to current technology leaving pillars behind. Also, this technology is somewhat more expensive. Although more oil shale is extracted, various construction works around building artificial pillars increases costs. Additional work procedures are for instance producing fill mixtures and transporting the filling material in the mine rooms.

Separation of Oil Shale

The current technology in Estonian oil shale mines is room-and-pillar mining: all the material that has been crushed with drilling and blasting is brought to the surface. Supporting pillars are left intact underground. These pillars hold the overburden layers and maintain the overlying ground surface stability. The geological conditions in Estonia oil shale mines dictate if the oil shale seam is blasted in the thickness of 2.8 m or 3.8 m. Pillars are left underground at regular intervals. These are designed to be as small as possible, but at the same time thus large that, theoretically, lasting stability of the mine rooms guaranteed also after finishing the mining operations. The aim is to prevent overlying ground subsidence from happening. The resource left in pillars is counted as loss, likely never becoming usable. Oil shale losses in the form of pillars are currently up to 30 % of the yearly production. However, when the mining depth has increased down to 60 m, the oil shale losses become as much as 40 %, or even more. This is a large proportion, indicating that room-and-pillar mining can be considered wasteful. It would be possible to decrease the losses considerably, if refilling of the rooms would be performed. This means that artificial supporting pillars would be constructed. With the use of backfilling technology it would be possible to increase ground stability and decrease the impact on the water system. In the case of an oil shale mine, it is possible to use waste created in heavy media separation (HMS) process, together with a mixture of oil shale ash and cement. The impact on landscape will also be diminished with room filling, as the waste of oil shale industry could be exploited as useful filling material. Thus, oil shale combustion ashes and separated waste rock would no more be stored on the surface. This would decrease environmental fees on waste storage. The drawback of such technology is that it is complicated compared to current technology leaving pillars behind. Also, this technology is somewhat more expensive. Although more oil shale is extracted, various construction works around building artificial pillars increases costs. Additional work procedures are for instance producing fill mixtures and transporting the filling material in the mine rooms.

The Room-and-Pillar Mining and Backfilling Technology

The current technology in Estonian oil shale mines is room-and-pillar mining: all the material that has been crushed with drilling and blasting is brought to the surface. Supporting pillars are left intact underground. These pillars hold the overburden layers and maintain the overlying ground surface stability. The geological conditions in Estonia oil shale mines dictate if the oil shale seam is blasted in the thickness of 2.8 m or 3.8 m. Pillars are left underground at regular intervals. These are designed to be as small as possible, but at the same time thus large that, theoretically, lasting stability of the mine rooms guaranteed also after finishing the mining operations. The aim is to prevent overlying ground subsidence from happening. The resource left in pillars is counted as loss, likely never becoming usable. Oil shale losses in the form of pillars are currently up to 30 % of the yearly production. However, when the mining depth has increased down to 60 m, the oil shale losses become as much as 40 %, or even more. This is a large proportion, indicating that room-and-pillar mining can be considered wasteful. It would be possible to decrease the losses considerably, if refilling of the rooms would be performed. This means that artificial supporting pillars would be constructed. With the use of backfilling technology it would be possible to increase ground stability and decrease the impact on the water system. In the case of an oil shale mine, it is possible to use waste created in heavy media separation (HMS) process, together with a mixture of oil shale ash and cement. The impact on landscape will also be diminished with room filling, as the waste of oil shale industry could be exploited as useful filling material. Thus, oil shale combustion ashes and separated waste rock would no more be stored on the surface. This would decrease environmental fees on waste storage. The drawback of such technology is that it is complicated compared to current technology leaving pillars behind. Also, this technology is somewhat more expensive. Although more oil shale is extracted, various construction works around building artificial pillars increases costs. Additional work procedures are for instance producing fill mixtures and transporting the filling material in the mine rooms.

Separation of Oil Shale

Oil shale seam have interlayered limestone and in separation process it is needed to separate oil shale and limestone. Separation of oil shale for useful material and limestone is currently conducted in separation plants on the surface. The limestone has to be separated, as large amount of it in the material makes the calorific value of the product low. Separation of limestone in magnetite suspension in an separation plant bases on the fact that oil shale is considerably lighter than limestone. Oil shale floats on a heavy liquid but the limestone sinks. The magnetite suspension heavy liquid has the density of approximately 2.1 g/cm^3. The approximate density of limestone is 2.5 g/cm^3. Waste and losses are created in each production phase, as such oil shale lumps sink that have some adherent limestone. Yearly transport of millions of tonnes of useless limestone to the separation plant consumes additional energy and adds up to the expenses. Because of this, waste heaps of limestone pile up next to the
separation plant. This can be used for producing low-quality aggregate, which can be used as filling material in road construction. Unfortunately, it is not economically worthwhile to transport such material to greater distances. On the other hand, local demand is very small. This leads to large scale storage in waste heaps. These hills cover already almost 790 ha of the Estonian territory [4].

II. METHODS

The crushing bucket is a rather new technology. The first patents of them showed up in 1990’s. Superficially, it appears as an ordinary bucket, which one can use with an excavator, front loader as well as with an ordinary tractor. However, it is a bucket with a special function. Inside it there are two or more axles with teeth, rotating in opposite directions. The material is loaded as usual, but this bucket has also the crushing, screening and sieving function. The teeth do the crushing, stripping the material inside the bucket. In principle this is a mobile rotating crusher, which can be used also for loading. Similar principle is used in rotary crusher and sizer, but the process is different, resulting different properties of the crushed material. The material comes out under the crushing bucket. The bucket does not have automonous engine but it has to be connected with a machine, which provides hydraulic force. The axles inside the bucket rotate with the aid of oil pressure. Several types of material can be crushed. The distance between the axles and length of crushing teeth constraint the minimal and maximal sizes of material, which can be crushed with the particular device. If the lumps are too large, the teeth may not get grip on them, and too small pieces fall out. Crushed output properties can be regulated by changing the distance between the axles, size and shape of teeth, and rotation velocity. Screening buckets have analogical design. They do not have crushing teeth on the axles but discs that stir the material inside the bucket. Such material will drop from the bucket, which is smaller in dimensions than the distance between the axles rotating at the bottom. The advantage of crushing and screening buckets is their mobility. Also, it is possible to do the whole procedure at one run: dig, transport, crush/screen, and load the product [4]. Crushing buckets are altogether used for grinding, mixing and airing varying material, such as soil, compost, building waste, glass, coal, or limestone. Currently, several companies through the world manufacture both crushing and screening buckets.

It has been tested in Estonia, if screening or crushing buckets are usable in oil shale mining. The first experiments with crushing buckets in oil shale processing were conducted in Estonia in 2011. Several experiments have been carried out since. As the device appeared promising, the Department of Mining of the Tallinn University of Technology purchased a crushing bucket for further experimenting. The aim was to study its performance on different rock and mining waste [5][6][7]. By now, the most tested devices in Estonia are various models of the crushing bucket produced by ALLU company (Fig. 1).

Environmental impact of various crushing buckets was assessed, estimating the amount of dust, noise and vibration. We evaluated productivity of various models, and found out that it is possible to separate oil shale with the crushing bucket on site. It is not only possible to dig, transport, crush and load the material at one run, but also remove limestone in the crushed rock. The principle of oil shale separation in a crushing bucket is based on the fact that oil shale has smaller compressive strength than limestone. Compressive strength is the main indicator of crushability of a material [13]. Compressive strength of oil shale is dependent of surface hardness, cracks and moisture. Oil shale with small compressive strength crumbles quicker in a crushing bucket than limestone drops out from the bucket between the axles. In addition, the teeth on the axles cut and tear the soft oil shale off from the limestone. Principally only limestone is left in the crushing bucket in the final stage of crushing, and can be put aside. Separation process by crushing buckets does not work ideally. A few smaller and softer limestone lumps disintegrate together with oil shale and end up in the final product. Respectively, some stronger oil shale lumps end up among the limestone. Additional experimenting and optimizing are required, although initial experiments clearly show the potential of this technology for separating on site.

The latest extensive experimentation was carried out at the end of summer 2013 in the Narva open cast oil shale mine [19]. It was the first time of testing the 6.9 m³ size of ALLU crushing bucket, designed especially for mining purposes. The exact name of the bucket was M-3-32 Prototype 001. Bucket was working with Komatsu WA600 modified wheel loader. Working cycle consist: loading, crushing, limestone removing (Fig. 2. M-3-32 Prototype 001 tests in Narva Open Cast.). For laboratory test was take crushed material samples.
M-3-32 Prototype 001 fieldwork samples was tested in laboratory of mining conditions: sieving test for particle size and separation test. For separation was used wet separation with water, where material by pulsating water forming layers of grains according to their density and subsequently separates the heavy material (limestone) from the stratified material (oil shale) bed. Test shows that samples taken under the crushing bucket, class 4mm-125mm where 70% oil shale and 30% of limestone. Also was noticed that the smaller size consist less limestone (Fig. 3. Separation results). The test works are still in progress and also needed to test the removed limestone [9].

### III. RESULTS

- If limestone can be removed in site, at least to some extent, amount of broken rock transported from a mine or open cast would be decreased, as well as expenses on transport to an separation plant.
- Halfway separated broken rock with less limestone burdens less the separation plant.
- Limestone remaining in the mine can be used for constructing artificial pillars.

The last one of these points is essential in replacing room-and-pillar mining with backfilling technology. If waste rock can be left underground already initially, expenses for bringing filling material become smaller. Backfilling technology makes it possible to mine the most of the geological resource and simultaneously lessen the amount of
environmental pollution. Losses in oil shale mining become smaller up to 30% and fewer waste hills are formed [[12]].

IV. DISCUSSION

If room-and-pillar mining method is continued, material losses in mining will remain. Currently, the resource losses are almost 30% and they will be increased in the future while mining progresses to a greater depth. A portion of the resource will now remain underground in the form of pillars, smaller up to 30% and fewer waste hills are formed [[12]]. It is also possible to conduct the initial oil shale and limestone separation in site, providing material for artificial pillars and decreasing load on separation plants. A crushing bucket may be one solution in decreasing oil shale losses and relieving environmental impact.

ACKNOWLEDGEMENTS

This research work has been supported by European Social Fund (project “Doctoral School of Energy and Geotechnology II”.

DAR8130/1.2.0401.09-0082 - http://mi.ttu.ee/doktorikool. This research is also supported by the grant AR12007—Sustainable and environmentally acceptable Oil shale mining —mi.ttu.ee/etp, B36 - Extraction and processing of rock with selective methods - mi.ttu.ee/rikastamine. We also want to thank PhD Heidi Soosalu.

REFERENCES

[3] Huang, YL.; Zhang, JX.; Zhang, Q.; nie, SJ.; Backfilling technology of shale ash and cement [2][17]. It is also possible to conduct the initial oil shale and limestone separation in site, providing material for artificial pillars and decreasing load on separation plants. A crushing bucket may be one solution in decreasing oil shale losses and relieving environmental impact.

ACKNOWLEDGEMENTS

This research work has been supported by European Social Fund (project “Doctoral School of Energy and Geotechnology II”), DAR8130/1.2.0401.09-0082 - http://mi.ttu.ee/doktorikool. This research is also supported by the grant AR12007—Sustainable and environmentally acceptable Oil shale mining —mi.ttu.ee/etp, B36 - Extraction and processing of rock with selective methods - mi.ttu.ee/rikastamine. We also want to thank PhD Heidi Soosalu.

REFERENCES

[3] Huang, YL.; Zhang, JX.; Zhang, Q.; nie, SJ.; Backfilling technology of shale ash and cement [2][17]. It is also possible to conduct the initial oil shale and limestone separation in site, providing material for artificial pillars and decreasing load on separation plants. A crushing bucket may be one solution in decreasing oil shale losses and relieving environmental impact.

ACKNOWLEDGEMENTS

This research work has been supported by European Social Fund (project “Doctoral School of Energy and Geotechnology II”), DAR8130/1.2.0401.09-0082 - http://mi.ttu.ee/doktorikool. This research is also supported by the grant AR12007—Sustainable and environmentally acceptable Oil shale mining —mi.ttu.ee/etp, B36 - Extraction and processing of rock with selective methods - mi.ttu.ee/rikastamine. We also want to thank PhD Heidi Soosalu.

REFERENCES

[3] Huang, YL.; Zhang, JX.; Zhang, Q.; nie, SJ.; Backfilling technology of shale ash and cement [2][17]. It is also possible to conduct the initial oil shale and limestone separation in site, providing material for artificial pillars and decreasing load on separation plants. A crushing bucket may be one solution in decreasing oil shale losses and relieving environmental impact.

ACKNOWLEDGEMENTS

This research work has been supported by European Social Fund (project “Doctoral School of Energy and Geotechnology II”), DAR8130/1.2.0401.09-0082 - http://mi.ttu.ee/doktorikool. This research is also supported by the grant AR12007—Sustainable and environmentally acceptable Oil shale mining —mi.ttu.ee/etp, B36 - Extraction and processing of rock with selective methods - mi.ttu.ee/rikastamine. We also want to thank PhD Heidi Soosalu.