GEOLOGICAL STORAGE AND MINERAL TRAPPING OF INDUSTRIAL CO_2 EMISSIONS IN THE BALTIC REGION: POSSIBLE SCENARIOS

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http://nts1.cgu.cz/geocapacity

http://co2neteast.energnet.com/

ABSTRACT

Estonia, Latvia and Lithuania have strong economic links and coordinated environmental policy. Furthermore, they are situated within the same geological unit, the Baltic Sedimentary cover. It urges the elaboration of the common approach in managing the CO_2 emissions, in particular as regards the geological sequestration. The smallest among three countries Estonia with 1.3 mln. population produces the highest CO2 emissions and is among the highest CO_2 producers per capita in Europe, mainly due to oil shale used for energy production. Geological conditions in three countries are rather different, resulting in zero potential for CO_2 geological storage (CGS) in Estonia located at the shallowest part of the Baltic sedimentary basin, low CGS potential in Lithuania located at the deepest part of the basin and high CGS potential of Latvia that contains large uplifts as the potential traps for CO_2 storage. Alternative approaches are suggested for Estonia and Lithuania, focusing on the mineral trapping of CO_2. The immobilization of CO_2 by the alkaline watered ash and ash transportation water from flue gas formed by shale combustion is a prospective option in Estonia. The serpentinites abundant in the crystalline basement is a prospective media for CO_2 immobilization in Lithuania. The other option for Estonia and Lithuania is a transportation of CO_2 to the Latvian structural traps for geological storage.

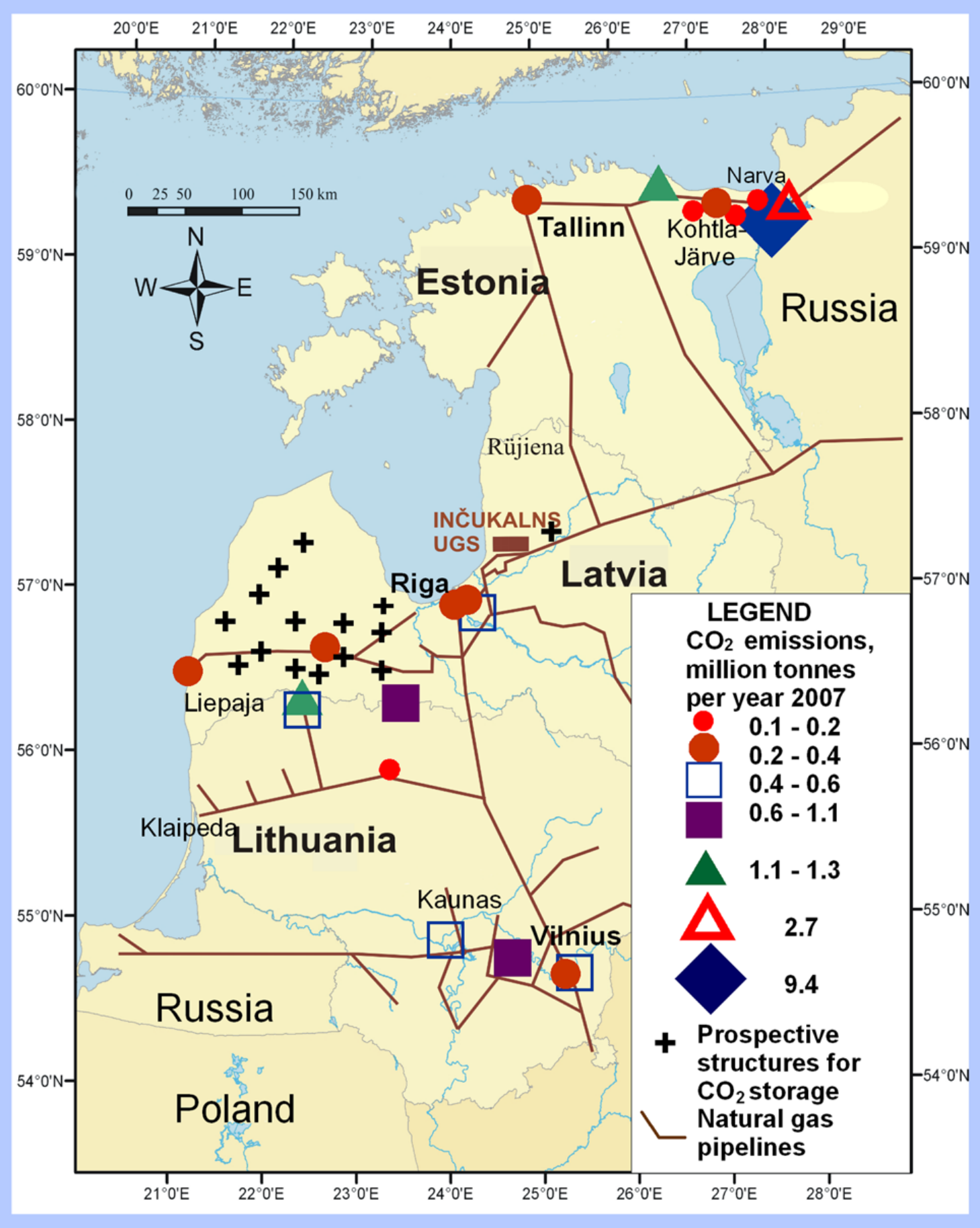
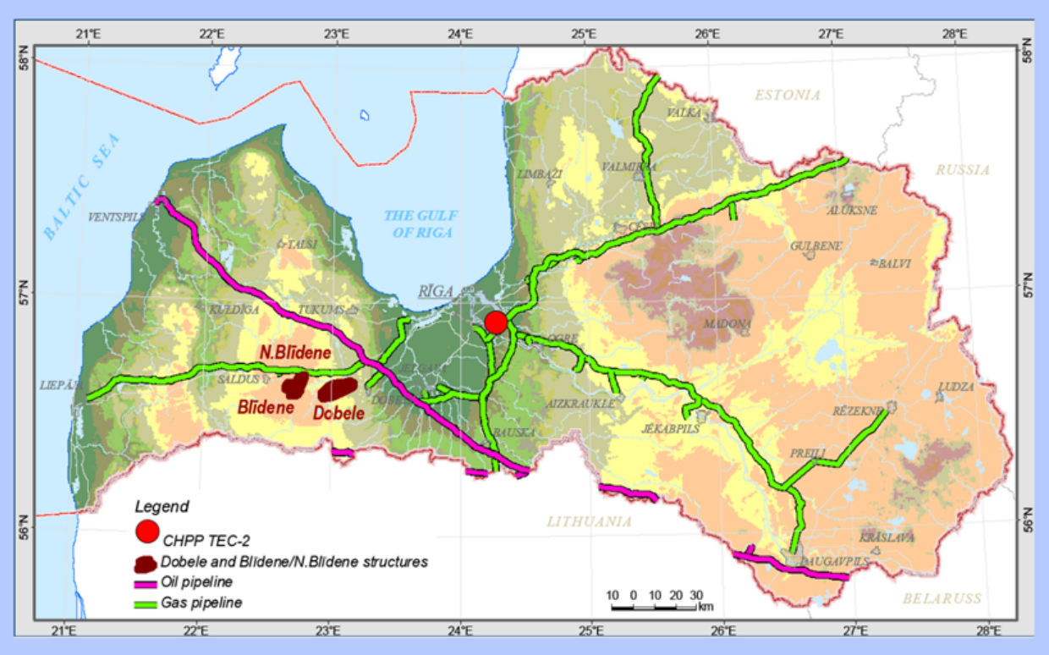


Figure 1. Large industrial CO_2 emissions in 2007 in Estonia, Latvia and Lithuania registered by the European Union Emissions Trading Scheme. Solid lines show the natural gas pipeline network. The rectangle shows the Inĉukalns underground gas storage (UGS). Structures prospective for CO_2 storage in Latvia are shown by black crosses.

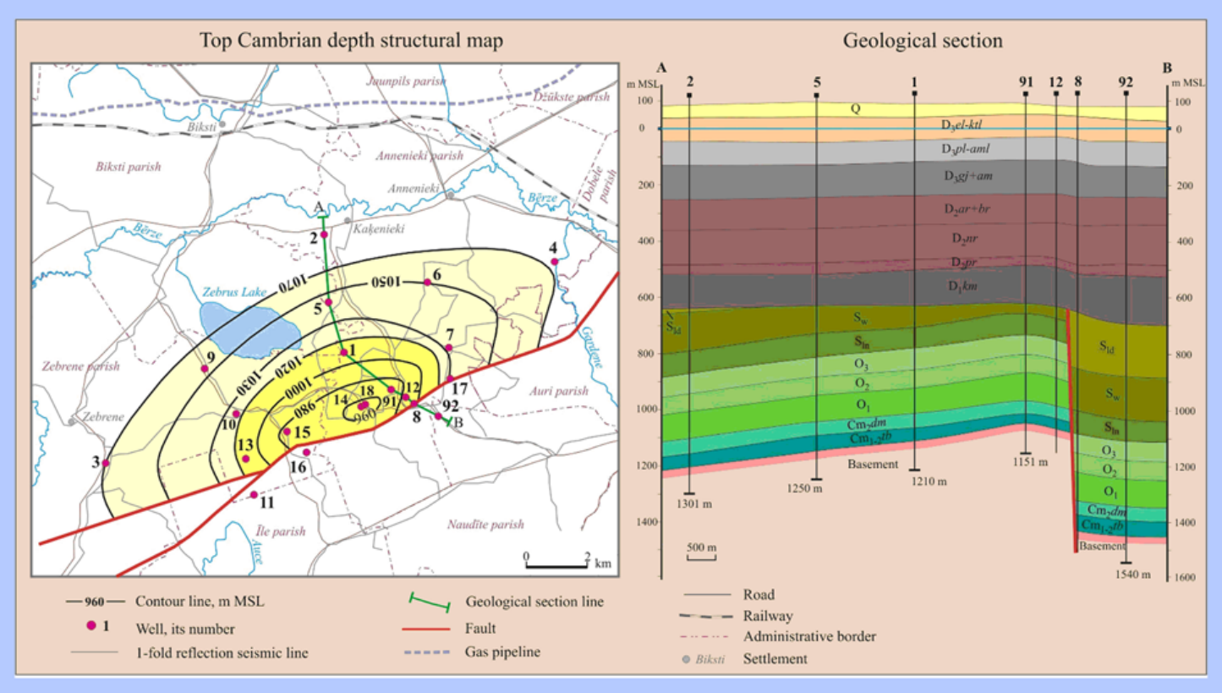
LATVIAN CASE STUDY

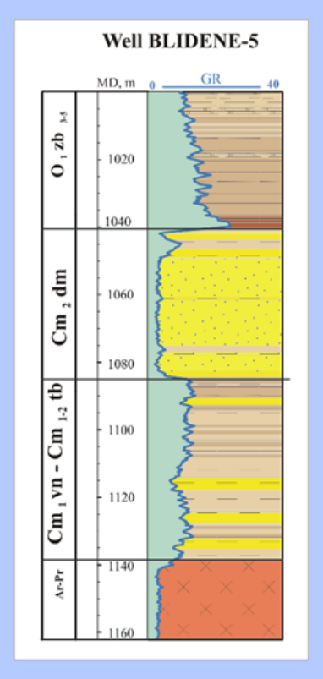


Location of "Latvenergo" plant CHPP TEC-2, Dobele and Blidene/N.Blidene structures

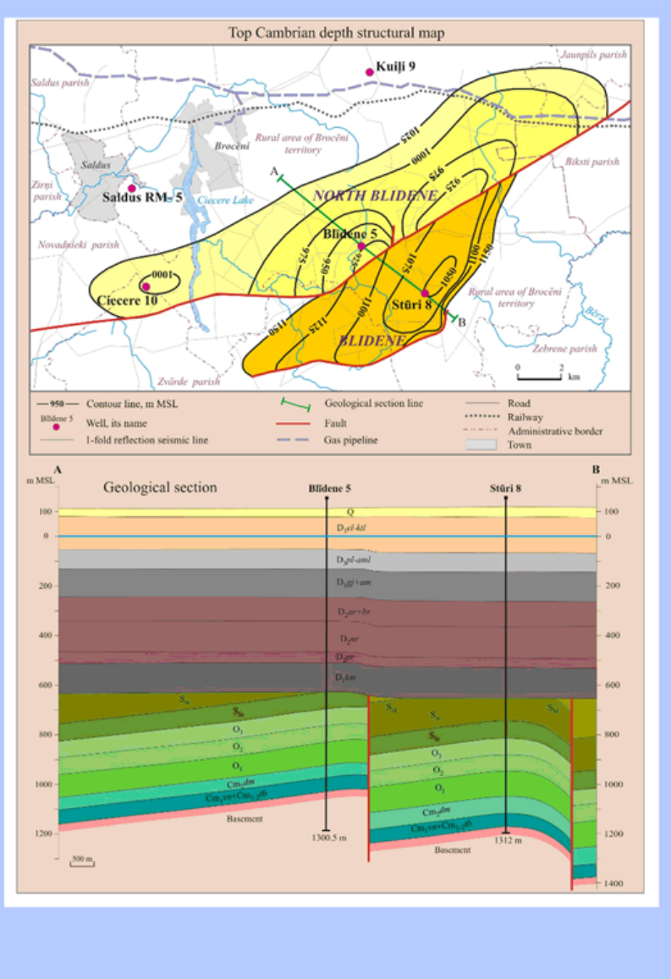
SJSC "Latvenergo" "Rigas Termoelektrostacija" TEC-2
© Latvenergo

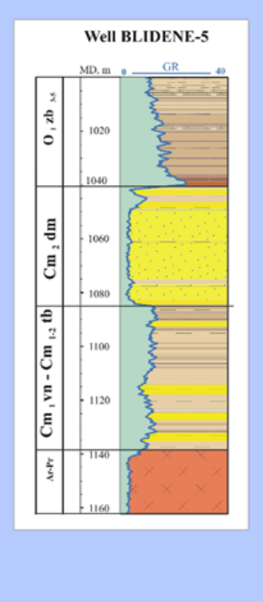
"Latvenergo, TEC-2" is the biggest source of CO_2 emissions in Latvia (0.79 Mt per year), was selected for a case study. Three anticline structures - North Blidene, Blidene and Dobele were chosen for CO_2 storage. The structures N. Blidene and Blidene are considered as a single storage site. The conservative volume in the Cambrian aquifer at the Dobele structure is estimated as 56 Mt, while at the Blidene structure - 132 Mt (N. Blidene structure – 74 Mt and Blidene structure – 58 Mt). The structures are located close to exited natural gas pipelines. The planned duration of the projects - 30 years





Dobele structure was drilled by twenty wells, allowing accurate estimation of its storage potential and elimination of drilling costs. The Dobele structure, with the EU support, is considered, primarily, as a potential natural gas storage. The Dobele high was included in the case study as the best studied anticlinal structure suitable for modelling of CO_2 storage. The transportation distance of CO_2 by pipelines is 122 km. It is planned to reactivate 2 old boreholes.
The trap is represented by an anticlinal structure, associated with a fault (amplitude is about 300 m). The depth of the Cambrian at the dome is –960 m. Sandstone of the Deimena Formation can be clearly revealed in the sections of all the wells. They are overlain by the lower Ordovician clay all over the area, with thickness exceeding 20 m.





The Blidene stucture is less studied. The high total capacity of the N. Blidene and Blidene structures (132 Mt) is a positive aspect for CO_2 storage. The total distance of transportation by pipelines is 134 km. Drilling of 2 new wells at the dome of the Blidene structure is planned. The Cambrian sandstone is overlain by a Lower Ordovician clay caprock, over 40 m thick. The top of the reservoir within the N. Blidene structure is at the depth 950 – 1050 m. The top reservoir of the Blidene structure is at the depth 1050 – 1150 m.

At the moment, there are no CO_2 sources with the emissions exceeding 1 Mt in Latvia. However, such sources exist in the neighbouring Lithuania. The Latvian government plans to build a new power plant in the Western Latvia with CO_2 emissions that would exceed 2 Mt per year. Therefore, the establishment of a storage using two structures (adjacent to a single fault) with the total capacity 132 Mt is a prospective to create CO_2 storage both for the Latvian and Lithuanian CO_2 sources. Geological conditions allow the establishment of a common infrastructure, which would greatly reduce the storage costs.

Acknowledgements

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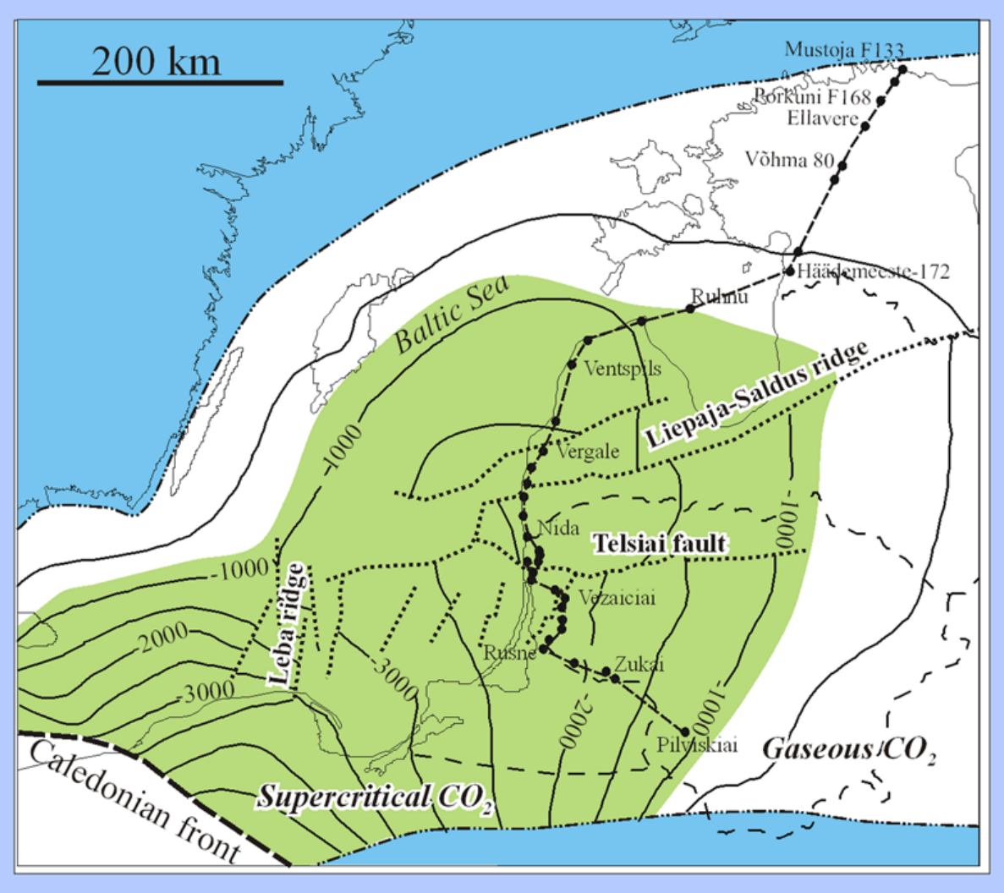


Figure 2. Depths of the top of the Cambrian aquifer. The contour lines indicate the depth of the top of the Cambrian. The hatched lines show major faults. The P–T fields of gaseous (white) and supercritical (green) state of CO_2 are indicated. The line of the geological cross-section shown in Fig. 3 is indicated.

Oil shale open cast in Estonia

Hydro Power Plant, Latvia

Ignalina Nuclear Power Plant, Lithuania

CO_2 SOURCES

The largest GHG emissions in the Baltic countries is produced by energy sector (Table 2), while contribution from other sectors is much less significant (1-4, Rimša et al, 2007, 2008). In 2007 twenty-two large sources exceeding 100 000 tonnes/year (Fig. 1, Table 3) produced 14.5 Mt of CO_2 in Estonia, 4.8 Mt in Lithuania and 1.9 Mt in Latvia. In Estonia CO_2 emissions per capita amounting 14.1 tonnes in 2004 are one of the highest in Europe (Table 1). For the sake of comparison it should be noted that in 2004 average CO_2 emissions per capita was 7.7 tonnes in Europe.

The high GHG emission rate in Estonia results basically from the use of oil shale for power production. Main CO_2 sources are located in the northeast of the country, close to the oil-shale deposits. The largest CO_2 sources in the Baltic countries are "Estonian" and "Baltic" electric power stations producing respectively 9.4 and 2.7 Mt of CO2 in 2007. The Kunda Nordic cement plant produced 1.17 Mt of CO_2 in 2007 (0.746 Mt of CO_2 in 2005) (Fig.1) The other concentration of CO_2 sources occurs in the Tallinn region.

In Latvia, the main CO_2 producers are located in the western part of the country. In 2007 the Liepaja metallurgical enterprise emitted 0.356 Mt of CO_2 and three electric power stations in the Riga area emitted 0.567, 0.386 and 0.23 Mt of CO_2 that is close to volumes of 2005.

HYDRODINAMIC TRAPPING

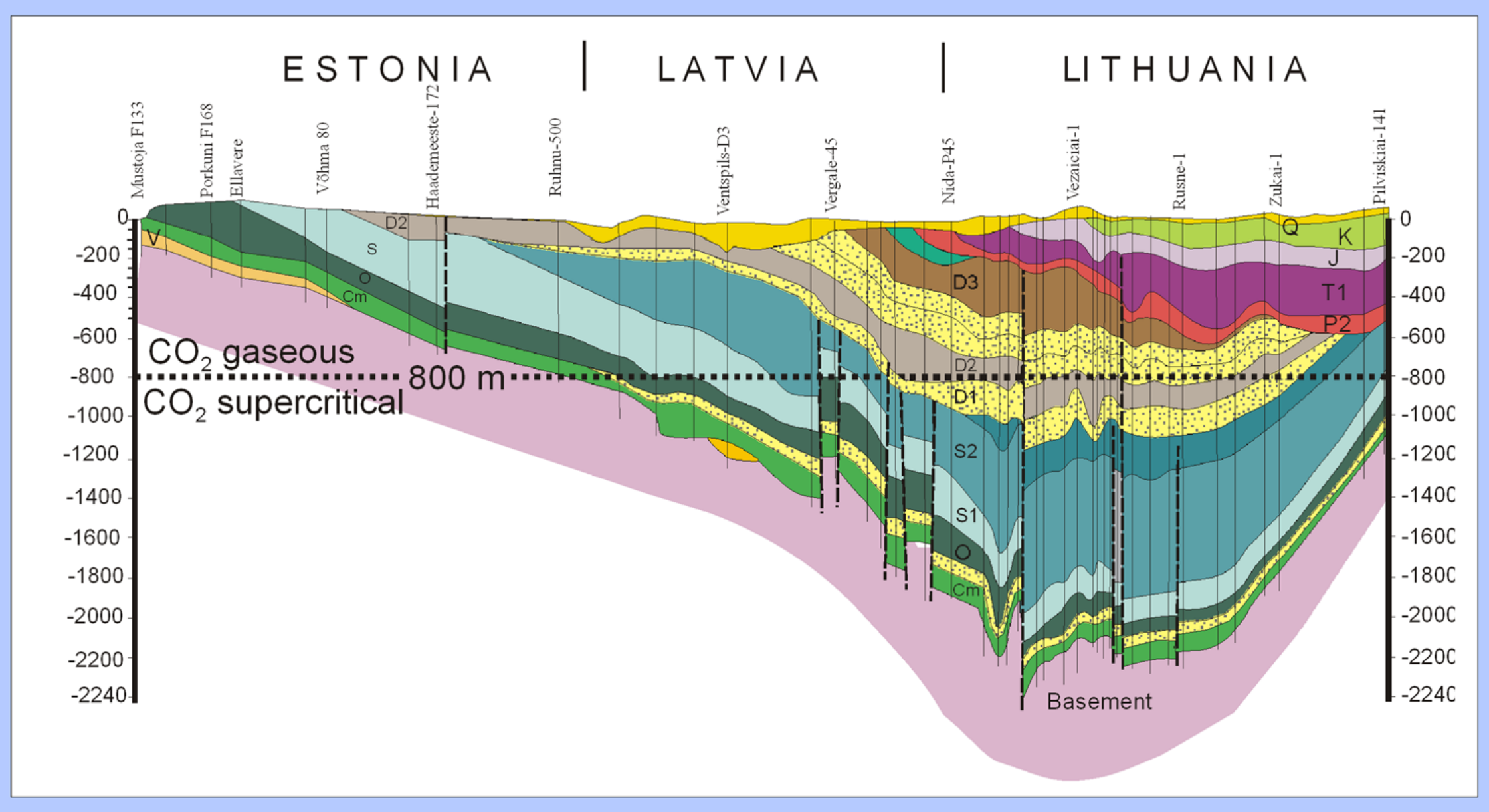
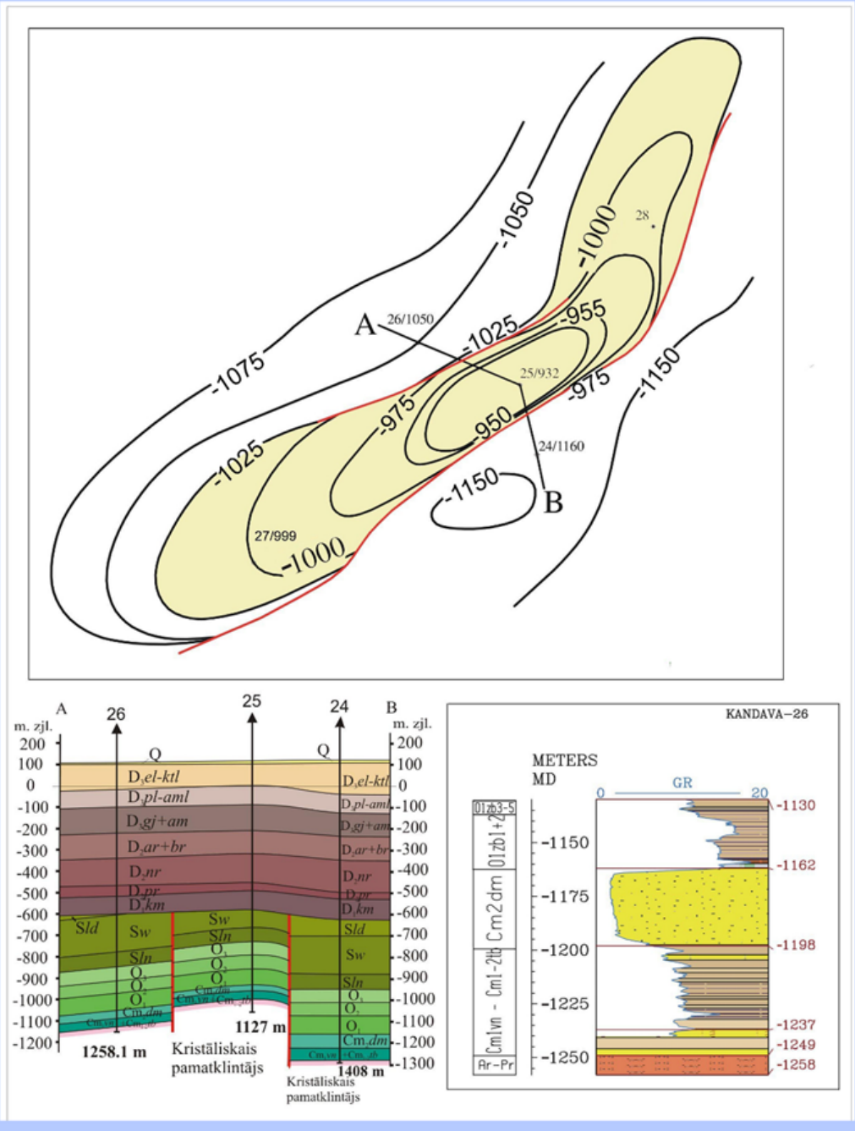


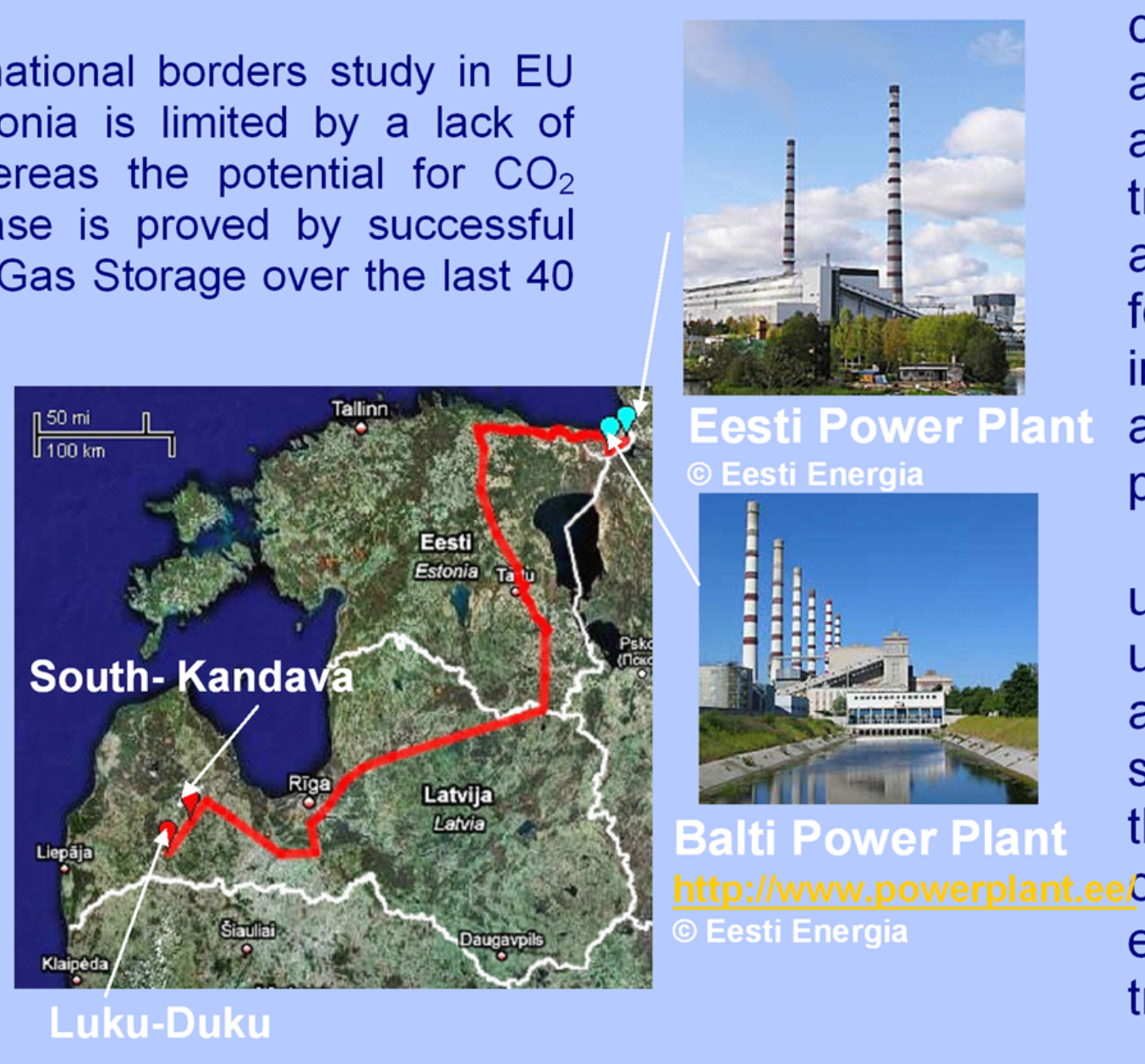
Figure 3. Geological cross-section across Estonia, Latvia and Lithuania. Major aquifers are indicated in yellow and by dots. V – Vendian (Ediacaran), Cm – Cambrian, O – Ordovician, S – Silurian, D1, D2 and D3 – Lower, Middle and Upper Devonian, P2 – Middle Permian, T1 – Lower Triassic, J – Jurassic, K – Cretaceous, Q – Quaternary.

ESTONIAN-LATVIAN CASE STUDY

The Estonian-Latvian case study is only one crossing national borders study in EU GeoCapacity project. The CO_2 storage potential in Estonia is limited by a lack of hydrocarbon fields and favourable saline aquifers, whereas the potential for CO_2 storage in Latvia is greater. The viability of such a case is proved by successful application in the Latvian Inĉukalns Underground Natural Gas Storage over the last 40 years, providibg Estonia with natural gas when necessary.

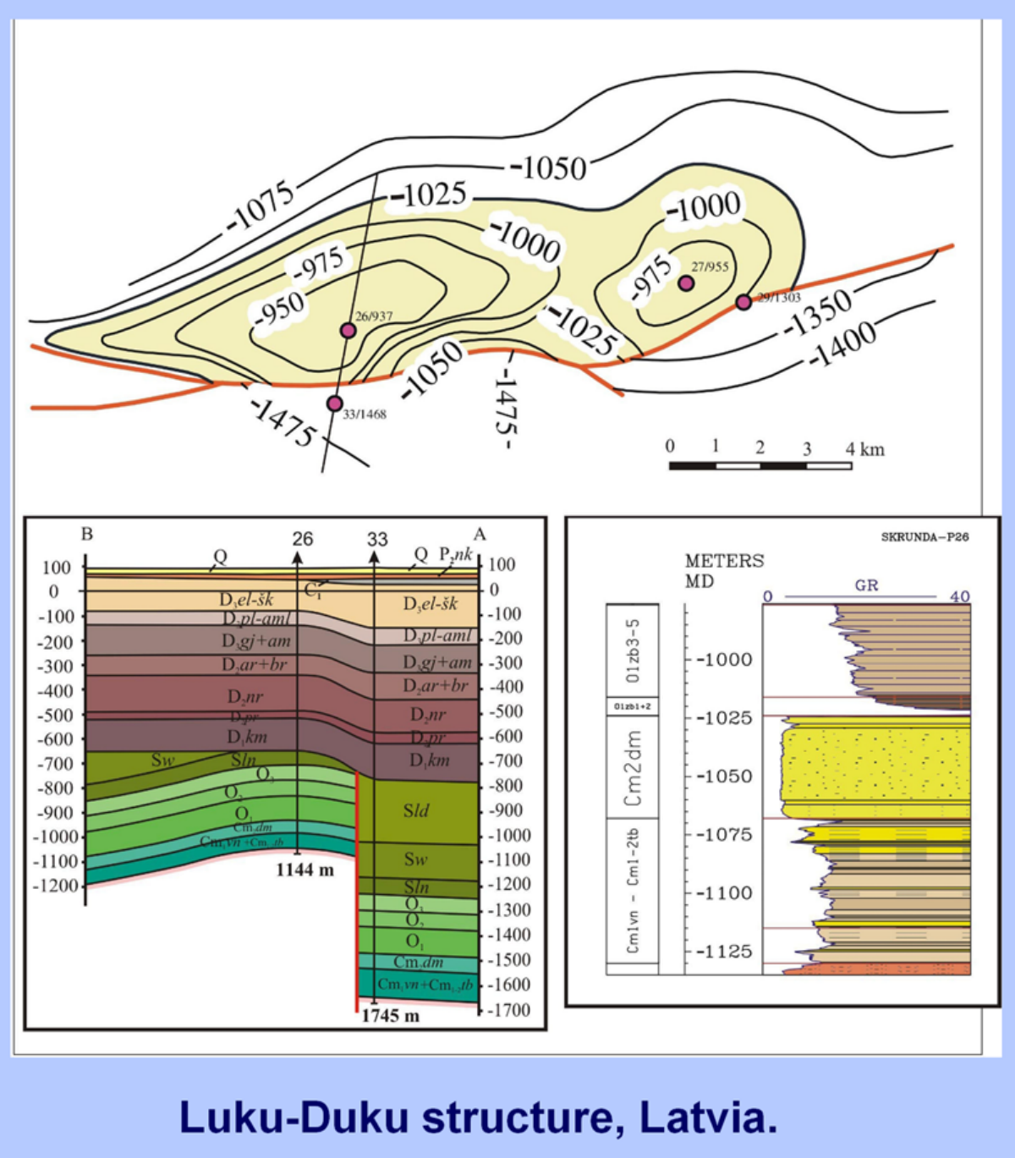


South Kandava structure, Latvia.



Two anticlinal structures in Latvia Luku-Duku and South Kandava are offered for the case study by LEGMA. The top of the Cambrian aquifer is located at the depth of 1024-1053 m. Reservoir thickness in the structures is 28-45 m. The area of the reservoirs is 50 and 69 km^2. CO_2 capacity of the structures is 40.2 and 44 Mt of CO_2 (*value in Geocapacity database)*. Their total minimal capacity in Cambrian aquifer is about 84 Mt of CO_2. This will be enough for 8-10 years for storage of CO_2 emissions from the Eesti and Balti Power Stations. CO_2 pipelines could be constructed along the available natural gas pipelines connecting Estonia and Latvia. The total distance to the structures using pipelines is about 650-800 km.

The two largest Estonian power stations "Eesti" and "Balti" produced respectively 7.7 and 2.25 Mt of CO_2 respectively in 2005. These two power stations as the largest industrial CO_2 emitters in Estonia and in the Baltic region are taken for the case study. They are located near Narva town and the north-eastern border of Estonia and Russia. The owner of the power plants are the main Estonian Power Company – Eesti Energia is planning to find CO_2 storage options in the neighboring regions. The planned construction of the two new "capture ready" power plant units in 2012-2018 at the premises of the largest Estonian Power Plant forced the finding of technological and geological decision of the problem.



Luku-Duku structure, Latvia.

REFERENCES

Geological structures for the establishment of underground gas storages. 2007: Latvian Environment, Geology and Meteorology Agency. Riga, 16 p.
Kuusik, R.,. Veskimäe H., Uibu M., 2002b: Carbon dioxide binding in the heterogeneous systems formed by combustion of oil shale. 3. Transformations in the system suspension of ash – flue gases. *Oil Shale*, vol.19, no.3, p. 277–288.
Shogenova, A., Sliaupa, S., Shogenov, K., Sliaupiene, R., Pomeranceva, R., Uibu, M. and Kuusik, R. 2008. Possibilities for geological storage and mineral trapping of industrial CO2 emissions in the Baltic region . Proceedings of GHGT-9 in Washington, 16-20 November 2008. Elsevier, The Netherlands. *Energy Procedia* 1-8.
Šliaupa S., Shogenova A., Shogenov K., Sliaupiene R., Zabele A., Vaher R., 2008: Industrial carbon dioxide emissions and potential geological sinks in the Baltic States. *Oil Shale*, vol 25, no. 4, p. 465−484.
Šliaupa, S., Satkūnas, J., Šliaupienė, R., 2005: Prospects of geological disposal of CO_2 in Lithuania . *Geologija*, vol .51, p. 20−31.
Uibu, M., Uus, M., Kuusik, R., 2009: CO2 mineral sequestration in oil-shale wastes from Estonian power production. *Journal of Environmental Management*, vol. 90, no.2. p. 1253 − 1260.

INTRODUCTION

Table 1. Total greenhouse gas (GHG) emissions and CO2 emissions per capita.

	Total GHG emissions			CO_2 emissions per capita	
	In CO_2 equivalents, million tonnes		Reduction compared to 1990, %	Tonnes CO_2/capita	Place in world rate
Year	1990	2006		2004	
Estonia	41.6	21.4	48.6	14.1	16
Latvia	26.4	11.6	56	3.87	90
Lithuania	49.4	23.2	53	3.07	100

Compared to 1990 the greenhouse gas (GHG) emissions decreased in Baltic countries for more than 50% (Table 1). However, the changing energy market (e.g. closure of the Ignalina NPP) and increasing industrial growth urge to evaluate different options of reducing CO_2 emissions, including the assessment of the potential of geological sinks and mineral trapping. In 2006 all three Baltic countries started inventory of their CO_2 industrial sources, infrastructure and geological capacity in the framework of EU GEOCAPACITY project supported by EU Framework Programme 6 (Shogenova et al, 2007, 2008, Šliaupa et al, 2008).

The geological setting of the Baltic States is rather different from that of the other European countries that comprise a number of small sedimentary basins, while Lithuania, Latvia and Estonia are situated within one common Baltic sedimentary basin. Therefore, a joint study is required for the assessment of geological sinks. The source types and emissions differ considerably in the Baltic countries, depending on the socio-economic conditions. The main energy and CO_2 emission in Estonia comes from oil shale combustion, while CO_2 emissions in Lithuania and Latvia are significantly lower due to the utilisation of other main energy sources (nuclear and hydro-energy) and imported energy by Latvia from other countries.

Table 2. CO_2 sources registered in EU Emissions Trading Scheme (ETS) in 2005 and 2007

Big sources (>100 000 t CO_2)				All sources registered in ETS		
	Million tonnes	Number of sources	Share in all ETS emissions, %	Million tonnes	Number of sources	ETS share in total GHG emissions
	2005/2007			2005/2007		2005
Estonia	11.5/14.5	9/9	91.3/94.6	12.6/15.3	41/47	59.3
Latvia	1.9/1.9	6/5	63.8/65.7	2.98/2.89	89/89	26.7
Lithuania	5.6/4.8	9/8	84.8/80	6.6/6	89/93	32.5

HYDRODINAMIC TRAPPING

Sixteen major structures, with estimated storage capacity 2−74 Mt CO_2, have been identified in west Latvia, while only small-scale uplifts were identified in Lithuania (Šliaupa et al, 2005). The storage capacity of a structural trap was estimated:

$$M_{CO2} = A \times h \times NG \times \varphi \times \rho_{CO2r} \times S,$$

where M_{CO2} is the storage capacity (kg), A is the area of a closure (m), h is the net thickness of reservoir sandstones (m) (typically is 20-40 m in Latvia and Lithuania), NG is an average net to gross ratio of aquifer in trap, φ is the porosity (typically ranges from 0.25-0.20 in central Latvia and central Lithuania to 0.06 in west Lithuania), ρ_{CO2r} is the in situ CO_2 density at reservoir conditions (ranges from 600 kg/m^3 in west Lithuania to 750 kg/m^3 in central Lithuania and central Latvia), S is the sweeping efficiency, often also referred to as the storage efficiency (assumed 0.35, taking into consideration very large size of the aquifer and proved high storage efficiency of the Inčukalns underground gas storage in Latvia operating since 1968).

The total capacity of 16 large structures of Latvia is conservatively estimated as 404 Mt of CO_2, with the potential of the greatest uplifts 40−60 Mt of CO_2, and even more using optimistic estimation of storage potential. The depths range from 650 to 1200 m. The thickness of Cambrian reservoir rock represented by sandstone is 40-60 m, average porosity 22%, permeability 3-7 Darcy. The structures are similar to the Inčukalns underground gas storage. The total volume of UGS was estimated as 5.7 billion m^3, from which 4.46 billion m^3 is filled now by natural gas. The major CO_2 emitting sources of Latvia are located close to major uplifts. Furthermore, the CO_2 sources and potential traps are located close to the existing gas supply pipelines, which potentially reduce the cost of CO_2 transportation.

MINERAL TRAPPING

Reducing CO_2 emissions using mineral sequestration involves the reaction of CO_2 with minerals to form geologically stable carbonates. Carbonation of the naturally occurring silicate minerals, such as serpentine and olivine, provides CO_2 storage capacity on a geological time scale. One of the advantages of this method is that magnesium and calcium carbonates are already plentiful in nature and are difficult to dissolve. Another option of mineral trapping is using of alkaline wastes, which are available in relatively large amounts and often rich in Ca and Mg. Such ash is formed during combustion of fossil fuels such as coal and oil-shale, and also by other industries such as steel industry, municipal soild-waste incineration ashes, paper-produced industry ash, medical solid-waste incinerator ash, etc. CO_2 mineral trapping by waste products could be performed ex-situ and in-situ.

The fastest mineral carbonation process could be achieved in reactors using high temperature and pressures and concentrated CO_2. For commercial use of such reactors, mining, crushing and milling of the mineral-bearing ores and their transport to a processing plant would be required. Concentrated CO_2 stream will come to reactor from a capture plant (IPCC report, 2005). In case of the ash, reactor could be filled with the ash and alkaline transportation water collected at the same plant where CO_2 is captured. At this case process needs extra energy for reactor, but there will be no costs for ash and CO_2 transportation.

MINERAL TRAPPING BY OIL SHALE ASH

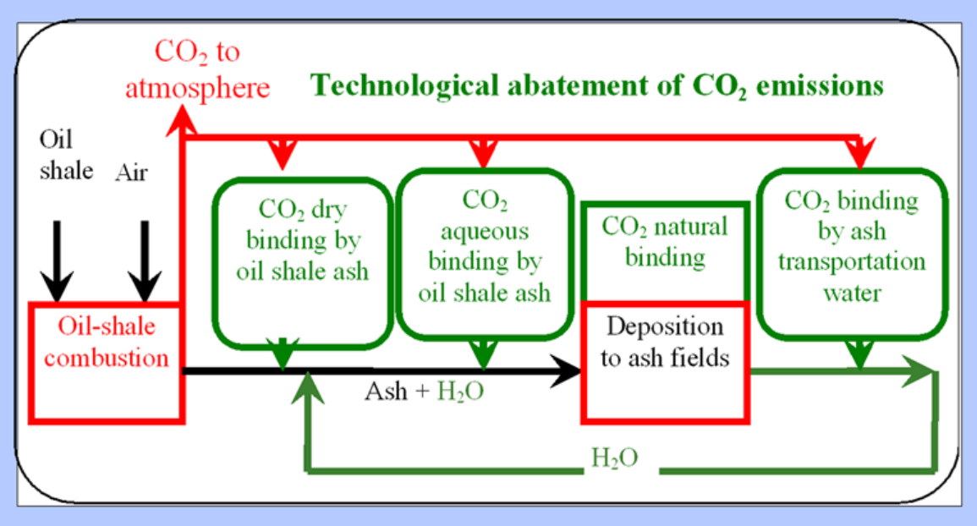
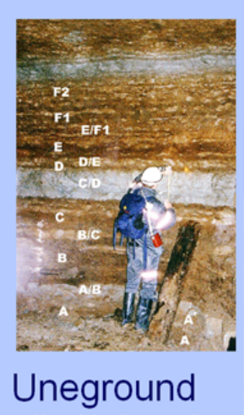


Figure 5. Concept for CO_2 binding in oil shale?based power production.



Uneground oil shale mine

Oil shale waste water, Eesti Power Plant

Oil shale ash heap

The technology of CO_2 mineral trapping with waste oil shale ash is under development in Estonia (Fig. 5). Estonian oil shale is a carbonaceous fine-grained sedimentary rock of Ordovician age containing 10–60% kerogen, 20–70% carbonates, and 15–60% siliciclastic minerals. During combustion of one tonne of oil shale 450-550 kg of ash is produced (in case of mineral coal only 100 kg of ash is produced). Oil shale ash contains up to 20–25% free Ca–Mg oxides. Portlandite $Ca(OH)_2$, forming from free lime during hydraulic transportation and wet deposition of ash, can bind CO_2 also from air. Batch and continuous mode experiments have demonstrated that by processing the ash–water suspension by flue gases, the CO_2 binding ability of ash could be utilized completely. The results of these experiments show that watered oil shale ash can bind 80–160 kg and more of CO_2 per one tonne of ash, and 30–80 kg of CO_2 can be bound by alkaline wastewater used for transportation of one tonne of ash. From the annual production of about 16.3 million tonnes of oil shale in Estonia in 2007, 14.3 million tonnes (88%) was combusted for energy production. The amount of CO_2 bound by oil shale ash in the wet mineralization process from flue gas is about 10-12% of CO_2 emissions produced by power plants in 2007. Carbonates that formed as result of the binding process could be separated and used as independent by-product, but it would be more useful to store them in closed oil-shale mines. The latter solution will permit filling underground mining cavities and prevent environmental problems arising from ash heaps.