CO_2 GEOLOGICAL STORAGE CAPACITY ANALYSIS IN ESTONIA AND NEIGHBOURING REGIONS

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INTRODUCTION

The inventory and mapping of large industrial CO_2 sources and geological storage sites were started in Estonia in 2006 in the frame of the EU GeoCapacity and CO_2NetEast projects supported by EU FP6 [1]. The industrial CO_2 emissions of Estonia are the largest in the Baltic Region and among the largest per capita in Europe and in the world. The high CO_2 emissions and the lowest in Europe energy price in Estonia are explained by the highest in the world use of local oil shale (13–15 million tonnes (Mt) per year) for energy and shale oil production. As Estonia is located in the northern, shallow part of the Baltic sedimentary basin, including potable water, its CO_2 geological storage capacity has been estimated as zero [2, 3]. At the same time, the high CO_2 emissions of the two largest Estonian power plants (15.3 and 3.2 Mt in 2009), near the town Narva, have forced the national energy company Eesti Energia to look for CO_2 storage sites in the neighbouring regions. This article is based on the research "CO_2 geological storage in Estonia and neighbouring regions: analysis of options and storage recommendations" compiled by the Institute of Geology at Tallinn University of Technology for the Eesti Energia company in 2009.

DATA AND METHODS

This research is based on the results of the GESTCO (EU FP5) and EU GeoCapacity (EU FP6) projects [1, 6], a report on CO_2 storage capacity in Sweden and Denmark [7], and also includes an overview of storage options in the adjacent to Estonia regions of Russia. The research covers the Baltic Region and Poland, the Nordic Region (Finland, Sweden, Denmark and Norway), and north-western and central Russia, including the Kaliningrad Region. The CO_2 geological storage capacity of Russia has not been studied earlier. The capacity of enhanced oil recovery (EOR) and enhanced gas recovery (EGR) in Russia has been roughly estimated using known volumes of recovered oil and gas and potential reserves of the oil and gas deposits [8, 9]. In order to estimate real prospects for CO_2 storage, the capacity of large prospective structures should be compared with large CO_2 emissions of the country. Only structures suitable for the storage of emissions of at least 20–30 years from the industrial source (its life period) could be a subject of the storage permit [10]. The storage potential of the above mentioned countries in saline aquifers, hydrocarbon and coal fields were considered in our study. Only conservative estimates calculated by common formulas and presented in the public EU GeoCapacity report on storage capacity were used [1]. The value of national storage capacity divided to the amount of annual large industrial emissions (>100 000 Mt of CO_2 per one industrial source) shows the number of years of the national storage potential in the country. The distance from the largest Estonian power plants, located near the town of Narva, to the storage sites was estimated as direct and real distances. Direct distances were measured using Google Earth maps and real distances were measured via natural gas pipeline routes onshore, and by using possible ship routes offshore.

GEOLOGICAL FRAMEWORK

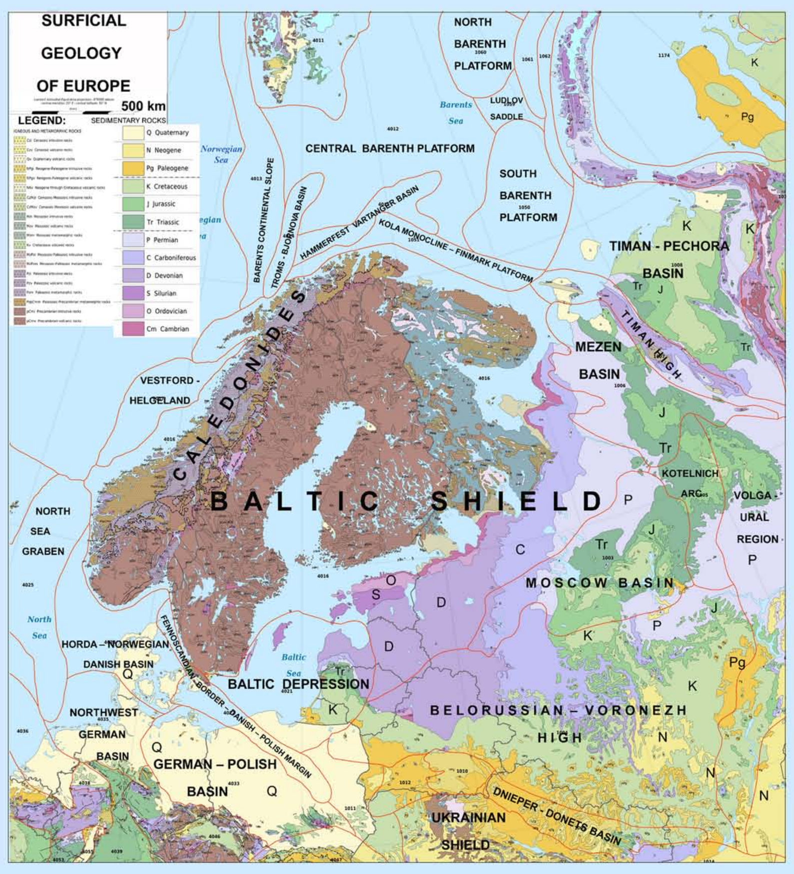


Figure 1 Geological map of the studied area with borders of oil and gas geological provinces according to [5]. Modified after Eric Gaba, Wikimedia Commons (2010).

GEOLOGICAL FRAMEWORK

The countries targeted in this research are situated on the East European Craton (EEC) and at/near its southern and western borders (Denmark, Poland and Norway). Within the EEC, the Precambrian crystalline crust is exposed in the Baltic (also Fennoscandian) and Ukrainian shields and in minor areas of Belarus and the Voronezh Massif of SW Russia. Elsewhere, the craton is covered by the Late Proterozoic and Phanerozoic sedimentary deposits of the Russian Platform (Fig. 1) [4]. The Ural Mountains of central Russia form the eastern margin of the EEC and mark the Late Palaeozoic orogenic collision of the EEC with the Siberian cratons. The southern margin of the craton is where Sarmatia is buried beneath thick Phanerozoic sediments and the Alpine orogens. The south-western boundary of the EEC is known as the Trans–European Suture Zone (Fennoscandian Border–Danish–Polish Margin Province in Fig.1) and separates the EEC from the Phanerozoic orogens of western Europe. The north– western margin of the craton is overlain by the fold–and–thrust Early Palaeozoic Caledonian orogen.

The thickness of the cover of the Russian Platform mostly ranges between some tens of metres and 2 km, locally reaching up to 3–5 km and even exceeding 15 km in the Ukraine and south-western Russia. The covered part of the EEC comprises several large basins of sedimentation, e.g. Moscow, Baltic and Peri–Caspian basins. Maxima of basin formation and filling occurred during the Riphean (Meso- to Neoproterozoic), Early Vendian (Ediacaran), late Cambrian–Ordovician, Middle to late Devonian, Carboniferous–Permian transition and Triassic. Large rifts and aulacogens divide the EEC into three parts: Fennoscandia, Sarmatia and Volgo-Uralia [4].

REGIONAL CO_2 STORAGE CAPACITY

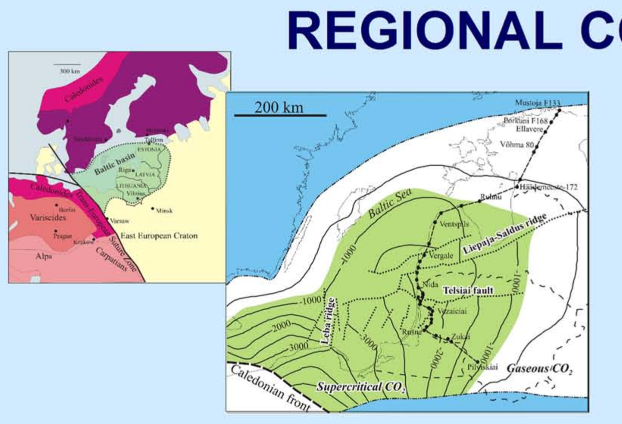


Figure 2. Structure map of the Baltic basin (modified after Sliaupa et al. 2008). The contour lines indicate the depth of the top of Cambrian. The dotted lines show major faults. The P-T fields of gaseous (white) and supercritical (green state of CO_2 are indicated. The line of the geological cross-section shown in Fig.3 is indicated.

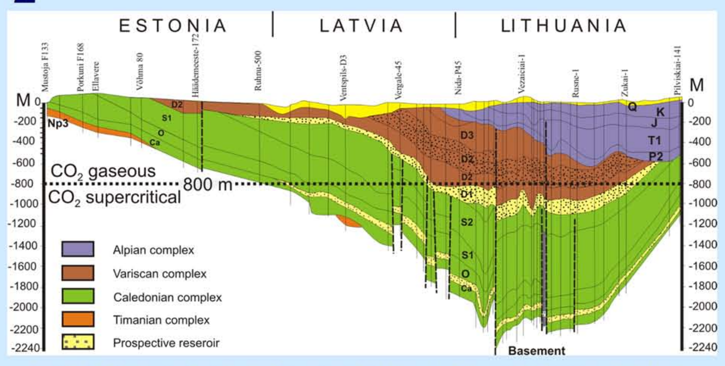


Figure 3. Geological cross-section across Estonia, Latvia, and Lithuania (modified after Sliaupa et al. 2008). Major aquifers are indicated by dots. Np3 – Ediacaran (Vendian), Ca - Cambrian, O – Ordovician, S1 – Lower Silurian (Llandovery and Wenlock series), S2 – Upper Silurian (Ludlow and Pridoli series) D1, D2 and D3 – Lower, Middle and Upper Devonian, P2 – Middle Permian, T1 – Lower Triassic, J – Jurassic, K – Cretaceous, Q – Quaternary.

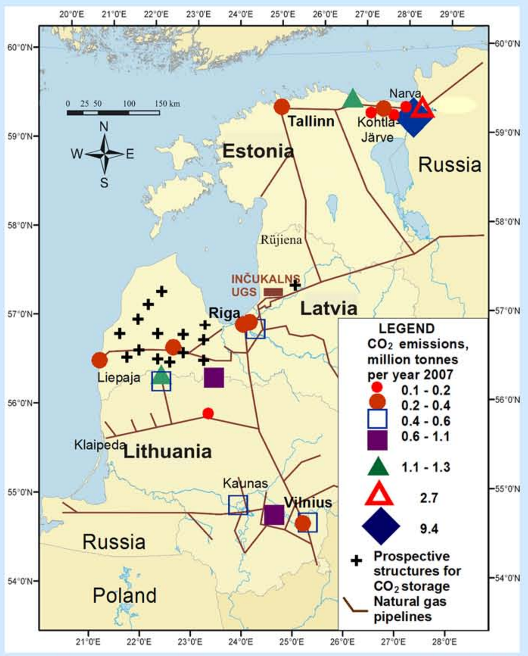


Figure 4. Big industrial CO_2 emissions produced in 2007 in Estonia, Latvia and Lithuania registered by European Union Emissions Trading Scheme. Solid lines show natural gas pipeline network. Rectangle shows In?ukalns underground gas storage (UGS). Location of prospective for CO_2 storage structures in Latvia is shown by black crosses.

REGIONAL CO_2 STORAGE CAPACITY

RUSSIA

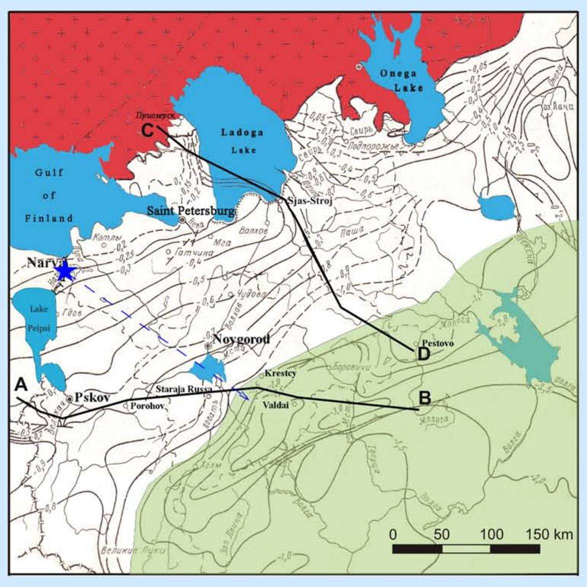
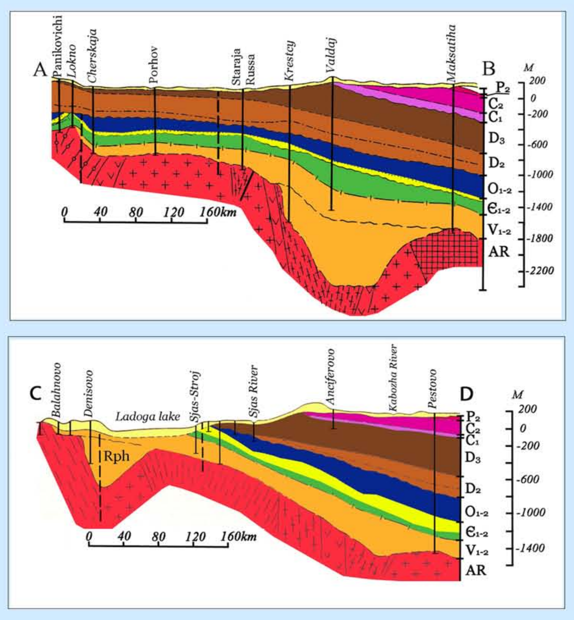


Figure 5. Map of the top of the crystalline basement. Baltic Shield not covered by sedimentary rocks is shown by red. Contours show depth of the crystalline basement. Area with the depth of the top of the Middle Cambrian reservoir rocks (sandstones of Tiskre Formation) more than 800 m is shown by green. White area shows the sedimentary cover with depth of the top of Tiskre Formation less than 800 m. Area of supercritical state of CO_2 for the Middle Cambrian reservoir is green (location of possible structures for CO_2 storage). AB and CD show the cross-sections lines (Figs. 6–7). Eesti Power Plant is marked by blue star. Possible storage directions are shown by dashed lines.



Figures 6, 7 Geological section across lines AB and CD (Fig. 5). Modified after Selivanova & Kofman, 1971. Middle Cambrian reservoir is shown by yellow (between green Lower Cambrian and blue Lower-Middle Ordovician Formations). Riphean (Rph, Ediacaran (Vendian, V), Early and Middle Cambrian (Cm_2 and Cm_1), Ordovician (O), Middle and Upper Devonian (D_2 and D_3), Carboniferous (C), Permian (P).

Figure 9 Aquifer injection points (boreholes penetrated prospective structures) in the region (Latvia, Poland, Norway, Denmark and Sweden) updated after the EU GeoCapacity project WEB GIS. The Eesti Power Plant is marked by a blue star. Possible storage directions are shown by dashed lines.

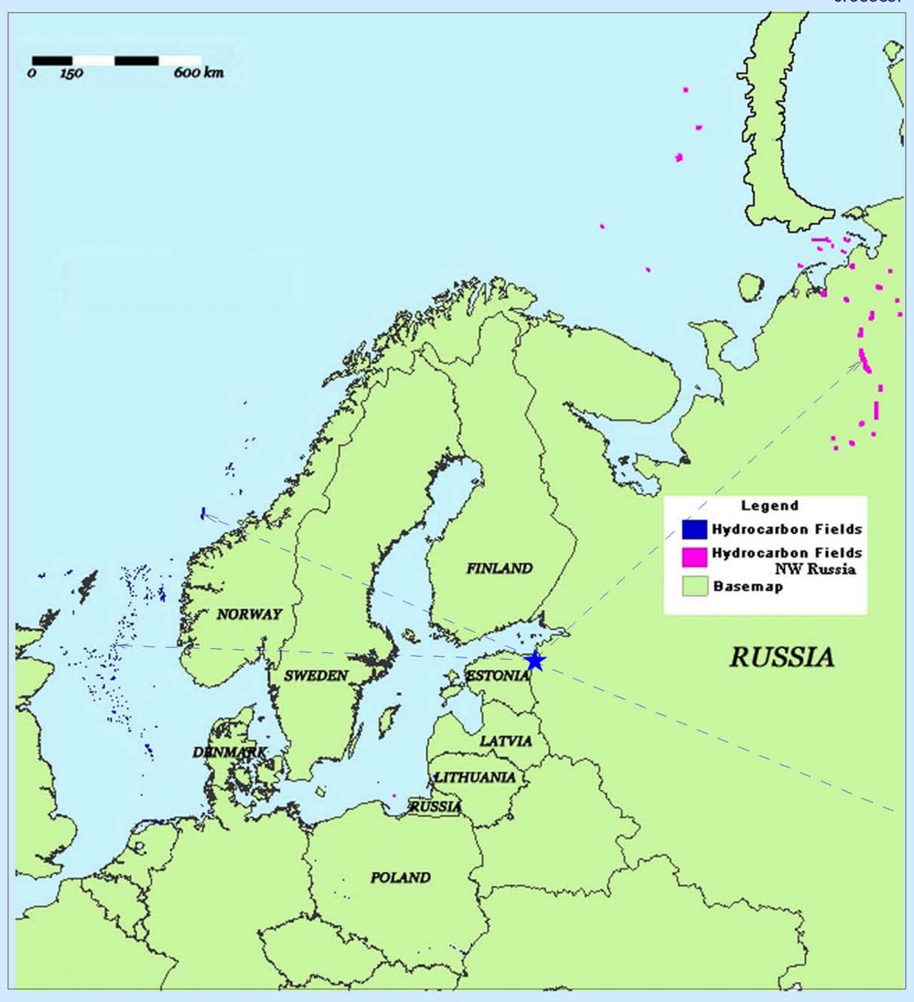


Figure 10 Hydrocarbon fields in the Nordic Region and NW Russia, updated after EU GeoCapacity project WEB GIS [1]. The Eesti Power Plant is marked by a blue star. Possible storage directions are shown by dashed lines.

Table 1. Distance from Eesti Power Plant to saline aquifers and hydrocarbon fields

Country	Direct distance to deep saline aquifers (km)	Direct distance to hydrocarbon fields (km)	Distance to deep saline aquifers by pipelines (km)	Distance to deep saline aquifers by sea (km)	Distance to hydrocarbon fields by sea (km)
Latvia	300-500		600-900		
Poland	900-1100	1100-1200	1800-2200		
Denmark	1060-1460	1400-1650		2150	2200-2400
Norway	1170-1450	1250-1850		2300-3000	2700-2900
Sweden	650-800			800-1550	
North-Western Russia	>200	>1500	>400		4500-5300

Table 2. Summary of conservative CO_2 storage capacity in all reported countries updated after [1].

	Annual CO_2 emissions (Mt)		CO_2 storage capacity (Mt)				Years
Country	Total	Large point sources	Deep saline aquifers	Oil and gas fields	Coal fields	Total	Total
Estonia	21	12	0	0	0	0	0
Latvia	4	2	404	0	0	404	202
Lithuania	18	6	30	7	0	37 /0	6/0
Poland	325	188	1 761	764	415	2 940	15.6
Denmark	52	28	2 553	203	0	2 756	98
Norway	No data	28	25 967	3157	0	29 188	1 042
Sweden	No data	15	1500–3000	0	0	1500–3000	100–200
Finland	69.3	28.7	0	0	0	0	0
NW Russia	No data	No data	No data	5 675	No data	5 675	No data
Total for the region		307.7	32 515	4 131	415	36 788	106

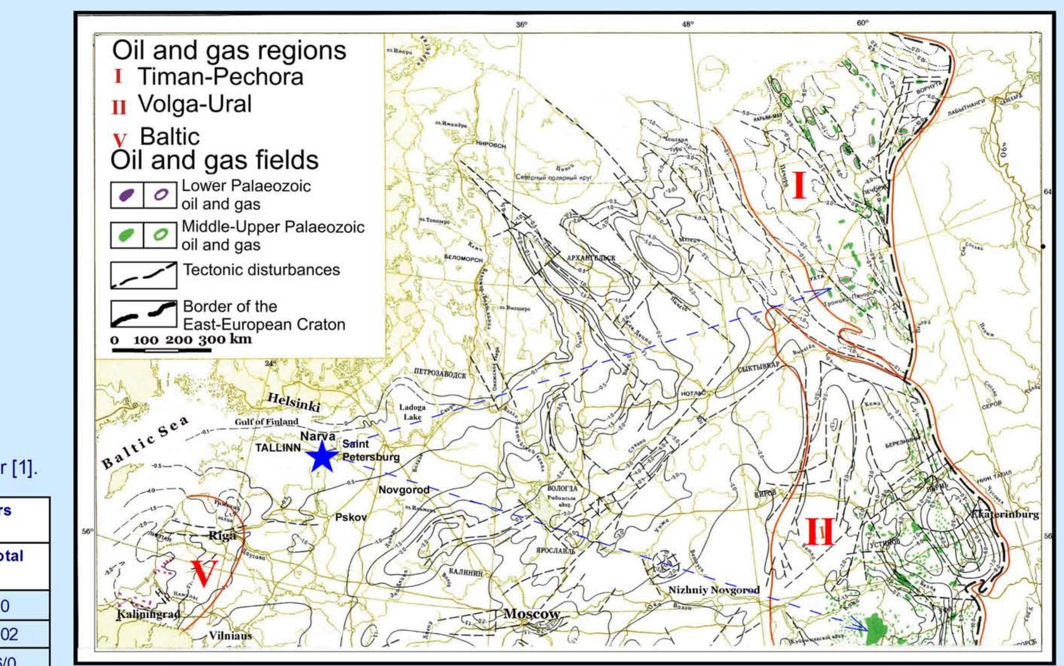


Figure 8 Oil and gas regions of NW (I), central (II) and W (V) Russia with contours showing depth of the crystalline basement (modified after [16]). Eesti Power Plant is marked by blue star. Possible storage directions are shown by dashed lines.

CONCLUSIONS

- Among reviewed countries Estonia, Finland and Lithuania have zero, or negligible CO_2 storage potential at the present state of technological, economical and legislative development. All three countries have potential for CO_2 carbonation, which is still an immature technology.
- The possible CO_2 storage sites closest to the largest Estonian power plants are saline aquifers located in Latvia (300–500 km direct and 600–900 km real distance by pipelines) and in Russia (>200 km direct and >400 km distance by pipelines). The potential of Latvian saline aquifers is enough for about 150 years of storage of Latvian CO_2 emissions.
- Only the largest of the 16 prospective Latvian structures (2–74 Mt CO_2) could be considered for storage, while the potential of Russian saline aquifers has not yet been estimated.
- Norway has the highest potential in the Nordic Region with a direct distance to the storage sites (including saline aquifers and hydrocarbon fields) of about 1200–1900 km and real distance by ship about 2300–3000 km.
- The direct distance to the Russian hydrocarbon fields is more than 1500 km and by ship about 5000 km.
- The distance to potential storage sites in Denmark is compatible with that to Norwegian sites, but conservative potential for storage of the national industrial CO_2 emissions is about ten times lower than in Norway.
- The most part of the reported storage potential of Sweden is in the open aquifers in the southern Baltic Sea, while it is much lower in the structures which should be studied additionally.

MINERAL CARBONATION

Fixation of CO_2 in the form of inorganic carbonates, also known as mineral carbonation, is a potential option for CO_2 storage. Carbonation of alkaline minerals mimics the natural rock weathering and involves the permanent storage of CO_2 as the thermodynamically stable form of calcium and magnesium carbonates. Unlike other CO_2 sequestration routes, it provides a leakage-free long-term sequestration option, without a need for post-storage surveillance and monitoring once CO_2 has been fixed. In Estonia, the oil shale ashes formed in the industrial-scale pulverized firing and circulating fluidized bed combustion boilers have been studied as sorbents for binding CO_2 from flue gases in mineral carbonation processes. As a result, the concept of CO_2 mineral sequestration in oil shale wastes from Estonian power production has been worked out and the main parameters of direct or indirect aqueous carbonation of ash with flue gases and of natural weathering have been elaborated [17, 18, 19]. An additional advantage of this approach is the neutralisation of the alkalinity of ash offering a possibility for environmentally sound landfilling of waste residue. It has been estimated that 10?12% of large CO_2 emissions produced by Estonian power sector (>2 Mt of CO_2 in 2009) can be bound by oil shale ash and waste water including 0.1-0.3 Mt in natural conditions [17, 19, 3].

FINLAND

The Hitura ultramafic complex in Finland consisting of three separate serpentinite massifs. The areal size of the complex is 0.3 x 1.3 km, the depth of the top is 500 m (Ni, Cu, Co, Pd and Pt deposit, © GTK, Finland).

Finland has large reserves of natural magnesium silicates, often available as tailings from mineral or metal processing industries [14]. Serpentinites have been studied as potential CO_2 sorbents considering mainly indirect gas/solid mineral carbonation [22]. The main focus has been upon improving the kinetics and energy efficiency of large-scale mineral carbonation [23]. Dissolution of steelmaking slags in acetic acid for precipitated calcium carbonate production has also been investigated. Carbonation of slag could provide a way to reduce CO_2 emissions from iron and steel industries, utilising the waste slag and producing a commercial product [24]. The magnesium silicate deposits in Eastern Finland alone could be sufficient for storing 10 Mt of CO_2 emissions each year during a period of 200–300 years. About 9% of the CO_2 from Finnish steel plants, or one per cent of Finland's annual anthropogenic CO_2 emissions could be carbonated using Finnish steelmaking slags [25].

MINERAL CARBONATION

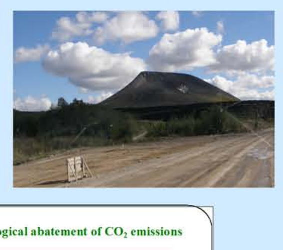
NORTH- EAST ESTONIA

Uneground oil shale mine with marked conmmercial bed A-F1 alternating with limestone inter-beds A/B, B/C, C/D, D/E, E/F1

Oil shale open cast

Oil shale ash transportation water, Eesti Power Plant

Oil shale heap



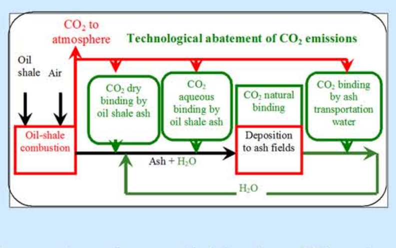


Figure 11. Concept for CO_2 binding in oil shale based power production.

SOUTH LITHUANIA

As the saline aquifers of Lithuania have been found unsuitable for CO_2 storage, alternatives to in situ CO_2 trapping are being sought [20, 21]. Several natural minerals (serpentinite, glauconite, opoka) have been studied as potential sorbents for CO_2 mineral sequestration. A large serpentinite province was discovered in the Palaeoproterozoic crystalline basement of south Lithuania. The estimated volume of serpentinites of the largest Varena Iron Ore Deposit is 1–2 Gt. Serpentinites are located at a distance of about 50–150 km from the south-eastern cluster of CO_2 emission sources in Lithuania. The sequestration potential is evaluated to be in the range of 0.5–1 Gt [20], which could be enough for carbonation of CO_2 produced by the south-eastern large Lithuanian sources during 200–500 years [3].

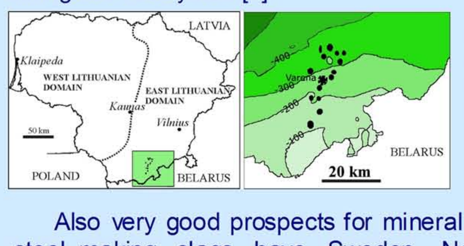


Figure 12. Left figure shows major lithotecotnic domains of the crystalline basement of Lithuania. The Varena Geological Province is green. Right figure zooms in the Varena Geological Province. The Varena Iron Ore deposit is distinguished. The depths of the top of the crystalline basement are indicated.

Also very good prospects for mineral carbonation with magnesium silicates and steel–making slags have Sweden, Norway and NW Russia located at the Baltic/Fennoscandian Shield. Altogether 168 major metallogenic areas, including 1300 mines and deposits, occur in Finland, Norway, Sweden and Russia (according to Fennoscandian Ore Deposits Database). Part of these resources is prospective for CO_2 mineral carbonation.

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