POTENTIAL SITES FOR CO2 GEOLOGICAL STORAGE IN LATVIA

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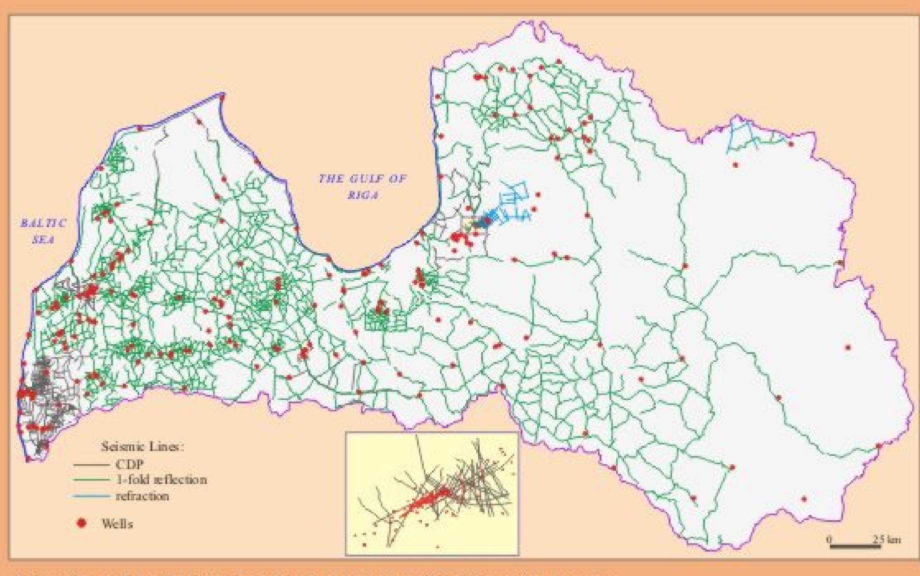
History of Geological Exploration



Seismic and well database for lower part of sedimentary cover

Seismic investigations in Latvia, predominantly, in its western part, were carried out during 1959 – 1985, with the total volume exceeding 10,000 line km, using the seismic reflection method (SR). During 1984 – 1994, modern common depth point (CDP) seismic investigations were carried out as well - in western Latvia and in the territory of the Inčukalns structure (approximately 2,500 line km).

The Cambrian deposits were penetrated in approximately 450 Latvian wells, including 200 wells in the territory of the Inčukalns Gas Storage. In general, the well locations' grid is far from uniform, which is explained by the purposes of drilling. E.g., in most of W. Latvia, especially in the south-west, the majority of deep wells were drilled as oil prospecting and exploration wells

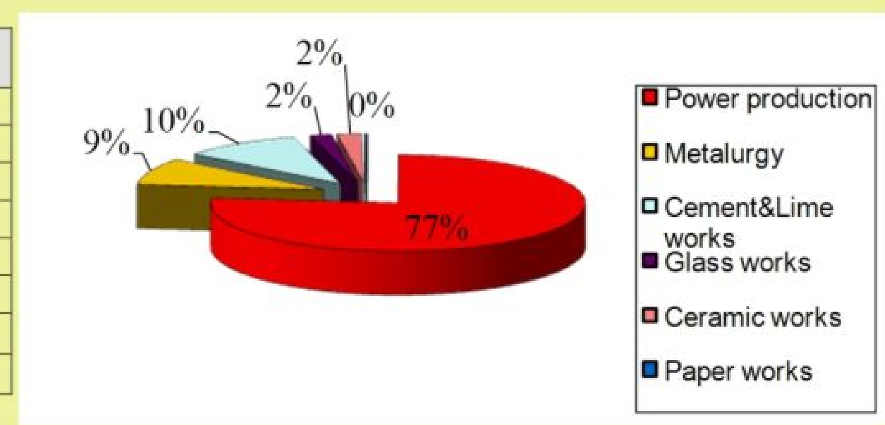
The reservoir as a whole was studied using different geophysical methods (well logging), cores were analysed to a lesser degree. It should be mentioned that the reservoir data from most of the local highs were obtained based on data from one well only, and very few specialised core studies were conducted there.

Only two Latvian local highs – the Inčukalns and Dobele structures were investigated with the purpose of determining their suitability for the establishment of gas storages.

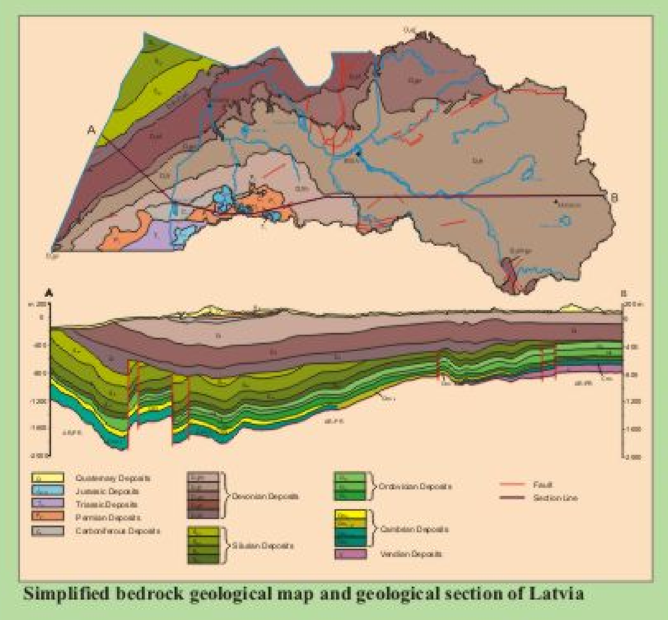
CO2 Industrial Emmiters/Sources

In 2005, the Latvian Register of Greenhouse Gas Emission Units incorporated 92 stationary sources of CO2 emissions. The emissions of CO2 from those sources was 4.09 Mt in 2005, including six CO2 sources with emissions exceeding 100 000 t per year.

CO_2 emissions	Total CO_2 emissions (Mt)
Latvenergo,TEC-1 JSC	0.23
Latvenergo,TEC-2 JSC	0.79
Rigas siltums JSC	0.13
CEMEX Ltd	0.29
Liepajas metalurgs JSC	0.36
Liepajas siltums JSC	0.11
CO_2 emissions from large point sources in database	**1.91**
Total CO_2 emissions	**4.09**



Geological Framework



Simplified bedrock geological map and geological section of Latvia

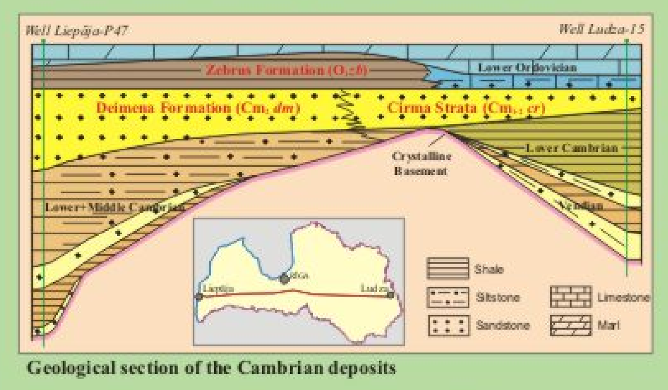
Latvia is situated in the territory of the East European Platform, where the Baltic Syneclise, the Latvian Saddle and the southern slope of the Baltic Shield are singled out in the top crystalline basement and lower part of the sedimentary cover as interregional structures.

Tectonic Setting

The sedimentary cover is represented by the Vendian, Cambrian, Ordovician, Silurian, Devonian, Carboniferous, Permian, Triassic and Jurassic deposits (Fig.2). Its thickness varies from 300-600 m in north-eastern Latvia to 1,900 m in its south-western part.

The sedimentary cover is subdivided into the Baikalian, Caledonian, Hercynian and Alpine structural complexes.

Deposits of the **Caledonian** complex occur all over Latvia. It incorporates the Cambrian, the Ordovician, the Silurian and the Lower Devonian successions, the thickness of which varies from 60 m in north-eastern Latvia to1,000 m in the south-western areas. The complex is characterised by a varying structure, with different structural components, including numerous faults and ramparts, as well as by local highs. Those elements of the Caledonian tectonics, as well as the existence of a reservoir (the Cambrian sandstone) determine favourable structural geological conditions for the establishment of underground storages of CO2. The largest local highs were observed within the Baltic Syneclise, and are situated in the western and central Latvia.

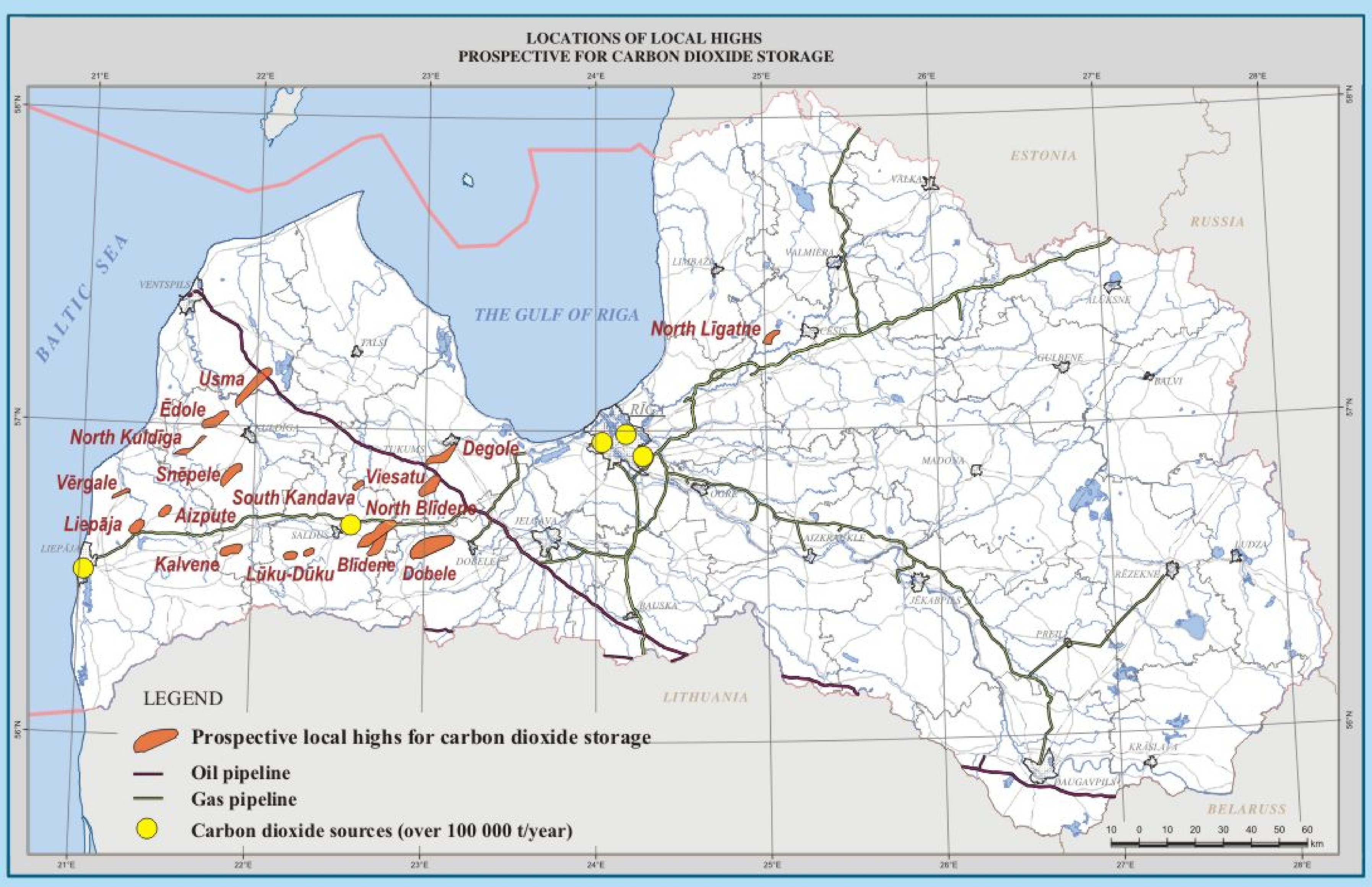


Geological section of the Cambrian deposits

Deposits of the Cambrian system (the Deimena Formation and the Cirma Strata) can be used as reservoirs for the storage of CO2; they occur all over the Latvian territory. As regards the depth of occurrence, the Cambrian aquifer is prospective for the storage of CO2 in Western and Central Latvia only, where its depth comprises 700 -1700 m. The top Cambrian horizon lies at the depth < 700-800 m in NE Latvia, and it is not suitable for the storage of CO2. No objects, which could be prospective for the storage of CO2, have been identified in Eastern and South-Eastern Latvia. The reservoir rocks consist of a rather uniform sandstone layer with good filtering and capacity properties. They also have an optimum location in relation to rocks that are impermeable for CO2, since they lie directly under the Ordovician caprock. In most of the Latvian territory, the average effective porosity of sandstone varies from 20 to 25%, the permeability reaches several hundred and thousands of mD. The effective thickness of the reservoir in the western and central parts of the country is 28 -70 m, varying from 5 to 30 m in the rest of the territory. The reservoir depth increases from 700 m MSL in central Latvia to 1,700 m MSL in the south-west. The shallowest reservoir (not deeper than 300-350 m MSL) is situated in the north-east and south-east. In the areas where the best prospects for CO2 storage – local highs (structures) are observed, the reservoir surface lies at the optimum depth – 700-1,100 m MSL. The reservoir contains highly mineralised groundwater. The salinity exceeds 100 g/l, the temperature is 11°C -25°C. The hydrostatic pressure in the aquifer reaches 70-116 atmospheres.

In Latvia, the Cambrian reservoir is overlain by a tight clayey-carbonaceous succession of Ordovician and Silurian deposits, the thickness of which varies considerably – from 40 m in north-eastern Latvia to 600 m in the south-west. Besides, in the western and central Latvia, the reservoir is overlain by a 15-40 m thick Lower Ordovician clayey layer of the Zebrus Formation, forming a safe and impermeable to fluids caprock, which prevents gas from entering into the overlying deposits. The properties of caprock worsen towards the north-east and east, since lower Ordovician clayey deposits are replaced by terrigenous-carbonate ones, with the thickness reduced to 5-10 m.

Latvia's Storage Potential



Only local structures in the Cambrian water-saturated sandstone are prospective for the establishment of CO2 storages. In one of such geological structures, an underground storage of natural gas was established already in 1968 – the Inčukalns gas storage.

The main criteria for the determination of prospective objects are as follows: the existence of a local high identified based on the seismic data, the size and depth of the trap, reservoir properties and existence of reliable caprock. Based on those criteria, the prospective structures suitable for the establishment of underground storages of CO2 are as follows: Dobele, North Blidene, Blidene, Snepele, South Kandava, Degole, Luku-Duku, Kalvene, Vergale, Edole, North Kuldiga, Viesatu, Aizpute, Usma, Liepaja and North Ligatne (Fig. 1).

The following structures were identified as belonging to the first group of prospective objects: Kalvene, Luku-Duku, N. Blidene, Blidene, Dobele and N. Ligatne. They are situated within the tectonically dislocated Saldus-Sloka-Inchukalns high and are represented by near-fault brachyanticline folds. Their area comprises 14-50 km2, the amplitude exceeds 55-80 m; the effective thickness of the reservoir exceeds 30 m. The depth of the Cambrian reservoir in the Kaltene, Luku-Duku, N. Blidene and Dobele areas reaches – 950-1050 m, while that of the N. Ligatne area - approximately 700 m.

Structure	Stratigraphic unit, Formation	Lithology	Top depth (m)	Permeability (mD)	Porosity	CO_2 density (t/m^3)	Storage efficiency factor	Area, km2	Reservoir volume, MMm3	Theoretical capacity, Mt	Capacity, Mt (optimistic values)	Capacity, Mt (conservative values)
Aizpute	M. Cambrian, Deimena Fm.	Sandstone	1120	300	0.21	0.720	0.40	51	587	72.8	31	**14**
Blidene	M. Cambrian, Deimena Fm.	Sandstone	1168	300	0.21	0.730	0.40	43	2091	259.3	112	**58**
N.Blidene	M. Cambrian, Deimena Fm.	Sandstone	1041	300	0.21	0.710	0.40	95	2655	329.2	142	**74**
Degole	M. Cambrian, Deimena Fm.	Sandstone	1094	300	0.21	0.720	0.40	41	782	97.0	41	**21**
Dobele	M. Cambrian, Deimena Fm.	Sandstone	1058	300	0.22	0.720	0.40	67	2000	248.0	105	**56**
Edole	M. Cambrian, Deimena Fm.	Sandstone	975	300	0.20	0.720	0.40	19	283	35.1	16	**7**
Kalvene	M. Cambrian, Deimena Fm.	Sandstone	1133	300	0.22	0.730	0.40	19	525	65.0	27	**14**
Liepaja	M. Cambrian, Deimena Fm.	Sandstone	1102	300	0.21	0.720	0.40	40	660.0	73.0	31	**6**
Luku-Duku	M. Cambrian, Deimena Fm.	Sandstone	1024	300	0.22	0.720	0.40	50	1440	179.0	75	**40**
N. Kuldiga	M. Cambrian, Deimena Fm.	Sandstone	1034	300	0.20	0.720	0.40	18	490	61.0	21	**13**
N. Ligatne	U.-M. Cambrian, Cirma Strata	Sandstone	700	300	0.22	0.560	0.40	30	810	100.4	41	**23**
S.Kandava	M. Cambrian, Deimena Fm.	Sandstone	1053	300	0.20	0.720	0.40	69	1573	195.1	82	**44**
Snepele	M. Cambrian, Deimena Fm.	Sandstone	1067	300	0.22	0.720	0.40	26	602	74.6	31	**17**
Usma	M. Cambrian, Deimena Fm.	Sandstone	1000	300	0.21	0.710	0.40	20	180	9.0	5	**2**
Vergale	M. Cambrian, Deimena Fm.	Sandstone	993	300	0.22	0.710	0.40	10	194	24.1	9	**5**
Viesatu	M. Cambrian, Deimena Fm.	Sandstone	1070	300	0.21	0.720	0.40	19	424	52.6	21	**10**
										1875.2	790	**404**

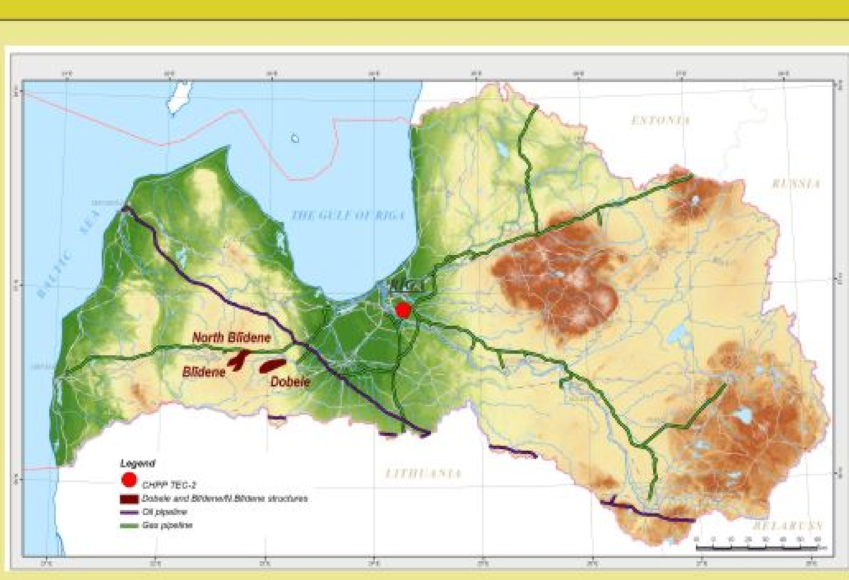
The assessment of CO2 storage capacity in deep saline aquifers in the Latvia is based on evaluation of 16 individual structural traps. The capacity estimates in the GeoCapacity database for all 16 structures have been calculated according to the methodology described for deep saline aquifers in the GeoCapacity deliverable D24 "Storage capacity standards", using the formula:

$$M_{CO2t} = A \times h \times NG \times \varphi \times \rho_{CO2r} \times S_{eff}$$ where:

MCO2t: "trap" storage capacity
A: area of aquifer in trap
h: average height of aquifer in trap
NG: average net to gross ratio of aquifer in trap (best estimate)
φ: average reservoir porosity of aquifer in trap (best estimate)
ρCO2r: CO2 density at reservoir conditions (best estimate)
Seff : storage efficiency factor (for trap volume)

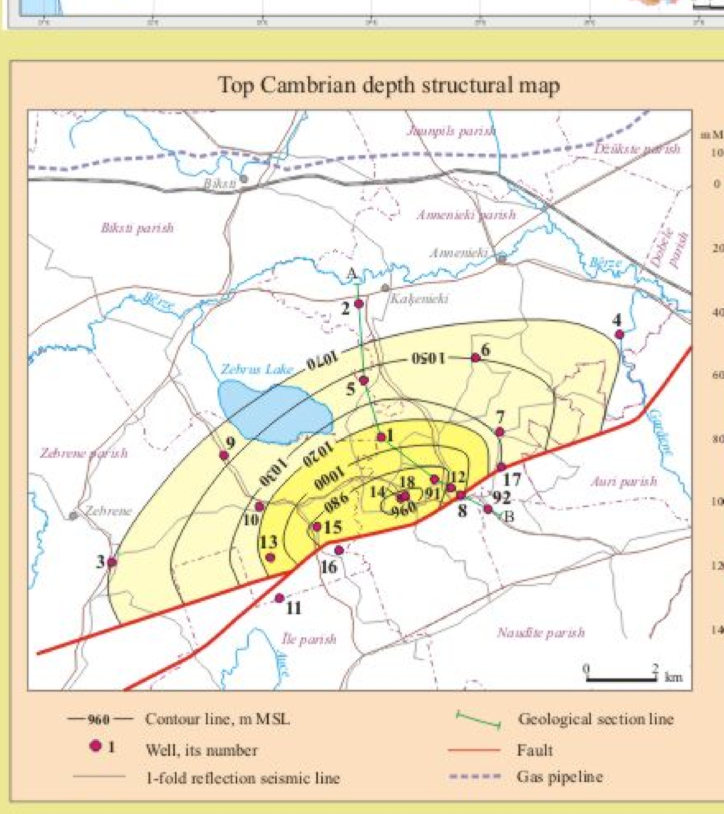
The area of the structures was determined on the base of contour maps at the top of the reservoir formation. Thickness, porosity and net/gross were evaluated using data from exploration wells drilled (based on log data interpretation) on the structure or extrapolating information from wells on nearby structures. The CO2 density varies with depth as a function of pressure and temperature.
Based on the "ruleof-thumb approach" described for open and semi-closed aquifers in GeoCapacity deliverable D24 Storage capacity standards, a storage efficiency factor of 40 % has been assumed corresponding to open high quality reservoirs.

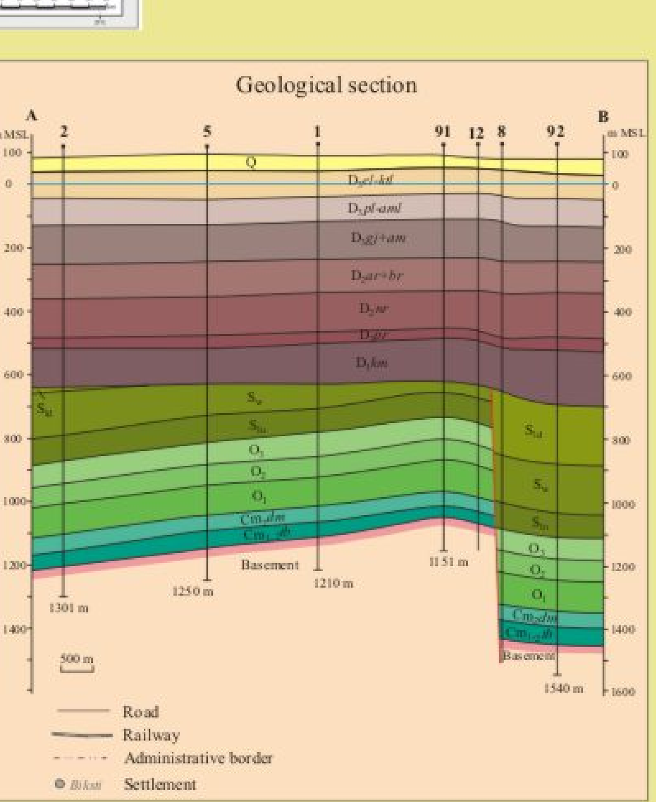
Economic Evaluations of source-to-storage-site



"Latvenergo, TEC-2" was selected for a case study. That object is the biggest source of CO2 emissions in Latvia – 0.79 Mt per year.
"Rigas Termoelektrostacija" TEC-2 is situated in Acone, Salaspils Rural Area, the Riga District. Subsidiary of SJSC "Latvenergo" "Rigas Termoelektrostacija" TEC-2 is the biggest combined heat and power plant in Latvia. During the period of 1973−1992 four water heaters were launched, but in 1975−1979 there were put into operation four steam boilers and four steam turbines. Riga TEC-2 electric capacity is 330 MWel, but heating capacity − 1148 Mwth.

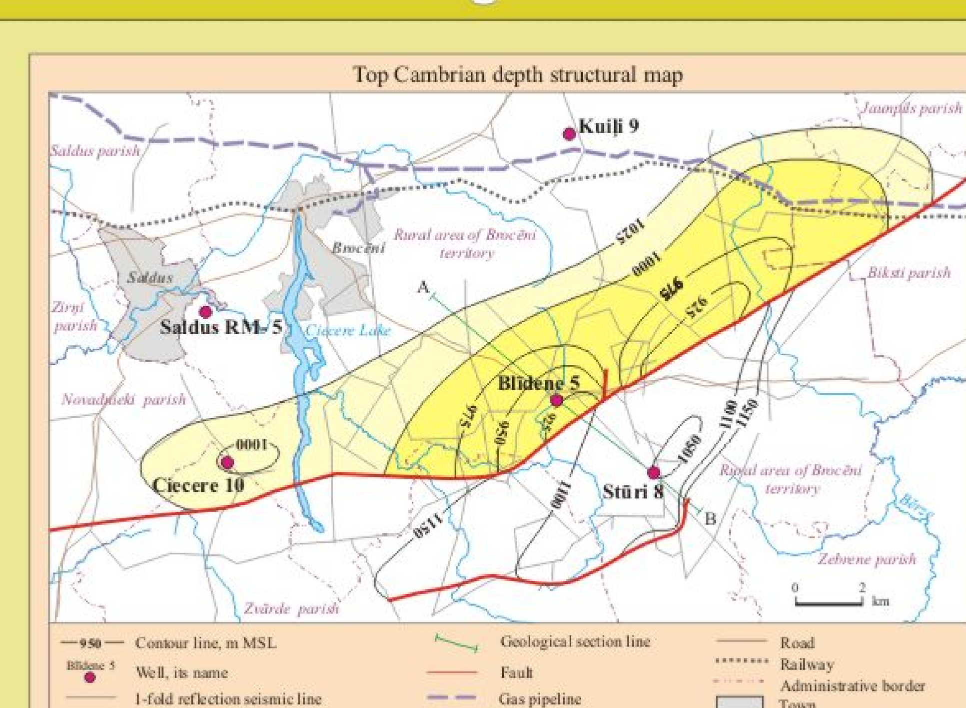
Three anticline structures - North Blidene, Blidene and Dobele are considered potential storages. The structures N. Blidene and Blidene are considered a single object for the purpose of the establishment of a CO2 storage. The conservative volume in the Cambrian aquifer at the Dobele structure is evaluated at 56 Mt, while that at the Blidene object - at 132 Mt (N. Blidene structure – 74 Mt and Blidene structure – 58 Mt). The locations of those structures are advantageous for the use as CO2 storages because of their proximity to pipelines.

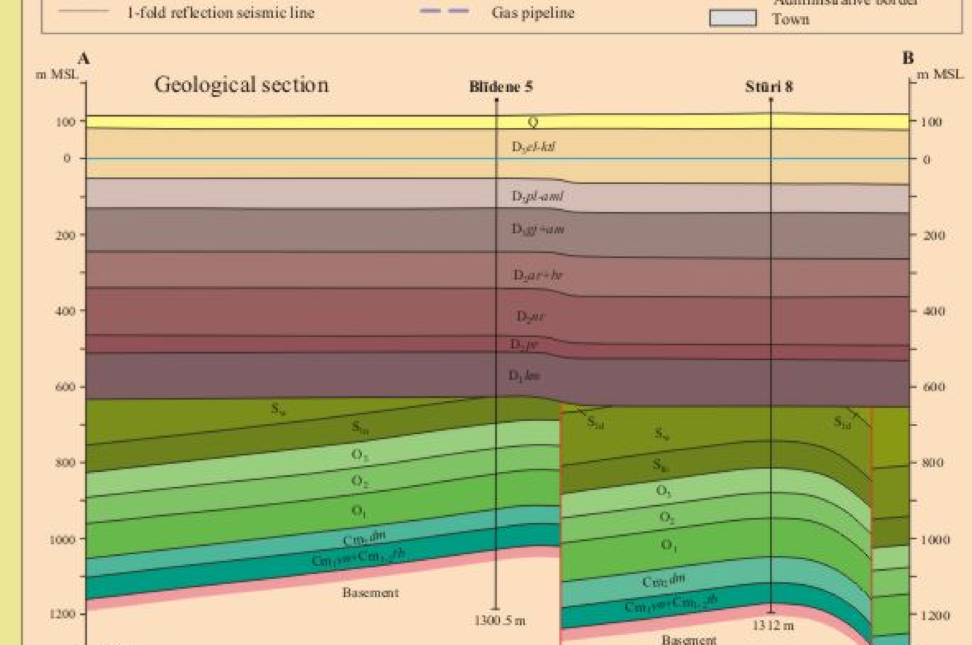




The Dobele structure situated in central Latvia, up to 75 km to the west of the Riga city, where the CO2 source – TEC – 2 is located. The Dobele local high is a well-expressed brachyanticlinal fold of the Caledonian structural complex, the southern flank of which is adjacent to a fault with the amplitude 300 m.
The Cambrian reservoir is shielded by the clayey-carbonate Silurian deposits in the fault zone.
The Silurian deposits are quite tight and would ensure the tightness of the reservoir within the structural trap. The hypsometrically closed area of the structure for the top of the Cambrian reservoir within the 1,070 m MSL contour line comprises 67 km2.

Compared to the rest (Lower) Cambrian, it is characterised by a more uniform, predominantly sandstone, composition and bettercapacity-filtering properties. The top of the reservoir of the Dobele local high lies at the depth of 950 m MSL in the dome of the structure, and at up to 1,070 m MSL – at the periphery of the flanks. The **effective thickness of the reservoir is 52 m**, the effective porosity – 22%, the permeability varies from a few tens to hundreds mD, reaching 1-1.5 Darcy in some cores.
„Rīgas Termoelektrostacija" TEC-2 connected with the Dobele structure via gas pipeline. The length of the gas pipeline is 110 km. The distance between the Dobele structure and the gas pipeline – 8 km. The minimum volume in the Cambrian aquifer at the Dobele structure is evaluated at **56 Mt**.
The planned duration of the project - 30 years. Drilling of new wells is not envisaged. It is planned to reactivate and inspect 2 wells drilled during exploration aimed at the establishment of a natural gas storage. It is planned to inject **0. 395 Mt CO2/year in each of the wells**.
The modelling using the DSS tool has demonstrated that the total cost of the implementation of the project will comprise **88.5 M€**. The highest costs would be for the establishment of the CO2 pumping system CO2 (40 M€) and for energy consumption (31M€).
The total price of the sequestered CO2 is 6.76 €/tCO2. Taking into consideration the market price of CO2 3-4 €/tCO2 the project is not sufficiently cost-effective. It is probably associated with the low CO2 emission of the selected source.





The North Blidene and Blidene structures are situated in western Latvia, up 89 km to the west from the CO2 source – TEC-2. The top of the reservoir within the N. Blidene structure occurs at the depth 950 – 1050 m. Its total thickness varies from 45 m at the dome of the high to 53 m in the periclinal zone, the effective thickness - from **37 to 41** m. The average open porosity of the sandstone comprises 21%, based on the results of log interpretation; the permeability reaches 370-400 mD. The top reservoir of the Blidene structure occurs at the depth 1050 – 1150 m.

The aquifer contains confined groundwater with the salinity 100-114 g/l. The well yield comprises about 100 m3/day. The hydrostatic reservoir pressure is 100 –115 atmospheres; the reservoir temperature is 18º-20ºC.

The structures N. Blidene and Blidene are considered a single object for the purpose of the establishment of a CO2 storage. The conservative volume in the Cambrian aquifer at the Blidene object - at 132 Mt (N. Blidene – 74 Mt and Blidene – 58 Mt). "Rigas Termoelektrostacija" TEC-2 is connected with the Blidene structures by a trunk gas pipeline. The length of the gas pipeline is 125 km.

The transportation of CO2 is suggested along the newly build pipeline adjusted to the existing gas transportation network. The total distance is 134 km. The planned duration of the project - 30 years. Drilling of 2 new wells at the dome of the Blidene structure is planned. It is planned to inject 0. 395 Mt CO2/year in each of the wells.

The modelling using the DSS tool has demonstrated that the total cost of the implementation of the project will comprise 99.5 M€. The highest costs would be for the establishment of the CO2 pumping system CO2 (41 M€) and for energy consumption (36M€).

The total price of the sequestered CO2 is 7.58 €/tCO2. Taking into consideration the market price of CO2 3-4 €/tCO2 the project is not sufficiently cost-effective.

Conclusion

The largest CO2 source in Latvia was selected for the project - "Rigas Termoelektrostacija" TEC-2 with the emission equal to 0.79 Mt per year. Two largest potential storages were selected as the storages – the Dobele structure and N. Blidene/Blidene structures.
The modelling results have demonstrated that the efficiency of the establishment of CO2 storages there is too low. The cost of projects for those objects is 88.5 M€ (Dobele) and 99.5 M€ (Blidene). The total price of the sequestered CO2 is 6.76 €/tCO2 for the Dobele structure and 7.58 €/tCO2 – for the Blidene object.

The unsatisfactory results are associated with the inefficient injection of small volumes of CO2 in the storages. The cost of the establishment of infrastructure is quite high, and the expenditure is unfounded with the low level of CO2 injection.