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CO_2 storage opportunities in Belgium

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Abstract

Potential CO_2 reservoirs in Belgium are poorly explored. Consequently, the estimated storage capacities are theoretical capacities. The total theoretical storage capacity for Belgium is conservatively estimated at about 1Gt, additional exploration and research are needed to make better capacity assessments. An onset towards prioritising such actions is given here.
Deep saline aquifers and coal sequences have created the geological storage options for CO_2 in Belgium. The main criteria for reservoir selection and evaluation are reservoir properties, sealing, depth and the occurrence of trapping structures. Aquifer storage opportunities are the Houthem and Maastricht Formations, the Buntsandstein Formation, the Neeroeteren Formation, the Carboniferous Limestone Group (Dinantian) and the Devonian, the latter two in both the north and the south of the country. Of these, the Buntsandstein and the Dinantian reservoirs appear the most promising. Unmined coal sequences have a relatively large capacity, but the low permeability will pose technical difficulties. Storage in abandoned coal mines is likely feasible but pressure and sealing issues will have to be solved.

CO_2 geological storage; capacity estimation; reservoirs; coal; Belgium.

1. Introduction

CO_2 emissions in Belgium reached about 120Mt in 2006 [1]. Almost half of these emissions are produced by large industrial sources, emitting each more than 500kt CO_2 per year. Most of these industrial sources are power generation installations. These numbers indicate a CO_2 intensive industry, compatible with CO_2 capture and geological storage (CCS).

Depleted oil and gas reservoirs are the most obvious choice for geological CO_2 storage since reservoir, sealing and trapping properties are proven. Since Belgium has no history in oil or gas production, other storage opportunities need to be considered. Laenen et al. [2] created a first inventory based on the known reservoir properties, structures and stratigraphy for northeastern Belgium. For the PSS-CCS projects [3] this list has been updated and complemented with other possible reservoirs, all which are discussed in this publication.

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For geological storage of CO_2 in Belgium, aquifers and coal deposits are viable options. Both in the Flemish region (north) and in the Walloon region (south) potential aquifer and coal reservoirs occur.

2. Geological setting

In the surroundings of the Caledonian London-Brabant Massif in Belgium sedimentary basins were formed in the Rhenohercynian Foreland (Fig. 1). It is in these basins that storage opportunities are located.

South of the London-Brabant Massif, Devonian and Carboniferous sediments deposited during the complete cycle of the Variscan orogeny [4][5], North of the London-Brabant Massif this succession started later and is less complete [6]. Under influence of the northward progradation of the Variscan front, the sedimentary succession terminated with a thick pile of Coal Measures [7]. Tectonic deformation towards the end of the Variscan orogeny resulted in the actual configuration of sedimentary-tectonic basins, creating the Namur parautochtonous ‘synclinorium’ of which the southern part is squeezed against the London-Brabant Massif and the folded Dinant synclinorium further south. The Campine Basin north of the London-Brabant Massif has only been affected by block faulting. Later Permian, Triassic and Jurassic sediments covered the area from the north at the southern margin of the Southern Permian Basin, until the Cimmerian tectonic phase caused an uplift of the London-Brabant Massif, effectively removing these sediments and monoclinally tilting the Campine Basin towards the Roer Valley Graben so that Permian to Jurassic sediments are only preserved in the deeper parts of the Campine Basin and adjoining graben [8]. The erosion as a result of this tilting movement caused an unconformity with the overlying subhorizontal Cretaceous to Cenozoic strata in the Campine Basin and Roer Valley Graben. Late Cretaceous sea level rise resulted in deposition of the Chalk Group, preserved over most of the London-Brabant Massif and reachting an average thickness of 250 m in the Campine Basin. During the Upper Cretaceous the Roer Valley Graben inverted but 30-70 m of Late Maastrichtian and Dinian (Lower Paleocene) strata were deposited during times of relaxation. From the Oligocene onwards the Roer Valley Graben became active again and rapidly filled with more than 1km of Neogene and Quaternary sediments [9][10][11]. During the Cretaceous, the Mons basin southwest of the London-Brabant Massif, rapidly but irregularly subsided, as a pull apart basin and/or due to halocinetic collapse of evaporates in the underlying Devono-Carboniferous [12].

Fig. 1. Belgium in northwest Europe. The major geological structures are indicated: the London-Brabant Massif; the coal-bearing Namur ‘synclinorium’ and the Dinant synclinorium in the south; the Mons basin in the west; the Campine Basin and the Roer-Valley Graben in the northeast.

3. Reservoir properties

In order to store CO_2 in underground reservoirs, several criteria should be met. A minimum depth of 800 meters is required for the supercritical storage of CO_2. Sealing should be present to prevent upwards migration to the surface and trapping structures are needed to minimise horizontal spreading. Injectivity and the total reservoir capacity should be high enough for injecting industrial amounts of CO_2. Therefore the most important basic reservoir properties are the reservoir's depth, horizontal extent and thickness, and the porosity and permeability. These parameters are discussed for the Belgian storage opportunities (Fig. 2, Table 1 & 2). Capacities per square kilometre (Table 2) are obtained from accessible pore space calculation and CO_2 density at reservoir conditions [3].

3.1 Houthem and Maastricht calcarenites

The Houthem and Maastricht Formations (Cretaceous to Palaeocene porous carbonates) occur at sufficient depth in the Roer Valley Graben and also in the north of the Campine Basin, with a thickness of around 60m. This reservoir just meets the 800 m depth criterium for supercritical storage in a limited area. Sealing may be present in the overlying Cenozoic clay layers. Average permeability and porosity are 29.3% and 2.5mD, and 14.5% and 65mD in the Campine Basin and the Roer Valley Graben respectively. Injectivity was calculated to be moderately high, with one well able to inject 1Mt CO_2 per year. The capacity of this reservoir is 6.5Mt/km². However, no trapping structures are identified. [3][13]

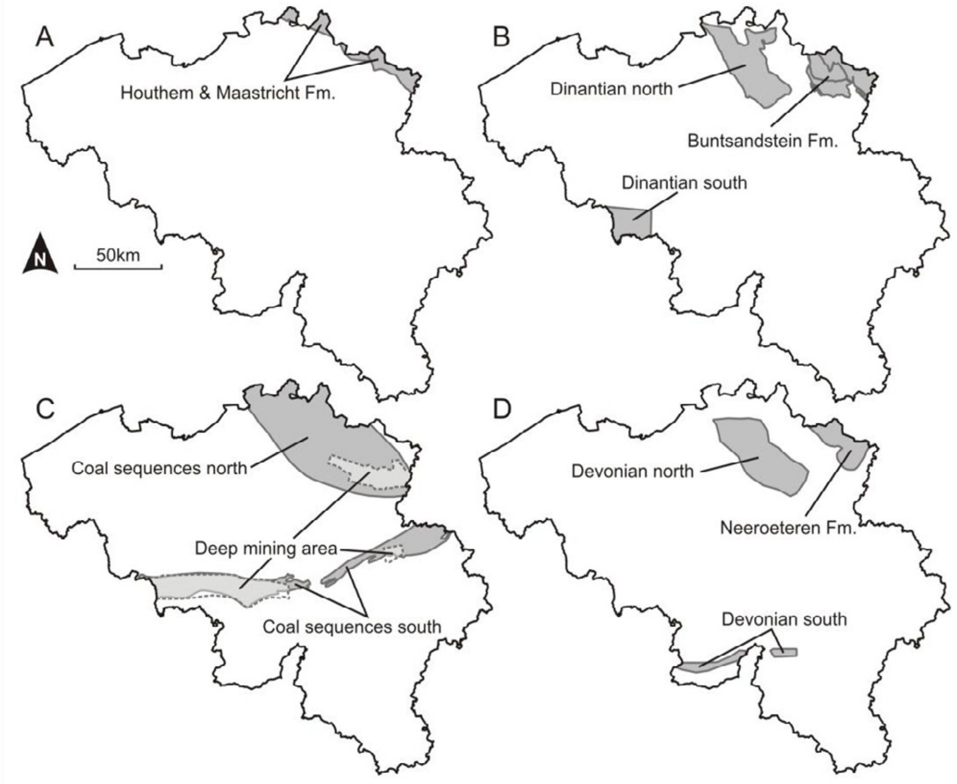

Fig. 2. Location of the storage opportunities in Belgium. A: the Houthem and Maastricht calcarenites; B: the Buntsandstein sandstones and the northern and southern Dinantian carbonates; C: the northern and southern coal sequences and deep coal mining areas; D: the Neeroeteren sandstones and northern and southern Devonian carbonates.

3.2 Buntsandstein sandstones

The Buntsandstein sandstones (Lower Triassic) also occur in the Campine Basin and Roer Valley Graben. Porosity and permeability vary with an average of 13.4% and 37mD. In the eastern area, Upper Triassic to Jurassic sediments can provide sealing. In the western area Cretaceous sediments with possibly insufficient sealing properties lie directly on top of the Buntsandstein. The assumed updoming Verloren Kamp structure in the eastern part could be one of the most promising reservoir structures in the Buntsandstein Formation. It has a surface area of 7 km² and a height of about 100m. Storage capacity in this structure would be 15 to 40Mt CO_2. Total storage capacity is calculated to be more than 880Mt [2] or 10.8Mt/km² for the whole of the Buntsandstein subcrop [3].

3.3 Neeroeteren coarse sandstones

The Neeroeteren Formation (Upper Carboniferous, Westphalian D) is present in the northeastern Campine Basin; its occurrence in the Roer Valley Graben is inferred from paleogeographic setting as there are no deep boreholes in the graben. It consists of coarse-grained to conglomeratic sandstones, which have an average porosity of 15% and a permeability of 115mD for the coarse grained intervals which make up about half of the formation's thickness. The Neeroeteren Formation is overlain by sealing Permian and Triassic sediments in the graben and by permeable Cretaceous sediments outside the graben. The estimated capacity of this reservoir is 11.8Mt/km². [3][13]

3.4 Westphalian coals

The most optimal depth range for adsorption of CO_2 to coal is 700-1300m. Unmined coal sequences within this depth range can be found in both the Campine Basin and the Namur synclinorium. The amount of coal in these Westphalian sequences is relatively low, on average approaching 3%, contributing only 15% to the total storage capacity. Most of the CO_2 will be adsorbed on coaly shales or stored in sandstone bodies, creating larger storage capacity (up to 1 Gton in the Campine Basin, up to 700Mt or 1.56Mt/km² in the Namur synclinorium). The coal sequences have an average porosity of 0.5% for the coal layers, 5% for the sandstone bodies and <0.1% for the shale layers. In the Campine Basin, average coal porosity is about 3% and average permeability 0.1mD. Porosity and permeability also depend on coal rank and burial history [14]. Due to the low permeabilities, it remains to be demonstrated whether industrial amounts of CO_2 can be injected in the coal layers. A CBM (CoalBed Methane) test well showed strong stress-dependent variations in permeability and affinity to swelling [15]. For economical and practical reasons, CO_2 storage in coals is most likely in areas with high coal-bed methane potential. [3][13]
The deep abandoned mining galleries in the coal strata are also a possible reservoir for CO_2 storage [16]. CO_2 injection in such a low-pressure reservoir poses technical difficulties, and abandoned coal mines should be investigated on the proper sealing of mine shafts and the natural seals, especially with respect to the mining induced fracture pattern. Piessens & Dusar [16] estimate 30Mt CO_2 can be stored in coal mines in the Campine Basin, and nearly similar amounts in the south [3].

3.5 Dinantian carbonates

The carbonate aquifers of the Carboniferous Limestone Group, regionally also known as the Dinantian, in both the Campine Basin and the Mons Basin consist of two stratigraphic parts: a lower dolomitised and an upper karstified part. The karstified horizons within the Dinantian aquifer in the Campine Basin have low porosities (2.4%) but high fracture permeabilities (100-1000 mD). Sealing is provided by Namurian and Westphalian shales, trapping occurs in small faulted dome structures, identified by Dreesen et al. [17] for the western Campine Basin. The estimated injectivity of the limestone reservoirs is high, and although the total reservoir surface is large, and total storage capacity is about 115Mt (1Mt/km²), currently identified dome structure traps appear small, with a few million tonnes of storage capacity per structure. [3][13]
The Dinantian aquifer in the Mons Basin is also large and covered by thick coal measures, creating a very good seal. This reservoir consists of two structural parts: a dipping and a tabular compartment. In total this reservoir has a capacity of 800 to 1300Mt CO_2. Without the dipping compartment, which is more likely to leak towards the surface, and including only the area on Belgian territory, the storage capacity is estimated to be 180 to 270Mt.

Due to existing natural gas storage at Loenhout (Heibaart dome) and geothermal energy (e.g. Beerse-Merksplas and Saint-Ghislain wells) there might be conflicts of use in the Carboniferous Limestone Group, limiting storage capacity. [3]

3.6 Devonian carbonates

The Devonian carbonate aquifers in the Campine Basin and the Fagne-Famenne are the oldest and also the least known reservoirs. Porosity is created by fractures and secondary dolomitisation in the anticlinal ridges of the Fagne-Famenne [13].
The probably karstified and partly dolomitised Devonian limestone aquifer in the Campine Basin is only known from one borehole, but Devonian analogues in the North Sea are good (oil)reservoirs (18). This reservoir possibly has a high injectivity [13].

4. Techno-economic resource pyramid

The capacities given here are calculated using accessible pore space, surface area and reservoir thickness. Sealing is also considered, but only to a limited extent because of uncertainty regarding the presence and the sealing properties of these layers. In the techno-economic resource pyramid for CO_2 reservoirs by Bachu et al. [19], these capacities are therefore located in the bottom most layer, the theoretical capacity, defined as the "physical limits of what the geological system can accept". Upgrading the Belgian reservoirs to the status of effective storage capacity or higher would firstly require additional raw data to verify the reservoir limits, sealing and the uniformity of the reservoir properties throughout the reservoir. This means storage capacities are likely to become smaller if more data becomes available. Another implication of this ranking is that it becomes apparent that at this moment, no reservoir in Belgium is ready to be used in a CCS project.

A method has been developed within the PSS-CCS projects [3] for upgrading this theoretical capacity first to the practical, and in a second step to the matched capacity [20].

Table1: Stratigraphical information of the storage options and comparison of basic reservoir properties, used for capacity calculations: reservoir thickness, average porosity and average permeability. (n/av: not available; n/ap: not applicable, CB: Campine Basin; RVG: Roer Valley Graben)

Reservoir name	***Strat. age***	***Lithology***	***Thickness***	***Porosity***	***Permeability***	***Type***
Houthem and Maastricht Formations	Maastrichtian - Danian	Calcarenite	65m CB 60m RVG	29.3% CB 14.5% RVG	2.5mD CB 65mD RVG	Aquifer
Buntsandstein Formation	Lower Triassic	Sandstone	200m	13.4%	37mD	Aquifer
Neeroeteren Formation	Late Carboniferous (Westphalian)	Sandstone	200m	15.0%	115mD	Aquifer
Coal sequences north	Late Carboniferous (Westphalian)	Coal, shales, sandstones	up to 3000 m	3% (coal)	0.1mD (coal)	Coal
Coal sequences south	Late Carboniferous (Westphalian)	Coal, shales, sandstones	600m effective sequence	Coal: 0.5% Sandst: 5% Shale: <0.1%	n/av	Coal
Coal mines north	Late Carboniferous (Westphalian)	Coal, shales, sandstones	400 m	n/ap	n/ap	Cavity
Coal mines south	Late Carboniferous (Westphalian)	Coal, shales, sandstones	1000 m	n/ap	n/ap	Cavity
Dinantian north	Visean & Tournasian	Limestone & dolomite	350-1200m	2.4% avg	<0.1-3000mD	Aquifer
Dinantian south	Tournaisian & Visean	Limestone & dolomite	500-2500m	4-6%	n/av	Aquifer
Devonian north	Devonian	Limestone & dolomite	n/av	n/av	n/av	Aquifer
Devonian south	Devonian	Limestone & dolomite	n/av	n/av	n/av	Aquifer

Table 2: Comparison of reservoir capacities, injectivity, sealing and trapping structures. (n/av: not available; n/ap: not applicable)

Reservoir name	***Capacity***	***Capacity/km²***	***Injectivity***	***Sealing***	***Trapping***
Houthem and Maastricht Formations	n/av	6.5 Mt	Moderate	Tertiary clays	Sheet
Buntsandstein Fm.	880 Mt	10 Mt	Low	East: Triassic-Jurassic shales West: no sealing	Dome structures
Neeroeteren Fm.	n/av	11.8 Mt	Low	Partly Permian shales, partly no sealing	Angular unconformity
Coal sequences north	1000 Mt	n/av	Low	Westphalian shales	Coal layers
Coal sequences south	700 Mt	1.56 Mt	Low	Westphalian shales	Coal layers
Coal mines north	30 Mt	n/av	High	Westphalian shales	Mined out zone
Coal mines south	Few 10's of Mt	n/av	High	Westphalian shales & Cretaceous marl	Mined out zone
Dinantian north	115 Mt	1 Mt	High	Namurian shales	Small dome structures
Dinantian south	180-270 Mt	n/av	n/av	Namurian shalesl	Tabular structure
Devonian north	n/av	n/av	n/av	Upper Devonian shales	Small dome structures
Devonian south	n/av	n/av	High	Upper Devonian shales	Anticlines

5. Discussion & conclusions

The Houthem and Maastricht Formations have rather poor reservoir characteristics, reaching sufficient depth in only a limited area, and lacking efficient trapping structures. The Neeroeteren Formation appears more promising, having good reservoir characteristics, although primary sealing is not always present outside the Roer Valley Graben. The Buntsandstein Formation has a relatively large theoretical capacity, adequate sealing in a large area and fault dome trapping structures are present. This reservoir therefore appears one of the better storage options at this moment but effectiveness of sealing has to be verified.

The unmined coal sequences have a relatively large theoretical capacity, but low injectivity. Most storage capacity will be provided by the intercalated shale and sandstone layers. Advanced drilling techniques will be required for injection in the coal sequences. Abandoned underground coal mines on the other hand have a very high injectivity. Pressure and sealing issues will be the main concern here.

The Dinantian reservoirs in both the Campine Basin and the Mons Basin have good reservoir characteristics, although their capacity is rather small compared to the surface area (only $1/10^{th}$ of the capacity per km² of the Buntsandstein Formation). Sealing and trapping structures are present, and injectivity is high. CO_2 geological storage projects may however lead to conflicts of use because these reservoirs are also known for geothermal energy and natural gas storage.

The Devonian reservoirs are poorly known at this moment, although if comparable to the North Sea analogues, this might also become a viable storage option.

The overview presented here attempts to compare geological storage options for Belgium in an equal manner. Storage capacity is potentially available, however due to the poor exploration of the aquifer reservoirs and the technical uncertainties surrounding the coal-related reservoirs, all capacity estimates have a status of theoretical capacity according to the techno-economic pyramid ranking of CO_2 reservoirs [19]. The total of this theoretical capacity for Belgium is estimated to be about 3Gt maximum. This number is in general conservatively lowered to 1Gt. Additional exploration is needed to successfully develop any of these potential reservoirs. Capacity numbers will most likely be lowered while upgrading the capacity status. With the current knowledge, the Buntsandstein and the Dinantian reservoirs appear the most promising for geological CO_2 storage. Storage in coal could deliver substantial capacity when technical difficulties are overcome.

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