



ANALYSIS OF THE SUITABILITY OF THE USE OF HYDROCARBON DEPOSITS FOR CO₂ AND HYDROGEN STORAGE IN THE NORTHERN MORAVIA REGION

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ABSTRACT

Geological storage of CO₂ is the final link in the technological chain CCS (Carbon Capture and Storage), one of the possible technologies for reducing greenhouse gas emissions arising from the burning of fossil fuels. CCS is one of the key energy technologies of the Strategic Energy Technology Plan of the European Union (SET-plan). In the Czech Republic, activities in the field of CCS have focused on research and development projects, including the mapping of geological structures suitable for potential CO₂ storage and the transposition of relevant European legislation – see Act No. 85/2012 Coll., on the Storage of Carbon Dioxide into Natural Rock Structures. One of the options for geological storage of CO₂ is the use of mined or mined hydrocarbon deposits. However, these structures could also be operated as underground CO₂ reservoirs, enabling its reuse. Yet some of them could also be used for hydrogen storage if these locations are appropriately incorporated into the construction of a new hydrogen infrastructure. The report presents part of the research results related to hydrocarbon deposits in the North Moravia region.

Keywords: Carbon Capture Storage (CCS); CO₂ geosequestration; Hydrogen storage; Oil and gas deposits.

1 INTRODUCTION

Capturing and storing carbon dioxide is considered one of the possible solutions to at least partially reduce CO₂ emissions from human activity and, at the same time, have a secondary profit in the form of, e.g., increasing the yield of some oil deposits. CO₂ is mainly produced through burning fossil fuels, e.g., in large units of coal-fired power plants and heating plants. Significant emissions of carbon dioxide are also the result of industrial activity associated with the extraction of mineral resources.

CCS includes the solution of several technologies. First, it is important to capture and concentrate the produced CO₂ in industry and energy sources, following its transport to suitable storage facilities and subsequent long-term storage outside the atmosphere, possibly with its later use. CCS technologies would thus enable the further use of fossil fuels with low greenhouse gas emissions. CO₂ capture, transport and storage are currently operationally possible. Capture involves the separation of CO₂ from flue gas. For combustion processes in power plants, separation technologies are applicable after combustion or to decarbonize the fuel before the actual combustion process. Transport requires bringing the captured CO₂ to a suitable location some distance from the source. To facilitate transport and storage, captured gaseous CO₂ can be compressed to a high density or liquefied at the point of capture. Potential disposal methods include injection into certain suitable geological formations. Another hypothetical possibility is the injection of CO₂ into the deep layers of the ocean or industrial fixation into inorganic

carbonates. [1,2] The focus of the article will be put on the possibilities of geosequestration of CO₂ into mined or mined hydrocarbon deposits.

The capture of CO₂ from energy sources for sequestration in geological structures is not yet industrially used in Europe, although technical development is already validating procedures applicable to large units. Its advantage is the possibility of significant capture of CO₂ generated during the processing of fossil fuels, but at the cost of high financial expenses, a reduction in the overall efficiency and an increase in their consumption. Current scientific and technical development is focused on procedures that would limit these negative factors [3].

These also include the re-use of CO₂ as part of the rapidly developing Power to Gas (PtG) technology, which means converting excess electricity into combustible hydrogen gas, methane or synthetic diesel, i.e. fuels that, unlike electricity, can be stored for lower financial costs [4].

Based on the European Commission's projections for the "Fit for 55" package, renewable and low-carbon hydrogen, together with synthetic methane and biomethane, should represent two-thirds of the gaseous fuels in 2050, the rest being natural gas with carbon capture and utilization technology [5].

2 FORMULATION OF PROBLEM

The term CO₂ geosequestration represents the long-term storage of captured carbon dioxide in various geological formations. The following geological formations can be used for long-term storage of captured carbon dioxide or the CO₂/N₂ mixture:

- mined or exploited oil and natural gas deposits,
- non-minable coal seams,
- saline aquifers,
- rock massif of suitable mineralogical composition.

Some of the mined natural gas deposits can also be used for hydrogen storage. Different options for CO₂ geosequestration are shown in Fig. 1.

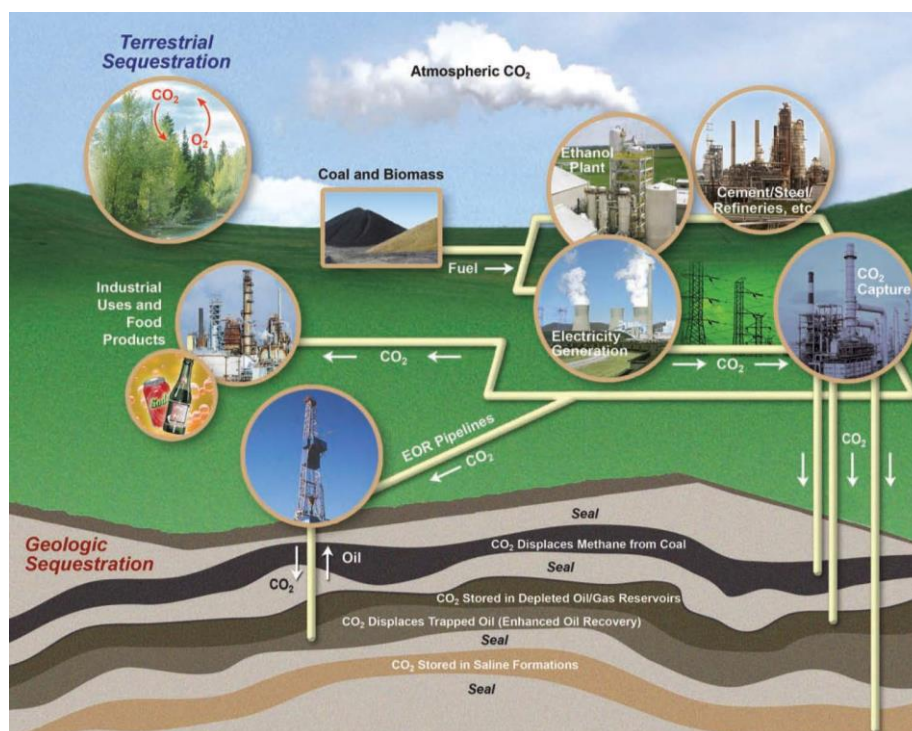


Figure 1. Geosequestration of CO₂ into various geological structures (modified according to [1])

From a technical point of view, “abandoned” spaces in collector layers after the extraction of hydrocarbons can be considered a completely ideal environment for CO₂ storage. These are spaces that, over many millions of years of their existence, have proven their ability to protect existing reserves of natural gas and oil from external influences. These structures can, therefore, be considered closed. Another advantage is their high level of research and, thus, sufficient information for choosing a suitable space for storage, managing its use, and long-term monitoring. Operating and observation probes are available. After the extraction of gas reserves, optimal access is an available environment for storing another gaseous medium. The situation is somewhat more complicated in the area of extracted oil deposits. Even after extraction, part of the oil remains bound to the rock environment, significantly reducing the effective porosity and, thus, the usable space for CO₂ storage. The use of CO₂ injection is far more suitable during oil extraction (EOR method = Enhanced Oil Recovery), which significantly increases mining efficiency.

For storing hydrogen, only gas reservoirs seem to be suitable, especially from a technological point of view.

Before implementing CO₂ storage, it is necessary to analyze the conditions that may affect long-term CO₂ storage in geological structures. It is about to launch the mineral transformation processes, influence groundwater, etc.

According to CO₂GeoNet, the European Network of Excellence’s report, there are several mechanisms:

- i. Accumulation of CO₂ under the ceiling insulation layer – The CO₂ is lighter than water and rises to the ceiling insulation layer. It must be hermetic and well-consolidated to prevent CO₂ leakage to the ground.
- ii. Immobilization in small pores – Geological structural small pores do not allow the migration of CO₂.
- iii. Dissolution – A small amount of CO₂ dissolves in and combines with a groundwater solution in place. Water with dissolved CO₂ is heavier and moves down the structure. The amount of dissolved CO₂ is limited by the maximal saturation degree and in situ temperature-pressure conditions. Besides, it is a relatively slow process (15% of injected CO₂ is dissolved in 10 years).
- iv. Mineralization – If groundwater is present, CO₂ can react to minerals that are forming the surrounding structure. Some minerals are dissolved. Others precipitate, depending on pH conditions and surrounding rock mineral composition. Gaseous water vapor saturated with CO₂ is more reactive than water with dissolved CO₂. According to the research, only a small amount of injected CO₂ is immobilized by incorporation into the structure’s newly emerging secondary phases. This process is very slow. After 10 000 years, only 5 % of injected CO₂ will be mineralized, but 95 % of the same amount of injected CO₂ will be dissolved at the same time.

Knowledge of mentioned processes comes from 4 main information sources:

- I) Laboratory research – Experiments that study the flows of CO₂ in the reservoirs, the influence of CO₂ on dissolution/precipitation, etc.
- II) Numerical simulations – The long-term evolution of injected CO₂ into a certain geological structure is studied with the use of geochemical software (e.g. GWB). Laboratory experiments are used for model calibration.
- III) The study of natural CO₂ reservoirs – Natural reservoirs where CO₂ has been captured for millions of years provide important information about the influence of a large amount of CO₂ on the surroundings.
- IV) The study of existing CO₂ storage projects into the geological structures – Sleipner (Norway), Weyburn (Canada), In Salah (Algeria), K12-B (Netherlands). Short-term simulation results can be compared with real data from existing projects and help specify the long-term numerical models.

Several authors [6,7,8] have done laboratory experiments that studied the influence of different concentrations of CO₂ on its dissolution in saline groundwater and its upcoming interaction with the gas-rock-water system. Research has shown that the presence of groundwater in the geological structures selected for CO₂ storage causes the dissolution of injected CO₂, even at high concentrations, which increases the ability of this water to interact with the minerals of surrounding rock. These processes are desirable in these structures because they increase the porosity of the collector, thereby increasing the space for CO₂ storage.

Other authors [9,10] have performed numerical simulations about the influence of injected CO₂ on certain geological structures. Modelling of kinetic reactions mostly dealt with assumed time limits required for gas capture. Model results have come with the following knowledge: information about the possible amount of gas deposited in the selected structure, changes in the overall porosity of the rock, and a description of mineralogical changes in the rock matrix due to contact with injected CO₂.

The mentioned examples present that geochemical models can be used to characterize the long-term evolution of injected CO₂ in the geological structure and simulate its influence on interactions in the gas-rock-water system. In conclusion, all experiments and numerical simulations have shown that the safety of stored CO₂ increases over time, mainly due to its dissolution in groundwater.

3 METHODOLOGY

From a technical point of view, the abandoned spaces after hydrocarbon mining are an ideal environment for CO₂ storage. It is the closed space that proved a perfect ability to protect existing oil and gas resources for millions of years. There is an accessible optimal area for storing different mediums in the gaseous state after gas resources are extracted. A lightly complicated situation is after oil field mining. Even after extraction, part of the oil remains bound to the rock environment, which significantly reduces the effective porosity and, thus, the usable space for CO₂ storage. Injecting CO₂ while extracting is more used nowadays, so the extraction effectivity increases. It is good to mention that the perspective structures are already used for gas storage or are in the main interest of gas companies.

With the research of possibilities of CO₂ utilization for recoverability increase, it has been published a lot of information about viscosity changes of oil by CO₂. Saturation was done with different conditions. The conclusion from the work was that next to the volume increase effect, there is also a significant effect of CO₂ on viscosity. The rate of influence on viscosity depends on saturation pressure and oil composition.

In general, viscosity decreases with both the pressure and the average molecular weight of oil. The effects of changes in the volume and viscosity of oil on the oil exploitation finishing process are as follows:

- due to the influence of CO₂, its volume significantly increases, which is positively reflected in its saturation in a porous environment;
- with the rising saturation, the relative permeability rises as well, which leads to higher viscosity. This process amplifies with laboratory-proven lower viscosity.

3.1 Technological options for depositing CO₂ in hydrocarbon deposits, including its re-use

In the case of deposition of CO₂ in deposits of under-exploited hydrocarbons, the possibility of an increase in oil yield or gas is assumed. Two different approaches can be applied here: “mining” and “sequestration”.

The first approach – “mining” – is aimed at maximizing the extraction of oil (gas). Here, CO₂ serves as a displacement and subsequently “rinsing” medium, often in combination with water. An amount of medium equal to three volumes of the effective pore space is usually injected. CO₂ is then extracted with oil (gas) at a certain stage and, after separation, is injected back into the deposit.

The second approach – “sequestration” – is aimed at depositing the maximum amount of CO₂ in the reservoir structure. The increase in oil (gas) recovery is not the main benefit here. In this case, an amount of medium is injected into the reservoir, which can theoretically be equal to one effective pore space. When CO₂ “rises” in the well, the injection process is finished [11].

For potential CO₂ storage, the reservoir must have the following basic properties [12]:

- **Size:** the repository must be large enough (in terms of pore volume) to hold the planned amount of CO₂, e.g. the emissions output of one coal-fired power plant over its lifetime. The storage capacity is determined by the volume of pores that can be filled with CO₂.
- **Porosity and permeability:** these parameters must be high enough to allow both a sufficient pore volume for CO₂ and its continuous injection. CO₂ is forced into the pores in the reservoir rocks and displaces the original (in situ) pore contents, the pore fluid. In the case of gas deposits, this is natural gas or reservoir water, which may be initially present in the deposit or may have entered it from the water field as a result of a drop in the reservoir pressure during the exploitation. If the permeability of the rock is low or there are barriers to fluid flow, such as fractures, the injection can cause a progressive increase in fluid pressure around the injection site. This limits the rate of CO₂ suppression and can be the limiting factor for the amount of CO₂ that can be stored. Therefore, structures that are too tectonically dissected are less suitable for CO₂ storage than extensive structures without faults, although having lower permeability.
- **Depth:** usually, only deposits deeper than 800 m are suitable storage for CO₂. At the temperature and pressure typical of this depth level, CO₂ changes its phase form, and its specific gravity is similar to values typical of liquids. This transition to the so-called supercritical state (critical point) is represented by the values of pressure 7.38 MPa and temperature 31.1 °C. Considering that the temperature gradient is on average 30–35 °C per 1 km depth, and the pressure (hydrostatic) increases with depth by an average of 10 MPa per 1 km depth, it is clear that only at depths greater than 800 m does a significant change in the specific gravity of injected CO₂.

E.g., at a depth of 1000 meters under the temperature and pressure conditions characteristic of this depth (35 °C, 10 MPa), 1 ton of CO₂ occupies only 1.5 m³ of space (CO₂ density= 650 kg/m³).

The injected CO₂ remains trapped in the repository rocks, isolated from the surface, and effectively permanently stored through a combination of three main processes [9]:

- capturing in a structural or stratigraphic trap,
- dissolution in solution in reservoir water (mostly brine),
- geochemical reactions and formation of minerals in pore spaces.

The main storage process, at least in the first phase of CO₂ injection, is immobilization in a structural or stratigraphic trap (“trapping”).

Over time, as the free pore capacity decreases, CO₂ dissolves in the reservoir water. The solubility of CO₂ in typical bearing water conditions of about 3% is about 49 kg/m³, corresponding to a volume of free CO₂ of about 7% of the pore volume [13]. By dissolving CO₂ in the reservoir water, its density increases and tends to decrease within the repository. However, according to many model scenarios, this process is slow [14].

Another process of long-term capture of CO₂ underground is the chemical bond between the injected CO₂ reservoir water or the actual rocks of the repository. The number of compounds or minerals created by this process and its time frame are dependent on the chemical properties of the reservoir water and minerals forming the reservoir rocks and on the length of the migration routes [9,12].

Two of the mentioned properties – the size of the storage, the porosity, and the permeability of the layers – are also decisive for the storage of hydrogen. The depth here depends on the presence of sufficiently strong insulating (impermeable) layers in the overburden of the collector of interest.

3.2 Criteria for characterizing and assessing a potential storage complex and surrounding area

The characterization and assessment of the potential storage complex and the surrounding area are carried out in three steps using the procedures that have proven to be the best at the time of the assessment and according to the criteria set out below. The competent authority may allow exemptions from one or more of these criteria if the

operator has demonstrated that the characterization capability to make suitability decisions is not adversely affected. These are the procedures:

Step 1 – Data collection,

Step 2 – Building a three-dimensional static geological model, and

Step 3 – Characterizing the dynamic behaviour of the repository.

4 DISCUSSION AND RESULTS

In the North Moravia region, indications and deposits of gaseous and liquid hydrocarbons of different ages were found in different stratigraphic units [15,16] (see Fig. 2).

Relatively smaller accumulations of gaseous and liquid hydrocarbons are linked to the Devonian and lower carboniferous carbonate complexes. The most significant accumulations of methane are bound to coal-bearing carbon, either in primary collectors that form coal seams and carbonaceous rocks or migrated methane with accompanying layer gases in secondary collectors in the weathered carbon mantle and overlying cover rocks (Carpathians, lower Baden). The indications of gaseous and liquid hydrocarbons in the Mesozoic and Paleogene sediments of the Carpathian blankets are younger. The youngest is the deposit accumulations of gaseous hydrocarbons in the autochthonous Carpathian sandstones and in the Baden sandstones where the proportion of migrated carbonaceous methane cannot be ruled out.

Gas migration and secondary accumulation of layer gases in the massif disturbed by mining activity is recent. This continues after the end of the activity in the Ostrava region [17,18].

Accumulation of thermogenically migrated layer gases (CH₄) in secondary collectors depends on the existence of suitable lithological traps. In places where the weathered mantle of carbon is covered by impermeable sediments, a secondary accumulation of methane occurs, referred to as zone III. If the collector is developed in the cover in the overburden of the carbon weathering jacket, gas accumulation occurs in the weathering coat and in the collector in the cover or only in the cover. If this collector is watered, as is the case with the Lower Baden clastics in the Bludovice and Dětmárovice potholes, methane is dissolved in salt water (the volume of CH₄ is approx. 0.7 to 1 m³ per 1 m³ of water, pressure up to 8 MPa). In both cases, a zone of reduced concentrations of layer gases (zone II) is developed below this zone, which passes into the zone of primary concentrations of layer gases (zone I). The zonality of the distribution of layered CH₄ is confirmed by the results of research on so-called layered methane. [9,15,16]

The small extraction of natural gas started in 1945 with the connection of a few coal exploration wells with natural gas to compress stations in Mitrovce and Příbor. Extraction has been extended since the early 1950s with the involvement of the Žukov deposit in the process. Significant extension of production has occurred since 1957 by using a higher number of natural gas wells from the Příbor-Klokočov deposits and extraction of Staříč and Stonava natural gas deposits. Since 1960, when the ZDO (currently Green Gas DPB) was founded, gas extraction has been on the rise. The modernization of technical equipment and construction of gas pipeline connections site built a united gas pipeline site of Severomoravské plynárny with connection to Příbor-jih (1964), Bruzovice (1969), and Kozlovice (1971) gas deposits. Thus, the connection between the Příbor area, the cracking station in Horní Suchá, the Žukov gas deposit, and the customer (Třinec Steelworks) was established. Other customers were the Sheet Rolling Mills in Lískovec, the Tatra and Loana plants in Příbor, etc. Gas was supplied from the Choryně deposit to the chemical plants in the Valašské Meziříčí. In the past, small reserves of the Komorní Lhotka deposit were extracted for the Radegast brewery in Nošovice, and gas was supplied from the Kozlovice deposit (well SV 1) to the local agricultural cooperative. In both cases, Unigeo was the miner.

Gas extraction in long-term summary: the most gas was extracted in 1960 (187,8 mil. m³); in the following years, the extraction was reduced – it was 145,2 mil. m³ in 1965, 113 mil. m³ in 1970, and 22 mil. m³ in 1980. The rapid drop in the 1970s was a consequence of the termination of gas extraction on the Příbor-jih deposit due to its conversion to underground gas storage.

From the ČHP Žukov, Bruzovice, Staříč-Lískovec, Příbor-Klokočov, Krmelín, and Choryně deposits, over 3 bil. m³ were extracted. The rest of the extractable supplies are very low; however, it is enough for only a few years of small extraction.

Other possibilities of increasing gas extraction are not real (absence of explored deposits). Carbonate Paleozoic (dolomites on Devon base, mixed facies collectors at the Devon-Carboniferous boundary), Paleozoic and Carpathians surface (the Frenštát, Těšín, Jablunkov area) are considered perspective deposits in a long-term view [2,19].

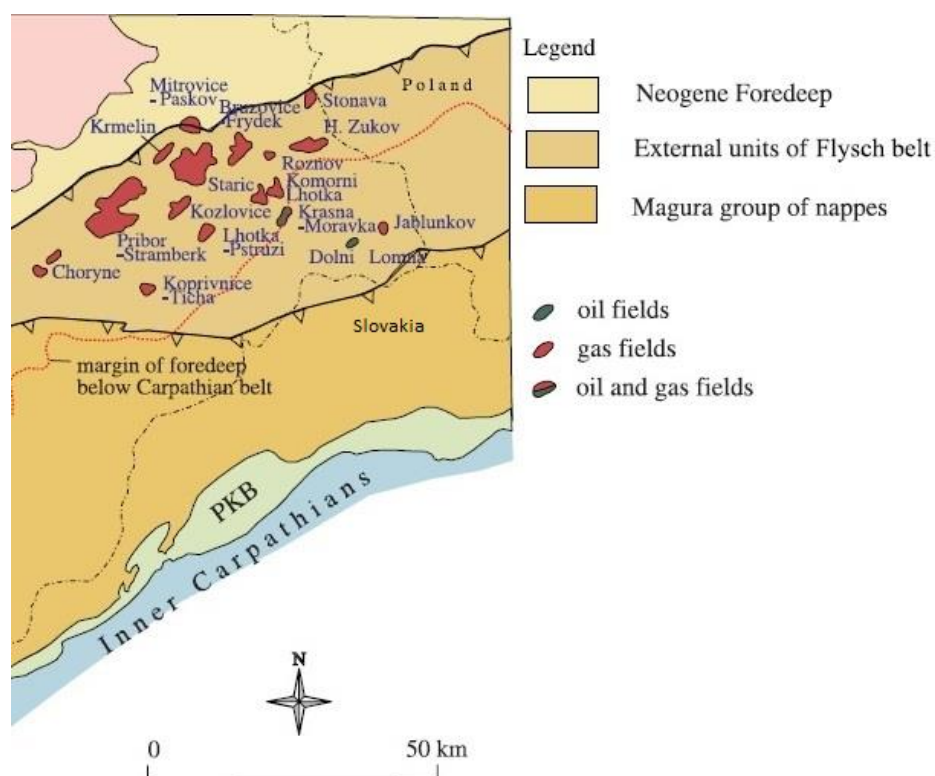


Figure 2. Localization of hydrocarbon deposits in the area of Northern Moravia (modified according to [19])

The summary of gas deposits with various genesis found in the region is shown in Table 1.

Table 1. Oil and gas fields in the Carpathian Neogene foredeep and the Flysch belt in Moravia

Field Name	Year of Discovery	Age of Reservoirs	Type of Reservoirs	Porosity (%)	Field Type	Production status	Initial Reserves Gas (bcf)
Carpathian foredeep							
Bruzovice – Frýdek	1952	Miocene Carboniferous	clastic	15–20 7–15	gas	coal degasification	5
Choryně	1908	Carpathian Carboniferous	clastic	15–20 7–15	gas	conservation	21
Horní Žukov	1915	lower Badenian Carboniferous	clastic	15–20 7–15	gas	gas storage	39.1
Komorní Lhotka	2001	Miocene Carboniferous	clastic	15–20 7–15	gas	development ongoing	3.7
Kozlovice – Lhotka	1975	Silesian unit Miocene Carboniferous	clastic	10–15 15–20 7–15	gas	development ongoing	0.9
Krmelín	1958	Miocene Carboniferous	clastic	15–20 7–15	gas	coal degasification	1.5
Mitrovice – Paskov	1909	Miocene Carboniferous	clastic	15–20 7–15	gas	coal degasification	10

Příbor Jih	1965	Carpathian Carboniferous	clastic	15–20 7–15	gas	gas storage	21
Příbor – Klokočov	1908 1912	Carpathian Carboniferous	clastic	15–20 7–15	gas	coversation	35
Stonava	1952	Miocene Carboniferous	clastic	15–20 7–15	gas	coal degasification	1.5
Staříč – Lískovec – Sviadnov	1913	Miocene Carboniferous	clastic	15–20 7–15	gas	coal degasification	7
Carpathian Flysch belt							
Lhotka – Pstruží	1975	Silesian unit	clastic	10–15	gas	producing	6
Rožnov	1983	Subsilesian unit	clastic	10–15	gas	development ongoing	0.3
Kopřivnice – Tichá	1982	Silesian unit Miocene Carboniferous	clastic	10–15 15–20 7–15	gas	producing	17.6

5 CONCLUSION

The location of hydrocarbon deposits in the North Moravia area is shown in Fig. 2. The collector properties of the reservoir rocks, geological characteristics, methods of opening, and mining the deposits were similarly analysed based on available archival materials. An overview of the most important parameters for geosequestration of CO₂ and hydrogen storage in selected hydrocarbon deposits of the given area is given in Table 1. The largest storage capacities are reported for the Bruzovice and Příbor-Klokočov deposits. However, these deposits are still mined by Green Gas DPB a.s. Paskov, and their current use for the needs of CO₂ geosequestration or hydrogen storage is not realistic. This also applies to the Janovice deposit, mined by UNIGEO a.s. Ostrava. Other deposits – Lubná, Morávka, and Komorní Lhotka – are located in the Beskydy Protected Landscape Area (PLA), and their use is, therefore, not possible from an ecological point of view. The Lhotka-Pstruží and Krmelín deposits have a very small storage capacity of approx. 1 million m³, and their use is, therefore, unsuitable from a technological and economic point of view. However, they could be used for testing as part of semi-operational research. The Choryně, Lískovec-Staříč and Kopřivnice-Tichá deposits are not located (from the point of view of geosequestration of CO₂ in the so-called supercritical state) at a suitable depth. This small depth of storage of production horizons also limits the possibility of using structures for hydrogen storage. The Horní Žukov and Příbor south deposits are already used for natural gas storage under the names Underground Gas Storage Třanovice and Underground Gas Storage Štramberk.

It is clear from the above that currently no suitable hydrocarbon deposits can be used for geosequestration and CO₂ storage in the North Moravian region. For semi-operational research, we recommend the Krmelín deposit. The obtained results could be used in the application of the given methodology and also at other deposits in the Czech Republic. Due to the difficult energy situation of the current time, it would be advisable to pay increased attention to unmined coal seams, especially in connection with the mining of coal bed methane (Coal Bed Methane = CBM).

In theory, existing mined deposits (Bruzovice and Příbor-Klokočov) could be used for hydrogen storage in the future. The possibility of converting the underground gas reservoirs of Underground Gas Storage Třanovice and Underground Gas Storage Štramberk can also be considered. These considerations are based on the key point of the draft Regulation No. 715/2009 of the European Commission [5] that states the requirement regarding the obligation to accept from 1 October 2025 at cross-border connection points natural gas with a hydrogen content of up to 5%.

Table 2. Overview of the most important parameters for geosequestration of CO₂ in selected hydrocarbon deposits on North Moravia according to [20]

	Estimated Bg coefficient	Pore volume (mil. m ³)	Estimated CO ₂ density (kg/m ³)	Theoretical storage capacity of CO ₂ (kt)	Distance from CO ₂ source (km)	Stratigraphy	Lithology	Depth to reservoir top m	Production per year (2005) th m ³	Production history th m ³	Proven reserves th m ³
Gas and oil reservoirs											
Lubná		0.13	650	85	96	Cambrian	Crystalline bas.	1500	1.3	130	2
Lubná	0.007	1.46	650	949	27	Cambrian	Crystalline bas.	1300	1.8	160	43
Oil reservoirs											
Krásná		0.04	650	26	27	Devonian	Carbonates	1580	1.1	5	33
Gas reservoirs											
Morávka	0.006	0.25	650	164	28	Miocene	sandstones	1430	2.9	20	22
Bruzovice-Frýdek	0.025	16.23	120	1948	12	Carboniferous	sandstones	460	6.8	385	264
Choryně	0.026	1.28	80	102	41	Miocene	sandstones	380	0.2	42	8
Kopřivnice – Tichá	0.015	0.74	230	169	25	Miocene	sandstones	640	1.8	23	26
Křmelín	0.023	0.47	110	52	9	Miocene	sandstones	440	0	20	1
Staříč	0.03	10.78	75	808	11	Carboniferous	sandstones	370	0.4	310	49
Příbor-Štramberk	0.053	48.13	40	1925	22	Miocene	sandstones	190	2.6	696	212
Lhotka-Pstruží	0.013	0.04	450	18	25	Flysch Nappe	sandstones	750	0	2	1

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