

# *Preliminary Exploration of Geological Storage Potential of Carbon Dioxide in Hunan Province under the Background of Carbon Neutrality*

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**Abstract:** As the largest greenhouse gas emitted, CO<sub>2</sub> contributes the most to global warming. The establishment and implementation of the target of carbon neutrality is not only beneficial to protecting the environment, but also beneficial to national security and sustainable development strategy. Hunan as a large industrial province in central China, carbon emissions remain high. The results show that the deep unminable coal seam and the deep salt water layer in Hunan Province have certain potential for CO<sub>2</sub> sequestration. In the future, the investigation, site selection, sealing stock calculation and sequestration technology can be carried out.

## 1. Carbon neutrality background

Since the Industrial Revolution, the scale of human use of fossil fuels has continued to increase, resulting in the production of large amounts of greenhouse gases such as carbon dioxide, methane, and nitrous oxide, leading to a gradual increase in global temperatures. As the most important greenhouse gas (accounting for more than 60%), CO<sub>2</sub> has a particularly significant effect on global warming<sup>[1]</sup>. As a big energy consumption country, China's coal consumption and CO<sub>2</sub> emissions are huge<sup>[2]</sup>. On March 15, 2021, 'Carbon peak' and 'Carbon neutrality' were written into the government work report and included in the overall layout of ecological civilization construction<sup>[3]</sup>.

Earth science is critical to achieving carbon neutrality. Global climate change is essentially a problem of earth system science. The realization of carbon neutrality is essentially the realization of carbon cycle balance, that is, the exchange balance of carbon between atmosphere, ocean and land. The natural factors leading to the increase of CO<sub>2</sub> are closely related to different geological processes, and the most important human factor is the use of fossil energy. Therefore, the key to achieving carbon neutrality is energy structure adjustment, man-made emission reduction and artificial sink increase, which are closely related to earth science.

## 2. Carbon pool and carbon cycle

Carbon storage refers to a storage facility that accommodates carbon elements and carbon containing compounds. There are four major carbon pools on Earth, namely the atmosphere, terrestrial, marine, and crust (lithosphere)<sup>[4]</sup>. Among them, the atmospheric carbon pool is the smallest, mainly carbon-containing gas ; the crust (lithosphere) has the largest carbon pool, which mainly contains carbon elements (such as graphite, diamond), hydrocarbons (such as hydrocarbons) and carbonate minerals (such as calcite, dolomite) ;The marine carbon pool is second only to the crust (lithosphere) carbon pool ; the carbon of terrestrial carbon pool is mainly distributed in terrestrial animals, plants, microorganisms, soil and water in the form of organic compounds. The process of material exchange between carbon pools in the form of organic carbon and inorganic carbon compounds is known as the global carbon cycle<sup>[5]</sup>. Carbon can enter the atmosphere from deep Earth through various geological processes, such as volcanic eruptions and mid ocean ridge expansion. However, the main pathway for carbon to return from the surface to the depths of the Earth is through plate subduction<sup>[6]</sup>. In addition, the surface ocean exchanges and dissolves CO<sub>2</sub> with the atmosphere, allowing it to enter the ocean carbon pool; The process of transporting carbon from deep oceans to the crust and exchanging carbon with surface oceans will also take thousands of years<sup>[5]</sup>. On the one hand, volcanic activity releases a huge amount of CO<sub>2</sub> (carbon source) into the atmosphere, which not only exacerbates the greenhouse effect, but also significantly changes local and even global weather and climate conditions; On the other hand, CO<sub>2</sub> in the atmosphere enters aqueous solutions through the weathering of siliceous rocks and carbonate minerals on the land surface, and ultimately converges into the ocean to form carbonate sediments that are fixed; Or participate in the weathering and alteration of rocks such as basalt and peridotite, forming carbonate minerals that are fixed in crustal rocks<sup>[7]</sup>, indirectly affecting and regulating global climate change by reducing atmospheric CO<sub>2</sub> concentration. It can be seen that the carbon cycling between the deep Earth and the atmosphere will have a significant impact on global climate change, both in the long-term and short-term time scales<sup>[8]</sup>.

## 3. Carbon sinks and sources, and geological carbon sink mechanisms

The process, activity or mechanism by which carbon dioxide is absorbed and stored is referred to as ‘carbon sink’; in contrast, the process, activity or mechanism of carbon release into the atmosphere is defined as ‘carbon source’<sup>[9]</sup>. In the global carbon cycle, the geological carbon sink mechanism is of great significance, including: (1) rock dissolution-weathering carbon sink mechanism; (2) Soil carbon sink mechanism; (3) Marine carbon sink mechanism. In addition, it can also include carbon dioxide geological storage mechanisms controlled by human activities.

The carbon sink mechanism of rock dissolution-weathering includes carbonate rock karst mechanism and silicate rock weathering mechanism. The former refers to the chemical reaction of CO<sub>2</sub> dissolved in water with carbonate mineral particles in surface rocks, mainly including two processes of carbonate dissolution and precipitation. The weathering carbon sink mechanism of silicate rocks refers to that CO<sub>2</sub> in the atmosphere participates in the weathering reaction of silicate minerals in the supergene environment, transforms into HCO<sub>3</sub><sup>-</sup> through the reaction, and finally inputs into the ocean to deposit as carbonates, which are fixed in the lithosphere. The mechanism of soil carbon sink mainly refers to the transformation of biological organic matter in the soil environment into soil organic matter under the influence of microbial action, and long-term stable storage in the soil to form soil carbon sink.

## 4. Geological utilization and storage of CO<sub>2</sub>

The main ways to achieve carbon neutrality, that is, the main measures for large-scale CO<sub>2</sub>

emission reduction are: (1) energy conservation and emission reduction ; (2) the use of low-carbon or carbon-free clean new energy, such as nuclear energy, wind energy, geothermal energy, water energy, solar energy and other renewable energy; (3) By protecting the ecological environment, such as afforestation, increasing wetland area and other means to increase carbon sinks; (4) The application of CO<sub>2</sub> capture and storage (CCS), which captures and stores the CO<sub>2</sub> generated by fossil fuels to achieve artificial carbon sinks, will bring great changes in the process of coping with climate change. This technology can reduce or even avoid CO<sub>2</sub> emissions from the source, and can reduce the existing CO<sub>2</sub> in the atmosphere on a large scale through CO<sub>2</sub> removal technology. Therefore, (CCS), as an emerging technology with large-scale CO<sub>2</sub> emission reduction potential, is of great significance for the long-term global response to climate change and the promotion of domestic green, circular and low-carbon development<sup>[10]</sup>.

CO<sub>2</sub> geological utilization is the process of injecting CO<sub>2</sub> into the ground to strengthen energy production and promote resource exploitation, such as improving oil and gas recovery, mining geothermal, deep saline (brine) water, uranium and other types of resources. CO<sub>2</sub> geological storage refers to the injection of captured CO<sub>2</sub> into deep geological reservoirs through a variety of storage methods, such as adsorption storage, structural trap storage, dissolution storage, mineralization storage and residual storage<sup>[11-12]</sup>, achieving long-term isolation from the atmosphere. Among them, adsorption storage, structural trap storage and residual storage belong to physical storage, dissolution storage and mineralization storage belong to chemical storage. At present, the main geological body storage methods include: (1) saline water layer storage; (2) Exhausted or exploited to the later stage of oil and gas reservoir storage; (3) Storage of deep unminable coal seam.

The saline aquifer refers to the rock layer containing groundwater salt solution with closed structure in the deep underground. The basic principle of CO<sub>2</sub> storage in saline aquifer is to inject CO<sub>2</sub> into the rock containing groundwater salt solution. In this process, CO<sub>2</sub> will be partially dissolved in underground salt water, or in a supercritical state, or fixed by chemical reaction with ions in underground salt water or mineral particles in rocks, so as to achieve the purpose of long-term storage of CO<sub>2</sub><sup>[13]</sup>. The saline aquifer has a suitable depth of CO<sub>2</sub> storage and a wide range of underground distribution. Therefore, saline aquifer has become the most promising geological storage site.

The storage of oil and gas reservoirs refers to the injection of CO<sub>2</sub> into the depletion or exploitation of oil and gas reservoirs in the later stage. It can not only achieve the purpose of CO<sub>2</sub> geological storage and obtain social benefits, but also improve oil and gas recovery and form economic benefits. Compared with saline aquifers and coal seams, the geological bodies that produce oil and gas often have better sealing properties. After the oil and gas are produced, the underground space that originally accommodates its volume is good for CO<sub>2</sub> geological storage, so it generally belongs to physical storage<sup>[12]</sup>.

China 's deep coal seams are widely developed, with good geological conditions and broad development prospects for the implementation of CO<sub>2</sub>-Geological Storage-Enhanced Coalbed Methane Recovery technology. Coal seam CO<sub>2</sub> geological storage technology refers to the injection of a certain amount of CO<sub>2</sub> into the coal seam, and the use of CO<sub>2</sub> is more easily adsorbed on the surface of the coal seam to replace more CH<sub>4</sub>. While realizing the purpose of storing CO<sub>2</sub> in the coal seam, it can improve the production and yield of coalbed methane, and has certain economic added value<sup>[14]</sup>.

## 5. Evaluation of carbon dioxide geological storage potential in Hunan Province

The potential evaluation of CO<sub>2</sub> geological storage is divided into four stages: national/state-level screening, basin-level evaluation, site description and site application. A series of basin-level evaluation index systems have been formed by taking the characteristics of storage geological bodies, regional geology, evaluation purposes, local protection, social health, storage safety and environmental risks as the main indicators. At the same time, for different storage

geological bodies, CSLF (Carbon Storage Leaders Forum) method, DOE (United States Department of Energy) method, EU method, ECOFYS and TNO-TING method are established to calculate the CO<sub>2</sub> geological storage capacity of deep saline aquifers<sup>[12]</sup>.

Hunan Province is a large province with both industry and agriculture in the central and southern regions of China, and its economic development momentum is good. From 2015 to 2019, Hunan's total carbon emissions fluctuated between 386 and 393 million tons of CO<sub>2</sub>e ; hunan 's energy consumption carbon emissions are in the range of 295 million to 319 million tons of CO<sub>2</sub>e, accounting for about 76% of the total carbon emissions, of which coal emissions account for 75% to 80 %<sup>[15]</sup>. As a central inland province with poor coal, no oil, less gas and relatively poor energy, it is highly dependent on foreign energy and has not yet established a CCUS project<sup>[16]</sup>. A total of 7 sets of hydrocarbon source rocks are developed in Hunan Province, which are concentrated in the central and western regions of Hunan Province. Among them, there are four sets of main source rocks, from Cambrian, Silurian, Devonian, Carboniferous ; there are three sets of secondary source rocks, which are Sinian, Permian and Triassic strata<sup>[17]</sup>. The aquifer system dominated by carbonate or mixed with clastic rocks is developed in the province. The ore-controlling mechanism of fracture enrichment and pore occurrence makes the brine resources more abundant<sup>[18]</sup>. Li Xiaochun et al. (2006) evaluated the CO<sub>2</sub> sequestration potential of deep saline aquifers in the Dongting Basin by using the CO<sub>2</sub> sequestration calculation method considering solubility, and concluded that the CO<sub>2</sub> geological storage capacity of deep saline aquifers in the Dongting Basin was  $4.39 \times 10^8$  t<sup>[19]</sup>. Li Qi et al. (2013) evaluated the CO<sub>2</sub> storage capacity of the Dongting Basin sedimentary basin by using the internationally accepted pyramid evaluation method, and believed that the CO<sub>2</sub> geological storage capacity of the deep saline aquifer in the Dongting Basin was  $5.04 \times 10^8$  t, and the potential water displacement was  $0.16 \times 10^8$  t<sup>[20]</sup>.

Liu et al. (2005) investigated the amount of coalbed methane resources in the range of 300-1500 m, and obtained the CO<sub>2</sub> geological storage potential of the main coal-bearing basins in China by combining CO<sub>2</sub>-ECBM technology, coalbed methane production coefficient of each coal rank and CO<sub>2</sub> / CH<sub>4</sub> volume replacement ratio<sup>[21]</sup>. Li X et al. (2009) evaluated the CO<sub>2</sub> sequestration of CO<sub>2</sub>-ECBM in deep unminable coal seams in 45 coal-bearing basins in China from a macro-scale<sup>[22]</sup>. Their evaluation results are basically the same. The geological storage of coal seam CO<sub>2</sub> in Lianyuan-Shaoyang evaluation area and Chenzhou-Zixing evaluation area in Hunan Province is only  $0.04-0.08 \times 10^8$  t<sup>[22]</sup>. Zheng et al. (2016) calculated the CO<sub>2</sub> storage potential of the Xiangzhong Basin based on the method recommended by the Carbon Sequestration Leaders Forum (CSLF), and the geological storage capacity was  $0.05 \times 10^8$  t<sup>[23]</sup>.

## 6. Conclusion

Considering the development limitations and difficulties of the Dongting Basin as a nature reserve, and the CO<sub>2</sub> storage capacity of the saline aquifer is relatively limited, it is urgent to carry out a detailed assessment of the CO<sub>2</sub> storage potential of the main storage geological bodies such as deep saline aquifers and deep unminable coal seams in other basins in the province. Compared with the deep unminable coal seams, the feasibility of CO<sub>2</sub> storage in the deep saline aquifers of the basin in the province is better, the research space is larger, and it has certain theoretical storage and effective storage potential.

Therefore, the focus of future work: (1) Further verify the CO<sub>2</sub> storage potential of deep saline aquifers in each basin in the province. Through more targeted and purposeful geological survey work, the favorable and unfavorable trap characteristics in the geological body are identified, the target area of CO<sub>2</sub> storage and the target reservoir and cap rock are clarified, and the potential of CO<sub>2</sub> geological storage in the province is estimated. (2) Clear basin saline CO<sub>2</sub> geological storage suitability evaluation system, according to local conditions to select indicators. Further, the suitability evaluation system and index of CO<sub>2</sub> geological storage are modified according to local conditions, so as to obtain more accurate actual storage capacity and matching storage capacity. (3)

Further improve the calculation method of CO<sub>2</sub> geological storage. For example, how to accurately determine the target reservoir volume and how to transfer the ideal pure NaCl solution hypothesis to the actual CO<sub>2</sub>-mixed salt system in the CO<sub>2</sub> geological storage of saline aquifers in the basin.

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