

The Vietnam carbon dioxide storage capacity

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Our planet is warmed by a natural greenhouse effect and without this natural greenhouse effect the mean annual temperature on the earth would be about -6°C instead of its present level. Most of the natural greenhouse effect is known to be caused by water vapor and carbon dioxide in the atmosphere. However, water vapor is not classed as an anthropogenic greenhouse gas. Carbon dioxide is released into the atmosphere by the burning of solid waste, wood and wood products, and fossil fuels (oil, natural gas, and coal). As a result of human's activities, the concentration of CO₂ in the atmosphere has risen from a relatively stable level around 275 part per million (ppm) in the pre-industrial era to about 355ppm (1994), and currently continues to rise at a rate of about 1.8ppm per year. According to a study by the United Nations, Vietnam is in the top rank amongst countries hardest suffer by climate change catastrophes. In 2006, Vietnam had 10 typhoons of which 3 were particularly destructive, resulting in 500 people being killed and 2,900 injured. Sea dykes were broken, 86,000 houses were destroyed, 74,000 roofs were blown away and 3,300 ships sank or were damaged.

In order to restrict global temperature rise due to rising CO₂ emissions into the atmosphere, one idea of is to capture such CO₂ and store this gas in reservoirs almost completely shut off from the atmosphere in the deeper subsurface. This paper presents an assessment of the theoretical carbon dioxide storage capacity of deep-seated reservoirs in Vietnam's oil and gas fields.

The concept of underground CO₂ disposal

There are two main concepts for CO₂ disposal in aquifers. The first requires a subsurface trap for buoyant fluids with defined lateral boundaries (spill point) and a closed structure, an analogue to oil and gas fields. In the second concept, carbon dioxide is disposed of directly into aquifers without the need for further confinement to traps. In both cases, the storage reservoir requires a cap rock to prevent vertical migration of CO₂ to the surface and sufficient permeability to allow the injection of great quantities of CO₂. From natural CO₂ reservoirs and modeling results it is known that the migration behavior of carbon dioxide is fairly similar to that of natural gas. Thus, CO₂ disposal underground is similar to natural hydrocarbon accumulations, and carbon dioxide would be retained for millions of years underground, far longer than necessary to prevent its release into the atmosphere.

The concept of disposal of CO₂ into a closed structure is applied in onshore Europe, where the sedimentary basins are mainly small. Some of the aquifers in the deeper parts of these basins may be in direct connection with nearby outcrops. These aquifers may have other uses at shallow

depth, for example water supply. Thus environmental constraints in the onshore area are likely to prevent the injection of CO₂ into an aquifer unless it is confined in a trap which will prevent it contaminating the useful parts of the aquifers. However, there may be some aquifers onshore which have no uses and are not connected to the surface onshore.

The second concept, which involves disposal into aquifers without the need for a closed structure to confine the CO₂, may be most widely applicable in large sedimentary basins where the aquifers have no current uses. In this case, carbon dioxide could be injected into an aquifer with only a top seal. If it was injected sufficiently far from the basin margins, reactions with the host rock and the surrounding formation water as is moved along a flow path within the aquifer would ensure that it did not emerge at the land surface or sea bed.

The storage capacity of aquifers is based on the available pore volume, and the CO₂ storage efficiency is the proportion of the pore volume that can be filled with carbon dioxide, in a fully water saturated reservoir with a hydrostatic pore pressure.

CO₂ disposal in oil and gas fields

The basic concept of CO₂ disposal in depleted oil and gas reservoirs is that the amount of CO₂ that can be stored in a reservoir is directly related to the amount of hydrocarbons that has been recovered from it. It is assumed that the reservoir volume of ultimately recoverable hydrocarbons can be replaced entirely by CO₂.

The major difference between CO₂ storage in aquifers and storage in hydrocarbon fields is that in the case of CO₂ storage in hydrocarbon fields a substantial volume of fluids or gases has been produced from the reservoir, will be replaced by CO₂ which enhances the storage capacity greatly. Additional benefits are that hydrocarbon traps have a proved capability to retain fluids and gases underground for thousands to millions of year and, based on the history of exploration and production, the reservoir is better understood. Moreover, some of the infrastructure used during hydrocarbon production may be re-used for CO₂ injection.

Vietnamese Cenozoic basins and their CO₂ storage capacity

Eight Tertiary basins have been identified in Vietnam comprising the Song Hong Basin, Phu Khanh Basin, Cuu Long Basin, Nam Con Son Basin, Malay - Tho Chu Basin, Tu Chinh - Vung May Basin and the group of Hoang Sa and Truong Sa Basins. Among these, petroleum potential has been confirmed in the Song Hong, Cuu Long, Nam Con Son and Malay - Tho Chu Basins. The inventory of the CO₂ storage potential of the Vietnamese Cenozoic Basins is based on the petroleum resource data. The pore rock volume of the CO₂ geological storage play is following petroleum play in hydrocarbon potential resources calculation (Table 2).

A play is a perception of how a producible reservoir, petroleum charge system, regional top seal and traps may combine to produce petroleum accumulation at a specific stratigraphic level. The geographical area over which the play is believed to extend is the play fairway. A play may be considered proven if petroleum accumulations are known to have resulted from the operation of the geological factors that define the play. In unproven plays, there is some doubt as to whether the geological factors actually do combine to produce a petroleum accumulation.

Plays are essentially reservoir defined. Hence, fairway at different stratigraphic levels in a basin may be stacked vertically. Within a single play, all leads, prospects and discovered fields share a common geological mechanism

for petroleum occurrence. Petroleum accumulations, discovered or undiscovered within a single play fairway can be considered to constitute a naturally occurring population of geological phenomena.

This inventory is further restricted by the burial depth of potential reservoirs. Only deep reservoirs which have the appropriate pressures and temperatures necessary to retain the CO₂ in a dense supercritical state are considered for average gradients of 30°C/km and 10.5Mpa/km. Generally, the cutoff-level of 1,000m below mean sea-level is used. That means only reservoir sediments below a depth of 1,000m are considered. Here the indication is that even if CO₂ escapes from the reservoir, it will take a very long time for it to reach the surface; based on the result of modeling, it would take at least five thousand years before a large bubble of free CO₂ released at a depth of 1,000m would reach the surface. Another constraint is that the reservoir should have an average permeability of at least 100mD. If CO₂ is injected with sufficient pressure into an aquifer which is in open communication with the surface (an "open" aquifer), the CO₂ is able to displace the formation water. Displaced formation water may eventually flow into surface water, which may be an ocean or lake, or into groundwater. The pressure will be hydrostatic again when the conditions in the aquifer have reached equilibrium after CO₂ injection. In a reservoir connected to an aquifer system that does not communicate with the surface (a "closed" system), water displacement by CO₂ must be accommodated by compression of rock and interstitial water. If the reservoir volume is insignificantly small compared to the volume of the connected aquifer system, formation water flowing out of the reservoir into the aquifer system will lead to a negligible increase of reservoir pressure. The pressure will increase significantly if the reservoir itself is "closed".

If CO₂ is intended to be injected into an aquifer, the CO₂ must be able to permeate the aquifer at a reasonable rate with limited pressure losses. Based on modeling of the radial pressure behavior of CO₂ injected into an "open" aquifer at a depth of 800 - 1,800m, Van der Meer at al. (1992) concluded that with permeabilities smaller than 50mD, unacceptable pressure losses occurred. CO₂ injection under these conditions was not workable. Between 50 - 100mD, CO₂ injection is only feasible if wells are used that have a negative skin factor, i.e an improved flow performance at the bottom hole injection point. He therefore suggests a cut-off level of 50 - 100mD.

In the case of a "closed" aquifer, the volume of CO₂ injected must be accommodated by compression of the

reservoir. The most practical parameter for estimating how pressure increases due to injection is pore volume compressibility, which is a function of the porosity and/or net overburden pressure. If the pressure is increased by 10Mpa (100 bar), the pore water and formation is compressed by 0.8% for consolidated sand, leading to an “extra” pore volume that can be occupied by CO₂. For typical North Sea conditions, the pore volume compressibility will be 1.5 x 10⁻⁴ bar⁻¹ on average, and the compressibility of formation water varies between 0.39 x 10⁻⁴ to 0.45 x 10⁻⁴ bar⁻¹, i.e. the sum of water and the pore compressibility will be 1.9 x 10⁻⁴ bar⁻¹. This implies that if 2% of the reservoir pore volume is filled, the pressure will increase by 10.5Mpa, assuming 100% efficiency of the compression during the injection operation. It is concluded that only an aquifer with an average permeability larger than 100mD can constitute a suitable CO₂ reservoir. In the inventory below the Oligocene Play in the Song Hong Basin is eliminated from this inventory because of improved tight reservoirs (permeability < 1 mD). The CO₂ storage potential of the Vietnamese Cenozoic Basins is based on the petroleum resource data contained in the published document Geology and potential petroleum resource of Vietnam [3] in 2007.

The theoretical storage potential calculation is based on the assumption that 4% of reservoir pore volume can be filled with CO₂ and that 3% of reservoir volume is in a trap. An underground CO₂ density of 700kg/m³ (i.e. dense supercritical) has been used. The storage capacity of the geological plays in Vietnamese Cenozoic Basins is calculated as follows:

$$Q_{\text{play}} = V_p \cdot \eta_{\text{st}} \cdot \rho_{\text{CO}_2}$$

Where: V_p = Total pore volume of the geological play below 1,000m (km³).

η_{st} = Storage efficiency, i.e. fraction of the pore volume that can be filled with CO₂ (as shown in the Table 1).

ρ_{CO_2} = CO₂ density at initial reservoir conditions (kg/m³) applied as 700kg/m³ by assuming a normal hydrostatic pressure (10.5MPa/km) and geothermal gradient (30°C/km).

Q_{play} = Storage capacity of entire play (Mt CO₂).

Table 1 of CO₂ storage efficiency, i.e. the fraction of the reservoir pore volume that can be filled with CO₂, is based on the recommendations of the report: The Underground disposal of CO₂ - Joule II Project NO. CT-92-0031 [1].

Table 1. Reservoir pore volume storage efficiency [1]

Reservoir type	Storage efficiency
Closed trap	2%
Open trap	6%
Traps from which it is unclear if they are “open” or “closed”	4%

Table 2. The theoretical storage capacity of the entire geological plays in Vietnamese sedimentary basins [2]

Basin	CO ₂ geological plays	Total Rock Vol. (km ³)	Total Pore Vol. (km ³)	Storage Capacity (Mt CO ₂)
Song Hong	1. Fractured basement	7,928	250	210
	2. Miocene sandstone	12,472	561	471
	3. Miocene carbonate	7,866	1,038	872
	4. Pliocene sandstone	24,296	1,042	876
Phu Khanh	1. Fractured basement	3,505	105	88
	2. Miocene sandstone	15,188	683	574
	3. Miocene carbonate	17,262	2,184	1,834
Cuu Long	1. Fractured basement	41,308	1,446	1,214
	2. Oligocene sandstone	19,527	410	344
	3. Miocene sandstone	4,929	237	199
Nam Con Son	1. Fractured basement	3,505	105	88
	2. Miocene sandstones	18,693	1,346	1,131
	3. Miocene carbonate	5,091	386	325
Malay - Tho Chu	1. Miocene sandstones	10,807	389	327
Tu Chinh - Vung May	1. Fractured basement	7,886	237	199
	2. Oligocene sandstone	46,315	973	817
	3. Miocene sandstones	20,636	854	718
	4. Miocene carbonate/ Lower Pliocene limestone	1,289	105	88
Truong Sa	1. Fractured basement	na	na	na
	2. Paleogene sandstone			
	3. Miocene sandstone			
	4. Cenozoic carbonate			
Hoang Sa	1. Fractured basement	na	na	na
	2. Oligocene sandstone			
	3. Miocene sandstone			
	4. Miocene carbonate			
Total		268,502	12,351	10,375

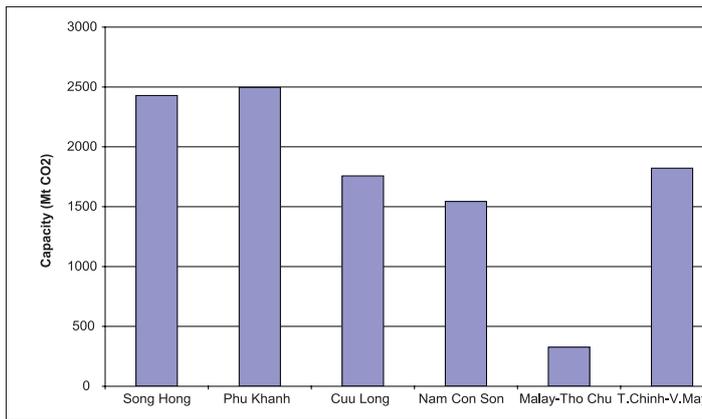


Fig. 1. CO₂ storage capacity for Vietnam's sedimentary basins

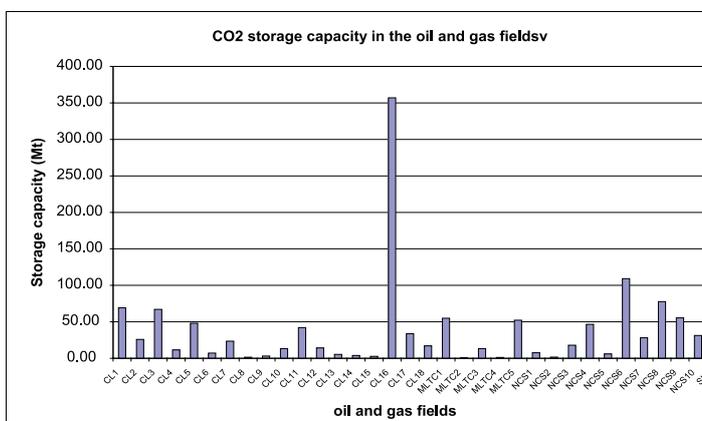


Fig. 2. Vietnam's oil & gas fields CO₂ storage capacity

Storage in oil and gas fields

The production in 2009 amounted to 8 billion cubic meters gas and 16.3 million tons oil (~20 million cubic meters oil under standard conditions, assuming an average crude oil density of 830kg/m³ at standard surface conditions). The cumulative production by 2009 was 250 million tons or 300 million cubic meters of oil and 50 billion cubic meters of gas.

Currently, in offshore Vietnam, over thirty hydrocarbon fields are in production and or will be in the near future. The production data are restricted and information on temperature, pressure and the properties of the oil and gas are scatter. In order to be able to give a broad inventory of the CO₂ storage capacities of most oil and gas fields, this inventory has been based on these accessible figures. Additionally, only storage capacities of fields >10 Mt CO₂ are considered for use.

The theoretical storage potential of oil and gas fields in Vietnam is simply calculated using the following equations that applied in the RETA 7575: Determining the Potential for carbon capture and storage in Southeast Asia

Project (Vietnam Ministry of Industry and Trade and Asian Development Bank co-project) [2]:

$$V_{Uoil} = V_{oil(st)} \times B_o / 1,000$$

$$V_{Ugas} = V_{gas(st)} \times 1/GEF$$

$$Q_{CO2} = (V_{Uoil} + V_{Ugas}) \times \rho_{CO2}$$

Where: V_u = Underground volume of oil or gas (millions m³)

V_{oil(st)} = Recoverable volume of oil at standard conditions (millions sm³)*

V_{gas(st)} = Recoverable volume of gas at standard conditions (millions sm³)

B_o = Oil formation volume factor

GEF = Gas expansion factor

ρ_{CO2} = CO₂ density at initial reservoir conditions (kg/m³) applied as 700kg/m³ by assuming a normal hydrostatic pressure (10.5MPa/km) and geothermal gradients (30°C/km)

Q_{CO2} = Total CO₂ storage capacity (Mt)

The theoretical storage capacity of the current oil and gas fields in Vietnam is estimated to amount to 1.15Gt CO₂, and Fig. 2 shows the largest field exceeds 350Mt CO₂ capacity.

To conclude, Vietnam has the capacity to store megatons of CO₂. The theoretical cumulative storage capacity of Vietnam's sedimentary basins exceeds 10Gt of CO₂ (Table 2), an order of magnitude larger than that calculated for Vietnam's Oil and Gas fields of 1.15Gt. As the geology of Vietnam's basins becomes better defined, this number will become more precise. However, the storage number is large enough to justify further quantification of Vietnam's geological storage potential.

References

1. *The Underground disposal of CO₂* - Joule II Project NO. CT-92-0031. ADB sources.
2. RETA 7575: *Determining the potential for carbon capture and storage in Southeast Asia, Viet Nam Country Report - Summary* (Vietnam Ministry of Industry and Trade and Asian development Bank co-project, 2011).
3. *Địa chất và Tài nguyên Dầu khí Việt Nam*. NXB Khoa học - Kỹ thuật. 2007.

* Standard conditions are at 20°C and 0.1 MPa (1bar).