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OVERVIEW OF DEEP GEOLOGICAL CO_2 STORAGE AND ITS AREA SELECTION METHOD

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Abstract

Geological sequestration of CO_2 inside deep geologic formations is revolutionary among several other initiatives to combat the global warming. This method is already approved globally as a reliable and likely to be the only option that will allow removing CO_2 in large enough quantities over short enough times to make a real difference. The first step of any geological CO_2 storage projects is to select appropriate sedimentary basins in which CO_2 will be injected and stored temporarily or permanently within permeable geological layers. The criteria for site selection methods are here explained based on summary from state-of-the-art research findings now exist. This method is planned to be applied for a more detailed mapping of potential sedimentary basins in Indonesia and neighboring regions.

Keywords: *Sequestration, sedimentary basin, geological layers.*

1 Introduction

Carbon dioxide is the main greenhouse gas that is considered to be the main source of global warming. Combating the global warming is therefore equivalent with reducing CO_2 emission. Unfortunately, fossil fuels (i.e. the main source of CO_2 emission) will continue to meet a large fraction of global energy demand for the foreseeable future (Bryant, 2007). Facing this situation, many progressive efforts are being done to reduce the emission of CO_2, such as energy efficiency improvements, a switch to less carbon-intensive fuels, nuclear power, renewable energy sources, enhancement of biological sinks, and reduction of non-CO_2 greenhouse gas emissions. A new revolutionary idea is to drill wells deep into the Earth's crust and pump pressurized carbon dioxide into salt water aquifers, where it is sequestered for geologic time scales. Although it first looks like impossible, researchers now feel that it is a viable option and even few countries have implemented pilot projects on this idea. In fact, geological sequestration is likely to be the only option that enables removing CO_2 in significant quantities over short times to make a difference (Dooley *et al.*, 2006; Bryant, 2007).

A global recognition on this initiative is reflected from the recent "Intergovernmental Panel on Climate Change (IPCC) Special Report on Carbon Dioxide Capture and Storage" which was written by 100 experts from over 30 countries and reviewed by many experts and Governments (IPCC, 2005). This report was requested by the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) to assess the most up-to-date literature available in scientific and technical journals. The result confirmed that the potential of CO_2 storage is considerable and can reduce the costs for mitigating climate change in case only other options are considered. However, the widespread application of carbon dioxide capture and storage (CCS) would depend on technical maturity, costs, overall potential, diffusion and transfer of the technology to devel-

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oping countries and their capacity to apply the technology, regulatory aspects, environmental issues and public perception. A critical issue for deep geological storage is ensuring that the captured and stored CO_2 does not escape from the host formation. Selection for the sites of deep geological storage is critical to achieve this purpose. This paper will describe such methods, based on the state-of-the-art research findings that are available today.

2 Overview of CO_2 capture and storage (CSS) technology

Carbon dioxide capture and storage (CCS) is a process consisting of the separation of CO_2 from industrial and energy-related sources, transport to a storage location and long-term isolation from the atmosphere (IPCC, 2005). Capture of CO_2 can be applied to large point sources of emission (e.g. large fossil fuel or biomass energy plants, major industries, and natural gas production), in which CO_2 is compressed and transported for storage in geological formations, in the ocean, in mineral carbonates, or for use in industrial processes. Potential technical storage methods are: geological storage (in geological formations, such as oil and gas fields, unminable coal beds and deep saline formations), ocean storage (direct release into the ocean water column or onto the deep seafloor) and industrial fixation of CO_2 into inorganic carbonates. Industrial uses of CO_2 are also possible, but this will not contribute much to the reduction of global CO_2. This paper concerns only on the geological storage method.

Research has demonstrated that CO_2 can be stored in the subsurface (Fig.1). Different types of geologic formation are possible, i.e. thick permeable coal seams, depleted oil and gas fields, and saline aquifers of regional extent (Haszeldine, 2005).

Coal Seams

Coal seams are abundant worldwide, but many are too deep or too complexly faulted to mine economically. These seams contain methane gas that can be extracted by drilling into the seams. Coalbed methane (CBM) industry is now operational, and it seems that injection of CO_2 into coal seams can be done to displace the methane. However many coal seams have poor permeability that CO_2 is difficult to inject with a wide geographical area from one well.

Depleted or Disused Oil and Gas Reservoirs

Depleted oil and gas reservoirs have high potential as CO_2 storages because they are proven to have contained hydrocarbon and gas for millions of years. Additionally CO_2 has been successfully injected into oil fields as part of EOR system (Bondor, 1992). The key advantage of depleted oil and gas fields is that huge volumes of site and numerous data are available from oil industry. The combination of CCS and Enhanced Oil Recovery (EOR) or potentially also with Enhanced Coal Bed Methane recovery (ECBM) can add revenues of oil or gas industry.

Saline Aquifers

Saline aquifers are water bearing porous layers in the subsurface of sandstone or limestone which are at present not being used for any other purpose. Because of the requirement that CO_2 should be at super-critical liquid, aquifers need to be greater than 800 m below the surface, to produce the required confining pressures. Consequently all these aquifers are confined.

In any geologic formations, if CO_2 is injected at depths more than 800 m, various physical and geochemical trapping mechanisms would prevent it from migrating to the surface. An essential trapping mechanism is the presence of a caprock (Bachu et al., 1994). When carbon dioxide is injected into a brine aquifer, one of four things will happen. The gas will either dissolve into the water, react with the rock to form a solid mineral, float to the top of aquifer as free gas, or it can be trapped in rock pores (Bryant, 2007). If the majority of the gas can be trapped in rocks, then it will stay underground for thousands of years as long as there is good geologic seal and no cracks.

Several components of carbon dioxide capture and storage technology are already developed and so far four CCS projects are already implemented in Algeria, Canada, the North Sea off the Norwegian coast, and in Japan (Haszeldine, 2005; Dooley *et al.*, 2006; Shigeo, 2007). In global view, suitable sediment sequences of saline aquifers exist in all hydrocarbon-producing areas, are volumetrically much larger than exploited oil and gas fields, and hold the potential to easily store all worldwide CO_2 emissions until 2050. This fact shows that the opportunity may be widespread, but it still needs more specific local investigations (Haszeldine, 2005).

3 General requirements for geological CO_2 storage

Geological media for the temporary or permanent storage of CO_2 must possess adequate volume, injectivity (i.e. an ability to inject a fluid) and confining ability (i.e. to prevent the leakage of these fluids to avoid losses, contamination of other energy, mineral or groundwater resources, and health and safety hazards). Sedimentary rocks meet all the above conditions. There is a spatial association between energy production and the potential for CO_2 geological storage. Hydrocarbons and coal are produced in sedimentary basins and are often used for power generation close to the point of extraction (Hitchon *et al.*, 1999).

CO_2 storage should operate at an intermediate scale somewhere between the geological time scale (millions of years and areas of thousands to hundreds of thousands of km^2 in size) and the engineering or reservoir scale (tens of years and areas of up to tens of km^2). This intermediate scale covers hundreds to thousands of years, and areas hundreds to thousands of km^2 in size. Therefore expertise from both geoscience and engineering has to be brought together for the identification and selection of sites suitable for CO_2 geological storage.

4 Basin selection criteria

The method for screening of sites for CO_2 storage in geological media has been proposed and refined several times (Bachu, 2000, 2002, 2007) and has been applied at national and global scale (Bradshaw et al., 2004; Bradsaw and Dance, 2004; 2005). The screening of sites for CO_2 storage can be applied at several scales, from the basin to the individual site. At regional-scale prospective basins can be analyzed based on the following criteria: geological characteristics, hydrodynamic and geothermal regimes, basin resources and maturity, industry maturity and infrastructure, and societal issues.

Geological Characteristics

Sedimentary basins can be broadly classified in relation to their position in regard to plate tectonics (Figure 2). The suitability of a given basin depends on their location within the plate tectonic setting. Divergent basins are the most suitable for CO_2 storage for their stability, reduced tectonic activity and favorable structure. Foreland basins are also favorable for CO_2 storage. Convergent basins which are located in tectonically active areas are less favorable due to subject to volcanism, earthquakes and active faulting. Convergent intramontane basins are largely unfavorable. Cratonic platforms usually lack the porosity and permeability required for CO_2 storage. On the other hand orogenic belts lack continuous seals. Therefore both basins are not suitable for CO_2 storage.

Suitable sites are sedimentary formations with adequate porosity, thickness and permeability, and confining unit cap. For being an effective CO_2 storage, basins should have the following characteristics (Bradshaw *et al.*, 2004): adequate thickness (>1000 m), strong reservoir and seal relationships, not highly faulted, fractured or located in fold belts, strongly harmonious sequences, no volcanogenic sediments, and have not undergone significant diagenesis.

Hydrodynamic Regime

Basin hydrodynamics and flow-driving mechanisms are essential in establishing strategies with regard to CO_2 injection and storage in various geological media. In this case there is a close link between the type of sedimentary basin and the flow of formation waters. In

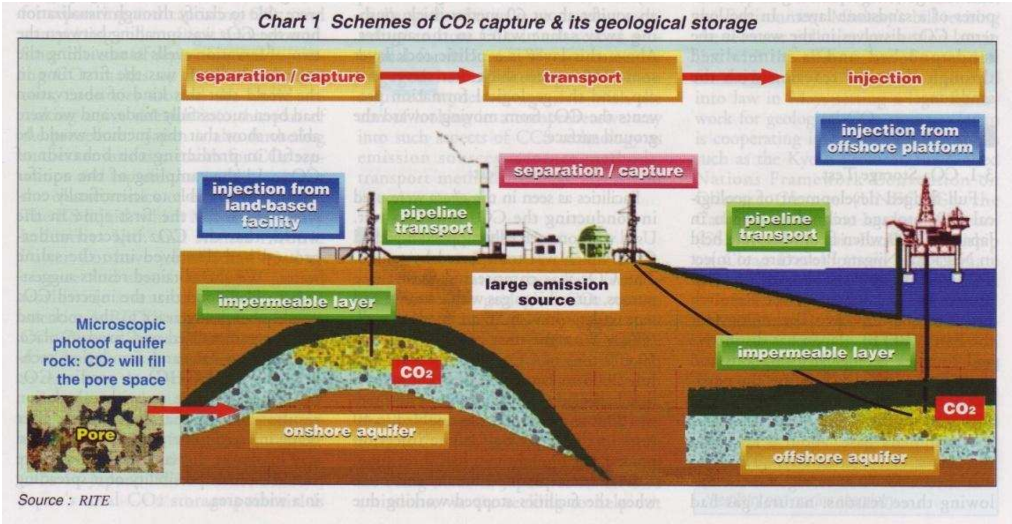

Figure 1: Idealized conceptual model of geological CO_2 storage (Shigeo, 2007)

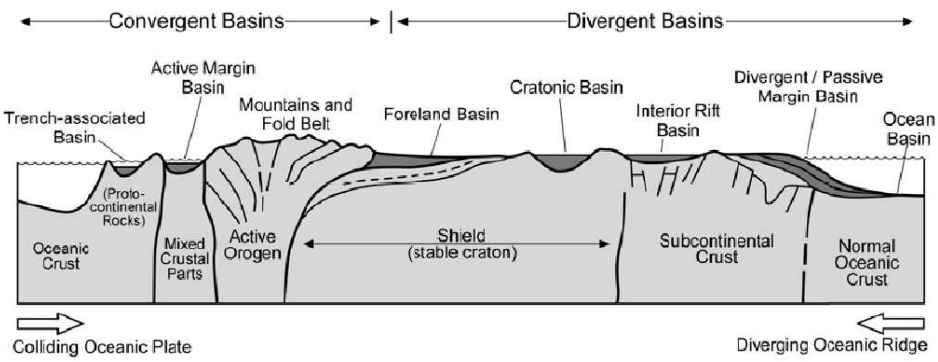

Figure 2: Various types of sedimentary basins for CO_2 storage (Hitchon *et al.*, 1999)

basins located on marine shelves, the flow of formation water is driven by compaction. Shaley aquitards and aquifers are usually much overpressured, in which CO_2 injection can raise technological and safety issues because of the increased potential of blow out. In basins adjacent to active orogenic belts, formation water is driven laterally out in the basin and toward its margin by tectonic compression. Waters expelled from underneath orogenic belts are usually overpressured, hot and very saline, thus these aquifers are not well suited for CO_2 storage.

In foreland and intracratonic basins that have undergone recent significant uplift and erosion, flow is driven by erosional rebound vertically into thick shales and laterally inward in thin adjacent aquifers. The aquitards and adjacent aquifers are underpressured. Such aquifers are the best suited for the long-term storage of CO_2. In continental basins most flow systems are driven by topography from recharge areas at high elevations to discharge areas at low elevations. Aquifer pressures are usually close to hydrostatic with slight over- or underpressuring being controlled by permeability distributions. In such cases it is better to inject CO_2 in the recharge areas, to increase the length of the flow path and residence time (hydrodynamic trapping). All active hydrocarbon basins are overpressured that may pose a risk for CO_2 disposal.

Geothermal Regime

The geothermal regime inside a basin impacts the type and depth of CO_2 injection and storage. The geothermal regime in sedimentary basins depends on: (1) Basin type, age and tectonism; (2) Proximity to crustal heat sources, such as magma chambers, intrusives and volcanoes; (3) Basement heat flow (that comes from the interior of the earth); (4) Thermal conductivity and heat production in the sedimentary succession; and (5) Temperature at the top of the sedimentary succession.

The amount of CO_2 that can be stored per volume unit increases with increasing the CO_2 density. Cold sedimentary basins (low surface temperatures and/or low geothermal gradients) are more favorable because CO_2 attains higher density at shallower depths than in warm sedimentary basins. Depending on geothermal gradients, the top of the injection unit must be at a depth of greater than 600-900 m for CO_2 to be in a dense fluid phase.

Basin Resources and Maturity

Mature sedimentary basins are preferable over immature ones for CO_2 storage, as their subsurface characteristics are already well constrained. Additionally, infrastructure to support CO_2 transportation and injection may be in place due to more advanced development of the region.

5 Non-geological criteria

Industry Maturity and Infrastructure

In mature continental basins, the infrastructure is already in place (access roads, pipelines and wells) and injection sites are easy to access and inexpensive to develop. In immature basins the infrastructure is usually either nonexistent or very rudimentary. In the case of marine basins, developing the necessary infrastructure for CO_2 injection in geological media is very expensive, particularly for harsh climatic conditions.

Economic and Societal Issues

Basin location (onshore or offshore), climate, accessibility, environmental issues, distribution of major population centres and infrastructure will certainly affect the movement and cost of captured anthropogenic CO_2 from source to the point of storage. Climatic conditions are an indirect indication of how difficult developing the necessary infrastructure for CO_2 capture, transportation and injection.

6 Site-scale criteria

Site-scale screening criteria are applied to ensure that the potential CO_2 storage site is safe, effective and economically feasible. These criteria include the safety issues, effectiveness, and economic feasibility (Bachu, 2007). The CO_2

storage site must avoid the risk of contaminating energy, mineral and water resources, or threaten animal and human life. The CO_2 storage site must also avoid or minimize CO_2 leakage for the desired time period. Economic feasibility is applied to reduce development and operation costs. These include plans for additional energy production (e.g. EOR or ECBM), avoiding very deep storage sites, availability and accessibility of existing ground infrastructure, location of the storage site near the CO_2 emission sources to minimize transportation cost, and avoiding conflicts of landuse (both surface and subsurface).

7 Reqired fields of expertise

For the complexity and multi-dimensional aspects of the assessment and selection of sites for the geological storage of CO_2, many fields of expertise are required. Here is the list of expertise as suggested by Bacu (2007):

- soft rock (petroleum) geology
- coal geology and petrography in the case of storage in coal beds
- hydrogeology
- geochemistry
- geophysics
- geomechanical/geotechnical engineering
- reservoir engineering in the case of oil and gas reservoirs, and ECBM
- facilities engineering
- pipeline engineering
- economics
- database management
- geographic information systems (GIS)

8 Closing remarks

Using similar method as described above, a full systematic approach on the scale of a whole continent has been undertaken in Australia (Bradshaw *et al.*, 2002). This assessment was then extended into the world in which Bradshaw and Dance (2004) have made the first maps to combine worldwide CO_2 point sources with worldwide candidate disposal sites (Fig. 3). Following this world-wide assessment, it is necessary to conduct more detailed investigations at the level of individual countries, or individual sedimentary basins. These first worldwide maps have generated focus attention on several prospective areas, including Southeast Asia (Haszeldine, 2005).

Therefore this preliminary global assessment result should be followed up with more detailed assessment in the SE Asian region. Several key improvements should be done as Bradshaw and Dance (2004) utilized only global USGS data on hydrocarbon provinces worldwide. This dataset is not suitable for detailed studies of CO_2 storage as this dataset is only dealing with hydrocarbon prospects (i.e. in fact not all sedimentary basins prospective for CO_2 storage must be associated with hydrocarbon), and it does not include coal deposits which may be suitable for CO_2 storage.

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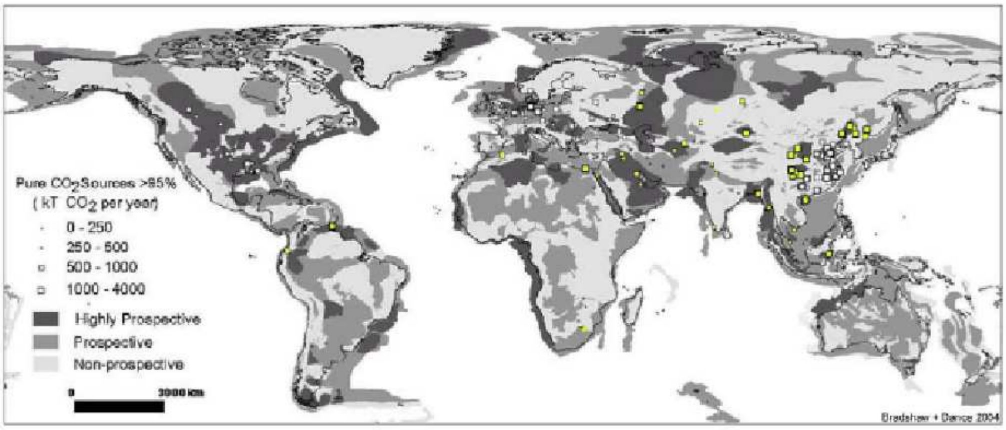

Figure 3: Global assessment by Bradsaw and Dance (2004) suggested the existence of potential geological CO_2 storage basins in Indonesia and SE Asia

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