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An overview of the IEA Greenhouse Gas R&D Programme regional geologic storage capacity studies

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Abstract

Mapping of CO_2 geological storage resources provides an important element in the planning of widespread CO_2 capture and storage (CCS) deployment. Recent high-level studies by the IEA Greenhouse Gas R&D Programme (IEAGHG) have estimated realistic global capacity available in depleted oil and depleted gas fields to be 130 and 65 Gt, respectively, based on mass balance considerations from hydrocarbon reserve information. However, comparable estimates for deep saline formation (DSF) storage require an analytical approach that considers the fraction of pore space in storage formations that could be occupied by injected CO_2. Many regional mapping initiatives have shown that potential DSF storage capacities are typically at least an order of magnitude higher than in depleted fields.

Computationally similar methodologies to estimate DSF storage resources have been developed by the U.S. Department of Energy (DOE) and the Carbon Sequestration Leadership Forum (CSLF); in both, a storage coefficient, E (or efficiency factor), is used to derive resource estimates. The E coefficient takes account of various geological and technical factors that could restrict the amount of pore space available for storage but does not take into account economic, regulatory, and source-sink matching considerations.

IEAGHG and DOE commissioned a study in 2008 by the Energy & Environmental Research Center (EERC), to improve the accuracy of storage coefficients for DSF. As there was insufficient real-world CO_2 injection data to derive a representative range for E, geological input parameters were derived from global hydrocarbon reservoir data as a proxy for DSF. Modeling allowed derivation of probabilistic ranges of storage coefficients at both site-specific and formation levels for clastic, carbonate, and dolomite lithologies. The overall mean value of E for all lithologies was calculated as 2.6% at the formation level. A key assumption made in the study was that DSF will predominantly act as “open” systems, whereby pressure and displaced formation fluids can be safely dissipated through the wider storage formation and adjacent strata.

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Intro

Regional mapping of CO_2 geological storage resources provides an important element in the planning of widespread CO_2 capture and storage (CCS) deployment. The International Energy Agency (IEA) Technology Roadmap for CCS suggests that by 2050 alone, up to 150 Gt of CO_2 will need to have been captured and stored if CCS is to make the required contribution toward the targeted reduction in emissions of greenhouse gases[1].

Table 1 below compares global storage capacity estimates from 2005 [IPCC, 1] with those derived for more recent studies by the IEA Greenhouse Gas R&D Programme (IEAGHG) [2, 3], that have estimated the realistic global capacity in depleted gas and oil fields as 130 and 65 Gt, respectively. Also listed are examples of regional storage estimates for the USA [4] and Europe [5].

Table 1. Examples of Estimated Storage Resources

Storage Scenario	**Global Storage Capacity (Gt CO_2)**		**Regional Storage Capacity (Gt CO_2)**	
	IPCC, 2005	**IEAGHG Studies**	**USA**	**Europe**
Deep Saline Formations	1,000 to 10,000		3,300 to 13,000	90 to 330
Depleted Gas Fields	680 to 900	160	140	20 to 32
Depleted Oil Fields		65		
Coal beds	3 to 200		160 to 180	1 to 2

Results quoted to 2 significant figures

The capacities listed in Table 1 have been estimated with various methodologies and levels of sophistication, and therefore comparison between the columns is not intended. However, two points can be deduced from the data presented:

- Storage capacities in DSF are typically an order of magnitude higher than available in depleted HC fields, but;
- There is greater uncertainty in estimates of DSF storage capacities, as shown by the greater range of values.

Many regional geological storage mapping projects have also shown potential storage capacities in DSF to be at least an order of magnitude higher than capacities in depleted hydrocarbon fields. Given that other geological storage scenarios such as coal seams and basaltic formations remain essentially unproven, the importance to commercial scale CCS implementation of storage in deep saline formations (DSF) becomes clear.

Problem statement

While high-level estimates of storage resources in depleted hydrocarbon fields can be made on a mass balance basis by consideration of ultimately recoverable oil and gas reserves, comparable estimates for DSF require an analytical approach that considers the fraction of pore space in storage formations that could be occupied by injected CO_2. At this time, two basic types of methodologies are proposed to estimate CO_2 storage capacity in DSFs; these are based on the premise that the DSFs are either open or closed systems. Methodologies to estimate storage resources in open systems have been developed by the U.S. Department of Energy (DOE) [4] and the Carbon Sequestration Leadership Forum (CSLF) [6, 7], and these have been found to be computationally equivalent [8]. The only significant difference in approach is conceptual, whereby the DOE methodology considers storage potential in an entire formation and whereas the CSLF method advocates consideration only of structural traps. An alternative approach is one that considers the storage formation as a closed system in which fluids cannot leave the system or leave the system so slowly that the system acts as though it is closed, creating a pressure buildup that does not subside as injection operations continue.

Background on Efficiency

In both the CSLF and DOE open-system methodologies and the closed-system compressibility methodology, a storage coefficient, E (or efficiency factor), is used as part of their analytical equations to derive resource estimates. The E coefficient in the open-system methods is a multiplicative factor which converts the theoretical pore space that could be available into an effective capacity (CSLF) or storage resource (DOE) according to the respective classification schemes associated with the two methods.

In a closed system, or perceived closed system, the potential storage resource is limited to the pore volume of the storage formation multiplied by a storage coefficient which is equal to the difference in pressure between the maximum injection pressure and the initial pressure multiplied by the total compressibility (the formation compressibility plus the fluid compressibility). As part of these effective capacity or storage resource calculations, in both open and closed systems, the E coefficient takes account of various geological and technical factors that could restrict the amount of pore space available for storage but does not take into account economic, regulatory, and source-sink matching considerations. It must be emphasised that the main use of these methodologies is for the estimation of regional storage resources; the analytical approaches described are not a substitute for the detailed investigation, modeling, and assessment required for individual storage sites.

Project overview

IEA GHG and DOE commissioned a study by the Energy & Environmental Research Center (EERC) [9] at the University of North Dakota to improve the accuracy of the storage coefficients for estimation of storage resources in DSF. Although the work examined CO_2 storage in both open- and closed-system DSFs, the focus of the study was on the open-system methodologies. Storage capacity coefficients developed by the study were derived at the equivalent storage resource (US DOE)/effective capacity (CSLF) classification levels within those respective methodologies. In broad terms this means that the coefficients take account of geological and technical factors that can restrict the proportion of formation pore space (theoretical capacity) that can be contacted by injected CO_2, but other factors such as regulatory and economic issues are not considered.

Project goal:

Whilst preliminary coefficients based on generalised simulations have been utilised in the assessments of storage capacity in the US and Canadian national atlas, no coefficients have yet been published for the CSLF methodology. The study set out to create a set of broadly applicable storage coefficients for DSF that could be applied to both methodologies.

Approach:

Since determination of coefficients relies on field based data and/or numerical modeling, the first step undertaken was a literature review of actual CO_2 storage projects. It was immediately evident that these are of insufficient number to adequately represent all possible DSF scenarios. Therefore, a simulation approach was adopted, whereby a significant range of representative 3D models were used to generate values for storage coefficients.

The construction of these models required the development of a database containing representative values for DSF properties, lithologies, depositional environments and structures. Since there is a general paucity of data available for DSF, the authors constructed the Average Global Database (AGD) by using hydrocarbon reservoir properties as a proxy for DSF characteristics as the rocks themselves should differ very little. The AGD was compiled through use of existing U.S. databases and an extensive literature review for other regions. With details of over 20,000 reservoirs, analysis of the AGD allows parameters to be defined as a statistical dataset. Table 2 below lists examples of general formation properties derived from the AGD.

Table 2. General Formation Properties from the AGD

Percentile Value	Depth, m	Salinity, ppm	Temp Grad, °C/m	Reservoir Thickness, m
10	900	8,200	0.020	3.4
50	2,300	53,000	0.025	26
90	3,800	170,000	0.033	190

All figures shown to 2 significant figures

Reservoirs in the AGD could also be classified according to 3 lithologies (clastics/limestone/dolomite), ten depositional environments, and five different structures.

Case criteria

A uniform injection and evaluation scheme was developed as a base for all of the modeling runs undertaken:

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- Areal dimensions of the models were set at 3.2km by 3.2km, thickness at 26m, whilst models were divided into 204,000 grid cells;
- CO_2 injection volumes were set at 1Mt over 1 year for homogeneous models and 1Mt over 5 years for heterogeneous models;
- Trapping was dominated by physical containment, but solution and residual trapping were also accounted for even though they were relatively minor contributors to trapping over the projected timescales of injection;
- Plumes were defined by the extent of free-phase CO_2;
- Coefficients were calculated at the projected time when injection stopped.

Sensitivity analysis

The first stage of the modelling process involved running a series of simulations using homogeneous models, constructed with average properties derived from the AGD. This enabled an assessment of the sensitivity of calculated coefficients to various key input parameters (table 3).

Table 3. Efficiency coefficients calculated for selected homogeneous cases.

Homogeneous case	Efficiency (%)
Standard (P50 properties, flat)	15
Structure - 1/2 avg. dome curvature	18
Structure - avg. dome curvature	25
P10 depth, P10 temp/pressure	7
P90 depth, P90 temp/pressure	17
kv/kh = 0.001	17
kv/kh = 0.1	16
kv/kh = 1	12
Rel Perm - Cardium SS, Swirr=0.197	16
Rel Perm - Basal SS, Swirr = 0.294	18
Rel Perm - Wabamun Carbonate, Swirr = 0.569	17

Results quoted as US DOE methodology coefficients, equivalent to Cc(1-S_{wirr}) for the CSLF method. Relative permeability curves from Bennion and Bachu [11].*

The results of this assessment showed that tightly closed structures, increased depth, lower temperatures, low ratios of vertical to horizontal permeability and high injection rates, all increased storage efficiency and the value of the calculated coefficient. Effects of relative permeability and irreducible water saturation appeared to be much less pronounced. The insights gained from the modeling using homogeneous conditions served as a basis for the design and execution of heterogeneous models subsequently used for calculation of the coefficients.

Lithology/depositional environment analysis

Heterogeneous models were developed for the various lithologies, depositional environments and structures, to derive ranges of storage capacity coefficients. Statistical distributions from the AGD were employed for key input parameters including porosity and permeability. These models were used in dynamic simulation to calculate expected efficiency using grouped sets of statistical variables unique to each combination of lithology and environment, set in each of the examined structural situations. In all, the study developed site-specific storage coefficients for 195 different simulation results using heterogeneous models before attempting to extrapolate the results to larger assessments.The issue of scale was considered in detail by the report, in particular whether calculation of coefficients and storage resource at localised scales can be applied to entire formations. The resulting values for the storage coefficient (E_E, US DOE method) ranged from 4% to 17% with an 80% confidence interval. Structural setting was found to exert the largest influence of any parameter on the results, with storage coefficients for effective resource exceeding 25% in some cases.

The site-specific results were then extrapolated to the formation scale. Table 4 below summarises the statistical distribution of coefficient values according to lithological type.

Table 4. Storage Coefficients Calculated at Formation Level by Lithology

Lithology	P10, %	P50, %	P90, %
Clastics	1.86	2.70	6.00
Dolomite	2.58	3.26	5.54
Limestone	1.41	2.04	3.27
All	1.66	2.63	5.13

Results quoted as US DOE methodology coefficients, equivalent to $Cc*(1-S_{wirr})$ *for the CSLF method.*

The authors stress that in order to calculate effective storage resource at the basin level, resources in individual DSF units should be assessed using the methodology outlined, and then results aggregated.

Closed formations

Where formations are closed, extrapolation of storage coefficients from site-specific assessment to formation level is problematic and instead, compartments within the formation require individual assessment. Note also that the storage coefficients presented above would not be applicable; storage coefficients for closed systems are likley to be at least an order of magnitude lower than those presented in Table 2 for open systems.

One possible solution to the problem of pressure increase in closed systems would be the production of brine, however this is an economic issue beyond the scope of this work.

Summary

The methodologies and storage coefficients presented can be used a guide for developing estimates of effective storage resources at the site-specific to the formation level and can further be expanded to cover other assessment areas. The tables of site-specific storage coefficients presented represent a range of values based on data collected in the AGD. They are not specific to any site but can be useful as a generalized comparison tool as well as an illustration of the expected ranges under different conditions.

It is important to understand that the methodology and coefficients presented can never be regarded as a substitute for detailed assessments at the site-specific level required during the design and implementation of CO_2 storage projects.

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