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Classification of CO2 Geologic Storage: Resource and Capacity

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Abstract

The use of the term capacity to describe possible geologic storage implies a realistic or likely volume of CO2 to be sequestered. Poor data quantity and quality may lead to very high uncertainty in the storage estimate. Use of the term “storage resource” alleviates the implied certainty of the term “storage capacity”.

Resource is a term used in the classification of oil and gas accumulations to infer lesser certainty in the commercial production of oil and gas. Likewise for CO2 sequestration a suspected porous and permeable zone can be classified as a resource, but capacity can only be estimated after a well is drilled into the formation and a relatively higher degree of certainty established. Storage capacity estimates are a lower risk or higher certainty estimate compared to storage resource estimates.

In the oil and gas industry, prospective resource and contingent resource are used for estimates with less data and certainty. Oil and gas reserves are classified as Proven and Unproven, and by analogy, capacity can be classified similarly. A geologic sequestration storage classification system is developed by analogy to that used by the oil and gas industry.

When a CO2 sequestration industry emerges, storage resource and capacity estimates will be considered a company asset and consequently regulated by the Securities and Exchange Commission. Additionally, storage accounting and auditing protocols will be required to confirm projected storage estimates and assignment of credits from actual injection. An example illustrates the use of these terms and how storage classification changes as new data is available.

Keywords: Type your keywords here, separated by semicolons ;

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1. Introduction

Assessments of the geologic CO2 storage in saline water bearing formations, are in progress.. While bulk volume or total pore volume may be a starting place, a potential emerging CO2 sequestration industry needs to establish guidelines for classifying CO2 storage so that policy makers and companies that engage in sequestration have a common basis for claiming CO2 storage. The petroleum industry has well established terminology for reserve and

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resource classification. Most of the data, conditions and methodology used to estimate and classify petroleum reserves are analogous to CO2 sequestration scenarios and could serve as a basis for developing a sequestration capacity classification.

In the 2008 US DOE National Atlas provides the following definitions:

> A CO2 resource estimate is defined as the volume of porous and permeable sedimentary rocks available for CO2 storage and accessible to injected CO2 via drilled and completed wellbores. Carbon dioxide resource assessments do not include economic or regulatory constraints; only physical constraints to define the accessible part of the subsurface. Economic or regulatory constraints are included in CO2 capacity estimates.

2. Sequestration Scenarios and Impact on Classification

Similar to a natural resource assessment such as petroleum accumulations, a sequestration resource assessment estimation is volumetrically based on physically accessible pore volume in specific formations in sedimentary basins without consideration of injection rates, regulations, economics, or surface land usage. To further exemplify the concept of resource and capacity, the following are example scenarios that would meet capacity and resource requirements and illustrate the dynamic nature of storage classification based on acquiring additional information (e.g. drilling and testing of new wells), changes in economics and new regulations. (These are taken from the 2008 DOE National Atlas.)

2.1 Injectivity, Regulations, and Economics for CO_2 Storage Classification

2.1.1 Injectivity

The daily or annual rate of CO_2 that can be injected into a specific geologic formation is described or inferred by the term “injectivity.” Relatively low or high injectivity for a formation is determined by the flow characteristics of the formation (e.g., pressure, permeability, and thickness), the type and size of wellbore drilled, the type of completion, and the number of wells.

No injectivity (zero) means there is no injection rate under any circumstances and as such a geologic formation without injectivity cannot be considered a CO_2 resource. However, a geologic formation with low injectivity that provides a CO_2 injection rate greater than zero does provide the opportunity to store CO_2 and is considered a CO_2 resource.

For selecting and designing specific storage sites, a minimum acceptable injection rate for a well is required to meet the capture rate of CO_2 emitted by the industrial site or utility. For example, if injectivity and storage for 1 million tons per year from an industrial plant is desired for 30 years, the first step in selecting an injection site is to find a geologic unit or group of units as close to the emission site as feasible (to minimize transportation costs) that has adequate CO_2 resource of at least 30 million tons. This industrial plant would likely have a budget (or economic limits) for capturing and storing CO_2 on a per-ton basis (e.g, $15/ton). One of the next steps is to establish the most affordable means of injecting CO_2 that does not exceed the $15/ton economic limit. One single well that could inject at least 1 million tons per year might be the least-cost option. However, if one well cannot provide this high rate of injectivity, additional wells or more expensive well types and completions will be considered. If the number of wells required to meet the 1 million tons per year has expenses that exceed $15/ton, then the site will not be selected and a different storage site further from the source may be considered.

For this example, the resource exists, but under the current economic conditions for this company at this emission site, the resource is not affordable. A different industrial plant with less CO_2 volume to store may find the same geologic unit acceptable with lower injection rate requirements or a higher economic limit than $15/ton. Moreover, the same plant, some time in the future, may have different economic drivers that can afford more wells or type of wells making the same site economical. Injection rate and the geologic parameters that determine injection rate do not affect the resource estimate, and only affect the use of the geologic unit at the present time. If the storage resource evaluated against a set of economic criteria is considered uneconomic, the storage capacity of the site is zero; however, the storage resource estimate remains unchanged.

By analogy, a producing oil well can be produced to the time that not a single drop of additional oil is produced; however, long before this time, the oil rate will be low enough that the income from the sale of oil from this well is not high enough to pay for the daily expense of operating this well. At this time the well is abandoned even though additional oil can be produced. If the price of oil increases or the operating expenses decrease, oil can continue to be produced. For either of these cases, the oil resource is the same and its availability as a resource is not changed by economic conditions.

2.1.2 Regulations

The use of any resource is governed by regulations; CO_2 storage will likely be similar. Some types of regulations may be similar to the oil and gas industry and underground gas storage. Examples of regulations are maximum injection pressure and rates, minimum formation water salinity, and monitoring and reporting requirements. In other industries, regulations have historically changed for technical and environmental reasons. Additionally, many regulations have exemption clauses. For example, the injection of water into an oil reservoir will have a regulated maximum pressure, but on a well-by-well, lease, or field case, a specific test can be conducted to allow injection pressure above the regulated maximum. Exemptions are added to regulations as new information or technology is available. Because of the dynamics of regulations, the use of regulations should not be imposed on the estimate of CO_2 resource.

The use of current regulations is very pertinent to a specific site assessment with projected start-up time and duration. To continue the example of the 1 million ton per year emission site, part of the $15/ton economic limit included a regulated monitoring technique that was relatively expensive. If later technology found a less expensive and equally effective method to monitor, the regulatory agency could be petitioned to consider the new technology and lower the storage cost, possibly transitioning the same geologic unit from uneconomical to economical for this industrial site.

21.3 Economics

Similar to the resource assessment of other natural resources such as petroleum accumulations and coal beds, the inclusion of economic considerations is inappropriate for a CO_2 resource assessment. In addition to project economic considerations, every company storing CO_2 will have different economic criteria to impose such as rate of return, payout, and profit/investment ratio that will affect the capacity of a geologic formation. In any storage industry scenario (e.g. carbon credits), each business will be making final estimates of available CO_2 capacity based on economic criteria. At this time it is unclear if a storage industry will emerge that has companies that provide dedicated storage services, or if corporations within existing industries, such as coal-burning power plants and ethanol-generating plants, will take on CO_2 storage as one of their business units.

Regardless of how the storage industry evolves, the assessment of CO_2 resources is unaffected by the projection of a new industry, and capacity of a site will be estimated by individual companies using their own economic criteria.

2.2 Storage Development Scenarios Affecting CO_2 Storage Estimates

For a given CO_2 storage resource estimate for a specific site, different development scenarios affect the estimate of CO_2 storage capacity. Wellbore type, transportation, and injection pressure are just a few examples of different site considerations that may increase or decrease the CO_2 storage capacity of a geologic formation.

2.2.1 Wellbore Type

Horizontal and vertical wells are two types of injection wells that could be considered for a storage site. In general, horizontal wells are expected to have a higher injection rate (tons per day) capability, especially in geologic formations with relatively small vertical thickness. Consequently, for a given CO_2 injection rate, fewer horizontal wells would be required as compared to the number of vertical wells. Fewer drilled wells also result in less impact at the surface.

For geologic formations that are compartmentalized horizontally, a horizontal well is more likely to attain a higher CO_2 storage capacity compared to a vertical well. Similarly, a geologic formation with vertical flow barriers is more likely to have relatively higher CO_2 storage capacity from injecting into vertical wells.

The decision to use horizontal or vertical wells has economic tradeoffs in terms of the number of wells, injection rate, and acquisition of surface acreage for well locations. Moreover, the effect of wellbore type on CO_2 capacity will vary based on the geologic formation. The storage capacity estimate in this example will be different for the well type, but the storage resource available would be the same (unless the drilled wells provided information that increased or decreased the resource estimate).

2.2.2 Transportation of CO_2

In most cases, a pipeline of some distance will be required to link the emission source and the injection site. Pipelines may be on the order of \$1 million per mile. A tradeoff between a closer injection site with lesser subsurface CO_2 storage capacity may be economically acceptable compared to the increased capital investment of a longer pipeline to a storage site with higher storage capacity. Likewise, a closer site that requires a greater number of wells, more expensive wells, or deeper wells may be much more economical compared to a geologic formation with fewer, less expensive wells that requires a 10-mile pipeline.

An estimate of CO_2 resource is not affected by the distance between source and sink and gives an estimate of the accessible pore volume regardless of the proximity to an existing or proposed CO_2 emission source.

2.2.3 Injection Pressure

All geologic formations have a threshold pore pressure that will begin to propagate a fracture within the injection formation if exceeded. Some caprocks withstand this pressure and the fracture terminates at the caprock. Many relatively thick shales constrain the growth of a fracture; however, in addition to a threshold fracture pressure, shales have a capillary pressure threshold that if exceeded, will breech and allow an injected fluid to pass through it.

Every formation (reservoirs and caprocks) has a pressure threshold that must be included in site-specific CO_2 capacity estimates. However, this pressure constraint can be managed during the planning and operation stages of development and should not influence the CO_2 resource estimate. A storage site with limited injection and/or pore pressure may reduce the CO_2 capacity, but due to number of injection wells required or length of pipeline, it may be economically the best choice. Moreover, drilling more wells can reduce the injection pressure into each well and keep reservoir pressure lower. Horizontal wells tend to have lower injection pressure as compared to vertical wells. Additionally, similar to natural gas storage, if regulations and economics are favorable, water production wells can be used to reduce pressure and increase capacity at a particular storage site.

All of these seemingly technical considerations have economic or regulatory components that must be considered. For a site-specific capacity assessment, technical, economic, and regulatory aspects must be considered collectively for the time and duration of the storage project. It is important to note that capacity estimates are dynamic and may change with new regulations, storage technology, or economic conditions. Additionally, new and different information found from characterization of new wells or application of new technology to existing wells can change resource and capacity estimates.

3. Direct Analogy to Oil and Gas Resource and Reserve Classification

Oil and gas reserves are the estimated quantities of economically recoverable petroleum from known accumulations. Reserves are further classified as Proved, Probable or Possible based on the relative risk that the estimated volume will be produced. The current hydrocarbon classification system has evolved over several decades. For a long period, the industry recognized definitions covering only Proved Reserves based on deterministic estimating methodology, which was the SEC requirement for reserve reporting by publicly traded companies. These definitions are currently widely accepted within the worldwide petroleum industry.

In recent years, the petroleum classification effort has focused on expanding petroleum resource classification to cover the total resource base. The discovered petroleum-initially-in-place is divided into production (history), reserves (commercial) and contingent resources (sub-commercial). Obviously, reserves are the main focus since they represent an asset that can be carried on the company books. Figure 1 is the classification system used in the petroleum industry.

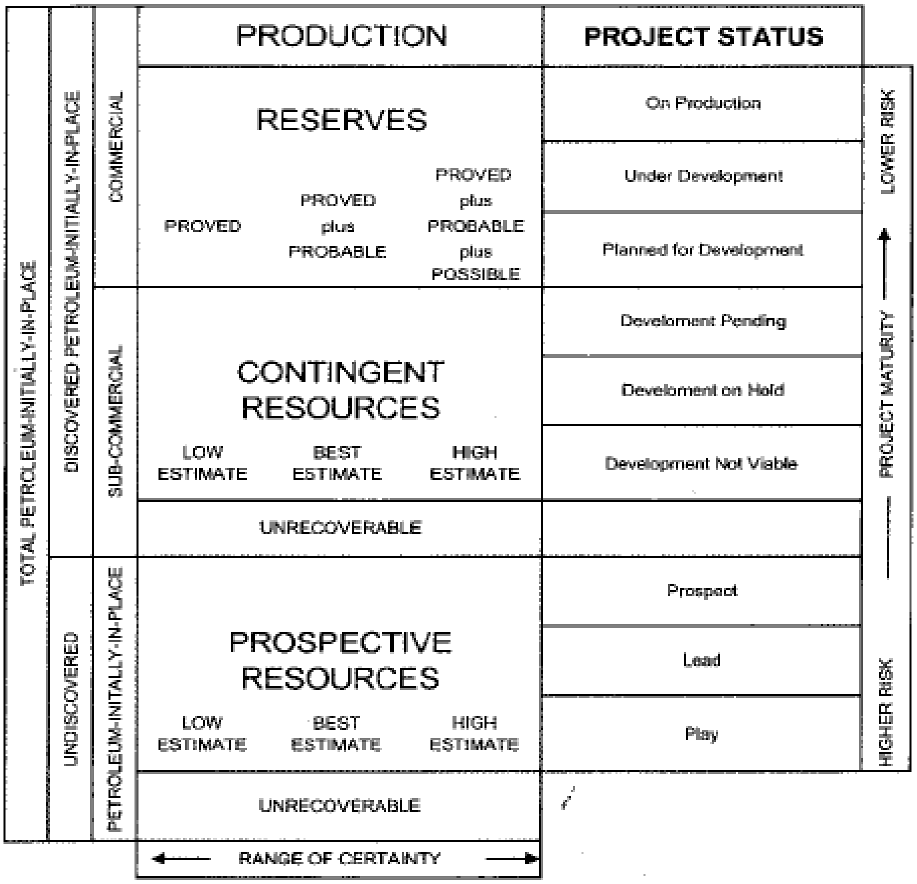

Figure 1: 2000 SPE/WPC/AAPG oil and gas resource and reserve classification system.

Figure 2 is an adaptation of Figure 1 using CO2 storage classification as an analogue to oil gas classification; i.e., the use of resource is the same and capacity is analogous to reserves.

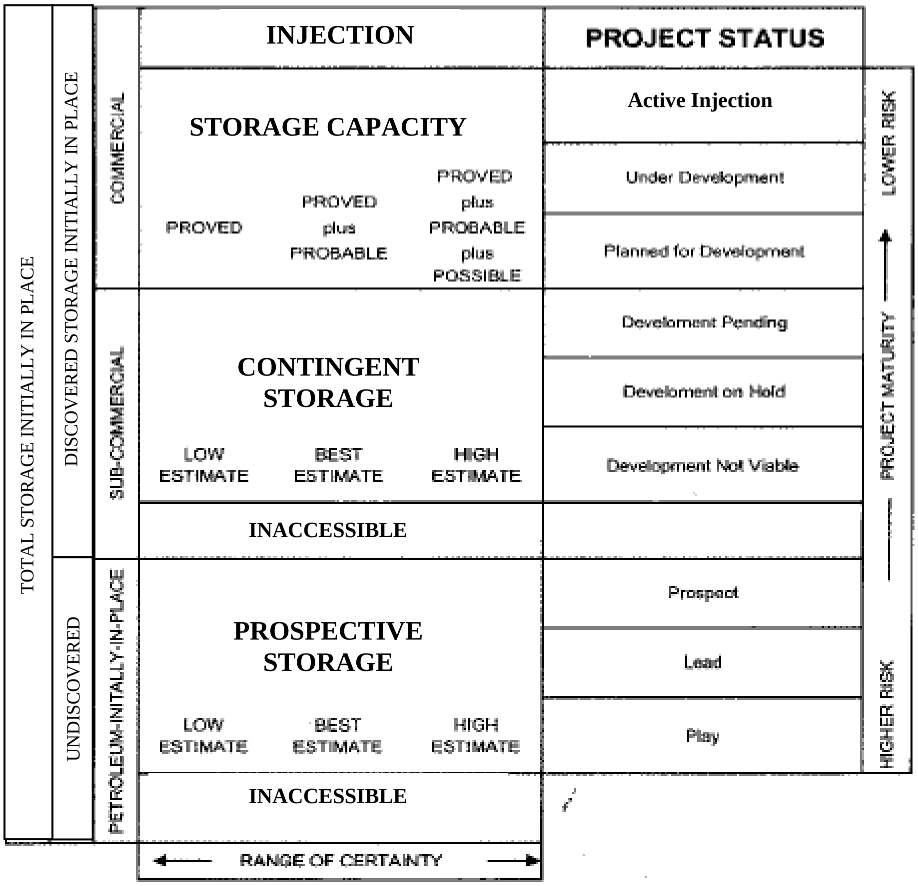

Figure 2: Proposed CO2 Storage Resource and Capacity Classification.

The five classifications from highest risk to lowest risk (or certainty in reverse order) are:

- Prospective Resources
- Contingent Resources
- Possible Storage Capacity (Unproved)
- Probable Storage Capacity (Unproved)
- Proved Storage Capacity

Estimated storage volume risk decreases with more and better information to change classification or move upward within this table. Within a given classification, the numerical estimate range can reflect certainty in the estimate.

Classifications are subjective and dynamic. Most all of the current sequestration storage assessment including the US DOE National Atlas I and II are considered the lowest as Prospective Storage Resource. In the US, a few wells may have tested CO2 injection and may have some radius around the well that is a higher classification within the Contingent Storage, but commerciality has not been met by a capture facility, and the Capacity classification is likely not been met. However, in projects like Sleipner and In Salah commerciality has been established and would meet the requirements of Storage Capacity.

Many parts of the definitions in the next sections have been directly adapted from the petroleum classification references. The developed examples illustrate the application of the classification system to CO2 sequestration.

4.1 Prospective Storage

Play: Recognized prospective trend of potential prospects, but requires more data acquisition and/or evaluation to define specific leads or prospects (directly from Reserve Guideline).

A CO2 Storage Example: No wells within 10 miles of study. General inference of storage from type of lithology and average properties of geologic formation within the geologic basin.

Lead: Potential storage is currently poorly defined and requires more data acquisition and/or evaluation in order to be classified as a prospect (directly from Reserve Guidelines).

A CO2 Storage Example: Well within 10 miles of study area with no porosity log. Log indicates gross thickness and acceptable lithology type.

Prospect: Potential storage is sufficiently well-defined to represent a viable drilling target (directly from Reserve Guidelines).

A CO2 Storage Example: Well within 10 miles of study area with porosity log. Log indicates net thickness, total porosity, and acceptable lithology type.

For a specific site, the data in the area looks good enough that plans are being developed to drill a well to attain additional data to assess CO2 injectivity.

(**Inaccessible**: Portion of formations pore volume considered inaccessible. In our case it would be based on the product of the four injection terms that went into the calculation of E.)

4.2 Contingent Storage

Development Not Viable: No further plans to develop or to acquire additional data at this time due to limited injection potential (directly from Reserve Guideline).

A CO2 Storage Example: From new well or well within 10 miles shows *low* porosity, low perm, low thickness and projected low injection rate and/or capacity; if closed system, pressure constraint may reduce injection rate and capacity; may be too far from existing and planned CO2 sources.

Development on Hold: Of significant size, but awaiting development of a market or removal of other constraints to development, this may be technical, environmental, or political. (directly from Reserve Guidelines).

A CO2 Storage Example: From new well or well within 10 miles shows *acceptable* porosity, low perm, low thickness and projected low injection rate and/or capacity; if closed system, pressure constraint may provide acceptable injection rate and capacity; may be acceptable distance between existing and planned CO2 sources.

Development Pending: Requires further data acquisition and/or evaluation in order to confirm commerciality (directly from Reserve Guidelines).

A CO2 Storage Example: From new well or well within 10 miles shows *acceptable* porosity, low perm, low thickness and projected low injection rate and/or capacity; if closed system, pressure constraint provide acceptable injection rate and capacity; acceptable distance between existing and planned CO2 sources.

(**Inaccessible**: Portion of formations pore volume considered inaccessible. In our case it would be based on the product of the four injection terms that went into the calculation of E.)

4.3 Storage Capacity

Storage capacity is the volumes of CO2 which are anticipated to be commercially stored within a known geologic formation from a given date forward.

Storage Capacity must satisfy four criteria, must be discovered, attainable, commercial, and available (presently has no CO2 stored). (In a developing sequestration area, it is foreseeable for a newly drilled well to discover that CO2 is already in some of the pore space and not available for additional CO2.)

Possible: Unproved storage capacity which analysis of geological and engineering suggests are less likely to be attainable than probable storage. When probabilistic methods are used, there should be at least a 10% probability that the quantities actually injected will equal or exceed the sum of estimated proved plus probable plus possible storage capacity (directly from Reserve Guideline).

A CO2 Storage Example: Storage capacity that appears attainable but injection may not be at commercial rates for a give CO2 source. A sequestration project is planned for a porous and permeable zone but not facilities are not in operation.

Probable: Unproved storage capacity which analysis of geological and engineering suggests are more likely than not to be attainable than probable storage. When probabilistic methods are used, there should be at least a 50% probability that the quantities actually injected will equal or exceed the sum of estimated proved plus probable storage capacity (directly from Reserve Guidelines).

A CO2 Storage Example: When wells in a sequestration field are too far apart to and additional wells will need to be drilled, this storage capacity between wells would be classified as probable. A zone penetrated by the well that looks like it has storage capacity from well logs, but has no core data or an and injection test may be classified as probable.

Proved: Proved storage capacity which analysis of geological and engineering data can be estimated with reasonable certainty to be commercially attainable, from a given date forward, into a know geologic formation and under current economic conditions, operating methods, and government regulations. Proved storage capacity can be categorized as developed or undeveloped. If deterministic methods are used, the term reasonable certainty is intended to express a high degree of confidence that the quantities will be recovered. If probabilistic methods are used, there should be at least a 90% probability that the quantities actually injected will equal or exceed the estimate. (directly from Reserve Guideline).

A CO2 Storage Example: Porous and permeable zones penetrated by a wellbore with perforations into the zone with active injection. Volume of storage around the well and between wells drilled on spacing that indicates volume between wells is attainable with the current well spacing and completions.

A zone penetrated by an existing well that has core data and/or an injection test that currently has no perforations or active injection can be classified as proved developed storage capacity. Deepening a well to a deeper geologic formation that has offset wells showing storage capacity can be classified as proved undeveloped.

4. Conclusions

The time tested oil industry resource and reserve classification is a direct analogy to CO2 sequestration. This paper is not intended to be exhaustive and cover all of the nuances of a classification system, but is intended to illustrate the importance of classifying a storage estimate based certainty and risk.

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