CO_2 Storage Resources Management System

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CO_2 Storage Resources Management System

Introduction

A CO_2 storage resource is defined as the quantity (mass or volume) of CO_2 that can be stored in a geologic formation. Resource assessments estimate total storable quantities in known, yet-to-be-discovered (i.e., identified) geologic formations; resource evaluations focus on those quantities that potentially can be used for commercial storage. A CO_2 storage resources management system (SRMS) provides a consistent approach to estimate storable quantities, evaluate development projects, and present results within a comprehensive classification framework.

It has been recognized for several years that quantitative estimates of CO_2 storage need to be better described in terms of data availability and certainty of the estimate, as well as the status of a related injection project; for example, The US Department of Energy's (DOE's) National Energy Technology Laboratory Atlas (US DOE 2015)

Over the past decade, authors around the world have proposed many methods to describe and systematically estimate storage resources; however, none of these methods have gained global acceptance. Several authors and institutes have recommended systems on the basis of the SPE Petroleum Resources Management System (PRMS). These include systems presented by Frailey et al. (2006), Kaldi and Gibson-Poole 2008, Frailey and Finley (2008), Gorecki et al. 2009, Allinson et al. (2010), Rodosta et al. (2010), and Liu et al. (2014). The Carbon Sequestration Leadership Forum has adopted a techno-economic resource-pyramid approach (Bachu et al. 2007). Liu et al. presented a summary of classification systems in 2014.

The United Nations Economic Commission for Europe (UNECE) has an overarching classification system for fossil energy and mineral reserves and resources called the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC-2009). Specifications for the Application of the UNFC-2009 to injection projects for the purpose of geological storage can be found through the UNECE website (UNECE 2016). The UNFC-2009, as applied to petroleum resources, has been mapped to the SPE/WPC/AAPG/SPEE PRMS by way of a bridging document. To maintain consistency between the two systems, the SPE Carbon Dioxide Capture, Utilization, and Storage Technical Section (CCUS) is working with the UNECE to apply the same approach to the SPE CO_2 SRMS.

This multiplicity of similar, but different, classification systems has a remarkable parallel to the petroleum industry, because it was before the coordinated efforts of a number of societies at the beginning of the 21st century to develop a PRMS. Drawing upon this experience, this document outlines a system based on the SPE/WPC/AAPG/SPEE PRMS, which is well-established and widely used and accepted by many organizations. It was very closely used in the development of this document. The PRMS definitions and the related classification system are now in common use internationally within the petroleum industry. The CO_2 SRMS is being developed to create a consistent set of definitions and a classification system for international usage. The SRMS will also provide a measure of comparability and reduce the subjective nature of resources estimation. As technologies and methodologies employed for CO_2 storage evolve, the CO_2 SRMS subcommittee will work closely with other organizations to update this document periodically to keep current with common practices and changing commerciality criteria.

The established use and acceptance of the PRMS provided the initial template for adaptation to this SRMS document. The PRMS classification concerns the commercial viability of hydrocarbon accumulations. The basis of the SRMS classification scheme is the accessible pore volume in a geologic formation in which CO_2 could be stored (i.e., storable quantities).

These definitions and guidelines are designed to provide a common reference for the international storage industry, including national reporting and regulatory disclosure agencies, and to support storage-project and portfolio-management requirements. They are intended to improve clarity in global communications regarding storage resources. It is expected that this document will be supplemented with industry education programs and application guides addressing their implementation in a wide spectrum of technical and/or commercial settings.

It is understood that these definitions and guidelines allow flexibility for users and agencies to tailor applications to meet their particular needs; however, any modifications to the guidance contained herein should be clearly identified. The definitions and guidelines contained in this document must not be construed as modifying the interpretation or application of any existing regulatory reporting requirements.

This SPE CO_2 Storage Resources Management System document, including its Appendix, may be referred to as SPE-SRMS or SRMS. This document is intended for use in geologic formations completely saturated with brine (i.e., saline formations or saline aquifers) and depleted hydrocarbon fields without hydrocarbon production. While the motivation for this document is to store CO_2, non-CO_2 constituents may be part of the injected CO_2 stream and stored. Furthermore, reference to storage, storage capacity, storage resource, and storable quantities implies the potential to store.

1.0 Basic Principles and Definitions

The estimation of storage resources involves the interpretation of the subsurface that has an inherent degree of uncertainty. These estimates are associated with development projects at various stages of design and implementation. Use of a consistent classification system enhances comparisons between projects, groups of projects, and storage efficiency. Such a system must consider both technical and commercial factors that impact the project's economic feasibility, its productive life, and its related cash flows. *Note: Inherent in the evaluation of storage resources is the evaluation of containment of the stored CO_2.*

1.1 Storage Resources Classification Framework. "Resources", as used herein, is intended to encompass all quantities of naturally occurring pore volume potentially suitable for storage within the Earth's crust—discovered and undiscovered (i.e., accessible and inaccessible)—plus those quantities already used for storage (i.e., stored).

Fig. 1.1 is a graphical representation of the SPE storage resources classification system. The system defines the major storage resource classes: Stored, Capacity, Contingent Storage Resources, and Prospective Storage Resources, as well as Inaccessible Storage Resources.

The "Range of Uncertainty" on the horizontal axis reflects a range of storable quantities (e.g., pore volume potentially accessible within a geologic formation by a project), while the vertical axis represents the "Chance of Commerciality," which is the chance that the project will be developed and reach commercial storage status. The following definitions apply to the major subdivisions within the resources classification:

- *Total Storage Resources.* The quantity of storage estimated to exist in geologic formations. It includes that quantity of storage estimated, as of a given date, to be possible in known and characterized geologic formations before injection, plus those estimated quantities in undiscovered or uncharacterized geologic formations. (Total Storage Resources is the sum of Discovered and Undiscovered Storage Resources.)
- *Discovered Storage Resources.* The estimated quantity of Total Storage Resources, as of a given date, in which the potential for storage has been ascertained within an assessed geologic formation.
    - *Stored.* The quantity of Discovered Storage Resources that has been exploited by a given date: This equates to the cumulative quantity of CO_2 injected and stored. While all storage resources are estimated, and Stored is measured in terms of CO_2 metering specifications, the total injected quantities (CO_2 plus associated injectants) are also measured, as required in support of engineering analyses.

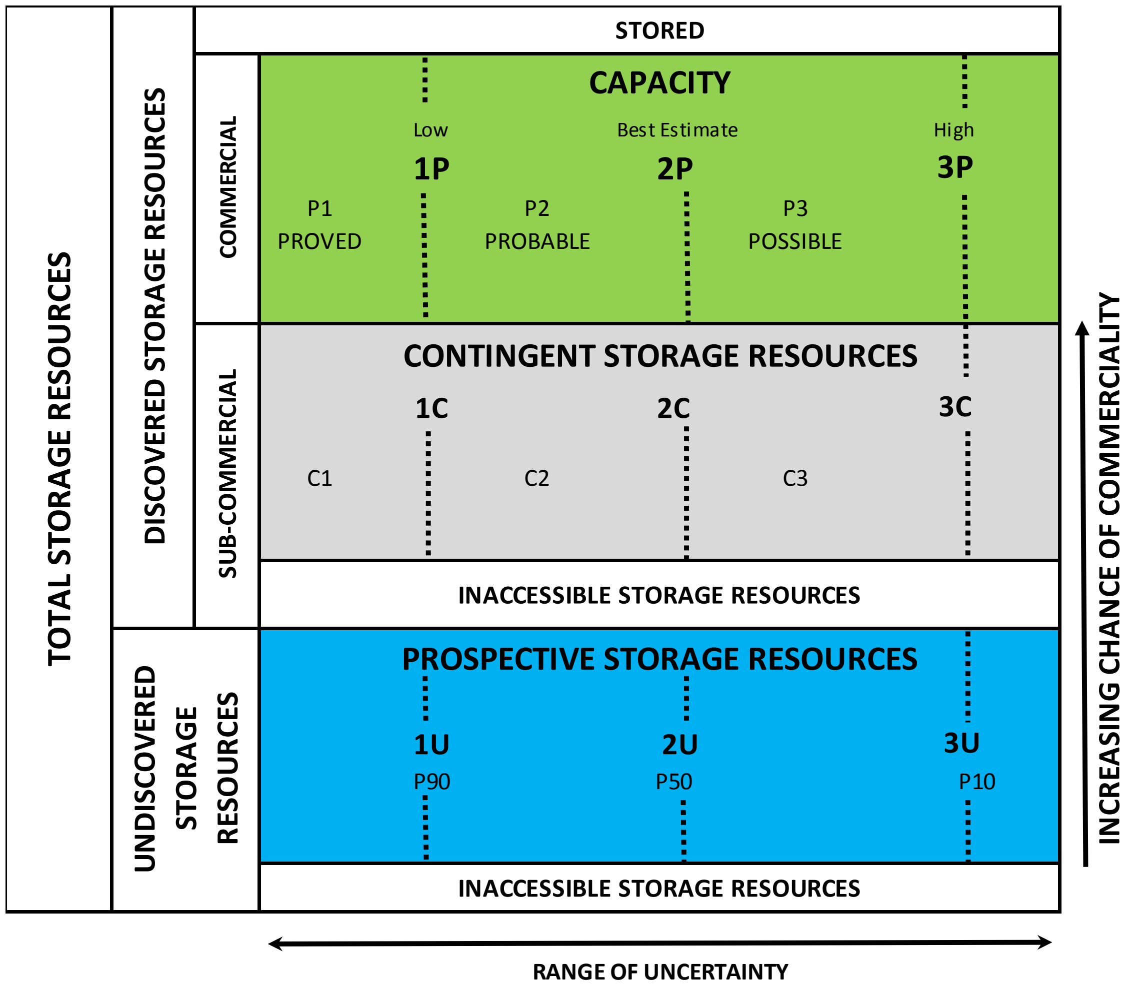

Fig. 1.1 – Resources Classification Framework

Multiple development projects may be applied to each characterized geologic formation, and each project will use a portion of the storable quantities estimated for the geologic formation. The projects and associated storable quantities will be subdivided into commercial and subcommercial, with the estimated storable quantities classified as Storage Capacity and Contingent Storage Resources, respectively, as defined below.

- *Storage Capacity*. Those quantities of Total Storage Resources anticipated to be commercially accessible in the characterized geologic formation by application of development projects from a given date forward under defined conditions. Commercial Storage Resources must further satisfy four criteria: The target geologic formation must be discovered and characterized (including containment); it must be possible to inject at the required rates; the development project must be commercial; and the storage resource must remain, as of the evaluation date (i.e., not previously used for storage), on the development project(s) applied. Commercial

Storage Resources are further categorized in accordance with the level of certainty associated with the estimates and may be subclassified on the basis of project maturity and/or characterized by development and injection status

- *Contingent Storage Resources.* Those quantities of Total Storage Resources estimated, as of a given date, to be potentially accessible in known geologic formations, but the applied project(s) are not yet considered mature enough for commercial development, as a result of one or more contingencies. Contingent Storage Resources must be discovered (characterized) and may include projects, for example, for which there are currently no viable CO_2 sources, and in which project value is insufficient to support development, permitting is still incomplete, commercial storage is dependent on technology under development, management is not committed, or evaluation of the geologic formation is insufficient to clearly assess commerciality. Contingent Storage Resources are further categorized in accordance with the level of certainty associated with the estimates and may be subclassified on the basis of the project maturity and/or characterized by their economic status and permitting/stakeholder status.

- *Undiscovered Storage Resources.* The estimated quantity of Total Storage Resources, as of a given date, in which the suitability for storage has not been ascertained within the target geologic formation.
  - *Prospective Storage Resources.* The quantity of Undiscovered Storage Resources estimated, as of a given date, to be potentially accessible within undiscovered geologic formations or uncharacterized parts of discovered geologic formations by application of future exploration/development projects. Prospective Storage Resources have both an associated chance of discovery and a chance of development. Prospective Storage Resources are further subdivided in accordance with the level of certainty associated with accessible estimates, assuming their discovery and development, and may be subclassified on the basis of project maturity.
- *Inaccessible Storage Resources.* The estimated portion of Discovered or Undiscovered Storage Resources, as of a given date (i.e., the time of the evaluation), that are not usable by future storage development projects. A portion of these Inaccessible Storage Resources may be used for storage in the future as commercial or regulatory circumstances change or technological developments occur; the remaining portion may never be used for storage resulting from physical/societal constraints of the storage location, both surface and subsurface

Estimated Ultimate Storage (EUS) is not a resources category, but a term that may be applied to any geologic formation (discovered or undiscovered) to define estimates of storable quantities of CO_2, as of a given date, to be potentially stored under defined technical and commercial conditions, plus those quantities already injected and stored.

Conceptually, the sum of Storage Capacity, Contingent Storage Resources, and Prospective Storage Resources may be referred to as "Remaining Storage Resources." When such terms are used, it is important that each classification component of the summation also be provided with the estimate of storable quantities for each. Moreover, these quantities should not be aggregated without due consideration of the varying degrees of technical and commercial risk involved with their classification.

Note: In the remainder of this document, the use of Capacity, Contingent, and Prospective Resources is synonymous with Storage Capacity, Contingent, and Prospective Storage Resources.

1.2 Project-Based Resources Evaluations. The resources-evaluation process consists of identifying a storage project or projects associated with one or more geologic formation(s), estimating the storable quantities, estimating the portion of those storable quantities that can be used by each project, and classifying the project(s) on the basis of its maturity status or chance of commerciality.

This concept of a project-based classification system is further clarified by examining the primary data sources contributing to an evaluation of storage resources (see **Fig. 1.2**), which may be described as follows:

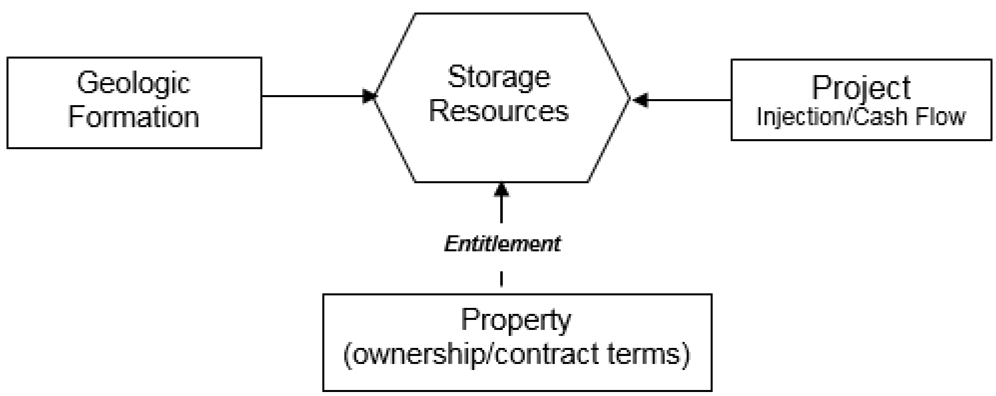

Fig. 1.2 – Resources Evaluation Data Sources

- *The Geologic Formation*–Key attributes include the storable quantities and the fluid and rock properties that affect CO_2 storage, including sustained injectability and containment (e.g., a seal or caprock).
- *The Project*–Each project applied to the storable quantities of a specific geologic formation generates unique injection and cash-flow schedules. The time integration of these schedules taken to the project's technical, economic, or contractual limit defines the estimated storage resources and associated future net cash-flow projections for each project. The ratio of EUS to a base (e.g., Total Storage Resources or total pore volume) defines

the ultimate storage efficiency for the development project(s) (see Appendix A—Glossary of Terms Used in Resource Evaluations). A project may be defined at various levels and stages of maturity; it may include one or many wells and associated injection and storage facilities. One project may develop storable quantities in many geologic formations, or many projects may be applied to storable quantities in one geologic formation.

- *The Property* (lease or license area)–Each property (i.e., subsurface) may have unique contractual rights and obligations, including the fiscal terms. Such information allows definition of each participant's share of storable quantities (entitlement) and share of investments, expenses, and revenues for each storage project and the geologic formation to which it is applied. One property may encompass storable quantities in many geologic formations, or storable quantities of one geologic formation may span several different properties. A property may contain both discovered and undiscovered storage resources.

In context of this data relationship, "Project" is the primary element considered in this resources classification, and net storage resources are the incremental storable quantities used by each project. Projects represent the link between storable quantities and the decision-making process. A project may, for example, constitute the development of storable quantities in a single geologic formation or multiple geologic formations, or an incremental development of storable quantities in a geologic formation, or the integrated development of storable quantities of several geologic formations and associated facilities with a common ownership. In general, an individual project will represent the level at which a decision is made to proceed (i.e., spend more money) or not, and there should be an associated range of estimated storable quantities for that project.

The CO_2 storage-resource evaluation, therefore, may be subject to several separate and distinct projects that are at different stages of exploration or development. Thus, a geologic formation simultaneously may have storable quantities in several resource classes.

To assign resources of any class, a development plan consisting of one or more projects needs to be defined. Even for Prospective Resources, the estimates of storable quantities must be stated in terms of the injected CO_2 derived from a development program, assuming successful discovery and commercial development. Given the major uncertainties involved at this early stage, the development program will not be of the detail expected in later stages of maturity. In most cases, storage efficiency largely may be based on analogous projects. Storable quantities for which a feasible project cannot be defined through use of, or reasonably forecast improvements in, current technology are classified as Inaccessible Storage Resources.

Not all technically feasible development plans will be commercial. The commercial viability of a development project depends on a forecast of the conditions that will exist during the time period encompassed by the project's activities (see Section 3.1 Commercial Evaluations). "Conditions" are defined as technological, economic, legal, environmental, social, and governmental factors. While economic factors can be summarized as forecast costs, the underlying influences include, but are not limited to, market conditions, transportation and infrastructure, fiscal terms, contractual liability, and taxes.

The storable quantities being estimated are those volumes (or mass) that can be stored from a project, as measured according to delivery specifications at the point of sale or custody transfer (see Section 3.2.1 Reference Point). For a specific project, the projection of the cumulative injection from the evaluation date forward to cessation of injection is the remaining storable quantities. The sum of the associated annual net cash flows yields the estimated future net revenue. When the cash flows are discounted according to a defined discount rate and time period, the summation of the discounted cash flows is termed Net Present Value (NPV) of the project (see Section 3.0 Evaluation and Reporting Guidelines).

Note: The supporting data, analytical processes, and assumptions used in an evaluation should be documented in sufficient detail to allow an independent evaluator or auditor to clearly understand the basis for estimation and categorization of storable quantities and their classification.

2.0 Classification and Categorization Guidelines

To consistently characterize CO_2 storage projects, evaluations of all resources should be conducted in the context of the full classification system shown in Fig. 1.1. These guidelines reference this classification system and support an evaluation in which projects are classified on the basis of their chance of commerciality (the vertical axis), and estimates of storable quantities associated with each project are categorized to reflect uncertainty (the horizontal axis). The actual workflow of classification vs. categorization varies with individual projects and is often an iterative analytical process leading to a final report. “Report,” as used herein, refers to the presentation of evaluation results within the entity conducting the assessment and should not be construed as replacing guidelines for public disclosures under processes established by regulatory and/or other government agencies.

2.1 Resources Classification. Basic classification requires establishment of criteria for the discovery of storable quantities, and thereafter, the distinction between commercial and subcommercial projects (and hence between Capacity and Contingent Storage Resources). Implicit in the assessment of storable quantities is the assessment of containment of the stored CO_2, as defined by the project.

2.1.1 Determination of Discovery Status. A discovery is one geologic formation or several geologic formations collectively, for which one or several wells have been established through testing, sampling, and/or logging the existence of a significant quantity of potential CO_2 storage for the proposed project. For a geologic formation to be deemed to have potential for CO_2 storage (i.e., storable quantities), it must be assessed as having both accessible pore volume (quantity and sustained injectivity commensurate with the project requirement) and as being suited to containment of the injected CO_2 over a time period established by the project.

In this context, “significant quantity” implies that there is evidence of a sufficient quantity of Total Storage Resources to justify estimating the storable quantity (volume or mass) demonstrated by the well(s) and for evaluating the potential for economic storage. Estimated storable quantities within such a discovered (known) and characterized geologic formation(s) will initially be classified as Contingent Storage Resources, pending definition of projects with sufficient chance of commercial development to reclassify all, or a portion thereof, as Capacity. Where Contingent Storage Resources are identified but are not considered currently storable, such quantities may be classified as Inaccessible Contingent Storage Resources, if considered appropriate for resource management purposes; a portion of this quantity may become accessible Contingent Storage Resources in the future as commercial circumstances change or technological developments occur.

2.1.2 Determination of Commerciality. Discovered Storage Resources may be considered commercial, and thus may be classified as Capacity, if the entity claiming commerciality has demonstrated firm intention to proceed with development and such intention is based on all of the following criteria:

- Evidence to support a reasonable timetable for development.
- A reasonable assessment of the future economics of such development projects meet defined investment and operating criteria.
- A reasonable expectation that there will be sustained demand (i.e., market) for storage from this development project and the expected stored quantities required to justify development.
- Evidence that the necessary injection facilities are available or can be made available.
- Evidence that legal, regulatory, contractual, environmental, and other social and economic concerns will allow for the actual implementation of the storage project being evaluated.

To be included in the Capacity class, a project must be sufficiently defined to establish its commercial viability. There must be a reasonable expectation that all required internal and external approvals will be forthcoming, and there is evidence of firm intention to proceed with development within a reasonable timeframe. A reasonable timeframe for the initiation of development depends on the specific circumstances and varies according to the scope of the project. While five years is recommended as a benchmark, a longer timeframe could be applied where, for example, development of economic projects are deferred at the option of the developer for, among other things, market-related reasons or to meet contractual or strategic objectives. In all cases, the justification for classification as Capacity should be clearly documented.

To be included in the Capacity class, there must be a high confidence in the commercial injectability of the characterized geologic formation, as supported by actual injection or formation tests and confidence in the containment assessment. In certain cases, Capacity may be assigned on the basis of well logs and/or core analysis that indicate that the subject geologic formation is capable of injectivity and containment, and is analogous to geologic formations in the same area that are injecting or have demonstrated the ability to inject through formation tests.

2.1.3 Project Status and Commercial Risk. Evaluators have the option to establish a more detailed resources-classification reporting system that can also provide the basis for portfolio management by subdividing the Chance of

Commerciality axis according to project maturity. Such subclasses may be characterized by standard project maturity-level descriptions (qualitative) and/or by their associated chance of reaching injection status (quantitative).

As a project moves to a higher level of maturity, there will be an increasing chance that the storage resources will be commercially developed. For Contingent and Prospective Storage Resources, this can further be expressed as a quantitative chance estimate that incorporates two key underlying risk components:

- The chance that the geologic formation will result in the discovery of storable quantities. This is referred to as the "chance of discovery."
- Once discovered, the chance that the storable quantities will be commercial is referred to as the "chance of development." This includes the likelihood that the project will receive stakeholder and regulatory approval.

Thus, for undiscovered storage resources, the "chance of commerciality" is the product of these two risk components. For a discovered injectable geologic formation in which the chance of discovery is 100%, the chance of commerciality becomes equivalent to the chance of development.

2.1.3.1 Project Maturity Subclasses. As illustrated in **Fig. 2.1,** development projects (and their associated storable quantities) may be subclassified according to project maturity levels and the associated actions (i.e., business decisions) required to move a project toward commercial injection.

Detailed definitions and guidelines for each project maturity subclass are provided in **Table 1** and the Glossary. This approach supports managing portfolios of opportunities at various stages of exploration and development and may be supplemented by associated quantitative estimates of chance of commerciality. The boundaries between different levels of project maturity may be referred to as "decision gates."

Decisions within the Capacity class are based on those actions that progress a project through final approvals to implementation and initiation of injection. For Contingent Storage Resources, supporting analysis should focus on gathering data and performing analyses to clarify and then mitigate those key conditions, or contingencies that prevent commercial development.

For Prospective Storage Resources, these potential storable quantities are evaluated according to their chance of discovery and, assuming a discovery, the estimated quantities that would be storable under appropriate development projects. The decision at each phase is to undertake further data acquisition and/or studies designed to move the project to a level of technical and commercial maturity in which a decision can be made to proceed with exploration drilling.

Evaluators may adopt alternative subclasses and project-maturity modifiers, but the concept of increasing chance of commerciality should be a key enabler in applying the overall classification system and supporting portfolio management.

2.1.3.2 Capacity Status. Once a project satisfies the chance of commerciality criteria, the associated storable quantities are classified as Capacity. These storable quantities may be allocated to the following subdivisions on the basis of the funding and operational status of wells and associated facilities within the development plan (detailed definitions and guidelines are provided in **Table 2**):

- Developed Capacity is the expected quantity that can be stored by leveraging existing wells and facilities at the injection rate required by the project.
    - Developed Injection Capacity is expected to be storable from completion intervals that are open and injecting at the time of the estimate.
    - Developed Non-Injecting Capacity includes shut-in and behind-pipe Capacity.
- Undeveloped Capacity is the expected quantity to be storable through future investments.

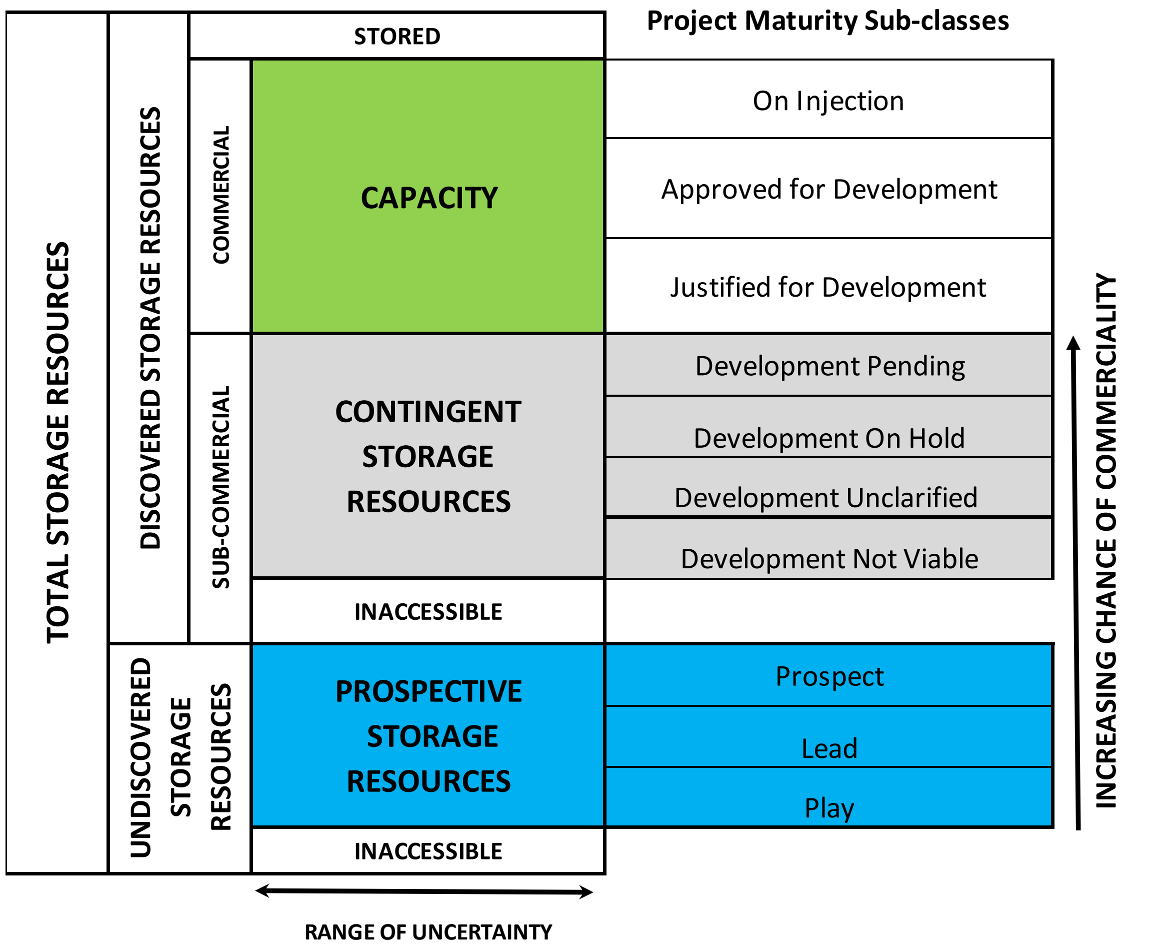

Fig. 2.1 – Subclasses based on Project Maturity

Where Capacity remains undeveloped beyond a reasonable timeframe, or has remained undeveloped because of repeated postponements, evaluations should be critically reviewed to document reasons for the delay in initiating injection and to justify retaining these quantities within the Capacity class. While there are specific circumstances in which a longer delay (see Section 2.1.2 Determination of Commerciality) is justified, a reasonable timeframe is generally considered to be less than five years.

Quantities may be subdivided by Capacity Status independent of subclassification by project maturity. If applied in combination, Developed and/or Undeveloped Capacity quantities may be identified separately within each Capacity subclass (i.e., On Injection, Approved for Development, and Justified for Development).

2.1.3.3 Economic Status. Projects may be further characterized by their economic status. All projects classified as Capacity must be economic under defined conditions (see Section 3.1 Commercial Evaluations). On the basis of assumptions regarding future conditions and their impact on ultimate economic viability, projects currently classified as Contingent Storage Resources may be broadly divided into two groups:

- Economically Viable Contingent Storage Resource—storable quantities associated with technically feasible projects that are either currently economic or projected to be economic under reasonably forecast improvements in commercial conditions, but are not committed for development because of one or more contingencies.
- Economically Not Viable Contingent Storage Resources—storable quantities for which development projects are not economic or not expected to be economic, even considering reasonable improvements in conditions.

Where evaluations are incomplete, such that it is premature to clearly define ultimate chance of commerciality, it is acceptable to note that project economic status is undetermined. Those discovered Total Storage Resource quantities for which a feasible development project cannot be defined through use of, or reasonably forecast improvements in, current technology are classified as Inaccessible.

Economic Status may be identified independently of, or applied in combination with, the Project Maturity subclassification to more completely describe the project and its associated resources.

2.2 Resources Categorization. The horizontal axis in the Resources Classification (Fig. 1.1) defines the range of uncertainty in estimates of the storable quantities associated with a project. These estimates include both technical and commercial uncertainty components as follows:

- The total storable quantities remaining within geologic formations.
- That portion of the storable quantities that can be used by a defined development project or projects.

The uncertainty in storable quantities is assessed separately from project classification. The assumed commercial conditions are associated with resource classes or subclasses and not with the resource categories. For example, the stored CO_2 price assumptions are those assumed when classifying projects as Capacity, and there would not be a different price used for assessing Proved vs. Probable Capacity. Use of different commercial assumptions for categorizing storable quantities is referred to as “split conditions,” which are to be avoided.

Moreover, a single project should be uniquely assigned to a subclass along with its uncertainty range. For example, a single project cannot have quantities categorized in both Contingent Storage Resource and Capacity as 1C, 2P, and 3P. This is referred to as “split classification.”

2.2.1 Range of Uncertainty. When uncertainty is such that the range needs to be investigated, storable quantities may be represented by either deterministic scenarios or by a probability distribution (see Section 4.2 Deterministic and Probabilistic Methods).

When the range of uncertainty is represented by a probability distribution, a low, best, and high estimate should be provided such that:

- There should be at least a 90% probability (P90) that the quantities actually stored will equal or exceed the low estimate.
- There should be at least a 50% probability (P50) that the quantities actually stored will equal or exceed the best estimate.
- There should be at least a 10% probability (P10) that the quantities actually stored will equal or exceed the high estimate.

When using the deterministic scenario method, low, best, and high estimates may be based on qualitative assessments of relative uncertainty by use of consistent interpretation guidelines. Under the deterministic incremental approach, quantities for each confidence segment are estimated discretely and separately (see Section 2.2.2 Category Definitions and Guidelines).

Resources are initially estimated through use of the above uncertainty-range forecasts by applying technical constraints related to wells and facilities. These technical forecasts then have the additional criteria applied (economics and license cutoffs are the most common) to determine the storable quantities attributed to resource classes: Capacity, Contingent Resources, and Prospective Resources.

While there may be significant likelihood that subcommercial and undiscovered storage resources will not achieve commercial storage, it is useful to consider storable quantities independently of such a likelihood or consideration of the resource class to which the quantities will be assigned.

2.2.2 Category Definitions and Guidelines. Evaluators may assess storable quantities and categorize results by uncertainty with the deterministic-incremental approach, the deterministic-scenario (cumulative) approach, or probabilistic methods. In many cases, a combination of approaches is used.

Use of consistent terminology (Fig. 1.1) promotes clarity in communication of evaluation results. For Capacity, the general cumulative terms low/best/high estimates are denoted as 1P/2P/3P, respectively. The associated incremental quantities are termed Proved, Probable, and Possible. Capacity is a subset of, and must be viewed within the context of, the complete resources-classification system. While the categorization criteria are proposed specifically for Capacity, in most cases, they can be equally applied to Contingent and Prospective Storage Resources, conditional upon their satisfying the criteria for discovery and/or development.

For Contingent Storage Resources, the general cumulative terms low/best/high estimates are used to determine the resulting 1C/2C/3C, respectively. The terms C1, C2, and C3 are defined for incremental quantities of Contingent Resources.

For Prospective Storage Resources, the general cumulative terms low/best/high estimates also apply and are used to determine whether the resulting 1U/2U/3U still apply. No specific terms are defined for incremental quantities within Prospective Storage Resources.

Quantities between classes and subclasses should not be aggregated without considering the varying degrees of technical uncertainty and commercial likelihood involved with their classification(s).

Without new technical information, there should be no change in the distribution of technically storable quantities and their categorization boundaries when conditions are satisfied sufficiently to reclassify a project from Contingent Storage Resources to Capacity. All evaluations require application of a consistent set of forecast conditions, including assumed future costs and prices, for both classification of projects and categorization of estimated quantities stored by each project (see Section 3.1 Commercial Evaluations).

Table 3 presents category definitions and provides guidelines designed to promote consistency in resource assessments. The following points summarize the definitions for each Capacity category, in terms of both the deterministic-incremental approach and scenario approach and also provides the probability criteria, if probabilistic methods are applied. For all methods (incremental, scenario, or probabilistic), a low-, best-, and high-estimate technical forecast may be prepared and then tested against the following criteria for assignment to appropriate SRMS categories:

- *Proved Capacity (P1)*—the storable quantities that can be estimated with reasonable certainty to be commercially used for storage by analysis of geoscience and engineering data from a given date forward and under defined economic conditions, operating methods, and government regulations. If deterministic methods are used, the term reasonable certainty is intended to express a high degree of confidence that the quantities will be stored. If probabilistic methods are used, there should be at least a 90% probability that the quantities actually stored will equal or exceed the estimate.
- *Probable Capacity (P2)*—the additional storable quantities, which analysis of geoscience and engineering data indicate are less likely to be used for storage than Proved Capacity, but more certain to be stored than Possible Capacity. It is equally likely that actual remaining quantities stored will be greater than or less than the sum of the estimated Proved plus Probable Capacity (2P). In this context, when probabilistic methods are used, there should be at least a 50% probability that the actual-stored quantities will equal or exceed the 2P estimate.
- *Possible Capacity (P3)*—the additional storable quantities, which analysis of geoscience and engineering data suggest are less likely to be used for storage than Probable Capacity. The total ultimately stored quantities from the project have a low probability to exceed the sum of Proved plus Probable plus Possible (3P) Capacity, which is equivalent to the high-estimate scenario. In this context, when probabilistic methods are used, there should be at least a 10% probability that the actual quantities stored will equal or exceed the 3P estimate

On the basis of additional data and updated interpretations that indicate increased certainty, portions of Possible and Probable Capacity may be re-categorized as Probable and Proved Capacity.

Uncertainty in resource estimates is best communicated by reporting a range of potential results. However, if it is required to report a single representative result, the best estimate is considered the most realistic assessment of storable quantities. It is generally considered to represent the sum of Proved and Probable estimates (2P) when using the deterministic scenario, or the P50 when using probabilistic-assessment methods. It should be noted that under the deterministic-incremental (risk-based) approach, discrete estimates are made for each category, and they should not be aggregated without due consideration of their associated risk.

2.3 Incremental Projects. The initial resource assessment performed on the basis of the application of a defined initial development project. Incremental projects are designed to increase stored CO_2, storage efficiency, and/or to accelerate injection by making changes to existing projects. Such projects should be classified according to the same criteria as the initial projects. Related incremental quantities are similarly categorized on certainty of Storage. The projected increased storage can be included in estimated Capacity, if the degree of commitment is such that the project will be developed and placed on injection within a reasonable timeframe.

Circumstances in which development will be significantly delayed should be clearly documented. If the likelihood of project execution is not reasonably expected, then the forecast incremental storage should be classified as Contingent Storage Resources (see Section 2.1.2 Determination of Commerciality).

3.0 Evaluation and Reporting Guidelines

The following guidelines are provided to promote consistency in project evaluations and reporting. "Reporting" refers to the presentation of evaluation results within the business entity conducting the evaluation and should not be construed as replacing guidelines for subsequent public disclosures under guidelines established by regulatory and/or other government agencies, or any current or future associated accounting standards.

3.1 Commercial Evaluations. Investment decisions are based on the entity's view of future commercial conditions that may impact the development feasibility (commitment to develop) and injection/cash-flow schedule of storage projects. Commercial conditions include, but are not limited to, assumptions of financial conditions (i.e., costs, prices, fiscal terms, taxes, credits, and subsidies), marketing, legal, environmental, social, and governmental factors. Project value may be assessed in several ways (e.g., historical costs, comparative market values); the guidelines herein apply only to evaluations based on cash-flow analysis. Moreover, modifying factors such as contractual or political risks that may additionally influence investment decisions are not addressed.

3.1.1 Cash-Flow-Based Resources Evaluations. Resource evaluations are based on estimates of future injection and the associated cash-flow schedules for each development project or related project wherein credits for said injection are being used. The sum of the associated annual net cash flows yields the estimated future net revenue.

Where the storage project revenue is from the sale of storage of CO_2 that has been generated and transferred from a separate project or entity (e.g., an industrial plant, power generation, or a hydrocarbon-producing project), the cash flow should be evaluated for the storage project alone on the basis of the forecast CO_2 supply (rate and total) and agreed fiscal terms, as laid out in the storage contract.

Where the storage project is developed (or retrofitted) in direct combination with a larger revenue-generating and CO_2-generating project, then the revenue and net cash flows should be evaluated at a combined project level (going forward from the date of evaluation), such that the storage costs are treated as additional capital expense and operating expense to the revenue-generating project.

When cash flows are discounted according to a defined discount rate and time period, the sum of the discounted cash flows is the NPV of the project. The calculation should reflect the following:

- The expected quantities of storage projected over identified time periods.
- The estimated costs associated with the project to develop, inject, and use the quantities of storage resources, as measured at the defined Reference Point (see Section 3.2.1 Reference Point), including environmental, abandonment, post-closure monitoring, and reclamation costs charged to the project, based on the evaluator's view of the costs expected to apply in future periods.
- The estimated revenues from the stored quantities, based on the evaluator's view of the prices, subsidies, and/or tax credits expected to apply to stored CO_2 in future time periods, including that portion of the costs and revenues accruing to the entity.
- Future projected storage and revenue-related taxes and royalties expected to be paid by the entity.
- A project life that is limited to the period of entitlement or reasonable expectation thereof.
- The application of an appropriate discount rate that reasonably reflects the weighted average cost of capital or the minimum acceptable rate of return applicable to the entity at the time of the evaluation.

While each entity may define specific investment criteria, a project is generally considered to be economic if its best-estimate case has a positive NPV under the organization's standard discount rate, or if it at least has a positive undiscounted cash flow.

For prospective resources, financial mechanisms in the context of a project may not be well defined compared with a project that is in a more mature stage of development. In these circumstances, the evaluator should state the assumptions and fiscal/economic mechanisms that would be required for a project.

3.1.2 Economic Criteria. While each organization may define specific investment criteria on the basis of Alternate Discount Rates to achieve commercial project returns, a project is deemed to be economic if its best-estimate case has a positive NPV under the organization's standard discount rate, or if it at least has a positive cash flow at 0% discount (i.e., undiscounted).

An ongoing field-development project is deemed economically viable when the revenue from the operation exceeds expenses and royalty or other share-of-production payments attributable to a certain interest in that operation. An economic evaluation refers to a specific period or collection of periods (most commonly a given month or year, or a cumulative period of time) in which these conditions are met. Future forecast-injection quantities must be economical under defined conditions to qualify as Capacity.

Evaluators must clearly identify the assumptions on commercial conditions used in the evaluation and must document the basis for these assumptions.

Future Abandonment, Decommissioning, and Restoration (ADR) costs are included in the economic analysis when reclassifying volumes from Contingent Storage Resources to Storage Capacity, or thereafter, when evaluating Undeveloped Capacity. When ADR is not required for Capacity estimation, such as determining the Economic Limit (see Section 3.1.3 Economic Limit) of a developed well currently in operation, the ADR costs may still need to be reported for other purposes, such as for a property sale/acquisition evaluation or an accounting report of future obligations, as appropriate to the circumstances for which the evaluation is being prepared.

The economic evaluation underlying the investment decision is based on the entity's reasonable forecast of future conditions, including costs, prices, subsidies, and tax credits of the project or related project (e.g., an industrial plant, power generation, or a hydrocarbon-producing project) that will exist during the life of the project (forecast case). Such forecasts are based on projected changes to current conditions; SPE defines current conditions as the average of those existing during the previous 12 months.

Alternative economic scenarios are considered in the decision-making process and, in some cases, to supplement reporting requirements. Evaluators may examine a case in which current conditions are held constant (no inflation or deflation) throughout the project life (constant case).

Evaluations may be modified to accommodate criteria imposed by regulatory agencies regarding external disclosures. For example, these criteria may include a specific requirement that, if the storage resources were confined to the technically Proved Capacity estimate, the constant case should still generate a positive cash flow. External reporting requirements may also specify alternative guidance on current conditions (e.g., year-end costs and prices).

There may be circumstances in which the project meets criteria to be classified as Capacity by use of the forecast case, but does not meet the external criteria for Proved Capacity. In these specific circumstances, the entity may record 2P and 3P estimates and note that the low estimate has a negative NPV. As costs are incurred and development proceeds, the low estimate may eventually satisfy external requirements, and Proved Capacity can then be assigned.

While SPE guidelines do not require that project financing be confirmed before classifying projects as Capacity, this may be another external requirement. In many cases, loans are conditional upon the same criteria as above; that is, the project (or combined CO_2-generating and storage project) must be economic on the basis of Proved Capacity only. In general, if there is not a reasonable expectation that loans or other forms of financing (e.g., farm outs) can be arranged in a way that development will be initiated within a reasonable timeframe, then the project should be classified as Contingent Resources. If financing is reasonably expected but not yet confirmed, the project may be classified as Capacity, but no Proved Capacity may be reported as above.

3.1.3 Economic Limit. Economic limit is defined as the injection rate below which the net operating cash flows from a project, which may be an individual well, lease, entire storage site, or related project (e.g., an industrial plant, power generation, or a hydrocarbon-producing project), are negative at a point in time that defines the project's economic life.

Operating costs should be based on the same type of projections as those used in price forecasting. Operating costs should include only those costs that are incremental to the project for which the economic limit is being calculated (i.e., only those cash costs that actually will be eliminated if project injection ceases should be considered in the calculation of economic limit). Operating costs should include fixed property-specific overhead charges, if these are actual incremental costs attributable to the project, and any injection and property taxes but—for purposes of calculating economic limit—should exclude depreciation, abandonment and reclamation costs, and income tax, as well as any overhead above that is required to operate the subject property itself. Operating costs may be reduced, and thus project life extended, by various cost-reduction and revenue-enhancement approaches, such as sharing of injection facilities, pooling, or maintenance contracts.

Interim negative-project net cash flows may be accommodated in short periods of low prices, tax credits, or major operational problems, provided that the longer-term forecasts must still indicate positive economics.

3.2 Injection Measurement. In general, the CO_2 stored, as measured according to injection specifications at a defined Reference Point, provides the basis for stored quantities and resources estimates. Operational issues enumerated in this section should be considered in defining and measuring injection. While referenced specifically to Capacity, the same logic would apply to projects forecast to develop Contingent and Prospective Resources conditional on discovery and development.

If reporting storage quantities (stored or storable) in units of volume, a standard pressure and temperature should be used and clearly stated with the volumetric estimate of CO_2 storage.

Associated injectants are measured, but should not contribute to the CO_2 stored.

3.2.1 Reference Point. Reference Point is a defined location(s) where the stored quantities are measured (metered) or assessed. The Reference Point is typically the point of transfer from a CO_2 generator or pipeline operator to the storage project operated by a third party or the CO_2 generator's storage operations. Metered injection and estimated Capacity is normally measured and reported in terms of quantities crossing this point over the period of interest. Furthermore, the CO_2 injection stream should be predominantly CO_2.

The Reference Point may be defined by relevant accounting regulations to ensure that the Reference Point is the same for both the measurement of reported stored quantities and for the accounting treatment of storage revenues. This ensures that stored quantities are stated according to their delivery specifications at a defined price. In integrated projects, the appropriate price at the Reference Point may need to be determined by use of a netback calculation.

To reduce risk of accounting for any CO_2 losses between the Reference Point and the injection well (downstream of the meter), placing the Reference Point near the injection wellhead is recommended.

3.2.2 Processing Losses. Any losses occurring between the Reference Point (meter) and the injection wellhead are not included in stored quantities.

3.2.3 Injection Balancing. Capacity estimates must be adjusted for stored quantities. This may be a complex accounting process when the allocation of injection among project participants is not aligned with their entitlement to Capacity. Stored overage or underage can occur in CO_2 injection records because of the necessity for participants to use their storage resources at an injection rate suitable to the CO_2 generator, as agreed among the parties. Similarly, an imbalance in CO_2 storage can result from the participants having different operating or marketing arrangements that prevent storage capacity use from equaling the entitlement share within a given time period.

On the basis of storage-resource matching the internal accounts, annual injection should generally be equal to the quantities stored by the participant and not on the stored entitlement for the year. However, stored quantities and entitlements must be reconciled in Capacity assessments. Resulting imbalances must be monitored over time and eventually resolved before project abandonment or closure.

3.3 Resources Entitlement and Recognition. While assessments are conducted to establish estimates of the Total Storage Resources, and that portion used by defined projects, the allocation of storable quantities, costs, and revenues impacts the project economics and commerciality. This allocation is governed by the applicable contracts between the pore space owners (lessors) and contractors (lessees) and is generally referred to as an "entitlement." For publicly traded companies, securities regulators may set criteria regarding the classes and categories that can be recognized in external disclosures.

Entitlements must ensure that storage resources claimed/reported by individual stakeholders sum to the Total Storage Resources; that is, none are missing or duplicated in the allocation process.

3.3.1 Royalty. Royalty refers to payments that are due to the host government or storage resource owner (lessor) in return for use of the storage resources by the operator (lessee/contractor) who has access to the storage resources.

Many agreements allow for the lessee/contractor to use the royalty-stored quantities and monetize it on behalf of—and pay the proceeds to—the royalty owner/lessor. Some agreements provide for the royalty to be taken only in-kind by the royalty owner. In either case, royalty-stored quantities must be deducted from the lessee's entitlement to resources. In some agreements, royalties owned by the host government are actually treated as taxes to be paid in cash. In these cases, the equivalent royalty-stored quantities are controlled by the contractor who may (subject to regulatory guidance) elect to report these stored quantities as Capacity and/or Contingent Resources, with appropriate offsets (i.e., increases in operating expense) to recognize the financial liability of the royalty obligation.

Conversely, if a company owns a royalty or equivalent interest of any type on a project, the related quantities can be included in Resources entitlements.

3.3.2 Injection-Sharing Contract Capacity. *Note: This section is from an analogous contract used in the oil and gas industry called a Production Sharing Agreement. Presently, there is not a known contract for CO_2 storage of this type.*

Injection-Sharing Contracts (ISCs) of various types may replace conventional tax-royalty systems in many countries. Under the ISC terms, operators have an entitlement to a portion of the stored quantities. This entitlement, often referred to as "net entitlement" or "net economic interest," is estimated with a formula based on the contract terms using project costs and project profits.

Although ownership of the stored quantities invariably remains with the government authority up to the export point of the project, the operators may take title to their share of the net entitlement at that point and may claim that share as their Capacity.

Risked-Service Contracts (RSCs) are similar to ISCs, but in this case, the operators are paid in cash rather than in stored quantities. As with ISCs, the Capacity claimed are based on the parties' net economic interest. Care should be taken to distinguish between an RSC and a "Pure Service Contract." Capacity can be claimed in an RSC on the basis that the operators are exposed to capital at risk, whereas no Capacity can be claimed for Pure Service Contracts, because there are no market risks and the operators act as contractors.

Unlike traditional royalty-lease agreements, the cost-recovery system in stored-quantities sharing, risk-service, and other related contracts typically reduce the stored-quantity share and, hence, Capacity obtained by the operator in periods of high value/low costs and increase volumes in periods of low value/high costs. While this ensures cost recovery, it introduces a significant price-related volatility in annual Capacity estimates under cases involving current economic conditions. Under a defined "forecast-conditions case," the future relationship of price (subsidies or tax credits) to Capacity entitlement is known.

The treatment of taxes and the accounting procedures used can also have a significant impact on the Capacity recognized and stored quantities reported from these contracts.

3.3.3 Contract Extensions or Renewals. As injection sharing, or other types of agreements, approach maturity, they can be extended by negotiating for contract extensions, by the exercise of options to extend, or by other means.

Capacity should not be claimed for those storable quantities that will be used beyond the end date of the current agreement, unless there is reasonable expectation that an extension, a renewal, or a new contract will be granted. Such reasonable expectation may arise on the basis of historical treatment of similar agreements by the license-issuing jurisdiction. Otherwise, forecast of storage-resource usage beyond the contract term should be classified as Contingent Resources, with an associated reduced chance of commercialization. Moreover, it may not be reasonable to assume that the fiscal terms in a negotiated extension will be similar to existing terms.

Similar logic should be applied in which third-party CO_2 storage agreements (e.g., a power-generation plant) are required to generate revenue for the storage project economics. Storage-resource quantities that will be used beyond those specified in the current agreement or reasonably forecast to be included in future agreements are considered Contingent.

Where the risk of cessation of rights to inject, or the inability to secure CO_2 for storage through storage contracts or continued integration with a CO_2-generating project is not considered significant, evaluators may choose to incorporate the uncertainty by categorizing quantities to be stored beyond the current contract as Probable or Possible Capacity.

4.0 Estimating Storable Quantities

Assuming that projects have been classified according to their project maturity, the estimation of associated storable quantities under a defined project and their assignment to uncertainty categories may be based on one analytical procedure or a combination of procedures. Such procedures may be applied by use of an incremental (risk-based) and/or scenario approach; moreover, the method of assessing relative uncertainty in these estimates of storable quantities may employ both deterministic and probabilistic methods. Furthermore, an assessment of injectability and of containment is a necessary part of the storable-quantities estimate.

4.1 Analytical Procedures. The analytical procedures for estimating storable quantities fall into three broad categories: analogy, volumetric estimates, and performance-based estimates, which include material balance and other injection-performance analyses. Reservoir simulation may be used in either volumetric or performance-based analyses. Pre- and early post-discovery assessments are typically made with analog field/project data and volumetric estimation. After injection commences and injection rates and pressure information become available, performance-based methods can be applied with site-specific data to improve the storable-quantities estimate.

In each procedural method, results are not a single quantity of remaining storage, but a range that reflects the underlying uncertainties in both the storable quantities and the storage efficiency of the applied development project. By applying consistent guidelines (see Section 2.2 Resources Categorization), evaluators can define remaining storable quantities with either the incremental- or cumulative-scenario approach. The confidence in assessment results generally increases when the estimates are supported by more than one analytical procedure.

4.1.1 Analogs. Analogs are widely used in petroleum- and mineral-resource estimation, particularly in exploration and early development stages, when direct measurements are limited. The methodology is based on the assumption that the analog's rock and fluid properties that control CO_2 storage are comparable to those that control the storable quantities estimated in the subject geologic formation. By selecting appropriate analogs in which performance data based on comparable development plans (including well type, well spacing, and stimulation) are available, a similar injection schedule may be forecast. Choice of analogous projects (e.g., CO_2 injection or CO_2 injection with brine extraction) is also important.

Analogous geologic formations in which CO_2 has been stored are defined by features and characteristics including, but not limited to, approximate depth, pressure, temperature, natural-drive mechanisms (e.g., closed system or strong aquifer), in-situ brine and CO_2 stream composition, formation size, gross thickness, net thickness, net-to-gross ratio, faulting and fault seals, lithology, heterogeneity, porosity, permeability, seal structure, presence of existing wells, and development plan. Analogous formations in which CO_2 has been stored are formed by the same, or very similar, processes with regard to sedimentation, diagenesis, pressure, temperature, chemical and mechanical history, and structural deformation. The analogues will also be in a similar setting with respect to containment: formation, dip angle (plume migration), geologic structure, seal integrity, fault age, stress regime, seal depth and composition, well construction, and abandonment practices.

Comparison to several analogs may improve the range of uncertainty in the estimated storable quantities in the subject geologic formation. While formations with stored CO_2 in the same geographic area and of the same geologic age typically provide better analogs, such proximity alone may not be the primary consideration. In all cases, evaluators should document the similarities and differences between the analog and the subject formation/seal/project. Review of analog storage-project performance is useful in quality assurance of resource assessments at all stages of development.

While there is limited experience in the CO_2 storage industry, analogs may not be readily available for a significant number of storage cases. As a result of this lack of maturity, storable quantities based on analogs, or volumetric methods with storage efficiency based on analog developments, may have significant uncertainty and may be classified as less mature than methods not based on analog development. However, analogs will become increasingly important as this industry matures and gains a breadth of experience.

4.1.2 Volumetric Estimate. This procedure uses rock properties to calculate storable quantities and then estimates which portion will be available to store CO_2 by one or more specific development projects or for basin-scale assessment. Key uncertainties affecting storable quantities include the following:

- Formation geometry and thickness that impact gross rock volume
- Geological heterogeneity of the pore volume
- Hydrodynamic and geochemical factors affecting the mobility and fate of the injected CO_2
- Extent and competence of containment system

The gross rock volume of interest is that for the total formation. While spatial distribution of porosity and permeability impact storage efficiency, the calculation of storable quantities often uses average net-to-gross ratio and porosity. In more heterogeneous formations, increased well density may be required to confidently assess and categorize resources. *Note: Storage efficiency may be defined on an effective or total pore volume or bulk volume basis and should be clearly stated.*

Given an estimate of the storable quantities, that portion that can be used for storage by a defined project must then be estimated on the basis of analog well performance and/or simulation studies by use of available geologic information. Key assumptions must be made regarding natural-drive mechanisms.

Key parameters include the following

- Permeability
- Pore and fluid compressibility (water compressibility for saline aquifer, and an average fluid compressibility for storage in depleted oil and gas reservoirs)
- Maximum storage and injection pressures defined not to damage the caprock
- Boundary conditions of the domain, enabling or not some lateral pressure dissipation
- CO_2 injection only or injection and water extraction to mitigate pressure buildup

The estimates of storable quantities must reflect uncertainty, not only in the storable quantities, but also in the storage efficiency of the development project(s) applied to a specific geologic formation.

Data permitting, geostatistical methods can be used to preserve spatial distribution information and incorporate it in subsequent storage simulation applications. Such processes may yield improved estimates of the range of storable quantities. Incorporation of seismic analyses typically improves the underlying geologic and flow models and yields more reliable resource estimates.

4.1.3 Material Balance. Material-balance methods to estimate storable quantities involve the analysis of pressure and geochemical behavior as CO_2 is injected. In ideal situations, such as injection in homogeneous, high-permeability formations in a closed system (e.g., bounded by impermeable faults), and in which sufficient and high-quality pressure data are available, estimation on the basis of material balance may provide very reliable estimates of ultimate storage at various storage pressures. In complex situations (e.g., open systems, natural water flow, geologic compartmentalization, and multilayered or low-permeability formations), material-balance estimates alone may provide erroneous results. Evaluators should take care to accommodate the complexity of the formation and its pressure response to injection when developing uncertainty profiles for the applied storage project.

Computer modeling or simulation can be considered a sophisticated form of material-balance analysis. While such modeling can be a reliable predictor of storage behavior under a defined development program, the reliability of input rock properties, formation geometry, pore and fluid compressibility, relative permeability functions, fluid properties, location of fault systems, and acceptable overpressures are critical. Predictive models are most reliable for estimating storable quantities when there is sufficient injection history to validate the model through history matching.

4.1.4 Injection Performance Analysis. Analysis of the changes in injection pressure vs. injection rates, time, and cumulative injection and pressure transients provides valuable information to predict ultimate storable quantities. The bottomhole or injection pressures can be extrapolated to an economic limit condition to estimate storable quantities.

Reliable results require a sufficient period of stable operating conditions after wells injecting into a formation have established their CO_2 injectivity. In estimating storable quantities, evaluators must consider complicating factors affecting injection performance behavior, such as variable rock and fluid properties, transient vs. stabilized flow, changes in operating conditions, interference effects, drive mechanisms, and storage mechanisms. In early stages of injection, there may be significant uncertainty in both the ultimate performance profile and the commercial factors that impact injection rate or project performance. Such uncertainties should be reflected in the resources categorization. For very mature storage projects, the future injection forecast may be sufficiently well defined that the remaining uncertainty in the technical profile is not significant; in such cases, the best-estimate 2P scenario also may be used for the 1P and 3P injection forecasts. However, there may still be commercial uncertainties that will impact the abandonment rate/pressure, and these should be accommodated in the resources categorization.

4.2 Deterministic and Probabilistic Methods. Regardless of the analytical procedure used, storable quantities may be estimated by use of either deterministic or probabilistic methods.

In the deterministic method, a discrete value or array of values for each parameter is selected on the basis of the estimator's choice of the values that are most appropriate for the corresponding resource category. A single outcome of storable quantities is derived for each deterministic increment or scenario.

In the probabilistic method, the estimator defines a distribution representing the full range of possible values for each input parameter. These distributions may be randomly sampled (typically through use of the Monte Carlo simulation) to compute a full range and distribution of potential outcomes of results of storable quantities. This approach is most often applied to volumetric-resource calculations in the early phases of exploitation and development projects. Moreover, the resource analysis must consider commercial uncertainties. Accordingly, when probabilistic methods are used, constraints on parameters may be required to ensure that results are not outside the range imposed by the category deterministic guidelines and commercial uncertainties.

Deterministic volumes are estimated for discrete increments and defined scenarios. While deterministic estimates may have broadly inferred confidence levels, they do not have associated quantitatively defined probabilities. Nevertheless, the ranges of the probability guidelines established for the probabilistic method (see Section 2.2.1 Range of Uncertainty) influence the amount of uncertainty generally inferred in the estimate derived from the deterministic method.

Both deterministic and probabilistic methods may be used in combination to ensure that results of either method are reasonable.

4.2.1 Aggregation Methods. Storable quantities are generally estimated and categorized according to certainty of storage within individual geological formations or portions of geological formations; this is referred to as the "storage-formation level" assessment. These estimates are summed to arrive at estimates for fields, properties, and projects. Further summation is applied to yield totals for areas, countries, and companies; these are generally referred to as "resource-reporting levels." The uncertainty distribution of the individual estimates at each of these levels may differ widely, depending on the geological settings and the maturity of the resources. This cumulative summation process is generally referred to as "aggregation."

Two general methods of aggregation may be applied: arithmetic summation of estimates by category and statistical aggregation of uncertainty distributions. There is typically significant divergence that results from applying these alternative methods. In statistical aggregation, except in the rare situation in which all the storable quantities aggregated are totally dependent, the P90 quantities (i.e., high degree of certainty) from the aggregate are always greater than the arithmetic sum of the formation level P90 quantities, and the P10 (i.e., low degree of certainty) of the aggregate is always less than the arithmetic sum P10 quantities assessed at the formation level. This "portfolio effect" is the result of the central-limit theorem in statistical analysis. Note that the mean (arithmetic average) of the sums is equal to the sum of the means; that is, there is no portfolio effect in aggregating mean values.

In practice, there is likely to be a large degree of interdependence among storable quantities estimated for hydraulically connected geologic formations, and such dependencies must be incorporated in the probabilistic calculation.

The aggregation methods used depend on the business purpose. It is recommended that for reporting purposes, assessment results should not incorporate statistical aggregation beyond the field, property, or project level. Results reporting beyond this level should use arithmetic summation by category but should caution that the aggregate proved may be a very conservative estimate and aggregate 3P may be very optimistic, depending on the number of items in the aggregate. Aggregates of 2P results typically have a smaller portfolio effect, which may not be significant in mature properties where the statistical median approaches the mean of the resulting distribution.

Various techniques are available to aggregate deterministic and/or probabilistic field, property, or project-assessment results for detailed business units or corporate portfolio analyses in which the results incorporate the benefits of portfolio size and diversification. Again, aggregation should incorporate the degree of dependency. Where the underlying analyses are available, comparison of arithmetic and statistical aggregation results may be valuable in assessing the impact of the portfolio effect. Whether deterministic or probabilistic methods are used, care should be taken to avoid systematic bias in the estimation process.

The monetary value associated with these storable quantities is dependent on the injection and cash-flow schedules for each project; thus, aggregate distributions of storable quantities may not be a direct indication of corresponding uncertainty distributions of aggregate value.

4.2.1.1 Aggregating Resources Classes. Storable quantities classified as Capacity, Contingent Resources, or Prospective Resources should not be aggregated with each other without due consideration of the significant differences in the criteria associated with their classification. In particular, there may be a significant risk that geologic formations containing Contingent Resources and/ or Prospective Resources will not achieve commercial storage.

Where the associated discovery and commerciality risks have been quantitatively defined, statistical techniques may be applied to incorporate individual project-risk estimates in portfolio analysis of volume and value.

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Table 1—Storage resources classes and subclasses.

Class/Subclass	Definition	Guidelines
Capacity	Capacity is the storable quantities anticipated to be commercially accessible by application of development projects to known geologic formations from a given date forward under defined conditions.	Capacity must satisfy four criteria: it must be discovered and characterized (including containment), injectable, commercial, and not include CO_2 previously stored on the basis of the development project(s) applied. Capacity is further subdivided in accordance with the level of certainty associated with the estimates and may be subclassified on the basis of project maturity and/or characterized by their development and injection status. To be included in the Capacity class, a project must be sufficiently defined to establish its commercial viability. There must be a reasonable expectation that all required internal and external approvals will be forthcoming, and there is evidence of firm intention to proceed with development within a reasonable timeframe. A reasonable timeframe for the initiation of development depends on the specific circumstances and varies according to the scope of the project. While five years is recommended as a benchmark, a longer timeframe could be applied where, for example, development of economic projects are deferred at the option of the storage-site operator for, among other things, market-related reasons or to meet contractual or strategic objectives. In all cases, the justification for classification as Capacity should be clearly documented. To be included in the Capacity class, there must be a high confidence in the commercial storage of the geologic formation as supported by actual injection or formation tests and containment. In certain cases, Capacity may be assigned on the basis of well logs and/or core analysis that indicate that the subject geologic formation has accessible pore volume and is analogous to reservoirs in the same area that are injecting or have demonstrated the ability to inject on formation tests.
On Injection	The development project is currently injecting and storing CO_2.	The key criterion is that the project is actively injecting CO_2, rather than the approved development project necessarily being complete. This is the point at which the project "chance of commerciality" can be said to be 100%. The project "decision gate" is the decision to initiate commercial injection from the project.
Approved for Development	All necessary approvals have been obtained, capital funds have been committed, and implementation of the development project is underway.	At this point, it must be certain that the development project is going ahead. The project must not be subject to any contingencies such as outstanding regulatory approvals or contracts. Forecast capital expenditures should be included in the reporting entity's current or following year's approved budget. The project "decision gate" is the decision to start investing capital in the construction of storage (injection) facilities and/or drilling development wells.

Table 1—Storage resources classes and subclasses (continued).

Class/Subclass	Definition	Guidelines
Justified for Development	Implementation of the development project is justified on the basis of reasonable forecast commercial conditions at the time of reporting, and there are reasonable expectations that all necessary approvals/contracts will be obtained.	To move to this level of project maturity, and thus have Capacity associated with it, the development project must be commercially viable at the time of reporting, on the basis of the reporting entity's assumptions including of future prices, costs (i.e., "forecast case"), and the specific circumstances of the project. Evidence of a firm intention to proceed with development within a reasonable timeframe will be sufficient to demonstrate commerciality. There should be a development plan in sufficient detail to support the assessment of commerciality and a reasonable expectation that any regulatory approvals or contracts required before project implementation will be forthcoming. Other than such approvals/contracts, there should be no known contingencies that could preclude the development from proceeding within a reasonable timeframe (see Capacity class). The project decision gate is the decision by the reporting entity and its partners, if any, that the project has reached a level of technical and commercial maturity sufficient to justify proceeding with development at that point in time.
Contingent Storage Resources	Those discovered storable quantities estimated, as of a given date, to be potentially accessible in known geologic formations by application of development projects, but which are not currently considered to be commercially accessible due to one or more contingencies.	Contingent Storage Resources may include, for example, projects for which there are currently no viable markets, or in which commercial storage is dependent on technology under development, or in which evaluation of the geologic formation is insufficient to clearly assess commerciality, or in which there is negative stakeholder or public acceptance. Contingent Storage Resources are further categorized in accordance with the level of certainty associated with the estimates and may be subclassified on the basis of project maturity and/or characterized by their economic status.
Development Pending	Discovered storable quantities where project activities are ongoing to justify commercial development in the foreseeable future.	The project is seen to have reasonable potential for eventual commercial development, to the extent that further data acquisition (e.g., drilling and seismic data) and/or evaluations are currently ongoing with a view toward confirming that the project is commercially viable and providing the basis for selection of an appropriate development plan. The critical contingencies have been identified and are reasonably expected to be resolved within a reasonable timeframe. Note that disappointing appraisal/evaluation results could lead to a reclassification of the project to "On Hold" or "Not Viable" status. The project decision gate is the decision to undertake further data acquisition and/or studies designed to move the project to a level of technical and commercial maturity at which point a decision can be made to proceed with development and storage (injection).
Development on Hold	Discovered storable quantities where project activities are on hold and/or where justification as a commercial development may be subject to significant delay.	The project is seen to have potential for commercial development. Development may be subject to a significant time delay. Note that a change in circumstances, such that there is no longer a probable likelihood that a critical contingency can be removed in the foreseeable future, for example, could lead to a reclassification of the project to "Not Viable" status. The project decision gate is the decision to either proceed with additional evaluation designed to clarify the potential for eventual commercial development or to temporarily suspend or delay further activities pending resolution of external contingencies.
Development Unclarified	Discovered storable quantities where project activities are under evaluation and where justification as a commercial development is unknown on the basis of available information.	The project is seen to have potential for eventual commercial development, but further appraisal/evaluation activities are ongoing to clarify the potential for eventual commercial development. This subclass requires active appraisal or evaluation and should not be maintained without a plan for future evaluation. The subclass should reflect the actions required to move a project toward commercial production.

Table 1—Storage resources classes and subclasses (continued).

Class/Subclass	Definition	Guidelines
Development Not Viable	Discovered storable quantities for which there are no current plans to develop or to acquire additional data at the time as a result of limited storage potential.	The project is not seen to have potential for eventual commercial development at the time of reporting, but the theoretically accessible pore-volume quantities are recorded so that the potential opportunity will be recognized in the event of a major change in technology or commercial conditions. The project decision gate is the decision not to undertake any further data acquisition or studies on the project for the foreseeable future.
Prospective Resources	Those undiscovered storable quantities of pore volume in a geological formation that are estimated, as of a given date, to be potentially accessible.	A geologic formation is evaluated for potential storage according to its chance of discovery and, assuming a discovery, the estimated accessible pore volume defined by development projects. It is recognized that the development programs will be of significantly less detail and depend more heavily on analog developments in the earlier phases of exploration.
Prospect	A project associated with undiscovered storable quantities that is sufficiently well defined to represent a viable drilling target.	Project activities are focused on assessing the chance of discovery and, assuming discovery, the range of storable quantities under a commercial development program.
Lead	A project associated with undiscovered storable quantities that is currently poorly defined and requires more data acquisition and/or evaluation to be classified as a prospect.	Project activities are focused on acquiring additional data and/or undertaking further evaluation designed to confirm whether or not the lead can be matured into a prospect. Such evaluation includes the assessment of the chance of discovery and, assuming discovery, the range of potential storable quantities under feasible development scenarios.
Play	A project associated with a prospective trend of potential prospects, but that requires more data acquisition and/or evaluation to define specific leads or prospects.	Project activities are focused on acquiring additional data and/or undertaking further evaluation designed to define specific leads or prospects for more detailed analysis of their chance of discovery and, assuming discovery, the range of potential storable quantities under hypothetical development scenarios.

Table 2—Capacity status definitions and guidelines.

Status	Definition	Guidelines
Developed Capacity	Developed Capacity is expected quantities to be stored from existing wells and facilities.	Capacity is considered developed only after the necessary equipment has been installed or when the costs to do so are relatively minor compared to the cost of a well. When required facilities become unavailable, it may be necessary to reclassify Developed Capacity as Undeveloped. Developed Capacity may be further subclassified as Injecting or Noninjecting.
Developed Injecting Capacity	Developed Injecting Capacity is expected to be stored from completion intervals that are open and injecting at the time of the estimate.	Improved storage capacity is classified as injecting only after the improved storage project is in operation.
Developed Noninjecting Capacity	Developed Noninjecting Capacity includes shut-in and behind-pipe Capacity.	Shut-in Capacity is expected to be stored from completion intervals that are open at the time of the estimate, but that have not yet started injecting; wells that were shut in for market conditions or pipeline connections; or wells not capable of injection for mechanical reasons. Behind-pipe Capacity is expected to be stored in geologic formations in existing wells, which will require additional completion work or future recompletion before the start of injection. In all cases, injection can be initiated or restored with relatively low expenditure compared with the cost of drilling a new well.
Undeveloped Capacity	Undeveloped Capacity is the quantity expected to be stored through future investments.	(1) Future investments, including those from new wells on undrilled acreage in geologic formations with known storable quantities; (2) from deepening existing wells to different geologic formations with known storable quantities; (3) from infill wells that will increase storage; or (4) where a relatively large expenditure (e.g., when compared to the cost of drilling a new well) is required to (a) recomplete an existing well or (b) install injection or transportation facilities for primary or improved storage projects.

Table 3—Capacity category definitions and guidelines.

Category	Definition	Guidelines
Proved Capacity	Proved Capacity is the quantity of storage that, by analysis of geoscience and engineering data, can be estimated with reasonable certainty to be commercially used for storage, from a given date forward, from known geologic formations and under defined economic conditions, operating methods, and government regulations.	If deterministic methods are used, the term reasonable certainty is intended to express a high degree of confidence that the quantities will be used for storage. If probabilistic methods are used, there should be at least a 90% probability that the quantities actually stored will equal or exceed the estimate. The area of the geologic formation considered as Proved includes the area delineated by drilling, and adjacent undrilled portions of the geologic formation that can reasonably be judged as continuous and commercially storable on the basis of available geoscience and engineering data. Capacity in undeveloped locations may be classified as Proved provided that: The locations are in undrilled areas of the geologic formation that can be judged with reasonable certainty to be commercially storable. Interpretations of available geoscience and engineering data indicate with reasonable certainty that the objective geologic formation is laterally continuous with drilled Proved locations. For Proved Capacity, the storage efficiency applied to these geologic formations should be defined based on a range of possibilities supported by analogs and sound engineering judgment considering the characteristics of the Proved area and the applied development program.
Probable Capacity	Probable Capacity is the additional Capacity that analysis of geoscience and engineering data indicate are less likely to be used for storage than Proved Capacity, but more certain to be used for storage than Possible Capacity.	It is equally likely that actual remaining quantities stored will be greater than or less than the sum of the estimated Proved plus Probable Capacity (2P). In this context, when probabilistic methods are used, there should be at least a 50% probability that the actual quantities stored will equal or exceed the 2P estimate. Probable Capacity may be assigned to areas of a geologic formation adjacent to Proved where data control or interpretations of available data are less certain. The interpreted geologic formation continuity may not meet the reasonable certainty criteria. Probable estimates also include incremental storage associated with project storage efficiency beyond that assumed for Proved.
Probable and Possible Capacity	(See above for separate criteria for Probable Capacity and Possible Capacity.)	The 2P and 3P estimates may be based on reasonable alternative technical and commercial interpretations within the geologic formation and/or subject project that are clearly documented, including comparisons to results in successful similar projects. Probable and/or Possible Capacity may be assigned where geoscience and engineering data identify directly adjacent portions of a geologic formation that may be separated from Proved areas by minor faulting or other geological discontinuities and have not been penetrated by a wellbore but are interpreted to be in communication with the known (Proved) geologic formation. In the case of storage in a geologic structure, Probable or Possible Capacity may be assigned to areas that are structurally higher than the Proved area. Possible (and in some cases, Probable) Capacity may be assigned to areas that are structurally lower than the adjacent Proved or 2P area. Caution should be exercised in assigning Capacity to adjacent geologic formations isolated by major, potentially sealing, faults until this part of the geologic formation is penetrated and evaluated as commercially suitable for storage. Justification for assigning Capacity in such cases should be clearly documented. Capacity should not be assigned to areas that are clearly separated from known storage by known parts of the geologic formation without storage (i.e., absence of porosity and permeability or negative test results); such areas may contain Prospective Resources.

Appendix A—Glossary of Terms Used in Resources Evaluations

The glossary provides high-level definitions of terms used in resource evaluations. Sections, tables, and figures within this SRMS are referenced.

1C: Denotes low-estimate scenario of Contingent Storage Resources.
2C: Denotes best-estimate scenario of Contingent Storage Resources.
3C: Denotes high-estimate scenario of Contingent Storage Resources.
1P: Taken to be equivalent to Proved Capacity; denotes low-estimate scenario of Capacity.
2P: Taken to be equivalent to the sum of Proved plus Probable Capacity; denotes best-estimate scenario of Capacity.
3P: Taken to be equivalent to the sum of Proved plus Probable plus Possible Capacity; denotes high-estimate scenario of reserves.
1U: Denotes low-estimate scenario of Prospective Storage Resources.
2U: Denotes best-estimate scenario of Prospective Storage Resources.
3U: Denotes high-estimate scenario of Prospective Storage Resources.

Accessible Pore Volume: Portion of a geologic formation with porosity that is connected and deemed suitable for CO_2 storage. Accessible pore volume is a requirement for a mass or volume to be called storable quantity. Accessible may also include access at the surface to the subsurface storable quantity.

Aggregation: The process of summing site (or project) level estimates of storage resources to higher levels or combinations such as field, country, or company totals. Arithmetic summation of incremental categories may yield different results from probabilistic aggregation of distributions. Consistent injectate composition is a requirement for aggregation of resources.

Analogous Projects: Analogous projects, as used in resources assessments, have similar rock and fluid properties, subsurface conditions (depth, temperature, and pressure), and drive mechanisms, but are typically at a more advanced stage of development than a geologic formation of interest and thus, may provide concepts to assist in the interpretation of more limited data and estimation of storage.

Approved for Development: All necessary approvals have been obtained, capital funds have been committed, and implementation of the development project is underway.

Assessment: See *Evaluation*.

Associated Injectants: Constituents present in the CO_2 stream, other than CO_2.

Behind-Pipe Capacity: Expected to be stored within geologic formations in existing wells, which will require additional completion work or future recompletion before the start of injection. In all cases, injection can be initiated or restored with relatively low expenditure compared with the cost of drilling a new well.

Best Estimate: With respect to resource categorization, this is the estimate of the quantity that will actually be stored by the project. It is the most realistic assessment of storable quantities, if only a single result were reported. If probabilistic methods are used, there should be at least a 50% probability (P50) that the quantities actually stored will equal or exceed the best estimate.

Capacity: Capacity refers to those storable quantities anticipated to be commercially stored by application of development projects to known storable quantities from a given date forward under defined conditions. Capacity must further satisfy four criteria: they must be discovered, storable, commercial, and remaining (as of a given date) on the basis of the development project(s) applied.

Chance: The probability of gain or success. As risk is generally associated with a negative outcome, the term chance is preferred for general usage to describe the probability of a discrete event occurring (see Risk).

Chance of Commerciality: The product of the Chance of Discovery and the Chance of Development.

Chance of Development: The chance that the storable quantities will be commercial after they are discovered.

Chance of Discovery: The chance that the geologic formation will result in the discovery of storable quantities.

Characterized Geologic Formation: Describes the status of an assessment to ascertain the presence of storable quantities in a specific geologic formation.

CO_2 Generator: Source of CO_2; typically anthropogenic industrial sites such as a coal-fired power plant, cement plant, ethanol plant, and natural gas processing.

CO_2 Stream: Fluid injected that is predominantly CO_2.

Commercial: When a project is commercial, this implies that the essential social, environmental, and economic conditions are met, including political, legal, regulatory, and contractual conditions. In addition, a project is commercial if the degree of commitment is such that the storage project is expected to be developed and placed on injection within a reasonable timeframe. While five years is recommended as a benchmark, a longer timeframe could be applied where, for example, development of economic projects are deferred at the option of the operator for, among other things, market-related reasons, or to meet contractual or strategic objectives. In all cases, the justification for classification as Capacity should be clearly documented.

Completion: Completion of a well. The process by which a well is brought to its final status: essentially dry hole, producer, injector, or monitor well. A dry hole is normally plugged and abandoned. A well deemed to be used as an injector is completed by establishing a connection between the geologic formation with storable quantities and the surface. Various methods are used to establish this connection, but they commonly involve the installation of some combination of borehole equipment, casing and tubing, and surface injection or storage facilities.

Completion Interval: The specific geologic formation(s) or portion of a geologic formation that is (are) open to the borehole and connected to the surface facilities for injection.

Conditions: The economic, marketing, legal, environmental, social, and governmental factors forecast to exist and impact the project during the time period being evaluated (also termed Contingencies).

Constant Case: Modifier applied to project resources estimates and associated cash flows when such estimates are based on those conditions (including costs and product prices) that are fixed at a defined point in time (or period average) and are applied unchanged throughout the project life, other than those permitted contractually. In other words, no inflation or deflation adjustments are made to costs or revenues over the evaluation period.

Containment: Part of the subsurface assessment that controls movement of stored CO_2 within a specific area. Necessary criteria for estimating and identifying storable quantities. A projected timeframe (e.g., 1,000 years) should be stated with the assessment.

Contingency: See *Conditions*.

Contingent Storage Resources: Those storage quantities, as of a given date, to be potentially stored in geologic formations by application of development projects, but which are not currently considered to be commercial because of one or more contingencies. Contingent Storage Resources are a class of discovered storage resources.

Cost Recovery: Under a typical storage-sharing agreement, the contractor is responsible for the field development and all exploration and development expenses. In return, the contractor recovers costs (investments and operating expenses) out of the gross injection stream. The contractor normally receives payment in CO_2 storage and is exposed to both technical and market risks.

Cumulative Injection: The sum of injection of CO_2 to date (see also *Injection*).

Current Conditions: Establishment of current economic conditions should include relevant historical prices, subsidies, tax credits, and associated costs of the project or related project (e.g., an industrial plant, power generation, or a hydrocarbon-producing project); and may involve a defined averaging period. The SPE PRMS guidelines recommend that a one-year historical average of costs and prices be used as the default basis of constant-case resources estimates and associated project cash flows. Where historic data are not available to define economic conditions, these must be assumed by the evaluator and assumptions clearly documented.

Custody Transfer Point: See *Reference Point*.

Decision Gates: The boundaries between different levels of project maturity.

Deterministic Method: The method of estimation of Capacity or Resources is called deterministic if a discrete estimate(s) is made on the basis of known geoscience, engineering, and economic data.

Developed Capacity: Expected to be stored from existing wells, including capacity behind pipe. Developed Capacity may be further subclassified as Injecting or Noninjecting.

Developed Injecting Capacity: Expected to be stored from completion intervals that are open and injecting at the time of the estimate.

Developed Noninjecting Capacity: Includes shut-in and behind-pipe Capacity. Shut-in Capacity is expected to be stored from: completion intervals that are open at the time of the estimate, but that have not yet started injecting; wells that were shut in for market conditions or pipeline connections; or wells not capable of injection for mechanical reasons. Behind-pipe Capacity includes those expected to be stored from zones in existing wells that will require additional completion work or future recompletion before the start of injection. In all cases, injection can be initiated or restored with relatively low expenditure compared with the cost of drilling a new well.

Development Not Viable: Discovered storable quantities for which there are no current plans to develop or to acquire additional data at the time as a result of limited storage potential. A project maturity subclass that reflects the actions required to move a project towards commercial storage.

Development On Hold: Discovered storable quantities for which project activities are on hold and/or in which justification as a commercial development may be subject to significant delay. A project maturity subclass that reflects the actions required to move a project toward commercial storage.

Development Pending: Discovered storable quantities for which project activities are ongoing to justify commercial development in the foreseeable future. A project maturity subclass that reflects the actions required to move a project towards commercial storage.

Development Plan: The design specifications, timing, and cost estimates of the development project including, but not limited to, well locations, completion techniques, drilling methods, processing facilities, transportation, and marketing. (See also *Project*.)

Development Unclarified: Discovered storable quantities in which project activities are on under evaluation and in which justification as a commercial development is unknown on the basis of available information.

Discovered: Refers to storable quantities for which one or several exploratory wells have established through testing, sampling, and/or logging the existence of a significant storage quantity. In this context, "significant" implies that there is evidence of sufficient storable quantities to justify estimating the in-place quantity demonstrated by the well(s) and for evaluating the potential for economic storage (see also *Discovered Storage Resources* and *Discovery*).

Discovered Storage Resources: That quantity of storage that is estimated, as of a given date, to be contained in geologic formations before injection. Discovered Storage Resources may be subdivided into Commercial, Sub-Commercial, and Inaccessible, with the estimated commercially storable portion classified as Capacity, and the estimated subcommercial recoverable portion classified as Contingent Storage Resources.

Discovery: One geologic formation, or several collective geologic formations, for which one or several wells have established through testing, sampling, and/or logging the existence of significant storable quantities. (See also *Discovered Storage Resources* and *Discovered*.)

Economic: In relation to Storage Capacity and Resources, economic refers to the situation in which the income from an operation exceeds the expenses involved in, or attributable to, that operation.

Economic Interest: An Economic Interest is possessed in every case in which an investor has acquired any Interest in mineral in place, and secures, by any form of legal relationship, revenue derived from the extraction of the mineral to which he must look for a return of his capital.

Economic Limit: The injection rate beyond which the net operating cash flows (after royalties or share of storage owing to others) from a project—which may be an individual well, lease, or entire field—are negative.

Entitlement: That portion of future storage (and thus resources) legally accruing to a lessee or contractor under the terms of the development and storage contract with a lessor.

Entity: A legal construct capable of bearing legal rights and obligations. In resources evaluations, this typically refers to the lessee or contractor, which is some form of legal corporation (or consortium of corporations). In a broader sense, an entity can be an organization of any form and may include governments or their agencies.

Estimated Ultimate Stored: Those storable quantities that are estimated on a given date to be potentially stored, plus those quantities already stored therein.

Evaluation: The geosciences, engineering, and associated studies, including economic analyses, conducted on an exploration, development, or storage project resulting in estimates of the quantities that can be stored and the associated cash flow under defined forward conditions. Projects are classified and estimates of derived quantities are categorized according to applicable guidelines. (Also termed Assessment.)

Evaluator: The person or group of persons responsible for performing an evaluation of a project. These may be employees of the entities that have an economic interest in the project or independent consultants contracted for reviews and audits. In all cases, the entity accepting the evaluation takes responsibility for the results, including Capacity and Resources and attributed value estimates.

Exploration: Prospecting for undiscovered petroleum.

Forecast Case: Modifier applied to project resources estimates and associated cash flow when such estimates are based on those conditions (including costs and product price schedules) forecast by the evaluator to reasonably exist throughout the life of the project. Inflation or deflation adjustments are made to costs and revenues during the evaluation period.

Formation Tests: Any type of direct injection or production test that is used to ascertain CO_2 injection rates.

Geostatistical Methods: A variety of mathematical techniques and processes dealing with the collection, methods, analysis, interpretation, and presentation of masses of geoscience and engineering data to (mathematically) describe the variability and uncertainties within any geologic formation, specifically related here to resources estimates, including the definition of (all) well and geologic formation parameters in 1, 2, and 3 dimensions and the resultant modeling and potential prediction of various aspects of performance.

High Estimate: With respect to resource categorization, this is considered to be an optimistic estimate of the quantity that will actually be stored by a project. If probabilistic methods are used, there should be at least a 10% probability (P10) that the quantities actually stored will equal or exceed the high estimate.

Hydrocarbons: Chemical compounds consisting wholly of hydrogen and carbon.

Inaccessible: Portion of discovered resources that are inaccessible from development as a result of a lack of physical, societal, or regulatory access at the surface or subsurface.

Inaccessible Contingent Storage Resources: Portion of Contingent Storage Resources' storable quantities that is identified but is not considered available for storage.

Inaccessible Resources: That portion of Contingent (Discovered) or Prospective (Undiscovered) Storage Resource quantities, which are estimated as of a given date, not to be used for storage. A portion of these quantities may become storable in the future as commercial circumstances change, technological developments occur, or additional data are acquired.

Inaccessible Storage: Storable quantities for which a feasible project cannot be defined by use of current, or reasonably forecast improvements in, technology.

Injection: The forcing, pumping, or free flow under vacuum, of substances into a porous and permeable subsurface rock formation. Injected substances can include either gases or liquids (see *Cumulative Injection*).

Injection-Sharing Contract: In an injection-sharing contract between a contractor and a host government, the contractor typically bears all risk and costs for exploration, development, and storage. In return, if exploration is successful, the contractor is given the opportunity to recover the incurred investment from storage, subject to specific limits and terms. Ownership is retained by the host government; however, the contractor normally receives title to the prescribed share of the stored quantities.

Justified for Development: Implementation of the development project is justified on the basis of reasonable forecast of commercial conditions at the time of reporting, and there are reasonable expectations that all necessary approvals/contracts will be obtained. A project maturity subclass that reflects the actions required to move a project toward commercial storage.

Known: The key requirement to consider storable quantities as known, and thus containing Capacity or Contingent Resources, is that it must have been discovered, that is, penetrated by a well that has established through testing, sampling, or logging the existence of a significant storable quantities.

Known Geologic Formation: A geologic formation that has been assessed and presence is verifiable.

Lead: A project associated with storable quantities that is currently poorly defined and requires more data acquisition and/or evaluation to be classified as a prospect. A project maturity subclass that reflects the actions required to move a project toward commercial production.

Low/Best/High Estimates: The range of uncertainty reflects a reasonable range of estimated storable quantities at varying degrees of uncertainty (using the cumulative scenario approach) for an individual storage project.

Low Estimate: With respect to resource categorization, this is considered to be a pessimistic estimate of the quantity that will actually be stored by a project. If probabilistic methods are used, there should be at least a 90% probability (P90) that the quantities actually stored will equal or exceed the low estimate.

Measurement: The process of establishing quantity (volume or mass) and quality of storage products delivered to a reference point under conditions defined by delivery contract or regulatory authorities.

Monte Carlo Simulation: A type of stochastic mathematical simulation that randomly and repeatedly samples input distributions (e.g., geologic formation properties) to generate a resulting distribution (e.g., storable quantities).

Net Present Value: The summation of the discounted cash flows when the cash flows are discounted according to a defined discount rate and time.

Net Storage Resources: The incremental storable quantities used by each project.

On Injection: The development project is currently injecting. A project status/maturity subclass that reflects the actions required to move a project toward commercial storage.

Operator: The company or individual responsible for managing an exploration, development, and/or storage operation of the storage site and project.

P1: Equivalent to Proved Capacity.

P2: Equivalent to Probable Capacity.

P3: Equivalent to Possible Capacity.

Penetration/ Penetrated: The intersection of a wellbore with a geologic formations.

Petroleum: Petroleum is defined as a naturally occurring mixture consisting of hydrocarbons in the gaseous, liquid, or solid phase. Petroleum may also contain nonhydrocarbon compounds, common examples of which are carbon dioxide, nitrogen, hydrogen sulfide, and sulfur. In rare cases, nonhydrocarbon content could be greater than 50%.

Play: A project associated with a prospective trend of potential prospects, but which requires more data acquisition and/or evaluation to define specific leads or prospects. A project maturity subclass that reflects the actions required to move a project toward commercial storages.

Point of Sales: See *Reference Point*.

Possible Capacity: An incremental category of estimated storable quantities associated with a defined degree of uncertainty. Possible Capacity is the additional Capacity that analysis of geoscience and engineering data suggest are less likely to be stored than Probable Capacity. The total quantities ultimately stored from the project have a low probability to exceed the sum of Proved plus Probable plus Possible (3P), which is equivalent to the high-estimate scenario. When probabilistic methods are used, there should be at least a 10% probability that the actual quantities stored will equal or exceed the 3P estimate.

Potentially Accessible: Quantity of Undiscovered Storage Resources estimated, as of a given date, to be potentially accessible within undiscovered geologic formations or uncharacterized parts of discovered geologic formations by application of future exploration/development projects.

Probability: The extent to which an event is likely to occur, measured by the ratio of the favorable cases to the whole number of cases possible. SPE convention is to quote cumulative probability of exceeding or equaling a quantity in which P90 is the small estimate and P10 is the large estimate. (See also *Uncertainty*.)

Probable Capacity: An incremental category of estimated storable quantities associated with a defined degree of uncertainty. Probable Capacity are those additional Reserves that are less likely to be stored than Proved Capacity but more certain to be stored than Possible Capacity. It is equally likely that actual remaining storable quantities will be greater than or less than the sum of the estimated Proved plus Probable Reserves (2P). In this context, when probabilistic methods are used, there should be at least a 50% probability that the actual quantities stored will equal or exceed the 2P estimate.

Probabilistic Method: The method of estimation of Resources is called probabilistic when the known geoscience, engineering, and economic data are used to generate a continuous range of estimates and their associated probabilities.

Project: Represents the link between the storable quantities and the decision-making process, including budget allocation. A project may, for example, constitute the development of a single site, or an incremental development in a storage site, or the integrated development of several sites and associated facilities with a common ownership. In general, an individual project will represent a specific maturity level at which a decision is made on whether or not to proceed (i.e., spend money), and there should be an associated range of estimated storable quantities for that project. (See also *Development Plan*.)

Property: A volume of the Earth's crust wherein a corporate entity or individual has contractual rights to extract, process, and market a defined portion of specified in-place minerals (including petroleum). Defined in general as an area but may have depth and/or stratigraphic constraints. May also be termed a lease, concession, or license.

Prospect: A project associated with a potential accumulation that is sufficiently well defined to represent a viable drilling target. A project maturity subclass that reflects the actions required to move a project toward commercial production.

Prospective Storage Resources: Those storable quantities, which are estimated as of a given date, to be potentially stored from undiscovered storage resources.

Proved Capacity: An incremental category of estimated storable quantities associated with a defined degree of uncertainty. Proved Capacity are those storable quantities which, by analysis of geoscience and engineering data, can be estimated with reasonable certainty to be commercially stored, from a given date forward, from known storable quantities and under defined economic conditions, operating methods, and government regulations. If deterministic methods are used, the term reasonable certainty is intended to express a high degree of confidence that the quantities will be stored. If probabilistic methods are used, there should be at least a 90% probability that the quantities actually stored will equal or exceed the estimate. Often referred to as 1P, also as Proven.

Pure-Service Contract: An agreement between a contractor and a host government that typically covers a defined technical service to be provided or completed during a specific period of time. The service-company investment is typically limited to the value of equipment, tools, and expenses for personnel used to perform the service. In most cases, the service contractor's reimbursement is fixed by the terms of the contract with little exposure to either project performance or market factors.

Range of Uncertainty: The range of uncertainty of the storable quantities may be represented by either deterministic scenarios or by a probability distribution. (See *Resource Uncertainty Categories*.)

Reasonable Certainty: If deterministic methods for estimating recoverable resource quantities are used, then reasonable certainty is intended to express a high degree of confidence that the estimated quantities will be recovered.

Reasonable Expectation: Indicates a high degree of confidence (low risk of failure) that the project will proceed with commercial development or the referenced event will occur.

Reasonable Forecast: Indicates a high degree of confidence in predictions of future events and commercial conditions. The basis of such forecasts includes, but is not limited to, analysis of historical records and published global economic models.

Reference Point: A defined location within an injection and storage operation where quantities of injected CO_2 are measured under defined conditions before custody transfer (or consumption). Also called Point of Sale or Custody-Transfer Point.

Remaining Storage Resources: The sum of Capacity, Contingent Resources, and Prospective Resources, excluding stored (i.e., previously injected) quantities.

Reservoir: A subsurface rock formation containing an individual and separate natural accumulation of moveable petroleum that is confined by impermeable rocks/formations and is characterized by a single-pressure system.

Resources: As used herein, is intended to encompass all storable quantities (accessible and inaccessible) within geologic formations—discovered and undiscovered—plus those quantities already stored.

Resources Categories: Subdivisions of estimates of resources to be stored by a project(s) to indicate the associated degrees of uncertainty. Categories reflect uncertainties in the total storage resources remaining, that portion of the total storage resources that can be used for storage by applying a defined development project or projects, and variations in the conditions that may impact commercial development (e.g., market availability, contractual changes). (See also *Proved, Probable,* and *Possible; 1C, 2C, 3C, 1P, 2P,* and *3P*.)

Resources Classes: Subdivisions of Resources that indicate the relative maturity of the development projects being applied to yield the storable quantities. Project maturity may be indicated qualitatively by allocation to classes and subclasses and/or quantitatively by associating a project's estimated chance of reaching injecting status.

Resources Uncertainty Categories: See *Resources Categories*.

Risk: The probability of loss or failure. As risk is generally associated with the negative outcome; "Chance" is preferred for general use to describe the probability of a discrete event occurring. (See *Chance*.)

Risked-Service Contract: These agreements are very similar to the injection-sharing agreements, with the exception of contractor payment, but risk is borne by the contractor. With a risked-service contract, the contractor usually receives a defined share of revenue rather than a share of the stored quantities.

Royalty: Royalty refers to payments that are due to the host government or storage-rights owner (lessor) in return for the operator (lessee/contractor) to have legal access to the storage resources. Many agreements allow for the operator to inject the royalty quantities, sell them on behalf of the royalty owner, and pay the proceeds to the owner. Some agreements provide for the royalty to be taken only in kind by the royalty owner.

Shut-in Capacity: Expected to be recovered from completion intervals that are open at the time of the estimate, but that have not started injecting; wells that were shut in for market conditions or pipeline connections; or wells not capable of injection for mechanical reasons.

Significant Quantity: Implies that there is evidence of a sufficient quantity of Total Storage Resources to justify estimating the storable quantity (volume or mass) demonstrated by the well(s) and for evaluating the potential for commercial storage.

Storable Quantities: Quantities of CO_2 that can be stored as part of an estimated pore volume of a geologic formation that is accessible to CO_2 via a CO_2 injection well (i.e., a storage project) sometime in the future and can be reported as mass or volume of CO_2. To be considered a storable quantity, an assessment of the longevity of the storage of the CO_2 is required (i.e., containment will be part of the analyses).

Storage Efficiency: Fraction of the Storage Capacity, Storage Resource, total pore volume, effective pore volume, bulk volume, and/or storable quantity expected to be used for storage by a specific project. May be based on actual injection, planned project, or a regional assessment. The basis for the storage efficiency must be clearly identified and documented.

Stored: A classification that includes the cumulative quantity of CO_2 that has been actually injected over a defined time. While all storage-resources estimates and injection are reported in terms of the metered CO_2 specifications, raw-injection quantities (including non-CO_2 constituents) are also measured to support engineering analyses requiring voidage calculations.

Stored Quantities: Part of the Capacity for a geologic formation that has injected CO_2 occupying pore volume; it can be reported as mass or volume.

Subcommercial: A project is Subcommercial if the degree of commitment is such that the storable quantities are not expected to be developed and placed on injection within a reasonable timeframe. While five years is recommended as a benchmark, a longer timeframe could be applied at the point at which, for example, development of economic projects are deferred at the option of the operator for, among other things, market-related reasons or to meet contractual or strategic objectives. Discovered subcommercial projects are classified as Contingent Storage Resources.

Taxes: Obligatory contributions to the public funds, levied on persons, property, or income by governmental authority.

Technical Uncertainty: Indication of the varying degrees of uncertainty in estimates of storable quantities influenced by range of storage resources and the range of the storage efficiency of the project being applied.

Total Storage Resources: Generally accepted to be all those estimated storable quantities contained in the subsurface, as well as those quantities already stored.

Ultimate Storage Efficiency: Defined as the ratio of EUS to a base, which can be the Storage Capacity, Storage Resource, total pore volume, effective pore volume, bulk volume, and/or storable quantity expected to be used for storage by a specific project. May be based on actual injection, planned project, or a regional assessment. The basis for the storage efficiency must be clearly identified and documented. (See *Storage Efficiency* and *Estimated Ultimate Storage*.)

Uncertainty: The range of possible outcomes in a series of estimates. For Storage Resource assessments, the range of uncertainty reflects a reasonable range of estimated storable quantities for a project. (See also *Probability*.)

Uncharacterized Geologic Formation: A known geologic formation that has inadequate data for estimating storable quantities to be considered discovered.

Undeveloped Capacity: Quantities expected to be stored through future investments: from new wells on undrilled acreage accessing known storable quantities; from deepening existing wells to known storable quantities; from in-fill wells that will increase storage; or in which a relatively large expenditure (e.g., when compared to the cost of drilling a new well) is required to recomplete an existing well or install injection or transportation facilities to increase storage efficiency.

Undiscovered Geological Formation: A yet-to-be-discovered geologic formation.