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Effective communication in an emerging CCS industry – an application of the SPE SRMS to convey contingencies, uncertainties, commerciality, and progress to project approval

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At COP28, Carbon Capture, Utilization, and Storage was declared a removal technology whose application must be accelerated. In 2017, the Society of Petroleum Engineers (SPE) published the CO₂ Storage Resource Management System (SRMS) as a framework for stakeholder communication. The SRMS guidelines were designed to support the creation of reports that inform readers regarding the contingencies that must be overcome to obtain project approval, uncertainty in the mass of CO₂ that can be stored, and the commerciality of the project. However, working examples where the SRMS has been used to communicate project status in the public domain are limited. In 2023, the authors of this paper referred to the SRMS as the standard for completing an expert report, termed a Competent Persons Report (CPR), for the Viking Carbon Capture and Storage (CCS) development in the United Kingdom. During the application of the SRMS framework, challenges were identified in conveying the progress made by the project proponent in identifying and addressing technical risks. This paper describes innovations developed to supplement the SRMS guidelines and improve communication with stakeholders. First, a flowchart was developed to explain a vital interpretation of the SRMS. Next, a defined framework of technical milestones was designed to assess the maturity of a given technical topic within the SRMS. This framework was combined with radial data visualization. The combination allowed multiple storage sites to be compared simultaneously and allowed stakeholders to quickly identify the maturity of technical analysis for any given site. We conclude that improving the consistency and clarity of CCS reporting to stakeholders can help build trust in this emerging industry.

KEYWORDS

CCS, SRMS, SPE storage resource management system, competent person, stakeholder reporting, CCS risk and uncertainty reporting, carbon capture and storage reporting

1 Introduction

How does a new industry build trust, especially a complex one like CCS? In this industry, many stakeholders, from regulators to the public to emitters, need to trust that a storage site will be both effective and safe.

Many articles have been published about establishing trust in corporate activities (Esser, 2021; Ryan, 2022; Vitasek et al., 2022). A constant across all recommendations is clear communication. Easy to say but difficult to achieve, clear communication embraces clarity, compassion, competency, connection, and consistency (Shapira and Horsager, 2022).

Industries build frameworks and guidelines as tools for engaging with people and communicating ideas. These tools can be found in virtually any sector. As an extreme example, within strategic consulting, frameworks are even made to summarize frameworks (Reeves et al., 2015).

Within the extractive resource industries, guidelines that help explain contingencies that must be overcome to obtain project approval, uncertainties in the amount of resource that can be extracted and the commerciality of the project play a vital role. They connect an industrial project or portfolio of projects to stakeholders via formal reporting that uses the guideline. In mining and oil and gas, some of these guidelines have been in use for decades to engage in activities such as:

- Annual Reporting
- Debt facilities, such as Reserve Based Lending (RBL)
- Bond and Equity Initial Public Offerings (IPOs)
- Supporting contracts
- Communicating projects and project values to owners

The following are examples of guidelines and frameworks currently in use in extractive industries (SPE, 2018; SPEE, 2018; CIM, 2019; JORC, 2012):

- Society of Petroleum Engineers (SPE) Petroleum Resource Management System (PRMS)
- Society of Petroleum Evaluation Engineers Canadian Oil and Gas Engineering Handbook (COGE Handbook)
- Canadian Institute of Mining, Metallurgy and Petroleum (CIM) Metals Mineral Resources Mineral Reserves (MRMR) Best Practice Guidelines
- Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves (JORC Code)

These guidelines are so well established that they are part of securities regulation. Be it in Canada under the NI 51-101 or NI 43-101 rules, Europe with European Securities and Markets Authority (ESMA) rules, the United Kingdom with the London Stock Exchange (LSE) rules, or Australia and the Australian Stock Exchange (ASX) rules, it is typical for reports conforming to required guidelines to be mandated as a method of investor communication (Canadian Securities Administrators, 2015; Canadian Securities Administrators, 2016; ASX, 2022; LSE, 2009; ESMA, 2011; ASX, 2013; ESMA, 2013; NPD, 2001; SEC, 2009; The Financial Services Authority, 2002).

In Europe, these reports are often referred to as CPRs. In other countries they may have different names, such as an “expert report” or an “independent reserves and resources report” or a “qualified persons report.” This paper will use the term CPR to refer to all such reports globally.

Securities regulations govern who can author these reports. Typically, the authors of CPRs must be registered members of securities-regulator-approved professional bodies¹. The authors are usually professional engineers and geoscientists with wide experience in technical and commercial matters related to the type of industrial activity they report on. CPR authors must also have demonstrable independence from project proponents. The securities regulator of the exchange under which their reports are issued typically oversees CPR authors and the work they produce.

Given their decades of use, the mineral extraction industries have well-established uses of CPRs. They serve as a communication tool for the mineral project developer (the company that extracts the mineral) to engage with those who ultimately own the commodities (usually governments), as well as those who finance commodity development and buy the commodities. In turn, these stakeholders use the information to make decisions, including whether to invest and how to establish and manage contracts (Figure 1).

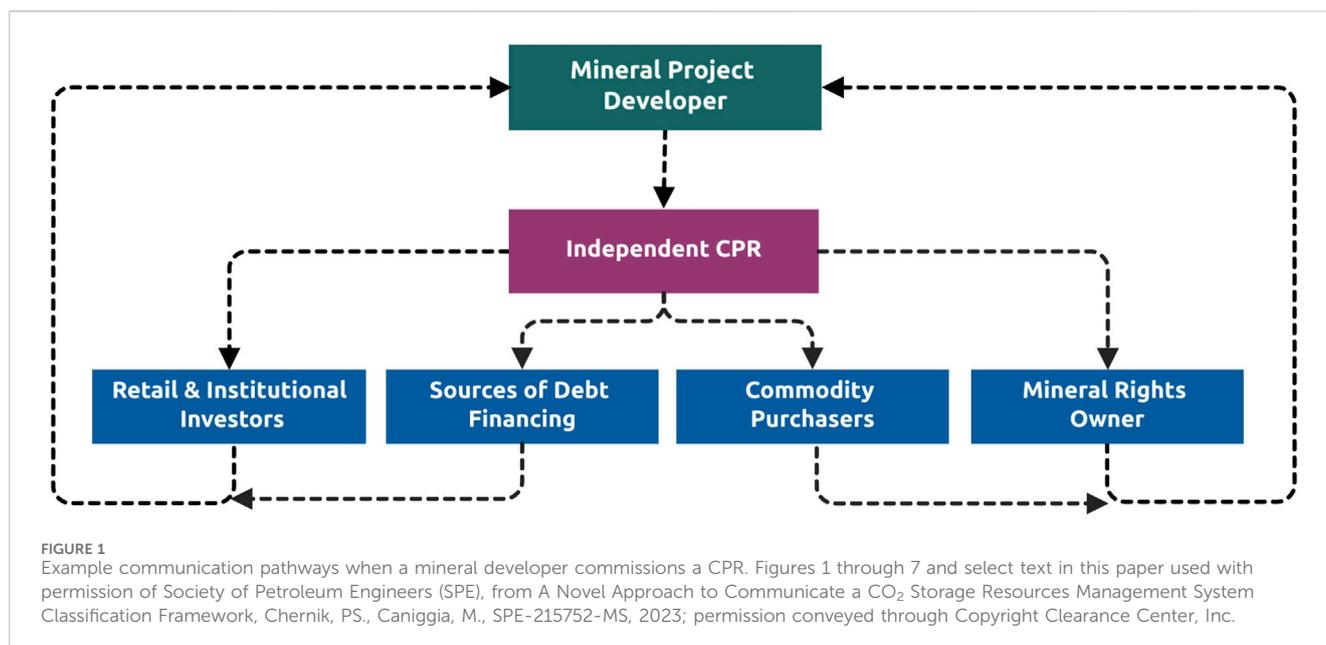
In the energy transition, additional industries that need guidelines and frameworks to communicate with stakeholders are expanding. A leader in developing new guidelines is the United Nations, which has created a framework designed to support any resource industry (UNECE, 2020). Industry-specific guidance has been developed for the geothermal industry (Delbert et al., 2010; AGRCC, 2010; National Renewable Energy Laboratory, 2021). Within the CCS industry, aside from UN efforts, several guidelines have also been developed² (SPE, 2017; International Organization for Standardization, 2017; Akhurst et al., 2021; DNV, 2021).

As of July 2024, there have been only a handful of CCS disclosures to equity markets, referencing CCS guidelines and frameworks. Examples include those by Santos (Wilson et al., 2023) and Pilot Energy (Pilot Energy, 2024) in Australia, Wintershall DEA in Denmark (Wintershall, 2020), Novatek in Russia (NOVATEK, 2022) and Harbour Energy in the United Kingdom (Harbour Energy, 2023).

Aside from public equity disclosures, there is evidence of CCS guidelines (meant to support reporting of contingencies, uncertainties and commerciality) playing a role in regulatory

¹ As an example see Canadian NI 51-101 Companion Policy (Canadian Securities Administrators, 2023, 5).

² It should be noted the guidelines referenced here are for reporting regarding contingencies preventing project approval, uncertainty in storage, and commerciality. They are designed with public disclosure and financing in mind. Additionally, there are regulatory guidelines and legal frameworks, that projects operate and report under, in each nation (Akerboom et al., 2021; National Energy Technology Laboratory, 2017; European Commission, 2023; EPA, 2024a; Alberta Energy Regulator, 2024; Australia DCCEEW, 2024).



processes in the United Kingdom (UK DESNZ, 2023a), Canada (DNV, 2010) and Norway (NOD, 2024).

In 2023, the authors of this paper referred to the SRMS as the standard to complete a Competent Person's Report (CPR), referred to by Harbour Energy in their disclosure to the London Stock Exchange (Harbour Energy, 2023).

Using the SRMS as a tool for stakeholder communication was challenging. Specifically, it was difficult to communicate the progress the project proponent had made in addressing technical contingencies (technical risks) within the SRMS classification of Contingent Storage Resources.

As a result of the challenges encountered, supplementary methods were developed, beyond those described explicitly in the SRMS, to improve communication. First, a flowchart was developed to explain a vital interpretation of the SRMS. Second, a defined framework of technical milestones was developed to assess the maturity of a given technical topic within the SRMS. The milestones were designed to convey the progress toward a complete risk system, Monitoring Measurement and Verification (MMV) plan, and Corrective Measures (CM) plan. Finally, the framework was combined with radial data visualization. The combination allowed multiple storage sites to be compared simultaneously and allowed stakeholders to quickly identify the maturity of technical analysis for any given site.

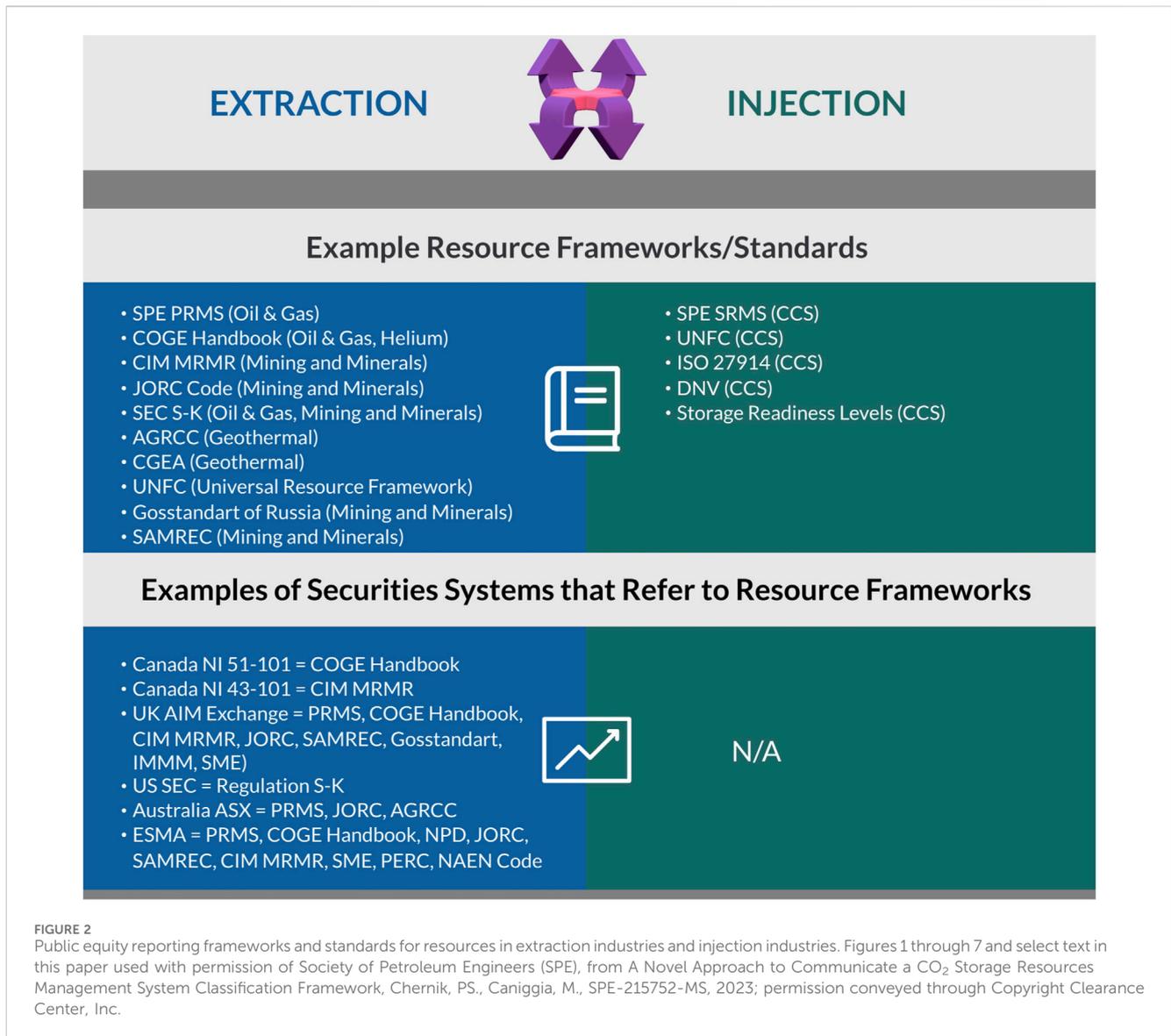
We believe this to be a simple but significant innovation in the applicability of the SRMS as a tool to communicate project status and the pace of addressing risks. First, the ability to systematically categorize the maturity of technical work in relation to an approved risk system, MMV, and CM plans allows for ease of comparison of projects. This is important for companies with large CCS portfolios, as it facilitates finance and mergers and acquisition (M&A) activity and helps regulators compare different activities within their jurisdiction. Second, the ability to visualize the progress of technical work across significant lines of analysis, highlighted by the SRMS, will allow managers and stakeholders to gain a consistent appreciation of project progress. This will aid in decision-making regarding where to allocate resources or estimate project timelines.

2 Carbon capture and storage – a unique resource industry

CCS has the potential to grow into a significant global industry (Holloway, 1996). COP28 declared it to be a key technology whose use needs to be accelerated (UNFCCC, 2023a) to achieve climate change goals. This declaration was consistent with the findings of the Intergovernmental Panel on Climate Change (IPCC), which identified CCS as a necessary mitigating technology to fight climate change (Metz et al., 2005; Shukla et al., 2022). The scale of the potential demand for CCS is significant, with an estimated 5,600 mega-tonnes per annum needed by 2,050 (Global CCS Institute, 2021). In 2023, it was estimated there were 26 CCS facilities under construction and 325 projects at various levels of development (Global CCS Institute, 2023b). Given government support through actions like the United Kingdom industrial carbon capture and storage business model (UK DESNZ, 2023b), the United States 45Q tax support for CCS (Bright, 2021), the EU Industrial Carbon Management Strategy (European Commission, 2024), and plans in a host of other countries including Saudi Arabia and Malaysia, (IEA, 2023; Global CCS Institute, 2023a) these project counts are likely to grow.

Alongside the growth of the CCS industry is an increasing need for stakeholder communication. Thus, guidelines and standards are being developed for CCS, as in other resource industries. As examples, the SPE, International Organization for Standardization (ISO), and the United Nations have all published guidelines and standards (SPE 2017; UNECE, 2016; International Organization for Standardization, 2017). In academia, a proposed Storage Readiness Level framework can be found (Akhurst et al., 2021). There are even private sector standards published by DNV (DNV, 2021).

However, CCS has a few key factors that differentiate it from other resource industries:

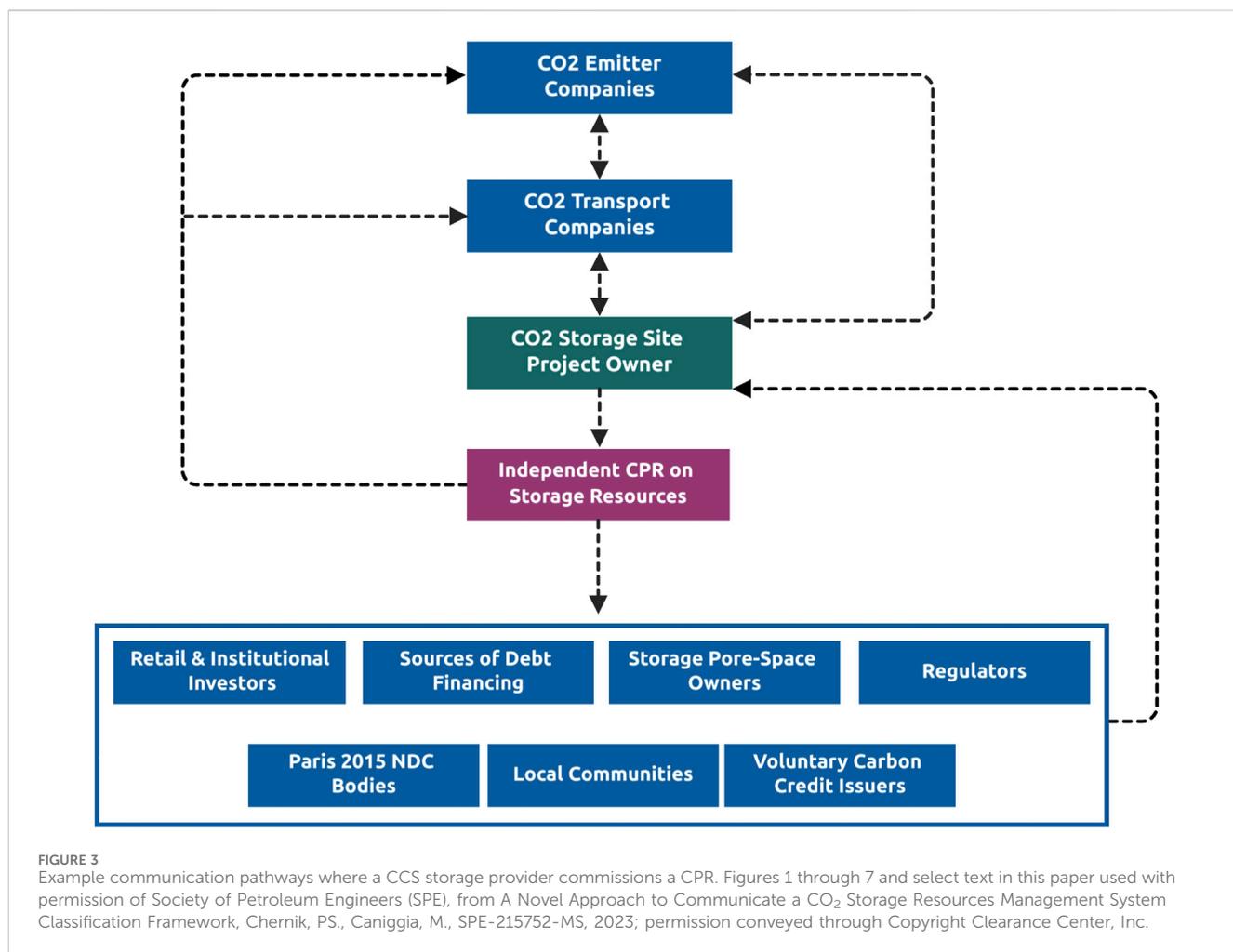


1. It is the opposite of the extractive industries. As the name says, rather than taking from the environment, CO₂ is stored. Therefore, the resource of a given project is its capacity to store CO₂.
2. CO₂ store sites do not extract a material to be sold. Instead, CO₂ storage is a service. The services may be provided to internal CO₂ emitters as part of a vertically integrated project. Or the service may be offered to external CO₂ emitters, who pay to access the store site. Some are also arguing that CO₂ storage is such an essential service it should be considered a public good and funded through tax bases ([The University of Edinburgh, 2021](#)).
3. Final Investment Decisions (FID) for CO₂ storage sites do not necessarily need the project to be economic. Traditional resource projects expect certain financial thresholds to be met. For example, typical investment worthy projects require a positive Net Present Value (NPV) accounting for cost of capital. However, CCS is a mitigation method that supports efforts in the fight against global warming. Therefore, FID may be taken, and the project may be treated as

commercial, even if the CCS investment is sub-economic. Objectives other than economics might drive the investment decision. Examples include organizational decarbonization targets, regulatory requirements, or corporate financing tied to portfolio emissions reduction. A sub-economic investment may then become economic through the generation of voluntary carbon credits ([Verra, 2022](#)).

- a. Whether a given CCS investment is economic is often a question of project boundaries. Is the project a dedicated CCS site? Is CCS treated as an incremental project³ to an existing industrial activity? Or is it treated as part of the lifecycle costs of a new industrial development that does more than just CCS?

³ Project boundary definitions and the meanings of incremental projects in investment decisions is discussed in the SPE SRMS and SPE PRMS Guidelines.



The unique nature of CCS projects means that there are a new range of stakeholders who will potentially use a CPR.

Figure 2 highlights how there is currently no regulated use of injection frameworks to engage with investors in the equity markets. This holds for a variety of injection projects, including CO₂, CH₄, and H₂. Figure 3 is an example of where a Storage Resource CPR could fit within a stakeholder group (note this is not meant to be an exhaustive list of potential stakeholders).

Important aspects to note from Figure 3 include:

- Upstream of the storage site project owner are the emitter of CO₂ and the transporter of CO₂. These are critical stakeholders in a CCS system. They provide the supply of the CO₂ to the storer, and rely on the store site to take their CO₂ at the agreed rates and volumes. Communication is flowing constantly between these emitters, the transporters and the storer.
 - In some cases, a single corporation may be two or all three stakeholders. In other cases, it may be multiple companies.
- There are a host of new stakeholders that may require, or benefit from, access to a CPR. These include voluntary carbon credit issuers, pore space owners and organizations involved with monitoring Nationally Determined Contributions (UNFCCC, 2023b).

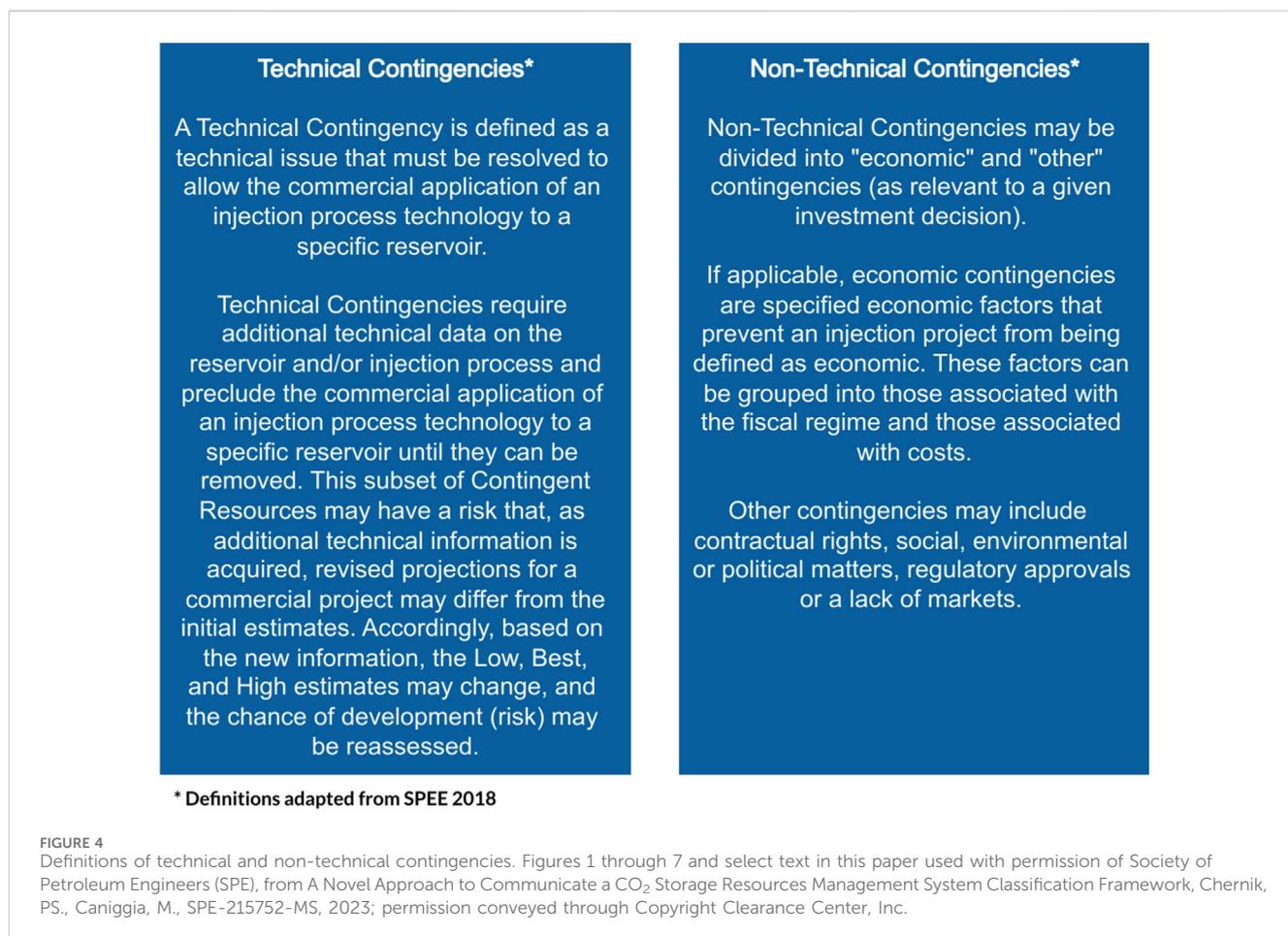
3 An early application of the SPE SRMS

In late 2022, a CPR was commissioned for the offshore storage related to the Viking CCS Project, United Kingdom (Harbour Energy, 2023; Viking CCS, 2023). The CPR used the SPE SRMS (SPE, 2017) as the standard to evaluate the project. This CPR was believed to be the first reported to the European equity markets according to the SRMS standard. It was also one of the earliest CPRs written after the publication of the 2022 SRMS Application Guidelines (SPE, 2022).

As such, when applying the SRMS, there was no custom or practice regarding measuring a project against the standard. There was also no common understanding of the terminology in the SRMS standard amongst stakeholders who would access the report.

Stakeholders were considered when executing the CPR mandate. Particular attention was paid to the fact that, for many readers, this would potentially be the first CPR they had ever had access to. With the variety of new stakeholders involved in CCS (Figure 3), all types of readers needed to be considered, each with varying levels of CCS knowledge.

Thus, clearly communicating what the SRMS framework requires and how projects are mapped to the framework was treated as a critical need in writing the report.



3.1 Implementing the SRMS

Early in the project, a key challenge was noted concerning CO₂ Storage Projects – there are irreducible risks that can never be eliminated. Instead, risks are identified (typically in a risk register), planned for, and incorporated into the Measurement, Monitoring and Verification (MMV) plan and Corrective Measures (CM) plan⁴. Regulators are establishing MMV and CM frameworks that companies will operate under (NSTA, 2022; NSTA, 2023; Alberta Government, 2022; EPA, 2024b; IEA, 2022).

As such, Technical Contingencies (Figure 4), are an area of considerable focus in CCS projects. Technical Contingencies are integral to the CCS licence application process with regulators. They are incorporated into a formal risk assessment process where CCS operators complete detailed studies to understand the likelihood and severity of the Technical Contingency. Then, each contingency is formally addressed and, where appropriate, incorporated into the MMV and CM plans.

⁴ Note that the terms like MMV and Corrective Measures vary between jurisdictions. In the United Kingdom, the terms Monitoring Plan and Corrective Measures Plan are used.

Technical evaluations of CCS can be broadly treated as studies on the mass of CO₂ that can be stored, the ability to inject the CO₂ at required rates, and the ability to contain the CO₂ (Wilson et al., 2023). Underlying all study work is an understanding of how injecting CO₂ increases pressure and how pressure impacts a storage project.

Our review of the SRMS identified that the SRMS recommends eight broad technical “Topics” to be addressed during the evaluation of a storage project:

1. Legacy well containment
 - a. Assessment of leakage potential of CO₂ and *in situ* fluids via legacy wells within the storage complex and surrounding area.
2. Geological containment
 - a. Vertical and lateral containment of CO₂ and *in situ* fluids.
3. Geomechanical modelling
 - a. Assessment of geomechanical modeling and integration into containment and injectivity.
4. Injectivity
 - a. Includes factors that impact CO₂ injection rate, such as phase behavior, skin, and injection pressure limits (pressure local to a well and at a reservoir scale).
5. Volumetric method
 - a. Total storage resources (TSR), storable quantity, or pore volume estimates using the volumetric method, if relevant.

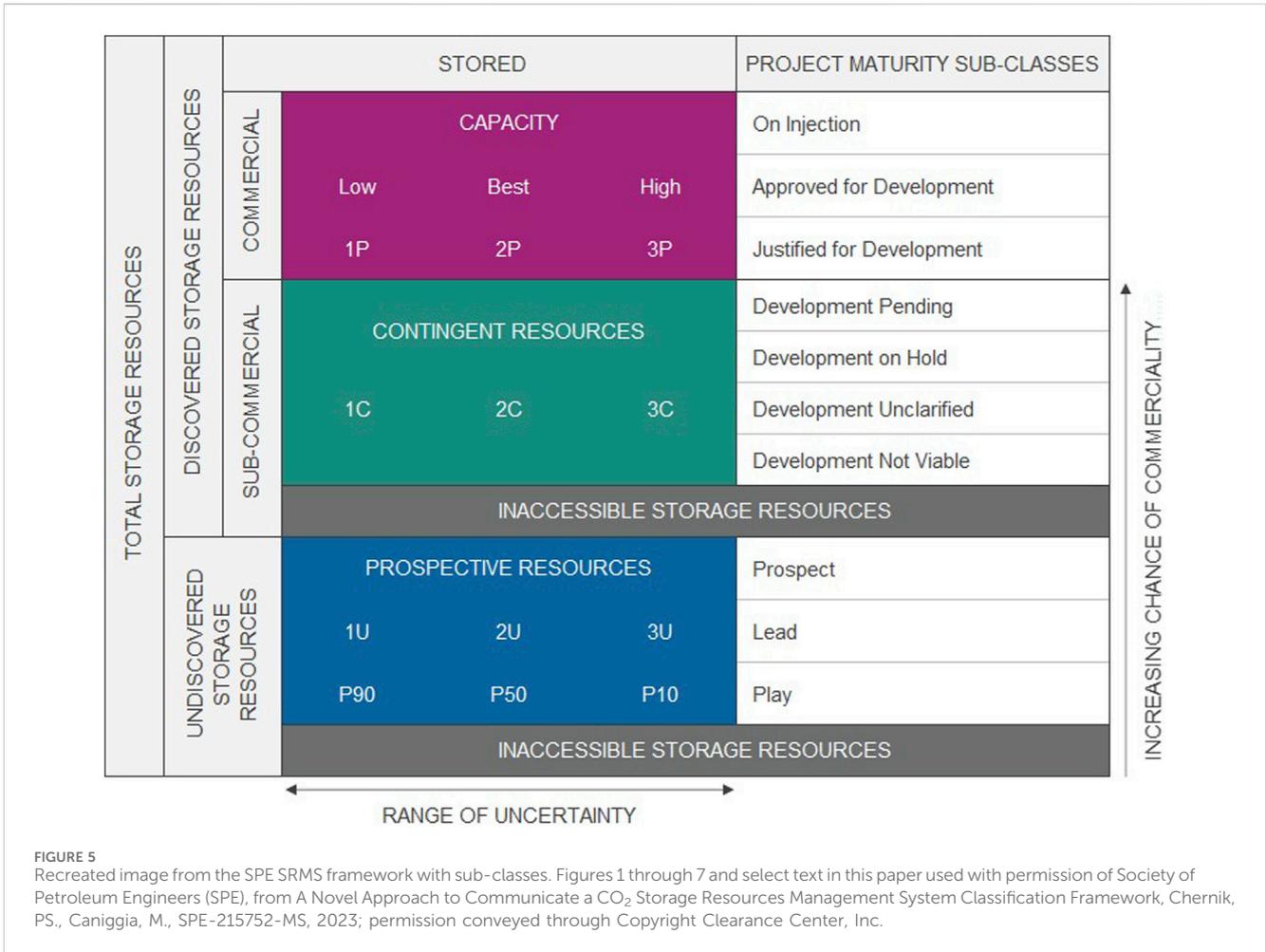


FIGURE 5
 Recreated image from the SPE SRMS framework with sub-classes. Figures 1 through 7 and select text in this paper used with permission of Society of Petroleum Engineers (SPE), from A Novel Approach to Communicate a CO₂ Storage Resources Management System Classification Framework, Chernik, PS., Caniggia, M., SPE-215752-MS, 2023; permission conveyed through Copyright Clearance Center, Inc.

6. Material balance method
 - a. TSR, storable quantity, or aquifer extent estimates using the material balance method, if relevant.
7. Reservoir simulation method
 - a. Numerical simulation models on which plume, pressure distributions and/or storable quantities are based.
8. Facilities development
 - a. Includes topside/onshore facilities, subsea infrastructure, umbilicals, risers and flowline analysis (as appropriate) within an integrated development plan.

Each of these eight topics comprises many technical sub-topics that need to be studied, often over months or even years. Each topic has Technical Contingencies (Figure 4).

When an independent audit or evaluation is commissioned to the SRMS standard for a CPR, the following guidance is provided to project proponents: “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” (SPE, 2017, 8).

Thus, in an SRMS process, our interpretation of the guidelines is that the author of a CPR is expected to study the information

available on the project, and be able to frame that information within the eight technical topics listed above (as applicable). Then, they must be able to “classify” and “categorize” the project⁵.

Guidance on the types of studies and information required to classify and categorize a project are found in the Guidelines for applications of the CO₂ SRMS (SPE, 2022). However, the state of progress towards a commercial project is a professional determination made by the CPR authors, independent of the project proponent.

As such, it is critically important that the authors of CPRs worldwide have a consistent method of assessing and presenting the

⁵ Classification and Categorization are key definitions described in Section 2 of the SRMS (see Figure 5). Classification, shown along the y-axis of Figure 5, is how projects are defined as either Prospective Storage Resources, Contingent Storage Resources or Capacity. This is effectively an assessment of project risk to achieve commerciality. Within these large classifications there are sub-classifications to provide more granularity as to the level of risk. Categorization, shown along the x-axis of Figure 5, is where estimates of the range of mass of CO₂ that can be stored in the project are made. It is an assessment of uncertainty. For a full explanation, please refer to the SRMS.

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."

FIGURE 6

SPE SRMS 2017 Definition of development unclarified. Figures 1 through 7 and select text in this paper used with permission of Society of Petroleum Engineers (SPE), from A Novel Approach to Communicate a CO₂ Storage Resources Management System Classification Framework, Chernik, PS., Caniggia, M., SPE-215752-MS, 2023; permission conveyed through Copyright Clearance Center, Inc.

maturity of the technical analysis as it relates to understanding project risk.

3.2 Barriers to using the SRMS framework as a communication tool

Traditionally, in extractive resource industries, frameworks use project maturity subclasses such as "Development Unclarified," "Development On-Hold" and "Development Pending" to explain progress toward commerciality (SPEE, 2018; SPE, 2018). These are also referred to in some detail in the SRMS Application Guidelines (SPE, 2022, 9). For ease of reference, they are presented in Figure 5.

The above are established terminology for oil and gas extraction projects, where a commercial project is also economic. However, as mentioned earlier, a positive NPV (accounting for cost of capital) in CCS may not be necessary for a final investment decision. In addition, projects may spend years in the Development Unclarified category as technical studies are completed to understand whether a site is technically suitable for CCS, before any Non-Technical Contingencies (Figure 4) are addressed.

As such, we found the SRMS framework challenging to use as a tool to explain the maturity of technical analysis as the project advanced towards FID, allowing for the range of stakeholders engaged in CCS. The reasons were as follows:

- SRMS currently provides definitions of the subclassifications but does not explain the path a site can take along the vertical axis. ERCE noted stakeholders, particularly those unfamiliar with reserves and resources assessment from extractive industries, assumed it was a linear progression along the y-axis of Figure 5. However, this is rarely the case.
- The available subclasses in SRMS lack the level of granularity necessary to explain progress in the eight technical topics (Section 3.1). The SRMS framework does not discuss the relationship between risk identification, an MMV plan, a

CM plan, and the SRMS subclassifications. Yet, we found that explaining the progress of technical studies in relation to addressing project contingencies (risks) was an important need for users of our report.

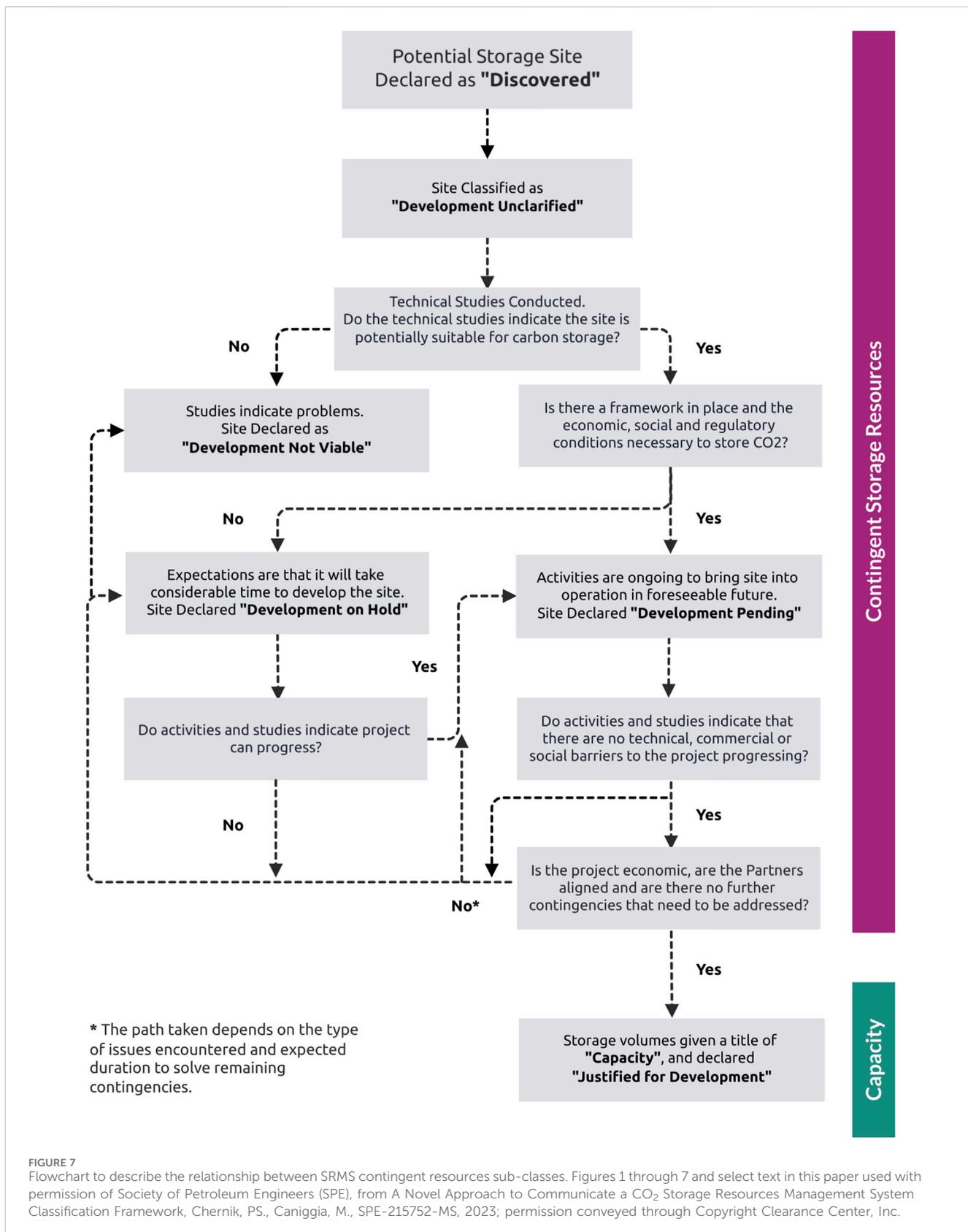
- The report we delivered had several CCS sites within it. We found it difficult to relate the progress of various sites using only words. All fit within the contingent resources classification, and many fit within the same subclassification. Yet the amount of technical study work completed on each site was not equal, as some sites had received more hours of analysis than others, as of the report's effective date.

3.3 A flow diagram to explain project maturity sub-classes

Our first challenge was explaining to stakeholders the context of the project maturity subclasses related to CCS. The SRMS lacks the descriptive flow charts found in other systems, that explain the decision-making process for contingent resource sub-classification. Such examples can be found in the COGE Handbook (SPEE, 2018; Figure 1-8).

A flowchart was therefore constructed to explain the relationship between study work and sub-classes to new stakeholders. A decision was taken to use the "Development Unclarified" subclass (Figure 6) as the step in which critical Technical Contingencies are identified and either addressed or incorporated into future planning. This is consistent with the United Kingdom NSTA's approach to applying the SPE SRMS. The NSTA has mapped their "Assess Phase" of the Carbon Storage licensing process to SRMS Development Unclarified (Kennedy and Moore, 2023).

Technical studies can and do occur at any point during the project journey from Contingent Resources to Capacity. However, in our application of the SRMS we elected to state that sufficient technical work was required in each of the eight Topics, where



relevant, to indicate that no “show-stoppers” existed. In other words, before progressing out of development unclarified, sufficient work was completed so that something very unusual would have to be

identified (from a technical perspective) at later stages of development to move the project to Non-Viable.

The resultant flow diagram is presented in Figure 7.

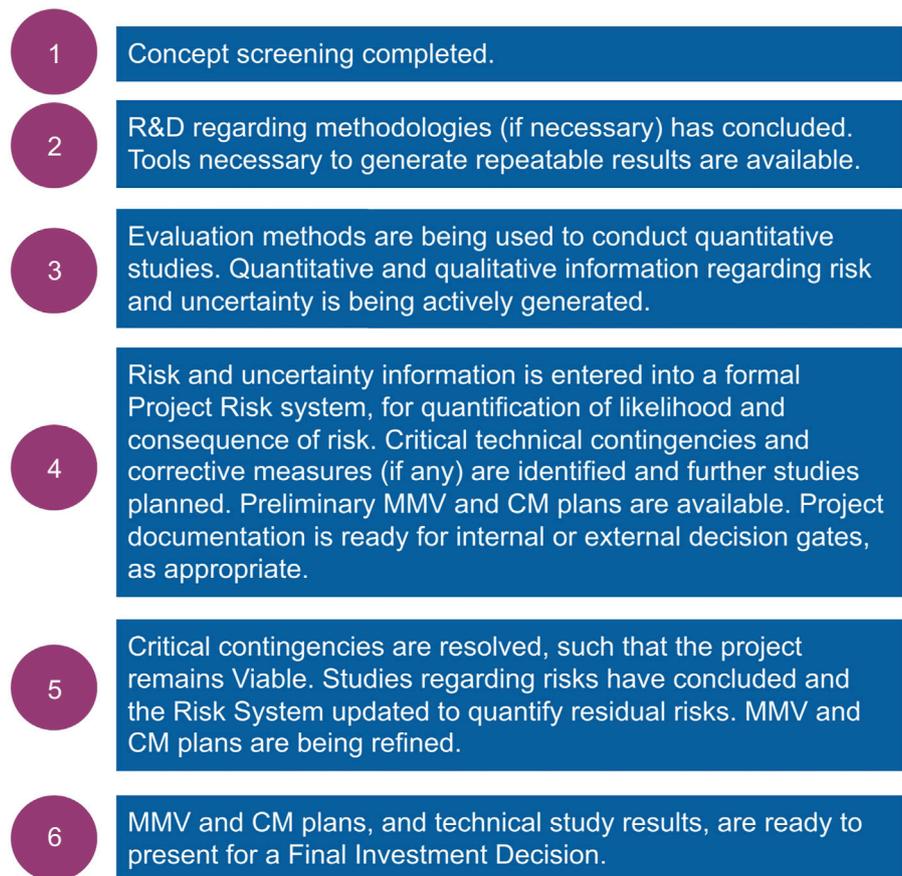


FIGURE 8

CCS technical maturity framework. Figures 1 through 7 and select text in this paper used with permission of Society of Petroleum Engineers (SPE), from A Novel Approach to Communicate a CO₂ Storage Resources Management System Classification Framework, Chernik, PS., Caniggia, M., SPE-215752-MS, 2023; permission conveyed through Copyright Clearance Center, Inc.

3.4 A new technical maturity framework developed

With this flowchart complete, our next challenge was to develop a methodology that would allow us to systematically categorize the maturity of technical work done to date, in each of the eight topics.

The framework was developed to link:

- Data gathering
- Technical studies
- The MMV and CM plans

It was also built to recognize that CCS developments can incorporate multiple storage sites. Each site can represent a different project, and these can be progressed at different rates. Yet, stakeholders need to be aware of the technical maturity of the multiple projects at once, to understand the relative progress of the CCS developments.

The framework incorporated six technical maturity steps (Figure 8). Each technical topic is assigned a maturity ranking as of the report's effective date. We have found that at a given date, some topics, such as reservoir simulation, may be very advanced. In contrast, other topics, such as legacy wells or facilities analysis may be at a much earlier stage. Assigning a numerical value helps stakeholders understand the level of

progress of technical work in each topic so that appropriate questions may be asked and to temper expectations regarding answers.

When assigning a ranking, the project technical topic must satisfy a step's criteria before being assigned to that step. The exception is step 3, which can be assigned while a company is carrying out the requirements under step 3.

In broad terms, at the end of step 1, the expectation is the project proponent has screened existing data and taken a high-level view if they think the project is worth further investment. It is an opportunity to halt work on projects that have apparent challenges. By the end of step 2, they will have identified the tools they need to carry out a detailed analysis of the eight technical topics and conclude any R&D necessary to build new tools. In step 3, the bulk of the technical study work is completed, so risks and uncertainties can be appreciated and quantified.

By the end of step 4, the project risk system, MMV, and CM plans should be progressed to a point where they are ready for detailed discussion and review. In certain countries this may mean being prepared to engage with relevant stakeholders, be it regulators or local communities or sources of finance. By the end of step 5, iterations of the risks system should be completed, and the focus should be on MMV and CM planning. When a given technical topic reaches the end of Stage 6, FID can be taken as the necessary information is available to make an informed decision.



3.4.1 Relating project work to the six maturity steps

CCS best-practice guidance currently exists on what types of study work should be completed and offers suggestions on the kinds of studies CPR authors might expect to review (International Organization for Standardization, 2017; SPE, 2022; National Energy Technology Laboratory, 2017). Regulators, management, boards of directors, sources of finance, and other stakeholders may request additional studies.

Therefore, the types of studies completed by project proponents will change depending on the location and type of the CCS site.

We have purposefully allowed for professional judgment in using the six-step maturity framework. The CPR author is responsible for determining when the technical work is mature enough to move the project up the maturity steps.

The key to the framework is linking technical maturity to creating a risk system and the MMV and CM plans. The MMV and CM plans, or equivalent, are the final step in managing residual technical risks for any CCS project. Under the six-step maturity framework, work on any of the eight technical topics is only complete when input from that technical topic has been addressed in the MMV and CM plans to the point that the project proponent is ready to make an investment decision.

We are not prescriptive on what studies should be completed at what maturity stage. Every CPR author will face the challenge of data availability at the effective date of the report commissioned. Some projects will have a wealth of data, while others will have scarce data. The amount of data and the ability to complete technical studies change the risk system's results and the type of MMV and CM plans required.

In addition, CCS is an area of active research, and best practices are evolving. Operators are still exploring the types of reservoirs (Wang et al., 2022), operating conditions, and risks associated with project designs that can be used to store CO₂.

Therefore, future CPR authors will need to form opinions on whether the extent and quality of technical studies are sufficient to move along the six maturity steps, considering best industry practices relevant to a specific CCS site type at the time of writing.

3.5 A method for data visualization

With the framework developed, the final step was to find a way to visualize the information. Under the current SRMS tools, and within reserves and resources reporting frameworks in general, there has been little emphasis on visualizing the progress of technical studies. The only tool available in the SRMS is the visual framework shown in Figure 5.

We therefore selected radial data visualization, as a way of showing the progress of the eight technical topics, as they move through the six maturity steps (see [Figure 9](#)⁶). Other radial visualization tools we have used, such as the BTI Transformation Atlas, inspired this choice ([BTI Project, 2024](#)).

The added benefit of a radial plot is that it allows multiple sites to be shown simultaneously. It provides an easy way to compare the progress. From [Figure 9](#) we can see:

- Site A is the most advanced. All technical topics in Site A have gone through risk and uncertainty studies and a preliminary MMV and CM plan has been created, incorporating information from all 8 technical topics. Geomechanical Modelling and Legacy Well Containment work is further progressed than the other topics, and studies regarding risk in those two technical topics have concluded.
- Site B is actively studying the subsurface and wells. For these topics, the project proponent is working to understand risk and uncertainties. However, they have not completed any material facilities studies.
- Site C has just concluded the first screening stage. However, the project proponent has not determined if the necessary methodologies and tools exist to complete a full technical study on the site, in any of the eight technical topics.

This type of systematic visualization will aid internal and external stakeholders, particularly if widely adopted across CCS projects globally. Understanding how advanced technical work is, in various topics, will support effective communication, lead to more timely questions and help set expectations.

4 Discussion

In the author's experience, there are inconsistencies in how CCS projects are currently evaluated, classified, and presented to stakeholders. This lack of consistency impacts stakeholders' ability to compare one project to another.

This is partly because different guidelines and standards are currently in use worldwide. Universal adoption of the SPE SRMS to convey information on contingencies, uncertainties and commerciality could help provide more consistent information to stakeholders. The framework allows for risk to be addressed through classification, and uncertainty through categorization.

During the SRMS Contingent Resources phase a project, project proponents are active in identifying risks, quantifying risks and uncertainties and then developing MMV and CM plans to address residual issues. Yet the SRMS framework is proving insufficient to explain the pace of these efforts. The tools we describe in [Sections 3.3–3.5](#) were designed to address this challenge.

The flowchart, six-step maturity framework, and radial visualization have provided a means to convey project progress, previously unavailable using the SRMS terminology and guidelines. They have allowed us to explain CCS project progress regarding

technical topics in a more systematic way. In recent projects, the tools have also allowed us to frame the pace of technical study work, including the need for R&D, in emerging projects like CCS in coal-seams ([Bergen et al., 2011](#); [Singh et al., 2021](#)). They are being used every day in an industrial setting, to address some of the communication challenges of the existing SPE SRMS guidelines. They have received positive feedback from stakeholders.

Additional research is required to support the tools proposed in this paper and ensure they are fit for purpose globally. The six-step maturity framework relies upon a need for a MMV and CM plan. Is it likely that MMV and CM plans will become the global norm? If not, what are alternatives to address residual risk? The entire toolkit proposed also relies upon best practice guidelines to support CCS professionals. Are guidelines such as ISO 27914 sufficient to define industrial best practices, especially as research evolves? If not, what should stakeholders expect of project proponents?

In addition, the tools in this paper only address technical contingencies. They ignore non-technical contingencies ([Figure 4](#)). Yet, non-technical contingencies have an equal role to play in project approval. A systematic way to convey progress in addressing non-technical risks would greatly benefit the CCS industry. This is a complex challenge that touches on topics such as the voluntary carbon credit market. ([Verra, 2022](#)), obtaining a social license to operate ([Stronge et al., 2024](#)) and legal considerations ([Bankes et al., 2008](#)).

It is an exciting time to be involved with CCS. As projects move from prospects to contingent resources to active storage sites, we will hopefully see CCS reach its potential as a critical mitigation measure in the fight against global warming. Tools, such as those described in this paper can help improve the consistency and clarity of information given to stakeholders, and help build trust in this emerging industry.

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Conflict of interest

Author PC was employed by ERCE, Canada. Authors MC and EM were employed by ERCE, United Kingdom.

⁶ Values shown in [Figure 9](#) are not from a real project.

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Nomenclature

1C	SRMS Terminology. Denotes low-estimate scenario of Contingent Storage Resources.	Development Unclarified	SRMS Terminology. 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.
2C	SRMS Terminology. Denotes best-estimate scenario of Contingent Storage Resources.	Discovered	SRMS Terminology. 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).
3C	SRMS Terminology. Denotes high-estimate scenario of Contingent Storage Resources.	ESMA	European Securities and Markets Authority
1P	SRMS Terminology. Taken to be equivalent to Proved Capacity; denotes low-estimate scenario of Capacity.	FID	Final Investment Decision
2P	SRMS Terminology. Taken to be equivalent to the sum of Proved plus Probable Capacity; denotes best-estimate scenario of Capacity.	High Estimate	SRMS Terminology. 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.
3P	SRMS Terminology. Taken to be equivalent to the sum of Proved plus Probable plus Possible Capacity; denotes high-estimate scenario of reserves.	IPCC	United Nations Intergovernmental Panel on Climate Change
1U	SRMS Terminology. Denotes low-estimate scenario of Prospective Storage Resources.	IPO	Initial Public Offering
2U	SRMS Terminology. Denotes best-estimate scenario of Prospective Storage Resources.	ISO	International Organization for Standardization
3U	SRMS Terminology. Denotes high-estimate scenario of Prospective Storage Resources.	JORC Code	Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves
ASX	Australian Stock Exchange	Justified for Development	SRMS Terminology. 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.
Best Estimate	SRMS Terminology. 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.	Low Estimate	SRMS Terminology. 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.
Capacity	SRMS Terminology. 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.	LSE	London Stock Exchange
CCS	Carbon Capture and Storage	MMV	Measurement, Monitoring and Verification
CIM MRMR	Canadian Institute of Mining, Metallurgy and Petroleum, Mineral Resources Mineral Reserves Committee	NDC	Paris Agreement 2015 Nationally Determined Contribution
CM	Corrective Measures	NDC Bodies	Organizations that track emissions reductions against NDCs
COGE Handbook	Canadian Oil and Gas Evaluation Handbook	NI	National Instrument
CPR	Competent Persons Report	PRMS	SPE Petroleum Resources Management System
Development Not Viable	SRMS Terminology. 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.	P10	SRMS Terminology. There should be at least a 10% probability that the quantities actually stored will equal or exceed the high estimate.
Development On Hold	SRMS Terminology. 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.	P50	SRMS Terminology. There should be at least a 50% probability that the quantities actually stored will equal or exceed the best estimate.
Development Pending	SRMS Terminology. 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.	P90	SRMS Terminology. There should be at least a 90% probability that the quantities actually stored will equal or exceed the low estimate
		R&D	Research and Development
		SEC	U.S. Securities and Exchange Commission
		SPE	Society of Petroleum Engineers

SPEE	Society of Petroleum Evaluation Engineers
SRMS	SPE CO ₂ Storage Resources Management System
RBL	Reserve Based Lending
TSR	Total Storage Resources
UK	United Kingdom
UN	United Nations
US	United States of America