SDG WHITE PAPER SERIES

Techniques to Maximize Value from CCUS Decisions at Every Stage

Brian Ruskin, PhD, *Strategic Decisions Group*

SDG

Strategic Decisions Group

sdg.com

EDITOR'S NOTE: *This case study examines the decisions inherent to a carbon capture, utilization, and storage (CCUS) project. The approach taken identifies the richness of decisions and challenges at each stage—technical, regulatory, financial, and strategic. This case is based on a composite of several CCUS projects and programs, including pilot efforts by national and international research consortia, large-volume and long-operating storage complexes, and CO_2 injection projects for enhanced oil recovery (EOR). Identifiable information has been removed, and the decisions described here are representative of those commonly faced in CCUS projects.*

Executives at an international energy producer were considering how to lessen the company's carbon dioxide (CO_2) emissions by undertaking carbon capture, utilization, and storage (CCUS) projects. Because the company operates oil- and gas-producing fields, the team quickly determined that subsurface storage of CO_2, known as geologic sequestration, would be a plausible solution. However, multiple alternatives were available for CO_2 capture technologies, transport, utilization, and permanent storage solutions, requiring many decisions. Further, subsurface CO_2 storage initiatives are typically conducted as staged programs, with decisions and uncertainties encompassing technical, economic, regulatory, operational, societal, and strategic concerns that may be conducted in parallel and have interdependencies. The time frame, costs, uncertainties, and success criteria can vary significantly between steps.

Projects of this complexity and magnitude involve strategic decisions and require a structured approach to decision making and quantifying uncertainty.

In this case study, we explore key decisions facing an energy producer pursuing CCUS opportunities and how the decision quality framework can enhance the economic and strategic value of the projects.

Applying the Decision Quality Framework to CCUS Projects

Strategic decisions—those that are organizationally and/or analytically complex and of great importance in terms of cost, risk, and reward—greatly benefit from evaluation using the decision quality (DQ) framework. The six requirements for decision quality—1) agreeing to an **Appropriate Frame**, 2) generating **Creative Alternatives**, 3) gathering **Relevant and Reliable Information**, 4) defining **Clear Values and Tradeoffs**, 5) applying **Sound Reasoning** during evaluation, and 6) securing **Commitment to Action**—can be applied to each stage of the project. Using the DQ model, alternatives are evaluated to estimate project value. Detailed attention is paid to identifying the key uncertainties and quantifying how they may impact project value. Insights arise when comparing the modeled value metrics and analyzing the reasons for expected value variations between alternatives. A quality decision is reached when each of the six DQ requirements are judged as fulfilled to 100%, meaning that the value from further improving that requirement isn't worth the time delay and effort. The goal is not perfection, since one can never know a future decision outcome with perfect certainty. Instead, the six DQ requirements allow decision makers to judge the quality of the decision *at the time it is made*, not by waiting to see how it turns out. By using the DQ framework, decision makers have a fuller view of the risks and rewards inherent to their alternatives and can be confident they are making quality investment decisions.

The energy company had used a stage-gate approach for its exploration and production (E&P) projects and corporate decision makers wanted to apply a similar approach to the CCUS project. The stages progress from **identification/regional assessment to site selection, site characterization, operations, site closure,** and **post-closure** monitoring and stewardship. Strategic Decisions Group (SDG) was brought in to implement decision quality as a framework and to guide the decision-making process at each stage. The decision makers were aware that their time frames for each step could vary from months to decades, depending on the project scale. They also realized there would be many uncertainties that could influence project value. At each step, there were fundamental decisions and many interrelated, supportive decisions to be addressed by subject-matter experts, project teams, and decision makers in multiple disciplines (Figure 1).

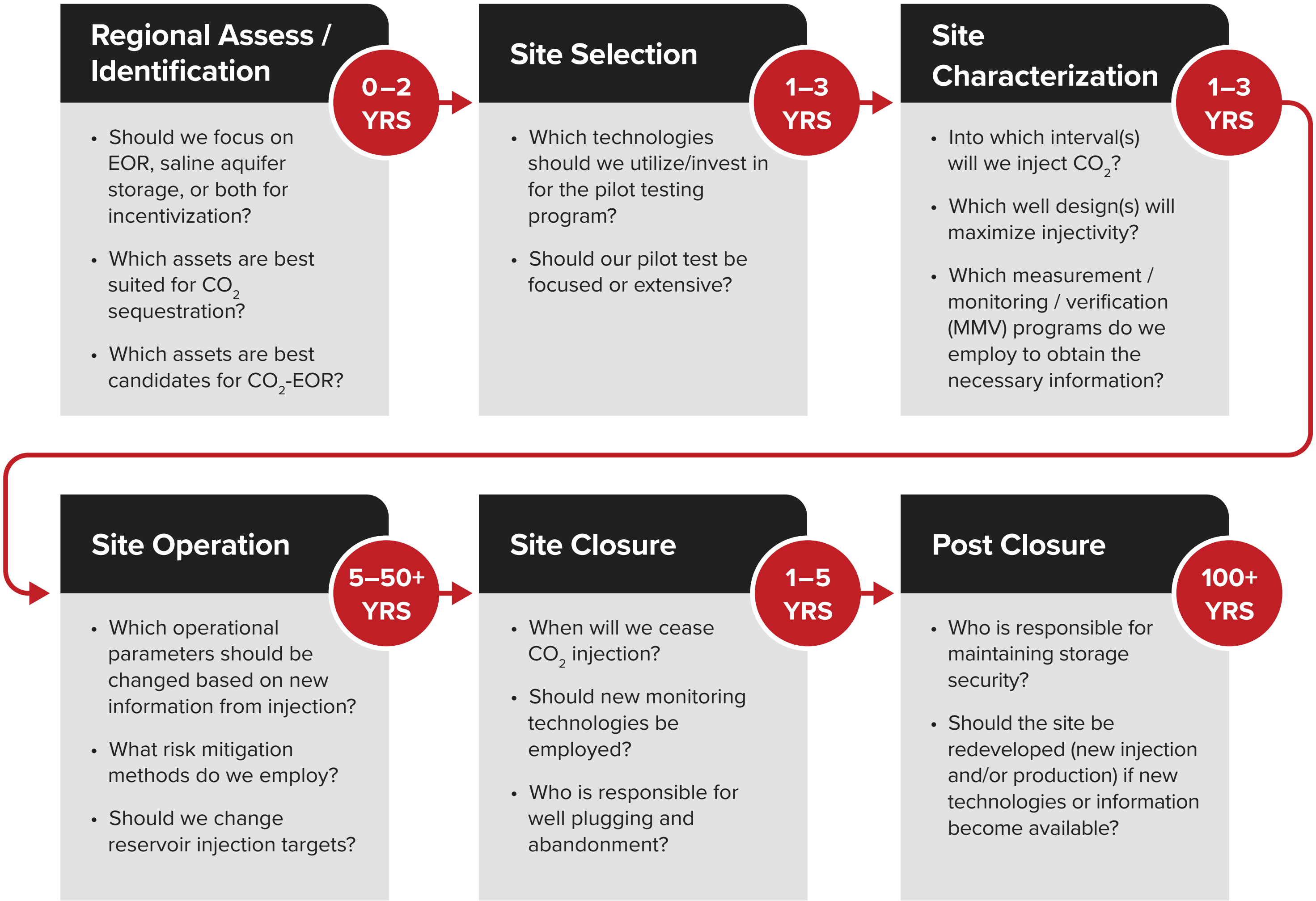

FIGURE 1: *Stages, key decisions, and durations for a hypothetical geologic carbon sequestration project. Note that while these decisions are representative, they are not an exhaustive list.*

Implementing Decision Quality to Maximize Value from Sequestration Projects

The company initiated the **identification/regional assessment** phase by conducting a framing session with guidance from decision professionals at SDG to determine the project's scope, purpose, and various stakeholder perspectives. From this insight, they assembled a **decision hierarchy** (Figure 2), which helped them focus on the key decisions at hand, maintain proper scope, and begin to formulate alternatives that would address the decisions. At this stage, the fundamental decision was whether to enter the operational phase of injecting CO_2 and represents a **commitment to act** over years or decades. As such, framing sessions would be required prior to the start of each new project stage to consider the many unique decisions, uncertainties, and other issues inherent to that step.

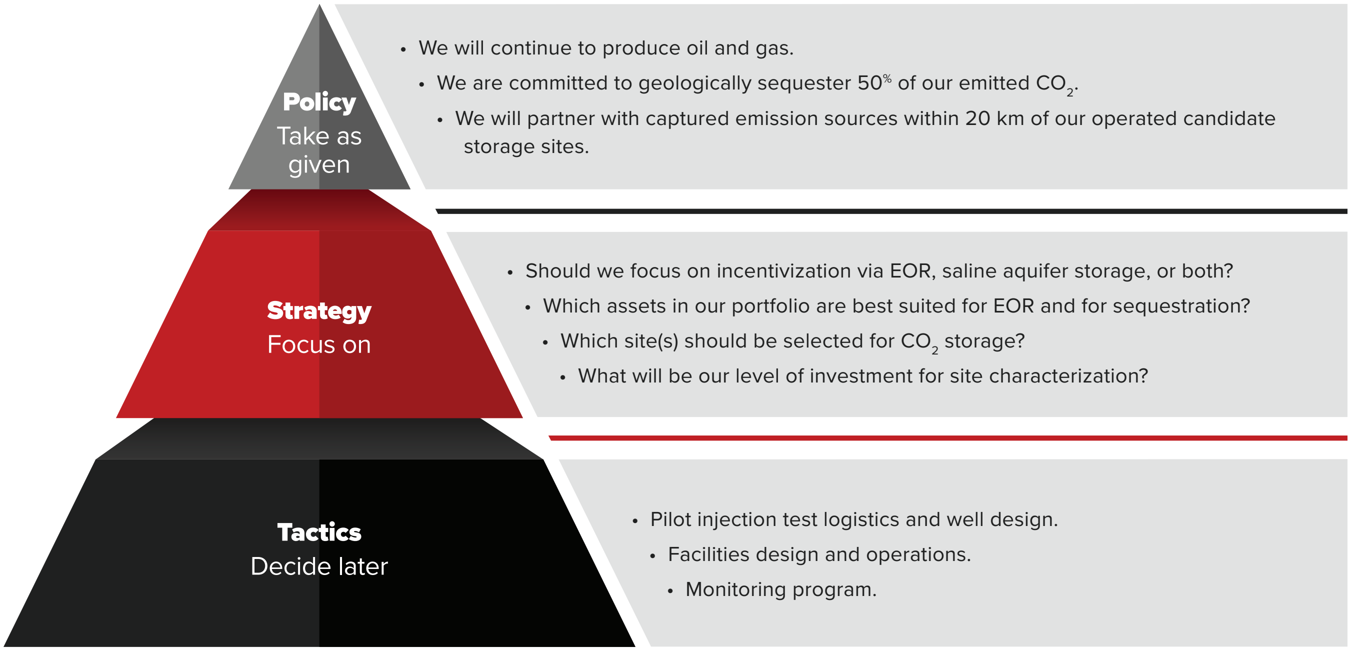

FIGURE 2: *Example of a decision hierarchy for the identification/regional assessment stage of an energy company's geologic sequestration initiative.*

The **scope** of the project included decisions around where and how to capture the CO_2 emissions, where to inject the gas for sequestration, and how to transport it from source to sink. They quickly realized that some decisions had already been made (e.g., "We are committed to geologically sequester 50% of our emitted CO_2"), some decisions required immediate focus ("Where and how do we capture the CO_2?" "What sites are best suited for permanent geologic sequestration?"), and many tactical or operational decisions could be addressed in later project stages ("How many wells are required to inject the source volume?" "What are the mitigation strategies in the case of a CO_2 leak?").

When considering the **purpose**, the decision makers' options included whether the project is for CO_2 utilization (for example, enhanced oil recovery—EOR—by injecting CO_2 to mobilize trapped hydrocarbon molecules), for dedicated storage (without associated production), or a combination. The EOR option could provide revenue from additional hydrocarbon production that might offset some of the storage project costs, while dedicated storage and EOR provide financial incentives (e.g., 45Q tax credits in the United States and capex grants or sales of carbon credits via a cap & trade system in some of the company's European assets).

As the conversation moved to incentivization and revenue, SDG urged the decision makers to also consider who their stakeholders were or could be, and their **perspectives** regarding the project. Potential stakeholders were both internal (the project teams and field operations staff as well as the decision makers) and external (shareholders, the investment community, joint venture partners, research consortia, environmental groups, and local communities). Each stakeholder has their own viewpoints on **values**. The company wanted to pursue projects that would generate positive cash returns, so decision makers agreed to economically model each alternative to understand the net present value (NPV) of cash flows and provide a meaningful comparison with other projects in the E&P portfolio. The company agreed it was a given decision to partner with power plants that were already using proven amine and novel technologies to capture large volumes of emissions (thereby removing direct input on decisions regarding capture technologies). They wanted to decide if they should use the captured CO_2 to enhance production in their nearby established operational fields. They would also consider the viability of injecting CO_2 into non-producing, non-potable (saline) aquifers within their operated fields for permanent storage.

The company assembled a project team to define the alternatives for **site selection**. Principally, the decision was which sites would provide permanent, secure CO_2 sequestration while maximizing value from enhanced hydrocarbon recovery and/or financial incentives. For each site, strategic-focused decisions must be made regarding land and well permitting, gas transportation and field infrastructure requirements and construction, regional technical assessments, and pilot test design, and investment decisions on all of these. This stage may also take several years to complete and new information will result in iterations through the decision quality framework. The team agreed to use SDG's **Dialogue Decision Process**, whereby the teams would meet with the decision makers to reach agreement based on clear deliverables and building quality in each DQ requirement before progressing to the next step. Once sites were selected, the **commitment to act** would be to begin site characterization.

At this point, the energy company had multiple candidate CO_2 storage sites around the world closely matched with a nearby captured emission source. The crucial decision for **site characterization** is what target(s) at each site is appropriate for effective subsurface storage of injected CO_2. However, by using a tenet of decision analysis—probabilistic modeling—the ranges of uncertainty for each influencing factor were assessed by gathering reliable and relevant information via expert opinions, practical knowledge, and site-specific reference conditions. Associated decisions included consideration of how much information would be sufficient to characterize the site and what would be the value of additional information (investment).

The project teams created a **strategy table** to explore the many alternatives for site characterization. Each strategy theme (row) is a string of choices from the key decisions (columns, e.g., the number of test wells, well design specifications, monitoring technologies employed, modeling approaches, baseline measurements) that support that theme (Figure 3). Examples of strategies might be a minimal evaluation approach, utilizing already available geologic and production data. Conversely, a significant investment strategy may be required in areas of geologic uncertainty. By considering a manageable number of compelling alternative strategies ranging from mild to wild, each associated string of decisions are modeled and evaluated to understand the impact of the many uncertainties on NPV and provide means of comparison. Oftentimes, the evaluation will reveal that a hybrid strategy, one that integrates elements of several evaluated alternatives, may contribute even higher value to the project.

	KEY DECISIONS			
Strategy Theme	**Injection Interval**	**Wells**	**Injection Test**	**Monitoring Program**
Minimal Investment	Producing reservoir	Drill new injector and monitor wells	Maximum economic and technical injection rate	Logs + 4D seismic + InSAR + groundwater wells and soil baseline
Scale Up Existing Field	Producing reservoir + Saline aquifer X	Repurpose existing producers as injection and monitoring wells	Ramp up injection to monitor pressure response and plume spread	Logs + Time-lapse 3D (4D) seismic
Exploratory	Producing reservoir + full evaluation of stratigraphic section	Drill new wells, gather core and log data over perspective reservoirs and seals	Short term, fixed-rate injection	Logs in injection and monitoring wells

FIGURE 3: *Abridged strategy table for CCUS site characterization decisions. In this example, the company is considering three strategy themes, ranging from "mild" to "wild," and decisions that involve choices that align with that theme. A financial model will evaluate each strategy. This strategy table is illustrative; often, there are additional strategies for evaluation and some strategies may have choices in common for the key decisions.*

To achieve storage security, a site must have adequate **capacity** (reservoir volume), **containment** (sealing unit) and **injectivity** (a multi-component function related to the product of reservoir permeability and thickness). A goal of geologic sequestration is to provide "permanent" storage of CO_2, at least over human time scales (decades to hundreds of years) and ideally over geologic time scales (tens of thousands to millions of years). The main risk for geologic sequestration projects is that injected CO_2 could leak out of the containment reservoir and migrate into freshwater aquifers or eventually reach the surface and reenter the atmosphere. Geologic and technical parameters can be calculated from influencing component values but are in fact estimates because the components have associated uncertainty due to incomplete or imperfect information. To structure the quantitative evaluation of storage security, the team constructed influence diagrams to relate the decisions, uncertainties, and value metric calculations and provide logic structure for quantitative models (Figure 4). These subsurface uncertainties, as well as many others related to site construction, operation, and regulation, were assessed with ranges (e.g., 10th, 50th, and 90th percentile value estimates) by the company's subject matter experts.

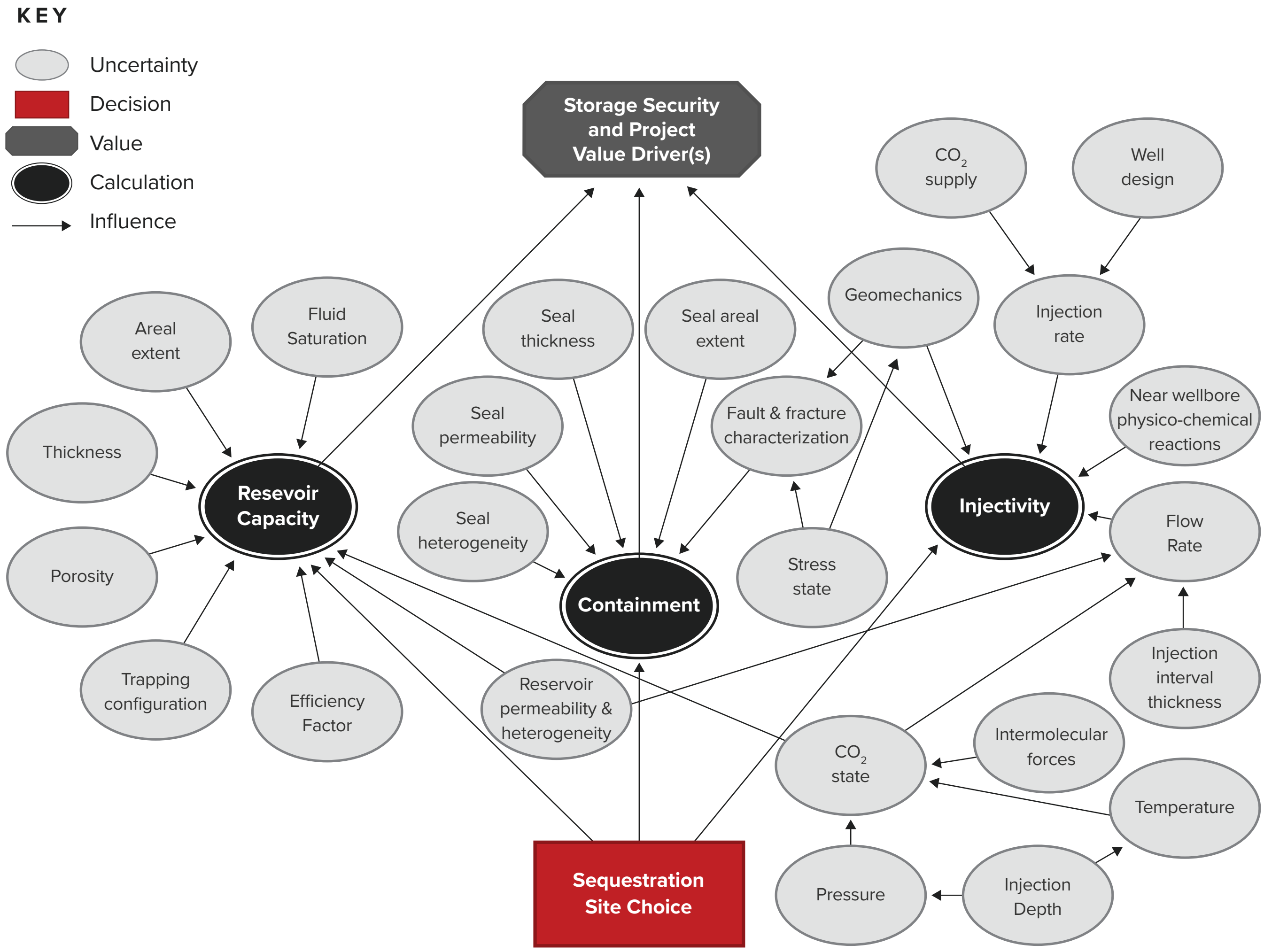

FIGURE 4: *Simplified influence diagram for the technical decision of whether a geologic carbon sequestration site provides storage security. The value metric is generalized but can be financially modeled from volumes of stored CO_2 and/or enhanced hydrocarbon production based on the incentivization of the mode of storage.*

An essential result of quantitative modeling is determining which uncertainties have the greatest impact on project value and how to mitigate risk and maximize upside potential. The economic model used Monte Carlo simulation to explore the range of uncertainty for a variety of subsurface variables (Figure 4) as well as financial and regulatory uncertainties. A “tornado” plot (so called because the diagram brings to mind a tornado) of the uncertainties illustrated how the range of each uncertainty impacted the project’s net present value (Figure 5). The company learned that obtaining and maintaining clean fuel credits during site operation, gaining approval for CO_2 injection in a timely fashion, and the price case for clean fuel credits had the greatest impact on one CCUS project’s net present value. Identification of the key uncertainties provided guidance as to where to focus future de-risking work.

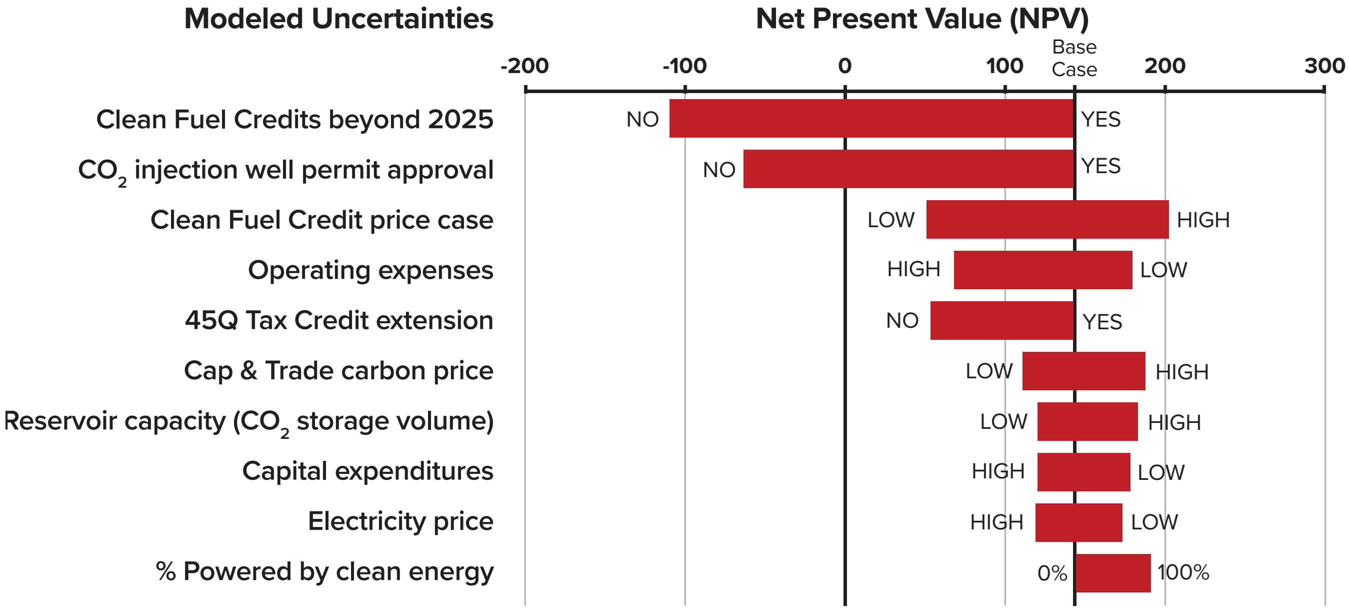

FIGURE 5: *Illustrative tornado diagram for hypothetical geologic carbon sequestration project. Key uncertainties were quantified using a probabilistic model and their impact on incremental NPV compared with the base case assessment provides guidance on where to focus future de-risking work.*

A subset of the characterized sites was selected for CO_2 injection **operations** based on evaluations and estimates that inform the economic model. The company's decision makers shifted their focus to decisions that were previously considered tactical ("decide later") but are now strategic, in-focus decisions relevant to maximizing CO_2 injection, storage, and enhanced hydrocarbon production at a given site. Initially, the key decisions related to maximizing injection, and choices included the number of wells, well design and purpose (e.g., injection, production, or monitoring), well location, reservoir interval(s) for injection and means of measuring, monitoring, and verifying that the injected CO_2 would migrate through and be securely stored within the reservoir but not escape from it. However, as the site operations phase may last for many years if there is sufficient capacity or incentives, the Dialogue Decision Process may need to be repeated as new information becomes available. Once initial injection has occurred, information will be acquired from field monitoring and storage-complex modeling (each with decisions to make regarding type and investment). Concurrent with operations is the potential for CO_2 leakage and microseismic events (small-magnitude earthquakes due to the change in reservoir stress state when CO_2 is injected), and associated decisions about risk identification, mitigation, and communication to the public may be required. Modeling the migration and retention of injected volumes in the injection reservoir(s) leads to a final decision for the operations phase: When will injection cease? For some assets, the value of the injection project may be measured in years; in others, decades. Field operational decisions (e.g., maintenance of injection volumes, drilling/completing/plugging wells, monitoring, and maintenance programs) will continue, and will also benefit from decision quality assessments.

For a few of the injection sites, the company's evaluations revealed that injection was no longer profitable after several years and decision makers should consider **site closure**. Major decisions at this stage related to the timing of the last injection, the technologies and investments needed to securely cap injection and production wells, and the identification of the parties responsible for site closure and future monitoring programs. With these long time frames, there are many uncertainties and decisions may be hard to conceptualize. For example, what if an unforeseen leak occurs? What if innovative technologies unlock additional injection opportunities or repurposing of the site? Many of these are "decide later" decisions, but a risk assessment and exploration of alternatives is useful in providing a roadmap for future operators and should be iterated as more global geologic sequestration projects mature and more information is available.

The energy company decision makers recognized that pursuing CCUS projects entails a myriad of decisions and uncertainties involving many stakeholders, disciplines, and timescales. It also represents a strategic initiative for the company, as it is organizationally and analytically complex and of tremendous importance from both a cultural and economic standpoint. The climatic implications of reducing CO_2 emissions are well-documented and there is tremendous pressure on energy producers from financiers, policy makers, technology providers, and consumers to lessen their carbon footprints by employing mitigation measures. CCUS is a viable contributor to the emissions reduction solution but requires commitment to large-scale projects from numerous producers who might not have previously considered the decisions involved in such projects. In this case example, the company team members discovered that by using decision quality throughout the staged project approach, they could best account for the many decisions they faced, as well as assess the impact of key uncertainties on the projects' value. The DQ framework and Dialogue Decision Process generated insights on key value drivers and provided decision makers with the confidence that they were making high-quality decisions regardless of the outcome.

***Brian Ruskin**, PhD is a Consultant at Strategic Decisions Group.*