A Digital-First Framework for CCS Screening and Site Characterization

P. Saini *
Product Leader, Baker Hughes, Delft, Netherlands

U. Biradar
Technology Leader, Baker Hughes, Mumbai, India

K. Sonawane
Product Manager, Baker Hughes, Mumbai, India

A. Mehta
Software Architect, Baker Hughes, Mumbai, India

D. Chauhan
Software Architect, Baker Hughes, Mumbai, India

S. Bordoloi
Sr. Director, Baker Hughes, London, United Kingdom

Abstract

Carbon Capture and Storage (CCS) has emerged as a critical technology for achieving global net-zero emissions targets by enabling the large-scale mitigation of industrial carbon dioxide (CO_2) emissions. Despite its strategic importance, many CCS projects fail to advance beyond early feasibility stages due to significant subsurface uncertainty, fragmented workflows, and late-stage regulatory or monitoring constraints. Screening and site characterization represent the most influential stages of the CCS project lifecycle because early decisions determine storage integrity, injectivity, capacity estimation, monitoring strategy, and long-term liability. Traditional approaches to CCS site screening typically rely on static geological assessments derived from legacy oil and gas datasets, evaluating parameters such as depth, porosity, caprock integrity, and structural closure. While technically robust, these methods often struggle to integrate heterogeneous data sources, quantify uncertainty, and dynamically evaluate risks associated with plume migration, pressure buildup, fault reactivation, and long-term containment. Moreover, monitoring, measurement, and verification (MMV) planning is frequently deferred to later project phases, which can lead to suboptimal monitoring designs, higher project costs, and regulatory delays.

This study proposes a digital-first framework for CCS screening and site characterization that integrates subsurface modelling, uncertainty quantification, and analytics-driven decision support within a unified digital architecture. The objective of this framework is to transform CCS site evaluation from a sequential and discipline-specific workflow into an integrated, iterative, and risk-informed process. By leveraging advances in subsurface digitalization, cloud computing, physics-based reservoir simulation, and data analytics, the framework enables continuous integration of geological, geophysical, and engineering datasets with predictive modelling tools. Methodologically, the approach combines multi-scale subsurface modelling with probabilistic uncertainty assessment to evaluate key performance indicators such as storage capacity, injectivity, pressure evolution, and containment risk. The framework further incorporates early alignment of MMV strategies with site screening and characterization, ensuring that monitoring considerations are embedded from the earliest stages of project design. Digital platforms facilitate rapid scenario testing, enabling stakeholders to evaluate alternative development strategies, refine assumptions, and assess trade-offs between storage performance, operational risk, and project economics.

A key novelty of the proposed framework lies in its holistic digital integration of screening, characterization, and pre-injection monitoring design within a single decision environment. Unlike conventional workflows that treat these activities sequentially, the digital-first approach supports simultaneous evaluation of geological suitability, operational feasibility, and regulatory readiness. The framework also promotes transparency and traceability in technical decision-making, which are increasingly required by regulators and project stakeholders. By creating a common technical environment where models, datasets, and analytical results are continuously updated and shared across disciplines, the system enables rapid iteration, collaborative interpretation, and defensible site selection decisions. Additionally, embedding uncertainty quantification and scenario analysis within the workflow improves risk management and enhances confidence in predicted storage performance.