

Cognitive CCUS Asset Intelligence: Multi-view Interactive Schematics and Ai Workflows for Safe, High-fidelity CCUS Operations Integrity

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Abstract:

The objective of this work is to introduce a Cognitive CCUS Asset Intelligence (CCAI) that enables safe, high-fidelity, and resilient operations across the full CCUS value chain. The scope covers capture, compression, transportation, injection, subsurface storage, and MMV systems, addressing limitations of fragmented monitoring by providing end-to-end operational integrity, emissions accountability, and decision support for large-scale CCUS deployments. The proposed CCAI architecture integrates heterogeneous operational, geospatial, subsurface, and emissions data into a unified digital representation of the CCUS lifecycle. The framework combines multi-view interactive schematics with AI-enabled workflows that continuously interpret system states, detect anomalies, and generate explainable insights. Real-time analytics and predictive AI models are coupled with dynamic process and operational modelling to evaluate integrity, performance, and emissions behaviour. Risk governance is embedded through a digitally integrated Bowtie Risk Matrix methodology, mapping threats, barriers, preventive controls, and mitigation pathways directly within the asset full value chain environment. The Cognitive CCUS Asset Intelligence transforms traditional siloed monitoring into an adaptive, intelligence-driven operational platform. Multi-view schematics enhance traceability and cross-domain understanding, while cognitive AI workflows enable proactive anomaly detection, integrity assurance, and risk-informed decision-making. The integration of emissions intelligence and predictive modelling strengthens operational safety, performance optimization, and regulatory confidence. The framework demonstrates that converging digital engineering, AI, and risk visualization significantly improves operational resilience, safety, and emissions accountability across CCUS operations. The key novelty lies in the introduction of contextual cognition within a CCUS asset landscape, extending beyond conventional digital intelligence. The framework uniquely unifies AI-driven interpretation, emissions intelligence, dynamic process modelling, and bowtie-based risk visualization into a single cognitive digital ecosystem. The establishment of an auditable digital thread supporting MRV, data lineage, and regulatory reporting further differentiates the approach. This work presents a scalable paradigm for next-generation carbon management, enabling autonomous insight generation, explainable decision support, and resilient governance across the entire CCUS value chain.