Making CCS Work:

Economics, Optimization & CMG Solutions

Your CCS Learning Journey

This is Part 3 of the three-part series on Carbon Capture and Storage (CCS). In this edition, you'll learn about the economics of CCS, pathways for optimization, and CMG's models backed by physics and workflows that operators use to reduce uncertainty and make projects viable.

If you haven't already, start with the preceding Ebooks:

Part 1 – The Science of Safe Carbon Storage

Part 2 – De-risking CCS Projects: Risks, regulations, site selection, and compliance.

Together, these three volumes provide a complete foundation, from the science to the strategies, for building successful CCS projects.

What You Will Learn

Introduction: Turning CCS from theory into practice

Carbon Capture and Storage (CCS) has the scientific foundation and field validation to prove its permanence, but scaling to global levels depends on more than subsurface security. Projects must make financial sense, optimize their technical execution, and use reliable tools to reduce uncertainty at every stage. Economics, optimization, and simulation transform CCS from concept to practice.

This ebook examines the economics of CCS, pathways for optimization, and the role of Computer Modelling Group (CMG) in providing models backed by physics and workflows that operators use to reduce uncertainty and make projects viable.

1. The economics of storage

CCS economics are shaped by the full chain of capture, transport, and storage. While capture typically represents the largest cost, transport and storage decisions often determine whether projects move forward.

Capture costs

- Capture accounts for 60–80% of total CCS expenses.
- Includes chemical solvents, membranes, or sorbents, plus compression and purification.
- Costs vary depending on source concentration (flue gas vs. natural gas processing).

Transport costs

- High-pressure pipelines are the dominant transport mode.
- Capital costs depend on length, diameter, terrain, and permitting.
- Shipping and trucking add flexibility for smaller volumes but increase operating expenses.

Storage costs

- Site characterization, seismic surveys, and exploratory drilling.
- Injection wells, monitoring wells, and compression facilities.
- Long-term monitoring and liability management.

Revenue streams

- Carbon credits and tax incentives, such as 45Q in the U.S. or EU ETS allowances.
- Enhanced oil recovery revenue where CO_2 is injected for hydrocarbon production.
- In some processes, saleable byproducts (e.g., nitrogen, hydrogen)

Projects succeed when simulation links technical design with these economic drivers. Accurate forecasts of injectivity, plume migration, and storage capacity reduce uncertainty in cost estimates and liability exposure. Overly conservative assumptions inflate costs, while underestimated risks can fail. Economic optimization balances these trade-offs.

2. Optimization in CCS projects

Optimization is the process of improving technical design to achieve secure, long-term storage at the lowest practical cost. It applies across the project lifecycle, from site selection to injection and monitoring.

A. Technical Optimization

- **Higher capture efficiency** without excessive energy penalty
- **Process integration** (e.g., using waste heat from the host facility)
- **Solvent or sorbent improvement** (lower regeneration energy)
- **Optimized compression & transport pressure** to minimize pipeline/energy cost
- **Shared infrastructure** for transport and storage between multiple emitters

B. Scale and Phasing

- **Economies of scale** (larger plants have lower cost per tonne)
- **Hub-and-cluster models** to spread transport and storage costs over multiple emitters

C. Financial Structuring

- Leveraging **government incentives** (tax credits, grants, low-interest loans)
- Securing **long-term CO_2 offtake contracts** to stabilize revenue
- Blending public-private financing to reduce cost of capital

D. Site Selection and Logistics

- Minimizing **transport distance** between capture site and storage
- Choosing storage sites with **low injection cost** and high capacity
- Avoiding **expensive permitting** or **politically sensitive** areas

E. Risk Management

- **Technical** risk (leakage, injectivity, induced seismicity, reliability of capture tech)
- **Market** risk (carbon price volatility)
- **Regulatory** risk (changes in policy/ incentives)

Optimization is not a one-time calculation but a continuous process that evolves with new data, making simulation essential at every stage.

Well placement

- Strategic positioning of injection wells maximizes capacity and distributes pressure.
- Poor placement can create local overpressures, increase risk of leakage, or lower storage efficiency.

Injection strategies

- Injection rates must stay below fracture thresholds while still meeting volume targets.
- Pressure management may involve brine extraction to balance pore pressure.
- Simulation allows testing of multiple injection schedules before implementation.

Monitoring design

- Seismic, pressure, and chemical monitoring must be targeted to the plume's behavior.
- Over-monitoring increases costs without adding security, while under-monitoring increases liability.

Optimization goals

- Maximize storage volume and trapping efficiency.
- Minimize injection costs and infrastructure.
- Reduce risk of leakage or regulatory non-compliance.

3. Addressing challenges with CMG

CCS faces technical challenges that differ from traditional oil and gas operations:

- **Heterogeneous reservoirs** create complex plume pathways.
- **Phase changes** in CO_2 under subsurface conditions impact injectivity.
- **Geomechanical stresses** alter fault and fracture stability.
- **Impurities in CO_2 streams,** such as H_2S, SO_2, and O_2, complicate both transport and storage.

CMG brings unmatched integration across the entire CCS lifecycle from scoping to injection, monitoring, and optimization. Seamlessly move from early planning to full-physics simulations and operational decision-making with one trusted solution suite.

4. CMG’s CCS toolkit

Initial Feasibility

Focus CCS

CMOST

- Geological site selection
- Validate asset viability quickly
- Access more storage capacity

De-risking

CMOST

GEM

CoFlow (IPSM)

- CO_2 trapping mechanism
- CO_2 plume monitor and surveillance
- CO_2 injectivity evaluation
- CO_2 chemical interaction with reservoir fluids
- Probabilistic storage capacity
- Reservoir and cap rock stress evaluation
- Evaluation of potential interference with legacy wells

Operations Optimization and Monitoring

GEM

CoFlow (IPSM)

CO2LINK + KDI LedaFlow

ABB CCS 360

- Sub-surface to surface modelling
- Well integrity assessment and flow assurance
- Regulatory reporting
- System corrosion monitoring
- MMV (Measurement, Monitoring and Verification)

5. Integrated Simulation & Modeling Tools for CCS

CCS projects require rigorous modeling of physical, chemical, and geomechanical processes to ensure long-term CO_2 containment. CMG provides a comprehensive suite of **integrated modelling tools** designed specifically for CCS applications, enabling rigorous simulation of subsurface flow, phase behavior, solubility, geochemical interactions, thermal effects, and geomechanical responses.

Convective & Dispersive Flow

Injected CO_2 migrates through reservoirs by both bulk flow (convection) and spreading (dispersion). CMG's GEM simulator models Darcy flow, buoyancy, solubility, mineral reactions, and hydrodynamic dispersion to predict plume migration and storage security. This allows operators to optimize well placement and injection rates while evaluating trapping mechanisms such as residual, solubility, and mineral trapping.

Relative Permeability Hysteresis

Residual trapping, the most secure short-term mechanism, depends on hysteresis, where flow properties reflect not just current saturation but the history of drainage and imbibition. GEM's advanced hysteresis models capture plume immobilization during brine imbibition, providing accurate forecasts of containment. Coupled geomechanics extend this to caprock integrity and stress-dependent permeability.

Solubility Trapping

When CO_2 dissolves into brine, it reduces mobility and gradually transitions into permanent mineral trapping. GEM models solubility using equations of state (Peng-Robinson, SRK, Span-Wagner) and multiple correlations (Henry's Law, Li-Nghiem, Harvey). Over decades to centuries, solubility and ionic reactions provide a critical pathway to long-term storage security.

H_2O Vaporization

CO_2 injection can cause local water vaporization, leading to dry-out zones, halite precipitation, and injectivity loss. GEM and WinProp simulate vaporization and precipitation under varying pressure, temperature, and salinity conditions, while CoFlow extends analysis to wells and pipelines. These workflows allow proactive management of injectivity risks.

Mineralization & Geochemistry

Over centuries, dissolved CO_2 reacts with reservoir minerals to form stable carbonates—the most permanent trapping mechanism. GEM models mineral dissolution, precipitation, ion exchange, and porosity changes. Integration with WinProp and external databases (PHREEQC, MINTEQ) provides realistic geochemical inputs, while CMOST enables uncertainty and sensitivity analysis.

Thermal Effects

CO_2 injection changes reservoir temperature, influencing viscosity, density, solubility, and geomechanics. GEM fully couples thermal and compositional modeling, simulating cooling near wells, phase-change interactions, and heat transfer across the reservoir. Accurate thermal modeling is critical for predicting injectivity, plume migration, and long-term containment.

Geomechanical Integrity

Maintaining caprock and wellbore integrity is essential for storage security. CMG simulators model stress/strain, fracture propagation, and stress-dependent permeability, with both one-way and two-way geomechanical coupling. This enables evaluation of risks such as caprock breach, induced seismicity, or wellbore leakage, ensuring CCS projects meet safety and regulatory standards.

By coupling these models, simulation allows operators to test long-term outcomes before injection begins. It supports project-level design and regulatory submissions, demonstrating that risks have been evaluated and mitigated.

6. Building the future of CCS

The next decade will bring rapid scaling of CCS as more regions adopt carbon pricing and emissions regulations. Future priorities include:

Expanding saline aquifer characterization to unlock large-scale storage capacity.

Building integrated capture, transport, and storage networks across national and regional boundaries.

Advancing mineralization projects in reactive formations such as basalts.

Improving monitoring technologies to increase resolution while reducing cost.

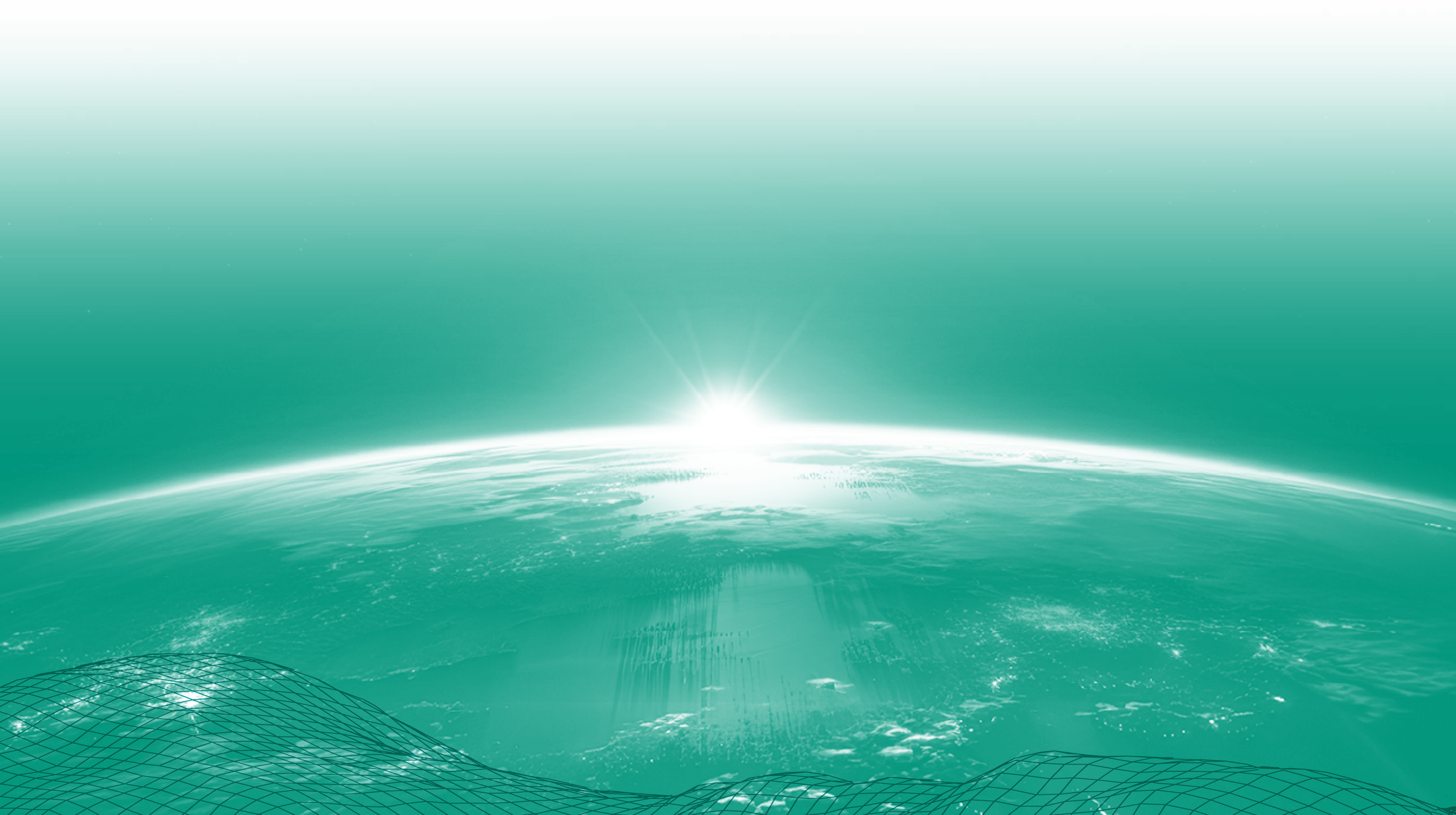
CMG continues to expand its platforms to address these priorities, linking scientific modeling with practical deployment.

7. From modeling to deployment

Making CCS work requires more than storage science. Projects succeed when economics, optimization, and modeling are integrated from the start. CMG's suite of solutions provides the framework for testing scenarios, reducing uncertainty, and building viable business cases.

From site screening to long-term stewardship, CMG's workflows connect capture, transport, and storage into one system. By aligning technical and financial planning, they make deployment at scale possible.

THE FUTURE OF CCS BELONGS TO THOSE WHO COMBINE SCIENCE, ECONOMICS, AND MODELING TO TURN PLANS INTO REALITY. CMG IS COMMITTED TO SUPPORTING THAT TRANSITION.



Learn more about how to de-risk your CCS project at

cmgl.ca/solutions/software/ccs/

/computer-modelling-group-ltd/

/compmodgr

www.cmgl.ca

Published by Computer Modelling Group Ltd.