CCS Chain Optimizer

An AI-enabled operations and assurance layer for CO_2 transport and storage networks
UK & Europe first; scalable to the Middle East

White Paper
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For: CCS transport & storage operators, cluster consortia, industrial emitters, regulators, and investors

Disclaimer

Abstract

As carbon capture and storage (CCS) scales across the UK and Europe, the operational and assurance challenges shift from building infrastructure to operating shared transport and storage networks under capacity constraints, multi-user nominations, and heightened verification expectations. (DESNZ, 2025; DESNZ, 2023) This white paper proposes the CCS Chain Optimizer: a modular, AI-enabled digital platform that combines network operations optimisation (forecasting, nomination workflow, constraint allocation, and rescheduling) with assurance-grade traceability (data provenance, audit trails, and MRV-ready evidence packs). The platform is designed to align with emerging governance patterns—including the UK CCS Network Code's emphasis on transparent constraint communications and allocation mechanisms—and EU policy direction accelerating cross-border CO_2 transport and storage markets.

Contents

1. Executive summary

CCS in the UK and Europe is evolving toward shared, multi-user CO_2 transport and storage (T&S) networks. In this model, multiple capture plants depend on common transport and injection capacity. The operational reality resembles regulated utility networks: users must submit nominations, capacity constraints must be handled fairly, and the operator must maintain records that withstand regulatory scrutiny and commercial dispute.

The CCS Chain Optimizer is a proposed AI-enabled operations and assurance layer that sits above operational systems (e.g., SCADA/historians) and commercial systems (entitlements registers, contracts), providing: (i) forecasting and feasibility checks; (ii) nomination and renomination workflows; (iii) constraint identification, allocation, and rescheduling; and (iv) traceable evidence packs for monitoring, reporting, and verification (MRV).

The concept is aligned to governance signals in the UK CCS Network Code, which anticipates capacity constraints and requires the T&S company to publish constraint information and notify affected users, with transparent allocation mechanisms used to manage constraints. (Ofgem, 2024) (DESNZ, 2025; DESNZ, 2023) In parallel, Ofgem's published CO_2 transport and storage enforcement guidance underscores the need for robust operational controls and auditability in the emerging regulatory regime.

In Europe, the policy direction is similarly supportive of scaled CCS infrastructure: the EU has articulated a target of at least 50 million tonnes per year of CO_2 injection capacity by 2030 under the Net-Zero Industry Act, and is progressing policy work on CO_2 markets and infrastructure to enable cross-border transport and storage services. (European Commission, 2025) (European Commission, n.d.) These trends increase the value of interoperable digital operations and verification workflows.

Recommended entry point (MVP): productise the daily nominations and constraint allocation workflow. This is the highest-frequency operational pain point and offers immediate, measurable benefits (utilisation uplift and curtailment reduction) while establishing the data backbone for MRV automation and, where commercially relevant, certificate-grade storage documentation.

2. The scaling problem: why CCS needs an operational and assurance layer

Shared CCS networks fail or succeed on operations. The critical shift is from "engineering a facility" to "running a network" where multiple parties submit competing demands into finite capacity, and where the evidence trail must be sufficient for regulators, auditors, and counterparties.

2.1 Where complexity enters (end-to-end)

- Capture variability: planned/unplanned outages, ramp limits, variable capture rate, and CO_2 quality/impurity fluctuations.
- Transport variability: compressor availability, pipeline operating envelopes, terminal constraints, and (where applicable) shipping windows.
- Storage variability: injection limits, well downtime, operating envelopes, and surveillance/integrity activity requirements.

- Commercial variability: multiple shippers/users with different entitlements, products, and priority/criticality to industrial operations.
- Verification variability: evolving MRV expectations and buyer requirements for robust, traceable proof of permanent storage.

2.2 What is at stake (operational, commercial, and reputational)

- Lost abatement and lost revenue from avoidable curtailment or unused capacity.
- Higher operating cost due to inefficient recovery from disruptions and manual coordination.
- Higher dispute risk (allocation disputes, claims, and settlement disagreements) without transparent rules and audit trails.
- Higher verification cost: evidence packs become expensive, bespoke, and slow without a traceable data backbone.
- Reduced investor and customer confidence if storage integrity and chain-of-custody documentation are not credible and repeatable.

A key design constraint is that CCS T&S operations are safety- and compliance-sensitive. The platform must support “human-in-the-loop” governance: recommendations may be AI-assisted, but operational decisions require approvals, explainability, and auditable records.

3. UK and European market context and regulatory signals

3.1 UK: Network Code obligations imply a digital operating requirement (DESNZ, 2025; DESNZ, 2023)

The UK CCS Network Code provides a framework for access and operation of T&S networks, anticipating capacity constraints and specifying that relevant constraint information should be published and affected users notified. (DESNZ, 2025; DESNZ, 2023) In practical terms, this requires systems to manage entitlements, forecast intake, nominations, allocation calculations, and notices at scale and with consistent auditability.

Ofgem’s work on CO_2 T&S enforcement guidelines and penalty policy further reinforces that this is not a “best-effort” environment: operational controls and auditability are integral to regulated network operation. (Ofgem, 2024) Any digital operating layer should therefore be designed to evidence compliance behaviours (process controls, record retention, decision rationales) as well as operational outcomes.

3.2 EU: scale targets and cross-border infrastructure

The EU is actively building the enabling conditions for scaled CCS. (European Commission, n.d.) The European Commission notes that cross-border CO_2 transport infrastructure projects fall within the Trans-European Networks for Energy (TEN-E) framework and may qualify as Projects of Common Interest or Projects of Mutual Interest, with potential access to Connecting Europe Facility support. The EU has also articulated a 2030 target of at least 50 million tonnes per year of CO_2 injection capacity under the Net-Zero Industry Act.

In October 2025, the Commission launched a public consultation on CO_2 markets and infrastructure, with an initiative planned for 2026. (European Commission, 2025) This signals that market rules (e.g., third-party access, interoperability, quality standards) will continue to evolve—strengthening the case for a configurable digital platform that can adapt without rebuilding core systems.

3.3 MRV and environmental integrity: EU CCS Directive monitoring requirements (EUR-Lex, 2018)

The EU CCS Directive (Directive 2009/31/EC) establishes a legal framework for environmentally safe geological storage, including monitoring obligations based on a monitoring plan approved by competent authorities (Annex II). (EUR-Lex, 2018) This reinforces the need for: (i) systematic monitoring plan mapping to data streams; (ii) provenance and data quality controls; and (iii) audit-ready reporting and record retention.

3.4 Industry benchmarking: digital CCS workflows are emerging

Digital workflow development is already visible in the market. (SLB, 2023) (Northern Lights, 2025) Northern Lights announced in December 2025 that it issued first CO_2 storage certificates, with documentation quantifying stored volumes and providing a breakdown of lifecycle emissions associated with transport and operations. Northern Lights has also partnered with SLB and Microsoft to develop digital CCS workflows and an open-source, Azure-compliant data platform approach. These signals suggest that “digital operations + verifiable documentation” is becoming core infrastructure for scalable T&S services.

4. What we are building: CCS Chain Optimizer

4.1 Product definition

CCS Chain Optimizer is a modular platform that orchestrates the operational-commercial interface of a CCS network. It is not SCADA and does not replace instrumentation. It is the "network operating system" layer that: (i) codifies rules (entitlements, nomination cycles, allocation logic); (ii) integrates measured and operational state data; (iii) supports optimisation and rapid rescheduling; and (iv) produces an auditable record of decisions and evidence packs for assurance.

4.2 What the platform must do on day one (minimum viable outcomes)

- Provide a single source of truth for entitlements and delivery points (who is entitled to deliver/inject, where, and under which capacity products).
- Accept and validate forecasts and nominations against entitlements and operational constraints.
- Detect and manage constraints quickly; compute allocations transparently; issue notices; and support renominations.
- Maintain immutable audit logs for submissions, calculations, approvals, notices, and changes to master data.
- Publish operator-facing and user-facing reports (nominations vs actuals, utilisation, constraint events, deviations, and trend analytics).

4.3 Primary users (personas) and decision points

The platform is designed around specific decisions and accountabilities:

- Control room / operations: accept or reject nominations; declare constraints; approve rescheduling plans; manage constraint events.
- Commercial / market operations: maintain entitlements and capacity products; approve allocation rule sets; oversee settlement artefacts.
- Users / shippers: submit forecasts and nominations; acknowledge constraint notices; submit renominations; monitor allocations and delivered volumes.
- Assurance / compliance: confirm evidence pack completeness; map monitoring-plan requirements to data checks; manage audit responses.

4.4 Functional modules

Module	Inputs (examples)	Outputs (examples)	Audit/governance artefacts
Capacity & Entitlements Register	Users, delivery points, registered capacity, capacity products, constraint rules	Entitlements snapshots, capacity reporting, allocation baselines	Versioning, approvals, change logs

Forecasts & Nominations	Forecast submissions (multi-horizon), daily nominations, cut-off times, validation rules	Accepted nominations, deviations, nomination packs	Submission records, acceptance/rejection rationale
Constraint Management & Allocation	Asset availability, available capacity envelopes, declared constraint windows, allocation rules	Constraint notices, pro-rata allocations, surplus reallocation recommendations, renominations triggers	Constraint log, allocation calculations, notices archive
Optimisation & Scenario Engine	Forecast distributions, constraints, objectives, safety/operability limits	Feasible schedules, recovery plans, scenario rankings	Scenario basis, sensitivity logs, decision record
Evidence Engine (MRV-ready)	Metered volumes, custody transfer records, injection records, monitoring-plan mapping	Evidence packs, reconciliations, exception reports	Provenance links, audit trails, verification pack
Integration & Governance	APIs, historian extracts, file drops, master data, quality rules	Validated datasets, canonical model, alerts	Lineage, data quality KPIs, immutable audit entries

4.5 Conceptual architecture

Figure 1 illustrates a layered design: data ingestion/validation; a canonical model with provenance; AI and optimisation services; operator workflows; and outputs (notices, nomination packs, and MRV evidence artefacts). The key principle is staged integration: start with minimum viable datasets and expand as value is proven.

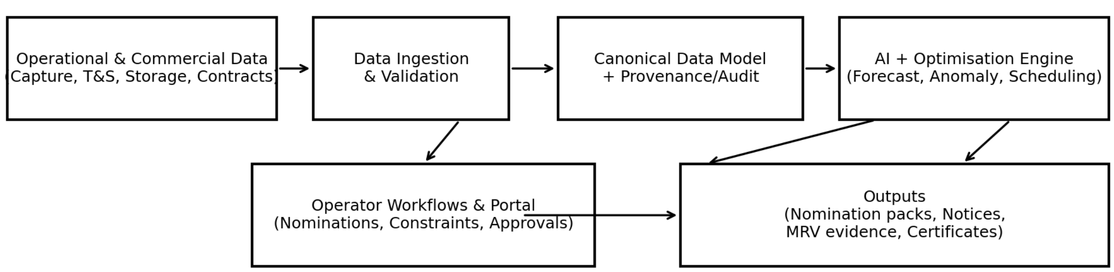

Figure 1: CCS Chain Optimizer conceptual architecture (illustrative).

4.6 What “success” looks like (operationally)

- Operators can produce a validated nomination and allocation pack within defined cut-offs, even during constraints.
- Users receive timely, consistent constraint notices and can submit renominations through controlled workflows.
- Allocated volumes, delivered volumes, and injected volumes can be reconciled with traceable, auditable calculations.
- Evidence packs can be generated on demand for audits, governance reviews, and (where applicable) customer documentation.

5. How AI works in the platform (and how it does not)

5.1 AI does not measure CO_2 directly

Measured values originate from instruments and operational systems (e.g., custody transfer meters, pressure/temperature sensors, composition analysers, injection metering, and operational status logs). AI does not replace calibrated instruments. Instead, AI is applied where it adds control-room value: prediction, anomaly detection, and decision support under uncertainty.

5.2 Measurement vs inference (a governance requirement)

The platform explicitly distinguishes between: (a) measured values; (b) derived values (engineering conversions and aggregations); and (c) estimated or inferred values (gap fills, forecasts, scenario outputs). Each record is tagged with provenance, model version (where relevant), and quality state so that auditors and operators can understand what is “fact” versus “estimate.”

5.3 Core AI/analytics functions

- Forecasting: probabilistic forecasts for capture availability, effective transport capacity, and injection availability across multiple horizons.
- Anomaly detection: early warning for meter drift, missing data, implausible readings, and deviations between nominated and delivered volumes.
- Recommendation generation: optimisation-driven schedules and allocations, supported by ML-driven heuristics and scenario ranking.
- Assurance automation: reconciliation and document intelligence to map monitoring requirements to checks, enabling fast evidence pack generation.

5.4 Optimisation is often the primary value engine

Many high-impact decisions are best solved with constraint-based optimisation rather than pure ML: allocating constrained capacity, producing feasible schedules, and recovering from disruptions while respecting safety and contractual rules. AI improves optimisation inputs (forecasts and uncertainty), and can accelerate computation (warm starts, heuristics), but governance logic remains explicit and configurable.

5.5 Explainability and human approvals

In regulated networks, accuracy alone is insufficient. Each recommendation should be accompanied by: (i) a feasibility proof (constraints satisfied); (ii) a rationale highlighting binding constraints and trade-offs; (iii) uncertainty indicators; and (iv) an auditable approval record. This makes the platform suitable for control-room adoption and for regulatory environments where decision processes matter.

5.5 Methods, model governance, and reproducibility

In regulated, safety- and commercially sensitive CCS environments, analytical performance must be matched by governance: recommendations should be explainable, reproducible, and reviewable by operators, auditors, and (where relevant) regulators. Accordingly, CCS Chain Optimizer adopts a hybrid decision framework in which measurement remains grounded in calibrated instrumentation and approved operational systems, machine learning supports probabilistic forecasting and anomaly detection, and operational decisions are computed via constraint-based optimisation subject to explicit rules, operating envelopes, and safety limits.

Model governance controls include: (a) version-controlled model artefacts and configuration; (b) documented training data lineage and feature sets; (c) performance monitoring and drift detection; (d) change control and approvals for any deployment to production; and (e) retention of the full decision artefact set (inputs, constraints, objective functions, solver outputs, and approvals) sufficient to reproduce outcomes for audit and dispute resolution. Where forecast uncertainty materially affects allocations or rescheduling, the platform publishes confidence intervals and scenario sensitivity rather than a single-point recommendation.

Allocation fairness is treated as a governance construct rather than an opaque model outcome. (DESNZ, 2025; DESNZ, 2023) Baseline allocations (e.g., pro-rata) are implemented as explicit, testable rules aligned to market frameworks, with any advanced products represented through transparent configuration and documented rule precedence .

6. Data: what is measured, where it comes from, and how it is governed

6.1 Data sources across the CCS chain

Representative data sources include:

- Capture: delivered CO_2 mass flow (custody transfer), pressure/temperature, CO_2 quality/impurity flags, plant availability states, outage plans.
- Transport: SCADA/historian summaries (flow/pressure), compressor status, pipeline operating envelopes, terminal capacity/inventory, maintenance plans.
- Storage: injection metering, well/manifold availability constraints, downtime plans, operational envelopes, surveillance/integrity event logs (where applicable).
- Commercial/governance: entitlements and capacity products, nomination cycles and cut-offs, allocation rules, notices and communications archive.

6.2 Data ingestion and validation

In the early market, integration maturity varies. The platform supports staged ingestion: secure file drops and scheduled extracts for pilots; APIs and event feeds for operational scaling. Regardless of integration method, validation rules are applied consistently: completeness checks, range and plausibility checks, time alignment, duplicate detection, and reconciliation across source systems.

6.3 Canonical data model and provenance

A canonical model is essential to avoid “spreadsheet sprawl.” The canonical model standardises entities (users, delivery points, entitlements, nominations, constraints, allocations, actuals) and preserves provenance (source system, transformation steps, timestamp, responsible party). This enables traceable reconciliation and repeatable evidence pack generation.

6.4 Data governance and auditability

- Defined data owners/stewards per domain (commercial, operations, storage, assurance).
- Immutable audit logs for changes to entitlements, nominations, allocations, and evidence packs.
- Data quality KPIs (completeness, timeliness, consistency, reconciliation breaks) and exception workflows.
- Retention policies aligned to regulatory audit expectations and contractual dispute windows.

7. MVP and pilot design for UK/Europe

7.1 Why nominations and constraints is the beachhead

Daily nominations and constraint allocation is the most pragmatic beachhead: it is high-frequency, value-linked, and governance-critical. It also provides a controlled environment to establish data provenance, audit trails, and user adoption—foundations needed for later MRV automation.

7.2 MVP scope (v1)

- Capacity and entitlements register (users, delivery points, registered capacity, products, rules).
- Forecast intake and validation (multi-horizon).
- Daily nomination and renomination workflow with cut-offs, validations, and approvals.
- Constraint workflow: event capture, baseline pro-rata allocation, notice generation and archiving, and renominations triggers.
- Dashboards and exports: nominations vs actuals, utilisation, constraint events, allocations, deviations, audit logs.

7.3 Minimum viable data for a pilot

- Per user/delivery point: delivered CO_2 mass flow time series and basic availability status.
- T&S network: available capacity or capacity proxies; planned outage schedule; key asset availability states.
- Storage: injection availability constraints by period and planned downtime schedule.
- Commercial: entitlements, nomination cycles/cut-offs, and constraint allocation rules.

7.4 Pilot plan (8–12 weeks, typical)

- Weeks 1–2: discovery, rules capture, data assessment, success metrics baseline, and security/access setup.
- Weeks 3–6: configure workflows, implement validations and allocations, ingest datasets, and establish dashboards/audit logs.
- Weeks 7–10: shadow-mode operations, tune rules and analytics, train users, and validate outputs against historical scenarios.
- Weeks 11–12: acceptance, handover pack, and scale plan to v2 (optimisation and MRV evidence packs).

7.5 Pilot acceptance evidence (what "done" looks like)

- Demonstrated end-to-end nomination cycle with controlled submissions, validations, and operator approvals.
- At least one simulated and one real (or historical) constraint event processed with transparent allocation outputs and notices.
- Reconciliation report showing nominations vs metered deliveries and injection (where available) with traceable calculations.
- Audit log export demonstrating who changed what and when, including approvals and notices.

- User training completion and operational playbook for recurring cycles.

8. Architecture, security, and deployment options

8.1 Security posture (design requirements)

CCS operational data is commercially sensitive and may be safety critical. The platform should support regulated operations through role-based access, segregation of duties, immutable audit logging, and secure integration patterns. It should also support evidence preservation for audits and disputes.

- Role-based access control (RBAC) with least-privilege defaults.
- Segregation of duties between operations, commercial, and assurance roles.
- Encryption in transit and at rest; secure key management.
- Immutable audit logs for operational actions and data changes.
- Controlled data sharing to users (publish what is required; protect what is sensitive).

8.2 Deployment options (fit to operator constraints)

- Cloud (UK/EU region): rapid deployment and scalable optimisation/analytics compute.
- Hybrid: sensitive data remains on-premise while portal/optimisation runs in controlled cloud.
- On-premise: for environments with strict data residency or network segmentation requirements.

8.3 Interoperability and configuration

Given evolving market rules, the platform should treat allocation rules, nomination cycles, and reporting templates as configurable artefacts rather than hard-coded logic. (DESNZ, 2025; DESNZ, 2023) This allows operators to adapt as the Network Code and EU market frameworks mature, without disruptive rebuilds.

9. Value case and success metrics

Value is realised through improved utilisation, reduced curtailment, reduced coordination cost, and lower verification overhead. The platform also reduces dispute risk by making allocations and decisions transparent and auditable.

9.1 Practical pilot metrics

- Utilisation uplift: delivered and stored CO_2 vs baseline (overall and during constraints).
- Curtailment reduction: fewer/shorter curtailment events attributable to earlier constraint detection and better rescheduling.
- Decision cycle time: time from constraint detection to issued allocation notice and revised nominations.
- Dispute indicators: number of contested allocations and time-to-resolution (supported by audit trails).
- Evidence effort: hours required to prepare periodic evidence packs before vs after platform adoption.

9.2 Illustrative value framing (operator and user)

A practical framing for early business cases is: (Utilisation uplift × throughput value) + (avoided curtailment cost) + (reduced manual effort) + (reduced dispute and audit risk). The pilot should define baseline periods and quantify each component using operational data and current process effort.

10. Product roadmap (v1–v3) and interoperability strategy

10.1 v1: nominations and constraints (MVP)

- Entitlements register, forecast intake, nomination workflow, constraint allocation (pro-rata baseline), notices, audit logs, and reporting.

10.2 v2: disruption optimisation and MRV evidence packs

- Probabilistic planning and advanced optimisation; automated reconciliation; monitoring-plan mapping; evidence pack automation; exception workflows.

10.3 v3: certificate-grade assurance and cross-border interoperability

- Certificate workflows; lifecycle emissions breakdown support; interoperability across networks/jurisdictions; portfolio-level optimisation.

10.4 Interoperability principles

- Standardise on canonical entities and time-aligned volumes.
- Preserve provenance and quality state for every record.
- Treat allocation rules and nomination cycles as configurable policy artefacts.
- Enable exportable evidence packs and API-based integration to operator and verifier systems.

10.4 Competitive landscape and differentiation

The CCS software ecosystem currently comprises (i) operational technology stacks (SCADA, pipeline management systems, terminal systems), (ii) bespoke reporting and integration solutions (dashboards and point integrations), and (iii) emerging MRV and environmental integrity platforms. These categories address important needs but typically cover only part of the shared-network operating model: OT systems excel within asset boundaries, while MRV tools focus on compliance reporting outputs. Multi-user CCS networks require an operational-commercial interface that can orchestrate entitlements, nominations, constraints, allocations, and auditable evidence across organisational boundaries.

CCS Chain Optimizer differentiates by integrating three capabilities in a single, auditable operating layer:

- Market-aligned operational workflows: entitlements, nomination cycles, constraint notices, allocations, and renominations implemented as first-class workflows rather than ad hoc spreadsheets and email chains (DESNZ, 2025; DESNZ, 2023).
- Optimisation with auditability: allocation and scheduling decisions computed under explicit constraints and objectives, with artefacts retained to reproduce outcomes for audit and dispute resolution.
- Assurance by design: provenance, data quality states (measured/derived/estimated), and evidence pack generation embedded from day one to reduce MRV and verification friction (EUR-Lex, 2018).

11. Commercial model and go-to-market approach (UK/Europe first, Middle East next)

11.1 Target customers

- Primary: CO_2 transport and storage operators (T&SCo) and cluster delivery organisations responsible for operations.
- Secondary: large emitters/anchor users (as co-sponsors where curtailment risk is material).
- Adjacent: EPC/PMC and integrators supporting operational readiness; assurance/verification firms.

11.2 Commercial model (initial hypothesis)

- Pilot fee (8–12 weeks) covering configuration, integrations, validation rules, training, and acceptance evidence.
- Annual subscription priced by scale drivers: number of users/delivery points, throughput band, and enabled modules.
- Optional professional services for deeper integrations, custom reporting, and extended MRV/certificate workflows.

11.3 Go-to-market phases

- Phase 1 (UK): pilot with a cluster operator or early T&S provider focusing on nomination/constraint workflows.

- Phase 2 (Europe): replicate into cross-border chains where interoperability and evidence are differentiators.
- Phase 3 (Middle East): adapt product for regional operating models (often large scale, hub-based) and data residency requirements.

11.4 Partner ecosystem

Partnership pathways include SCADA/historian providers, metering vendors, engineering consultancies supporting T&S operators, cloud and data platform partners, and assurance providers. (SLB, 2023) (Northern Lights, 2025) The Northern Lights collaboration with SLB and Microsoft is a market signal that operator-led partnerships may be a preferred model for accelerating digital capability.

12. Risks, limitations, and mitigations

Key risks and mitigations include:

- Data access and quality risk: mitigate with staged integration, robust validation, and clear data-sharing agreements.
- Model risk and explainability: mitigate with transparent optimisation, uncertainty reporting, model/version governance, and approval workflows.
- Operational adoption risk: mitigate by aligning to control-room processes, keeping humans in the loop, and delivering playbooks and training.
- Regulatory evolution risk: mitigate through configurable policy artefacts and continuous mapping to Network Code and monitoring requirements. (DESNZ, 2025; DESNZ, 2023)
- Cybersecurity risk: mitigate with security-by-design, RBAC, encryption, immutable logs, and regular assurance testing.

13. Conclusion

CCS networks in the UK and Europe are moving toward multi-user, regulated operating models that demand robust operational coordination and auditable assurance. The CCS Chain Optimizer is intended to become the digital operating layer that enables this transition: a repeatable, productised workflow for nominations, constraints, and transparent allocation, built on a data backbone that supports MRV evidence generation and (where required) certificate-grade documentation. Establishing a UK/Europe beachhead creates a scalable foundation for expansion into the Middle East.

Appendix A: Glossary

- CCS: Carbon Capture and Storage.
- T&S / T&SCo: Transport and Storage / Transport and Storage company (operator).
- Nomination: A user-submitted schedule/quantity request to deliver/inject CO_2 over a defined period.
- Constraint: A period where available network capacity is below demand or entitlements, requiring allocation.
- MRV: Monitoring, Reporting, and Verification.
- Pro-rata allocation: A proportional allocation approach based on registered capacity or entitlement.
- Provenance: Metadata describing data origin, transformations, validation, and ownership.

Appendix B: Canonical data model (high-level entities)

A minimal canonical model for MVP typically includes the following entities and relationships:

- User / Shipper
- Delivery Point (connection point) and associated metering
- Entitlement / Registered Capacity (by user and delivery point; time-bound)
- Forecast submission (by horizon)
- Nomination / Renomination (by day/hour; status and approvals)
- Constraint event (time window, affected points, available capacity envelope)
- Allocation (per user; basis and calculation metadata)
- Actuals (metered delivery, transport, injection) and reconciled volumes
- Notice / Communication (constraint notices, acceptance/rejection notices)

Appendix D: Constraint event worked example (illustrative)

This worked example demonstrates how the platform produces a transparent allocation and rescheduling pack during a constraint event. Figures are illustrative; the intent is to show logic, audit artefacts, and operator outputs.

Scenario: A transport segment becomes constrained for 24 hours. Available capacity is 800 tCO_2/day. Three users have registered capacity of 500, 300, and 200 tCO_2/day (total 1,000 tCO_2/day) and each nominates its full registered capacity. The baseline rule is pro-rata allocation across constrained users.

Step 1 — Establish constraint envelope and affected parties:

- Constraint window: 00:00–24:00 (day D).
- Available capacity envelope: 800 tCO_2/day.
- Affected users: U1, U2, U3.
- Captured artefacts: asset status snapshot, constraint rationale, nominations received, and available-capacity calculation.

Step 2 — Compute baseline pro-rata allocations (transparent rule):

Step 3 — Operationalise: the platform generates a constraint notice, prompts users to renominate to allocated capacity, and records approvals. If surplus reallocation is permitted, the platform applies configured reallocation rules and records the calculation basis and approvals.

Evidence outputs: (i) notice/publication record; (ii) allocation worksheet; (iii) accepted renominations; (iv) deviations monitoring; and (v) post-event reconciliation linking nominations, allocations, and metered actuals.

Appendix E: Minimum viable data dictionary (MVP)

Table E1 summarises a minimum viable dataset for piloting the nominations and constraints MVP. Each field is stored with provenance metadata and a quality-state label.

Appendix F: MRV-ready evidence pack contents (illustrative)

The assurance layer produces an evidence pack compatible with monitoring-plan expectations and third-party verification workflows (e.g., EU CCS Directive monitoring requirements and operator-specific monitoring plans) (EUR-Lex, 2018). An illustrative structure is:

- Executive summary (period, scope, key events).
- System boundary and monitoring-plan mapping (included/excluded, instrumentation list).
- Metering and data provenance register (sources, transformations, quality flags).
- Nominations and allocations log (constraint events, notices, calculations, approvals).
- Delivered vs nominated vs stored reconciliation (time-series, totals, gap handling).
- CO_2 quality/specification compliance summary (where applicable).
- Exception register (anomalies, overrides, investigations, closures).
- Verification artefacts (sign-offs, version history, retained source links).

Domain	Field	Granularity	Typical source	Quality state	Operational purpose
Entitlements	Registered capacity by user & delivery point (versioned)	As-defined	Commercial register / contract system	Administrative	Baseline allocation and validation
Nominations	Day-ahead nomination (hourly)	Hourly	User submission portal	Measured (submission)	Feasibility checks; constraint handling

Capture	Delivered CO_2 mass flow	5–60 min / hourly	Custody transfer meter + historian	Measured/Derived	Actuals vs nominations; deviations
Transport	Available capacity envelope by segment	Event/daily	Ops calc + asset status	Derived	Constraint detection and allocation
Transport	Compressor status + outage plan	Event	CMMS / ops log	Measured	Constraint drivers; recovery planning
Storage	Injection availability constraint	Event/daily	Field ops / well system	Derived	Feasibility and rescheduling
Governance	Constraint notice issuance record	Per event	Optimizer workflow	Measured (system)	Auditability and compliance

User	Registered capacity (t/day)	Nomination (t/day)	Pro-rata share	Allocated capacity (t/day)
U1	500	500	500/1000 = 0.50	0.50 × 800 = 400
U2	300	300	300/1000 = 0.30	0.30 × 800 = 240
U3	200	200	200/1000 = 0.20	0.20 × 800 = 160

- Audit log (immutable record of changes and approvals)

Appendix C: Pilot discovery checklist

A pilot discovery typically confirms the following:

- Network topology and delivery points in scope; current nomination and communications processes.
- Entitlement definition and current contractual allocation rules (including constraint handling).
- Available data sources, access methods, and data quality for metered flows and availability signals.
- Operational constraints and safety/operability limits that must be respected by scheduling.
- Governance requirements: approvals, segregation of duties, audit retention, reporting cadence.
- Success metrics and baseline definition for utilisation/curtailment and decision cycle times.

References

18. Department for Energy Security and Net Zero (DESNZ) (2023). Carbon capture and storage (CCS) Network Code: Heads of Terms consultation. UK Government. Available at: https://www.gov.uk/government/consultations/carbon-capture-and-storage-ccs-network-code-updated-heads-of-terms (Accessed: 19 December 2025). (DESNZ, 2025; DESNZ, 2023)
19. Ofgem (2024). CO2 Transport and Storage Enforcement Guidelines (PDF). Available at: https://www.ofgem.gov.uk/sites/default/files/2024-09/CO2_Transport_and_Storage_Enforcement_Guidelines.pdf (Accessed: 19 December 2025).
20. European Commission (n.d.). The EU's 2030 carbon storage target (Net-Zero Industry Act). Available at: https://climate.ec.europa.eu/eu-action/industrial-carbon-management/eus-2030-carbon-storage-target_en (Accessed: 19 December 2025).
21. European Commission (n.d.). Industrial carbon management (including support for cross-border CO2 transport infrastructure under TEN-E). Available at: https://energy.ec.europa.eu/topics/carbon-management-and-fossil-fuels/industrial-carbon-management_en (Accessed: 19 December 2025).
22. European Commission (2025). Commission launches public consultation on CO2 markets and infrastructure (6 October 2025). Available at: https://energy.ec.europa.eu/news/commission-launches-public-consultation-co2-markets-and-infrastructure-2025-10-06_en (Accessed: 19 December 2025).
23. EUR-Lex (2018). Directive 2009/31/EC on the geological storage of carbon dioxide (consolidated version). Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02009L0031-20180704 (Accessed: 19 December 2025).
24. Northern Lights JV (2025). Northern Lights has issued first CO2 storage certificates. Available at: https://norlights.com/news/northern-lights-has-issued-first-co%E2%82%82-storage-certificates/ (Accessed: 19 December 2025).
25. Northern Lights JV (2023). Northern Lights collaborates with SLB and Microsoft to digitalise carbon capture and storage value chain. Available at: https://norlights.com/news/northern-lights-collaborates-with-slb-and-microsoft-to-digitalise-carbon-capture-and-storage-value-chain/ (Accessed: 19 December 2025). (Northern Lights, 2025)
26. SLB (2023). SLB collaborates with Northern Lights JV and Microsoft. Available at: https://www.slb.com/news-and-insights/newsroom/press-release/2023/slb-collaborates-with-northern-lights-jv-and-microsoft (Accessed: 19 December 2025). (Northern Lights, 2025)