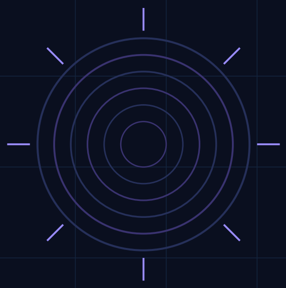

SECTOR DOCTRINE · INDUSTRIAL THERMODYNAMIC INTELLIGENCE

CCS / CCUS PARASITIC ENERGY

Capture-Loop Thermodynamics and Host-Asset Coupling

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EXECUTIVE SUMMARY

Capture economics are governed by parasitic thermodynamics

Carbon capture, utilisation and storage (CCS / CCUS) projects are commonly evaluated as flowsheet additions — a capture island, a compression train, a transport interface. Operationally, however, CCS facilities behave as: a coupled thermodynamic environment whose economics are dominated by parasitic energy demand on the host asset.

The parasitic load of a typical amine-based post-combustion capture system is not a single number. It is the integrated thermodynamic cost of:

- solvent regeneration steam,
- lean / rich solvent circulation,
- intercooled CO_2 compression to pipeline pressure,
- auxiliary cooling duty,
- and host-asset steam-cycle perturbation.

> **CCS economics live or die on parasitic thermodynamic behaviour — not on the capture chemistry alone.**

THE CAPTURE LOOP IS A THERMAL ENVIRONMENT

Post-combustion capture is fundamentally a heat-transfer and phase-equilibrium problem. Solvent absorbs CO_2 at low temperature in the absorber and releases it at elevated temperature in the regenerator. Every part of that loop is thermodynamic:

- absorber temperature profile and intercooling,
- rich-lean cross-exchanger approach,
- reboiler duty and steam quality,
- stripper overhead condensation and reflux,
- and solvent degradation pathways.

Small deviations in any of these variables — sustained over operating periods — translate into measurable changes in specific reboiler duty (GJ per tonne CO_2 captured) and therefore in total parasitic load.

HOST-ASSET COUPLING

CCS does not operate in isolation. It is thermodynamically coupled to the host asset — whether that host is a thermal power unit, a refinery, a cement kiln, a steel facility, an industrial heater, or a gas processing train.

The coupling occurs through:

- low-pressure steam extraction from the host steam cycle,
- auxiliary power demand on the host electrical system,
- cooling-water and ambient-coupling effects,
- flue-gas conditioning and pressure-drop effects,
- and operational dispatch interactions.

A host-asset thermal-performance perspective is therefore inseparable from a credible interpretation of capture-loop performance.

PARASITIC LOAD AS AN OPERATIONAL VARIABLE

Parasitic energy is often presented as a project-design figure. Operationally it is highly variable, responding to:

- host-asset load and steam-cycle state,
- ambient and cooling-water temperature,
- solvent composition and degradation state,
- fouling of cross-exchangers and reboilers,
- compressor inlet conditions and intercooling effectiveness,
- and operator-set control envelopes.

Historian-derived interpretation reconstructs how parasitic load actually behaves across the operating envelope — not how it was assumed to behave in the design basis.

CO2 COMPRESSION AS A THERMODYNAMIC LOAD

Compression of captured CO_2 to dense-phase or pipeline pressure is a major component of total parasitic energy. Interpreted thermodynamically, the compression train reveals:

- stage-level polytropic and isentropic efficiency drift,
- intercooler effectiveness over time,
- ambient-coupled performance envelopes,
- drying and dehydration loop interactions,
- and recoverable margin against the train's own demonstrated best.

DRIFT IS THE SILENT COST OF CAPTURE

Capture facilities, like other large industrial thermal systems, do not typically lose performance through discrete events. Reboiler duty creeps. Cross-exchanger approach widens. Solvent quality slowly drifts. Compressor efficiency edges down.

Each individual drift may appear operationally insignificant. Aggregated across the operating year, they may represent a materially significant increase in GJ per tonne captured — and therefore in the marginal cost of every tonne abated.

> **Across a fleet of capture trains, even small parasitic-energy drift becomes commercially material.**

MRV-GRADE THERMODYNAMIC INTERPRETATION

Monitoring, reporting and verification (MRV) frameworks increasingly require defensible, traceable interpretation of how capture facilities actually performed — not how they were designed to perform.

Historian-derived operational thermodynamics intelligence supports MRV by providing:

- deterministic reconstruction of operating-envelope behaviour,
- traceable interpretation of parasitic-energy performance,
- engineering-reviewable comparison against demonstrated best,
- and consistent treatment across operating periods.

READ-ONLY, NON-INTRUSIVE, INTEGRATION-SAFE

Capture facilities sit on, or beside, large industrial assets governed by strict integrity regimes. The interpretive framework is intended to be:

- read-only against existing historian environments,
- non-intrusive to control and safety systems,
- deterministic and engineering-reviewable,
- and operationally contextualized to the host-asset coupling.

CLOSING OBSERVATION

The economics of carbon capture will not be decided by capture chemistry alone. They will be decided by how effectively the parasitic thermodynamic loop is interpreted, sustained, and improved across operating life.

> **The next phase of CCS / CCUS operational maturity is systematic interpretation of capture-loop thermodynamics and host-asset coupling as a single industrial thermal environment.**

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