

Methodology and Assumptions

Study overview

This study evaluates how different approaches to flue gas characterization affect both the cost and capture efficiency of a carbon capture plant. This study modeled a hypothetical post-combustion amine-based carbon capture plant with the capacity to capture 1 million tonnes of CO₂ per year, retrofitted to an existing facility across various industries, as outlined below.

Industry	Flue Gas Source
Cement	Natural gas fired kiln
Iron and Steel	Boilers, reheaters, and stoves
Pulp and Paper	Recovery and power boilers
Coal-fired Power Plant	Lignite coal-fired boiler
Refinery	Fluid catalytic cracking unit
Steam Assisted Gravity Drainage	Once-through steam generator
Natural Gas Combined Cycle	Heat recovery steam generator

The study involved process simulations and detailed design using Aspen HYSYS. All existing facilities were assumed to supply a constant flue gas flow with consistent composition to the capture plant. The capture model assumed a 95% carbon capture efficiency and a plant availability of 85%. CO₂ transportation and storage fall outside the scope of this project and were therefore excluded from the analysis.

Determining the CapEx and OpEx for the capture plant

The Capital Expenditures (CapEx) for the capture plant were estimated using Aspen Capital Cost Estimator (ACCE) based on the Association for the Advancement of Cost Engineering (AACE) Class 5 estimates. This included direct field costs, indirect field costs, non-field costs (taxes, permits, other project costs, escalation), in addition to contingency.

Both fixed operating and variable Operating Expenses (OpEx) were included in this analysis. The fixed OpEx considered the costs of:

- (i) Labour and support
- (ii) Property taxes and insurance
- (iii) Operations and operating consumables
- (iv) Maintenance

The variable OpEx considered all utility and chemical consumptions, such as amine, chemical solvents, fuel, and electrical power.

Determining the Levelized Cost of Capture (LCOC)

The LCOC represents the average price per tonne of CO₂ required to cover all costs over the plant's lifetime (see [LCOC calculator](#) for details). Determining LCOC is essential for accurately assessing the economic viability of a carbon capture project. Table 1 shows all the assumptions used for the LCOC calculation.

Table 1: Financial Model Inputs

Parameter	Assumption
CapEx Period	3 years
Start CapEx Year	2027
Operational Period	25 years
Distribution of Capital	
- 1 st Year	20%
- 2 nd Year	50%
- 3 rd Year	30%
First Year of Operation	2030
Escalation of CapEx	3%
Escalation of Fixed OpEx and Variable OpEx	3%
Discount Rate	8%

Flue gas characterization approaches

This study compares three flue gas characterization approaches across multiple industries:

1. Detailed flue gas characterization
2. Minimum required characterization with site optimization
3. Minimum required characterization, unmitigated

The next section outlines the design assumptions for each characterization approach for the cement industry. While other industries follow the same design principles, the equipment configuration may vary depending on their specific flue gas characteristics.

1. Detailed flue gas characterization

This approach assumes that detailed flue gas characterization was conducted upfront using testing methods specifically tailored for carbon capture. The pre-treatment and capture systems are designed using this comprehensive data, enabling them to address known contaminants and reduce operational risks.

The pre-treatment equipment included an upsized quencher to provide margins for particulate loading, with a caustic polisher to improve SO₂/NO₂ removal, along with dedicated particulate removal technology for aerosols and fine particulates. Solvent health was managed by a thermal reclaimer,

anti-foam injection, filtration, and a metals removal unit. Equipment redundancy and isolation capabilities were incorporated to allow for online maintenance, ensuring plant reliability.

This proactive approach required higher upfront capital costs but was assumed to achieve design targets of 95% carbon capture efficiency and 85% plant availability from the start of operations. This leads to lower operating costs and increased capture rates over the plant's lifetime.

2. Minimum required characterization with site optimization

This approach assumes the initial design was based on standard environmental flue gas testing, which overlooks critical contaminants that can negatively impact capture systems. As a result, the plant was built using a standard design with a lower upfront capital costs compared to Case 1, omitting key pre-treatment equipment for fine particulate and metals removal.

These design omissions led to accelerated amine degradation, foaming, and fouling. This resulted in higher operating costs from increased chemical consumption and waste disposal, as well as reduced plant availability from frequent cleaning related shutdowns. Ultimately, this lowered capture rates. Within the first four years of operation, a capital maintenance program was initiated to retrofit the plant with the missing pre-treatment equipment for fine particulate and metals removal, as well as redundancy and isolation features.

This reactive approach resulted in a higher total capital cost compared to Case 1 due to expensive retrofits, along with significant early losses in CO₂ capture volume. After modifications, the plant's performance was assumed to match that of Case 1.

3. Minimum required characterization, unmitigated

This approach mirrored the initial flawed design of Case 2 but assumed no corrective capital maintenance was ever implemented. As a result, this scenario had the lowest upfront capital cost of the three cases.

However, the plant faced persistent operational challenges, including high solvent degradation and severe equipment fouling. These issues led to chronically high operating costs and caused a permanently reduced CO₂ capture rate throughout its 25-year lifespan. The significantly lower capture volume resulted in the highest LCOC among all three cases.

Design assumptions

Table 2: Design Assumptions for each Flue Gas Characterization Approach

	Case 1	Case 2	Case 3
Pre-treatment	Upsized quencher Caustic polisher Particulate removal technology	Standard quencher Caustic polisher Particulate removal technology*	Standard quencher Caustic polisher
Solvent Health Management	Thermal reclaimer Anti-foam injection Metals removal	Thermal reclaimer Anti-foam injection Metals removal*	Thermal reclaimer Anti-foam injection
Redundancy and Isolations	Yes	Yes*	No
Annual Captured CO ₂ (tonnes)	1,000,000	800,000 (Years 1-2), 850,000 (Years 3-4), 1,000,000 (Years >5)	800,000

*Added via retrofit within the first four years of operation