



Integrating Carbon Capture, Utilization, and Storage (CCUS) into Petrochemical Value Chains: Techno-Economic Feasibility and Financing Models for Emerging Economies

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Abstract : Carbon capture, utilization, and storage (CCUS) is increasingly recognized as a cornerstone of industrial decarbonization, particularly in hard-to-abate sectors such as petrochemicals, where process emissions are unavoidable. The petrochemical industry, responsible for producing plastics, fertilizers, and chemical intermediates, is simultaneously one of the fastest-growing and most carbon-intensive sectors. CCUS offers a pathway to reconcile continued growth with climate imperatives. This paper provides an integrated assessment of the techno-economic feasibility of CCUS deployment in petrochemical value chains, focusing on emerging economies such as India and Saudi Arabia, where hydrocarbon resources remain central to economic development. Capture technologies, utilization pathways, and storage options are examined, alongside market dynamics, financing models, and regulatory frameworks. Three case studies - SABIC's Jubail CCUS plant, Reliance Industries' Jamnagar pilot, and Occidental Petroleum's direct air capture hub - illustrate opportunities, challenges, and strategies for scaling CCUS. A framework for CCUS-enabled petrochemical clusters is proposed, emphasizing process integration, infrastructure development, policy support, and stakeholder engagement. The paper also explores policy, business, and sociological implications of large-scale deployment.

Keywords - Carbon Capture, Utilization and Storage (CCUS); Petrochemical Industry; Industrial Decarbonization; Emerging Economies; Techno-Economic Feasibility; Sustainable Finance

I. INTRODUCTION

The petrochemical sector is both a driver of global economic development and a significant contributor to greenhouse gas emissions. Demand for plastics, methanol, and ammonia is expected to grow steadily, particularly in emerging economies, despite the global shift toward decarbonized energy systems. This growth is driven by population expansion, urbanization, and increased consumption of fertilizers and consumer goods. Petrochemical production processes, notably steam cracking and ammonia synthesis, are inherently carbon-intensive. Unlike power generation, where renewable substitution is possible, petrochemical emissions are embedded within chemical processes, necessitating process-level mitigation strategies.

Carbon capture, utilization, and storage represents one of the most pragmatic solutions to this challenge. By capturing CO₂ at emission points and either utilizing it industrially or storing it geologically, CCUS allows continued petrochemical growth while aligning with climate goals (IEA, 2023). Emerging economies like India and Saudi Arabia must integrate CCUS to reconcile industrial expansion with environmental responsibility, requiring coordinated innovation across engineering, market design, and governance.

II. PROCESS ENGINEERING OF CCUS

The chemical engineering of CCUS is structured around three stages: capture, utilization, and storage, each with unique technical and economic considerations.

Capture Technologies underpin CCUS feasibility. Post-combustion capture using amine-based solvents is the most commercially deployed, retrofittable to existing plants, but imposes an energy penalty of 15–30% of plant output (Boot-Handford et al., 2021). Alternative technologies, such as membranes and solid sorbents, offer lower energy intensity and operational flexibility. Pre-combustion capture suits ammonia and methanol production, while oxy-fuel combustion produces high-purity CO₂ streams, simplifying downstream processing.

Utilization Pathways create market demand for captured CO₂. Enhanced oil recovery (EOR) has been the traditional outlet, but conversion into chemicals, plastics, and construction materials is gaining traction. CO₂ is already used in urea production and can

be incorporated into methanol, polycarbonates, and other polymers (IRENA, 2022). Mineralization into construction materials offers durable sequestration.

Storage Options act as a final safeguard. Deep saline aquifers and depleted hydrocarbon reservoirs are technically proven storage sites, especially when multiple emitters share transport and storage infrastructure in industrial clusters, achieving economies of scale (Rubin, Davison & Herzog, 2022).

III. MARKET ANALYSIS

The global market for CO₂ utilization is poised for growth due to industrial demand, regulatory incentives, and evolving sustainability commitments. Methanol, projected to exceed 120 million tonnes by 2030, is a particularly promising pathway (IRENA, 2022). Methanol can be synthesized directly from CO₂ and serves as both fuel and feedstock for olefins and aromatics, creating scalable demand. Fertilizers, especially urea, continue to be critical in India and the Middle East, providing a natural sink for CO₂ captured from ammonia plants. Beyond chemicals, CO₂-derived plastics, polycarbonates, and construction materials are emerging sectors. Leading consumer goods companies are specifying low-carbon polymers in packaging, creating commercial pull for CCUS-based products (Geyer, Jambeck & Law, 2021).

Storage markets are influenced by carbon pricing, border adjustment mechanisms, and voluntary carbon markets. CCUS costs, between USD 40–80 per tonne of CO₂ avoided, challenge deployment in regions lacking policy incentives (Rubin, Davison & Herzog, 2022). Regulatory trends, such as the EU's carbon border adjustment mechanism, increase demand for low-carbon petrochemical products, creating indirect incentives. Strategic integration of CCUS within industrial clusters further improves economic feasibility by sharing infrastructure, pipelines, and storage facilities.

IV. FINANCING MODELS

The financial barriers to CCUS are substantial due to high capital intensity and long payback periods. Innovative financing mechanisms are crucial. Carbon pricing remains underdeveloped in emerging economies, but voluntary carbon markets are beginning to offer meaningful revenue streams (IFC, 2022). Green bonds and sustainability-linked loans are increasingly used by companies like SABIC and Reliance to fund low-carbon initiatives, linking investment performance to sustainability outcomes.

Public-private partnerships are essential to mitigate investment risks. Shared CO₂ transport networks and storage hubs exemplify cost-effective PPP structures. Blended finance, combining development bank funding, sovereign wealth contributions, and private-sector capital, is critical to de-risk projects. For example, Saudi Arabia's Public Investment Fund and India's National Investment and Infrastructure Fund could provide initial capitalization for cluster-scale CCUS deployment. Contracts for difference guarantee revenue for avoided CO₂, stabilizing investor returns. Together, these financing tools create an ecosystem capable of supporting long-term CCUS deployment.

V. CASE STUDIES

SABIC Jubail CCUS, Saudi Arabia

SABIC's Jubail CCUS facility captures approximately 500,000 tonnes of CO₂ annually from ethylene glycol and ammonia production, converting much of it into methanol and urea for global markets (SABIC, 2023). The plant is integrated into existing processes, optimizing energy recovery and lowering operating costs. Jubail also serves as a center for workforce training and applied research, enhancing local technical capacity. The project demonstrates the commercial logic of embedding CO₂ into products rather than treating it solely as a regulatory burden.

Reliance Industries, Jamnagar, India

Reliance Industries has piloted CCUS technologies at its Jamnagar complex, focusing on CO₂-to-syngas and CO₂-to-methanol pathways (Reliance, 2023). The company leverages refining infrastructure, capital-raising capability, and global partnerships to integrate CCUS into a broader strategy that includes hydrogen and renewables. Reliance's approach exemplifies how conglomerates can embed decarbonization within diversified investment and technology portfolios.

Occidental Petroleum, United States

Occidental's 1PointFive project combines direct air capture with geological storage, capturing 500,000 tonnes annually (Occidental, 2022). Benefiting from the U.S. 45Q tax credit and voluntary carbon markets, the initiative monetizes CO₂ as a carbon-neutral commodity. Occidental demonstrates the critical role of regulatory and market incentives in scaling CCUS, emphasizing lessons for emerging economies.

Table 1: CCUS Project Data Comparison

Project	Annual CO ₂ Captured (kt)	Utilization Pathway	Capital Investment (USD bn)	Year Operational
SABIC Jubail	500	Methanol, Urea	0.6	2015
Reliance Jamnagar	150	Syngas, Methanol	0.4	2022 (Pilot)
Occidental 1PointFive	500	Geological Storage & Carbon Markets	0.5	2021

VI. FRAMEWORK FOR EMERGING ECONOMIES

Emerging economies face specific technical, financial, and social challenges in scaling CCUS. Process integration is essential: capturing CO₂ from high-purity, low-cost streams such as hydrogen and ammonia production offers immediate advantages. Industrial clusters reduce unit costs by 30–40%, facilitate shared R&D, and enhance workforce development. Jubail Industrial City and Dahej Petrochemical Complex exemplify effective cluster deployment.

Policy support is critical. Regulatory clarity, carbon pricing, tax incentives, and contracts for difference establish revenue certainty required to mobilize large-scale investments. Financing innovation - blended finance, ESG-linked instruments, and sovereign wealth participation - de-risks projects. Stakeholder engagement ensures social license, building trust through transparent monitoring, job creation, and visible environmental benefits. Together, these measures form a systemic framework for CCUS adoption.

VII. POLICY, BUSINESS, AND SOCIOLOGICAL IMPLICATIONS

CCUS deployment in petrochemical clusters has wide-ranging implications. Policy-wise, CCUS enables countries to decouple industrial growth from emissions. India can protect export markets against carbon border taxes, while Saudi Arabia can achieve Vision 2030 targets by positioning itself as a hub for sustainable energy and chemicals (IEA, 2023).

Business implications are significant. Early movers gain competitive advantage by accessing ESG-aligned capital, securing premium low-carbon markets, and diversifying revenue streams. Firms integrating CCUS demonstrate sustainability leadership and attract international partnerships.

Sociologically, CCUS creates employment in engineering, operations, monitoring, and infrastructure. Reducing local pollution improves health and community trust. Transparent integration into broader sustainability strategies is critical to avoid public perceptions of a “license to pollute.” Engagement must include education, local employment, and visible community benefits.

VIII. CONCLUSIONS

CCUS provides a pragmatic pathway to reconcile petrochemical growth with climate goals. Expanded case studies from SABIC, Reliance, and Occidental demonstrate technical feasibility, business logic, and regulatory integration. Emerging economies can implement cluster-based approaches combining process engineering, financing innovation, policy clarity, and social engagement. Collaboration among governments, companies, and communities is essential to ensure CCUS is technically feasible, financially viable, and socially acceptable.

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