Technology Choice & Innovation, Policy Design and Leveraging Strategic Advantages are Critical for Viable CCUS Projects

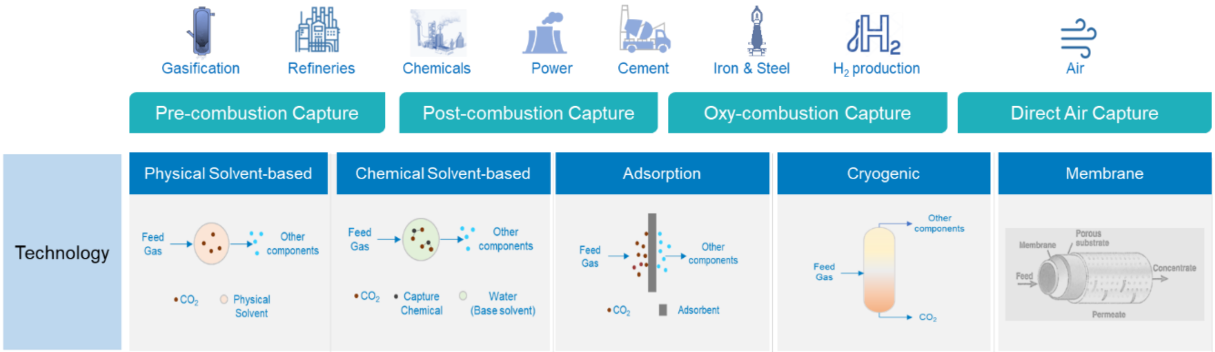
Introduction: CCUS is a critical decarbonization lever for limiting greenhouse gas emissions from industrial and hard to abate sources. The successful design and implementation of commercial scale CCUS projects depends on the right combination of technology, capture source & volumes, decarbonization targets, and appropriately leveraging project strategic advantages & factors. Based on the experience of designing and engineering economically viable CCUS projects across different geographies, sectors, and flue gas streams, this paper presents Dastur Energy's perspective on design choices for CCUS projects, tradeoffs between different interplaying factors, innovations in gas conditioning and pre-treatment, and the right policy design.

The ultimate goal is to design and engineer viable CCUS projects that are commercially implementable and operable, with the operating and amortized capital cost of carbon capture being within the envelope of policy incentives, have minimal impact on the economics of the final product or can be absorbed by the emerging premium for decarbonized products.

Abstract: The continued use of fossil fuels in sectors such as power generation, steel, cement, oil & gas, petrochemicals, fertilizers is critical for ensuring energy, materials and food security & abundance, which is fundamental to the modern way of life. Even as the contribution & share of renewable energy continues to grow and new energy carriers such as green hydrogen emerge, CCUS offers the only viable and commercially scalable alternative for meeting the long-term decarbonization and climate goals of these sectors. Around the world, most CCUS projects with decades of successful operations are typically found in natural gas & fertilizer production applications (with high CO_2 concentration in the flue gas) coupled with downstream EOR application for supporting additional crude oil recovery. To make CCUS economically viable across diverse sectors & geographies without EOR opportunities, the design and implementation of projects need to integrate the interplay and synergy between technology & innovation, scale, right policy design and downstream product portfolios.

Technology: Many capture technologies are reasonably well developed, with several commercial-scale projects operating across the world. The choice of technology is primarily driven by the flue gas composition and CO_2 concentration, as shown in Figure 1 below. However, factors such as utility availability and cost are critical for ensuring the right technology choice. The pre-dominant technology of choice in North American carbon capture projects is amine based solvents, supported by the availability of abundant & inexpensive natural gas, used to generate steam for solvent regeneration. However, for countries such as India, where CCUS deployment is expected to accelerate with recent budgetary support, natural gas is imported, extremely expensive, and not easily available. The widescale adoption of amine based technologies could mean using more coal to generate steam, leading to high secondary CO_2 emissions, significantly lowering the effective decarbonization achieved. Hence, there is a need to look at cryogenic technologies which primarily use electricity, and thus reduce secondary/Scope 2 emissions by leveraging India's accelerating renewable penetration and increasing availability of green power. This is especially pertinent for large industrial sectors such as steel and cement, where appropriate gas conditioning techniques can be used to increase the CO_2 concentration in the flue gas, making it suitable for cryogenic technologies.

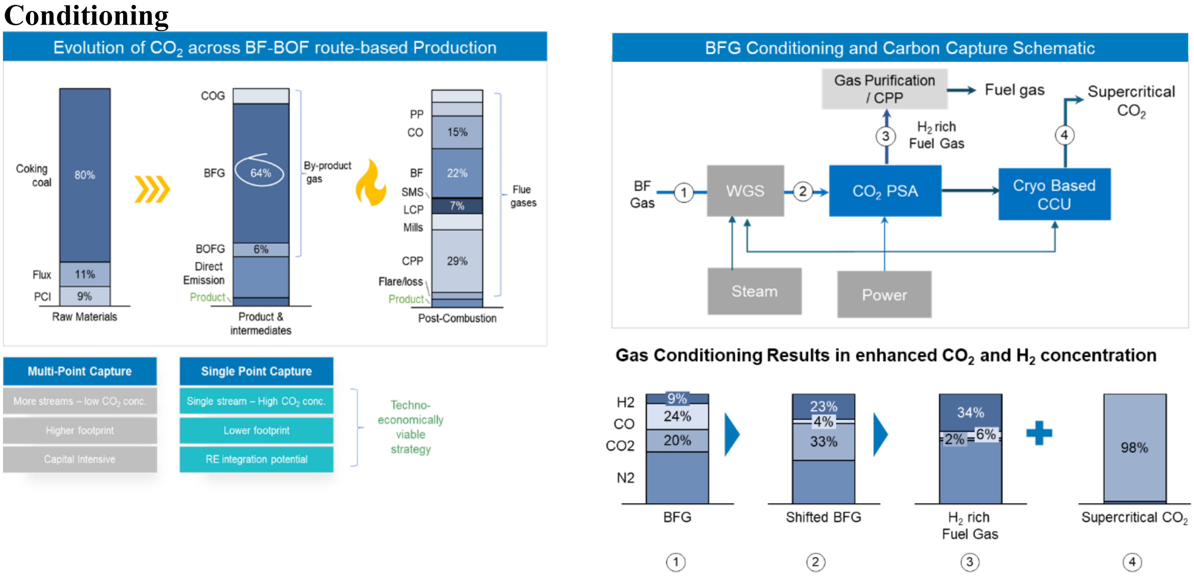
Figure 1: Selection of Appropriate CO2 Capture Technology is Key to Successful CCUS



	Physical Solvent-based	Chemical Solvent-based	Adsorption	Cryogenic	Membrane
Working principle	CO_2 solubility in solvent	Chemical binding of CO_2 with solvent	Difference in diffusivity & heat of adsorption	Low temperature fractional distillation	Relative diffusivity and surface adsorption
Stream press.	Med to High pCO_2	Low pCO_2	High pCO_2	Low to medium pCO_2	Med to high pCO_2
Application & Economics	Gasification : 15-17 $/T	Power plant : >60 $/T	NG processing : >35 $/T	SMR based H_2: ~ 30-35 $/T	Gas Processing: 50 – 70 $/T
Examples	Rectisol™ , Selexol™	BASF / OASE®, ICE-21, ICE-31, KS-1™, KS-21™, UCARSOL™	PSA, VSA, TSA	Cryocap™, Ortloff Dual Refrigerant CO_2 Fractionation (DRCF)	PRISM, MEDAL™, PolySep™, CYNARA

Innovations in Gas Conditioning: Innovative techniques such as gas conditioning and pre-treatment can significantly improve the economics of carbon capture. One example is the steel sector, and particularly Integrated Steel Plants (ISP), which have the highest volume and intensity of CO_2 emissions. In ISPs, focusing on a single point of capture (i.e. Blast Furnace gas vs. multiple CO_2 emission points) and conditioning the BF gas using Dastur Energy's unique gas conditioning scheme increases the CO_2 concentration and appropriate for the application of cryogenic technologies (Figure 2), and ultimately a project design with significantly better carbon capture economics, at the cost of capturing only 50-60% of the overall plant emissions at a modest cost (within 10% incremental cost of steel production) vis-à-vis full/higher decarbonization at prohibitive costs.

Figure 2: Improving Carbon Capture Economics with Single Point Capture and Innovative Gas Conditioning



Policy Design: Appropriate policy design is imperative to ensure the sustainability of CCUS projects. Sectors such as power generation, steel, cement, oil & gas refining, petrochemicals & chemicals, fertilizers etc., which are prime candidates for decarbonization through CCUS, are all commodity sectors, and the required premium for "green" or "low-CO_2 footprint" products is not established or accepted in most of these sectors. Hence, there is a need to focus on CCUS sectors and projects, where the cost of capture (both opex and capex) is less than the envelope of available credits/penalties, leveraging factors such as the scale of the carbon capture operations, high CO_2 concentration in the flue gas, or project specific advantages such as onsite sequestration sites or surplus steam availability (at marginal or no cost) within the plant.

However, for certain sectors, such as natural gas based power generation appropriately designed policy incentives are also important. Existing incentives for carbon capture/penalties for unabated emissions are based on a per tonne of CO_2 basis, say up the 45Q tax credit of US$ 85/tonne of CO_2 for each tonne of CO_2 captured and stored for CCUS projects in the United States. It does not matter whether the tonne of CO_2 comes from coal or from natural gas; the payment/incentive is the same. But the underlying physics are not. Capturing CO_2 from natural-gas exhaust is dramatically harder than from coal exhaust—not because of exotic engineering, but because of the composition of the flue gas itself.

Coal flue gas contains 12 to 15 percent CO_2 and only about 5 percent oxygen. Natural-gas flue gas contains just 3 to 4 percent CO_2 but nearly 14 percent oxygen. That high oxygen level accelerates solvent degradation, increases corrosion, and reduces the working capacity of the capture solvent. Combined with the low CO_2 concentration, it forces much larger absorbers, higher circulation rates, and greater parasitic energy use. The result is predictable: capturing a tonne of CO_2 from coal typically costs about US$ 75 dollars; from natural gas, roughly US$ 120 dollars.

Under a flat per-tonne of CO_2 credit, the coal plant gets a US$ 10 margin per tonne of CO_2 captured, while the gas plant loses about US$ 35 per tonne of CO_2 captured. So coal capture proposals advance while gas proposals die before they begin. However, electricity systems do not operate in tons; they operate in megawatt-hours. A coal plant emits almost a tonne of CO_2 per megawatt-hour. Capturing 90 percent at roughly US$ 75 tonne implies an added decarbonization cost of around US$ 40 to 60 per megawatt-hour. A gas plant emits roughly a third as much CO_2 - about 0.35 to 0.40 tonne of CO_2 per megawatt-hour. Even with a higher capture cost of US$ 120 a tonne, the added decarbonization cost is roughly US$ 30 to 40 dollars per megawatt-hour. The coal plant has high volumes of cheap tonnes of CO_2, while the natural gas plant has much lower volumes of expensive tonnes of CO_2. On the delivered-electricity basis that matters, the differences narrow into the same tens-of-dollars range.

Appropriate policy design is needed to incentivize not only captured tonnes of CO2 but also low-carbon megawatt-hours, to make carbon capture projects in natural gas based plants viable and financeable.

Conclusions: Commercially viable CCUS deployment requires the deliberate integration of context-specific technology selection, innovation in gas conditioning and process integration, strategic leverage of plant-specific advantages (scale, utilities, co-location, storage access), and intelligent policy design aligned with physical realities and market economics.

When these elements are engineered in synergy, CCUS projects can achieve bankable economics within available incentive envelopes while minimizing impact on end-product competitiveness. The transition to large-scale CCUS deployment will not be driven by technology alone—but by disciplined system design that integrates engineering, economics, and policy.

References

Mukherjee, A. and Chatterjee, S. [2022]. Carbon Capture, Utilization and Storage (CCUS) Policy Framework and its Deployment Mechanism in India

Mukherjee, A. and Chatterjee, S. [2023]. Carbon Capture, Utilization and Storage (CCUS) Technology Gaps and International Collaboration