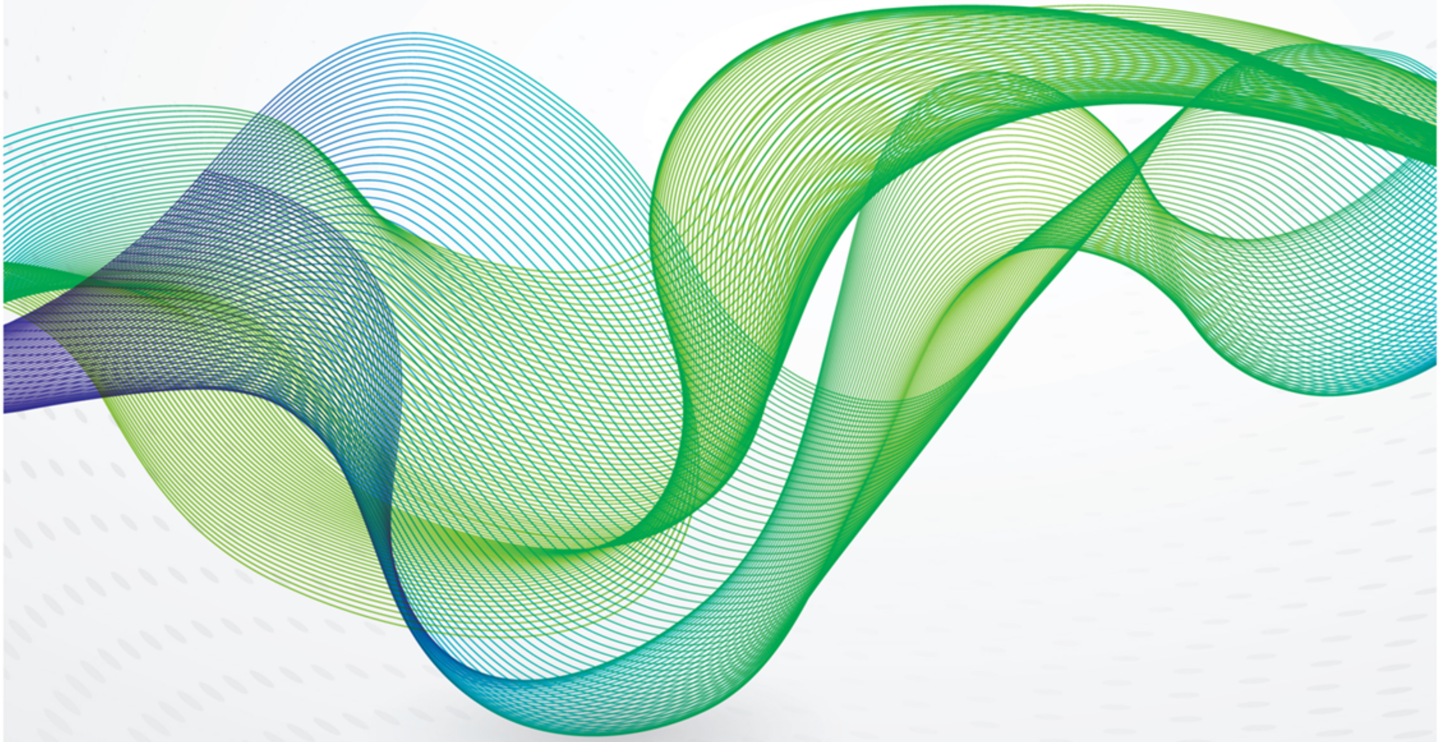
THE OXFORD
INSTITUTE
FOR ENERGY
STUDIES

July 2023

Deal or No Deal:

Will the US Inflation Reduction Act (IRA) push Carbon Capture and Storage (CCS) and Carbon Dioxide Removal (CDR) technologies over the line?



OIES Paper: CM05

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ISBN 978-1-78467-211-9

Acknowledgement

The author acknowledges the valuable review and suggestions provided by OIES Research Associates Nnaziri Ihejirika and Peter Findlay which notably enhanced the quality of this study, as well as the guidance and mentorship provided by Hasan Muslemani, Head of Carbon Management Research at OIES.

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Introduction

A portfolio of carbon management solutions is required to achieve the United States' commitment to economy-wide net-zero emissions by 2050 in line with the Paris Agreement (PA) targets.[1] In doing so, forecasts suggest that the US will need between 0.65 and 1.7 Gt/y of capacity in carbon capture and storage (CCS) and carbon dioxide removal (CDR).[2][3] Federal and state governments will be unable to finance this future without substantial private sector co-investment. Attracting private investment is particularly important given that global deployment of carbon capture technology has not kept pace with policy commitments: just over 42 Mt/y of capacity was operational as of September 2022 and less than 10 Mt/y of additional capacity is in construction.[4] The difficulties of financing carbon management development and deployment are documented thoroughly.[5]

Signed into law in the US on August 16, 2022, the Inflation Reduction Act ("IRA") announced $369 billion in total investment across a broad set of clean energy, emissions reductions, decarbonization and environmental protection programming. The IRA is described as "the most significant federal climate and clean energy legislation in US history."[6] The IRA is expected to facilitate significant reductions in domestic greenhouse gas ("GHG") emissions and contribute to the government's commitment to reaching net-zero emissions by 2050. The IRA includes material improvements to financial supports for carbon management, including an extension and set of enhancements to *Section 45Q* of the US *Internal Revenue Code* (hereinafter "45Q", or "45Q tax credit").

This study evaluates the implications of the IRA on the ability of carbon management activities to attract private sector finance at sufficient levels to enable net-zero by 2050 in the US. This paper will primarily appraise the enhanced 45Q tax credit given its dedication and specificity to CCUS, with some consideration paid to other measures. In the sections to follow, the study considers three applications that are deemed necessary to achieve net-zero: CCS in heavy industry, direct air capture (DAC), and CO_2 utilization. The study then examines key risks and returns across cases and assesses how the IRA addresses these risks before offering additional considerations and final conclusions. The study uses the theoretical underpinnings of 'blended finance', the strategic use of certain sources of capital to spur additional private investment, to inform its assessment of key risks. The study finds that unique and difficult-to-mitigate risks are likely to persist despite the IRA and strengthened 45Q tax credit.

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[1] "Carbon capture and storage (including DACCS and BECCS) is central to IPCC mitigation pathways" quoted from https://www.catf.us/2022/04/what-does-latest-ipcc-report-say-about-carbon-capture/ on the WG III contribution to the 6th Assessment Report.

[2] Greig, Chris, and Sam Uden. "The value of CCUS in transitions to net-zero emissions." The Electricity Journal 34.7 (2021): 3-4

[3] US Department of Energy. "Carbon Capture, Transportation and Storage: Supply Chain Deep Dive Assessment." *US Department of Energy Response to Executive Order 14017, "America's Supply Chains".* (February 24, 2022): 8.

[4] Global CCS Institute, 2022. Global Status of CCS: 2022. Australia.

[5] International Energy Agency (IEA), "Net-Zero by 2050: A Roadmap for the Global Energy Sector." (2021). Paris, France.

[6] Mahajan, Megan, et al. "Modeling the Inflation Reduction Act Using the Energy Policy Simulator." *Energy Innovation. https://energyinnovation. org.* (2022): 1

1. Carbon Management and Net-Zero in the US

1.1 Policy Objectives and Carbon Management

Carbon management solutions like CCS, CDR and CO_2 utilization are essential tools to meet federal climate targets in the US. The Long-Term Strategy of the United States[7], announced in 2021, clearly outlines US climate targets: (a) the Nationally Determined Contribution (NDC) under the Paris Agreement of 50-52% reductions below 2005 levels by 2030, (b) 100% carbon pollution-free electricity by 2035, and (c) net-zero emissions no later than 2050. The Strategy does not make specific commitments on the capacity of CC(U)S or CDR required but emphasizes 100% clean electricity and scaling-up of carbon removal as key priorities. Further, a 2021 report to Congress by The Council on Environmental Quality, a division of the executive office of the President, stated that: “to reach the President’s ambitious domestic climate goal of net-zero emissions economy-wide by 2050, the United States will likely have to capture, transport, and permanently sequester significant quantities of carbon dioxide (CO_2).”[8] The 2022 Strategic Vision of the Department of Energy’s Office of Fossil Energy and Carbon Management (FECM) states objectives to help support net-zero by 2050, including: demonstrating first-of-a-kind carbon capture in power and industrial sectors; supporting research, development and demonstration of CO_2 conversion technologies; and advancing diverse CDR approaches in service of facilitating gigaton-scale removal by 2050.[9] The section below outlines the importance of carbon management to help the US achieve its policy objectives by examining heavy industry, carbon removal, and CO_2 utilization.

1.1.1 Industrial Emissions

Carbon capture has substantial value as a tool for lowering industrial emissions in the US toward net-zero. First, carbon capture is a decarbonization option that is applicable to notably high-emitting sectors. In recent years, emissions from industry have accounted for the third largest portion of total US GHG emissions, specifically 23.8% in 2020, behind transportation and emissions from electric power. Industry emitted 766.3Mt of CO_2 from the combustion of fossil fuels (‘combustion emissions’) in 2020.[10]

Second, carbon capture has unique technical capabilities to reduce industrial emissions where few options exist. In addition to emissions from combustion, industry emitted an additional 163.3Mt of CO_2 from industrial processes that are not related to the combustion of fossil fuels (EPA category: Industrial Processes and Product Use). In 2020, these emissions accounted for 6.3% of total GHG emissions in the US. These ‘process emissions’ are produced primarily as a by-product of various non-energy-related industrial activities. Where combustion emissions have generally declined over the last decade due to available emissions reduction measures, process emissions have been relatively stagnant since 2016. In 2020, process emissions from the production of cement (40.7Mt) and iron and steel (35.4Mt) topped the list of sectors in this category, followed by emissions from the production of petrochemicals, ammonia, lime, glass, metals, and chemicals (2020 data).[11]

The significance of industrial process emissions is that decarbonization pathways outside of carbon capture are generally unavailable or technically unfeasible, particularly in the cement sector.[12,13]

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[7] The White House. "The long-term strategy of the United States: pathways to net-zero greenhouse gas emissions by 2050." (2021).

[8] Executive Office of the President of the United Stated. “Council on Environmental Quality Report to Congress on Carbon Capture, Utilization, and Sequestration. Delivered to the Committee on Environment and Public Works of the Senate and the Committee on Energy and Commerce, the Committee on Natural Resources, and the Committee on Transportation and Infrastructure of the House of Representatives, as directed in Section 102 of Division S of the Consolidated Appropriations Act, 2021”: 6

[9] Ibid, 9-22.

[10] US Environmental Protection Agency (EPA), Inventory of Greenhouse Gas Emissions Sources and Sinks: 1990-2020.

[11] Ibid: 17-18 (EPA)

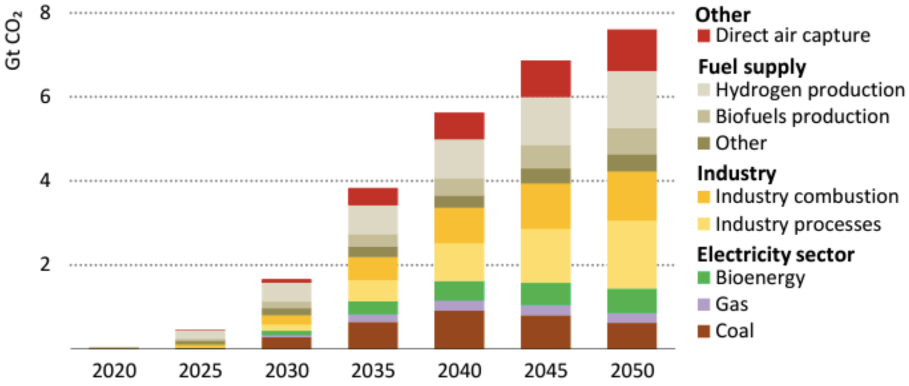
[12] Gross, Samantha. "The challenge of decarbonizing heavy industry." (2021).

[13] Plaza, Marta G., Sergio Martínez, and Fernando Rubiera. "CO_2 capture, use, and storage in the cement industry: State of the art and expectations." *Energies* 13.21 (2020): 5692.

Industrial energy efficiency improvements may reduce emissions intensity and lower operational costs at the same time. Electrification and switching to lower carbon-intensity fuels are also available measures, to varying extents. However, these measures primarily address combustion emissions, and are not appropriate to abate process emissions. Further, it has been highlighted that reducing emissions in these sectors by reducing demand for their corresponding products may not be feasible.[14] In particular, both iron/steel and cement have a large role to play in a net-zero US and global economy, in contrast to fossil fuels.[15] Therefore, carbon capture is an essential option to abate emissions in these sectors.

Lastly, net-zero-aligned scenarios show that carbon capture is required to achieve the necessary volumes of emission reductions and enable the most cost-effective and economically feasible transition possible.[16] In this analysis, the most capital-intensive pathways to net-zero see the least carbon capture, highlighting that the most efficient path to net-zero includes the right carbon capture projects, not all carbon capture projects. Importantly, the need for carbon capture for decarbonizing cement is confirmed in all IEA transition scenarios[17], where a large share of process emissions remains in existence globally by 2050 relative to capture needs across other applications. Figure 1 shows the importance of CCS as the only feasible option to address long-term volumes of industrial process emissions.

Figure 1: Expected Global Volume (per annum) of Captured CO_2 Through 2050.[18]



Source: International Energy Agency (2021)

1.1.2 Carbon Dioxide Removal (CDR)

US net-zero policy emphasizes the need to scale CDR solutions. This includes technologies and practices that remove 'legacy' CO_2 from the atmosphere and ones which potentially result in 'carbon negative' emissions.[19] There are several CDR options available at varying levels of readiness. For instance, *natural* methods of CDR leverage CO_2 sequestration through afforestation, ocean fertilization, soil additives, and reforestation. These often require vast amounts of land, limiting their potential utility to scale appropriately to contribute emission reductions against net-zero objectives. On the other hand, *technology*-based CDR requires less land and is more scalable. Bioenergy with carbon capture and storage (BECCS) is the process of generating energy from biomass (e.g., plants, wood, waste), coupled

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[14] Ibid. (Gross)

[15] Larson, J., Greig, Jenkins, Mayfield, Pascale, Chang, Drossman, Williams, Pacala, Socolow, Baik, Birdsey, Duke, Jones, Haley, Leslie, Paustian, and Swan. "Net-Zero America: Potential Pathways, Infrastructure, and Impacts," Final report, Princeton University, Princeton, NJ,29 (October 2021):73-74; 206.

[16] Greig and Uden, "The value of CCUS in transitions to net-zero emissions," 7-8.

[17] Ibid: 2. (Grieg and Uden)

[18] International Energy Agency (IEA), "Net-Zero by 2050: A Roadmap for the Global Energy Sector." (2021). Paris, France: 80.

[19] By John Larsen, Whitney Herndon, Mikhail Grant and Peter Marsters, Rhodium Group, LLC. "Capturing Leadership: Policies for the US to Advance Direct Air Capture Technology," Rhodium Group, LLC. (May 2019): 8.

with CCS to avoid emissions. BECCS results in carbon negative power given that the CO_2 captured in the process had been previously stored from the atmosphere through biological processes.

As evident in Figure 1, direct air capture (DAC) is expected to play a key role by 2050 globally. DAC technologies capture CO_2 directly from ambient air for later use or permanent storage. DAC can target difficult-to-avoid emissions, such as those from highly distributed sources like aviation. Emissions from hard-to-abate sources (concrete, transportation, iron/steel, and wildfires) may remain following 2050, and so will need to be offset if net-zero is to be realized.[20] DAC is unique among CDR options in that the technology is limited primarily by economics, and not land usage, and may have the highest potential of all other CDR options to reach global scale.[21] In addition to DAC being important to hold global average temperature increase to 1.5ºC, forecasts suggest that it can also limit the marginal abatement costs associated with the scenario.[22] Due to the high degree of uncertainty in estimating to 2050, modeling accounts for sensitivities of energy supply, fossil energy demand, and readiness of natural or technology-based solutions. It finds that, while DAC may not be necessary if these other factors deliver above expectations, a significant amount of DAC will be needed in the most likely scenarios. At the very least, DAC represents an important insurance policy, if currently very expensive, if other decarbonization strategies fall short.[23] Often-cited modeling estimates that the US may need more than 850 Mt of installed DAC capacity in 2050.[24] For comparison, CO_2 emissions from the US power sector were roughly 1,850 Mt in 2016.[25] As a result, DAC is the primary focus of analysis on CDR in later sections of this study.

1.1.3 CO_2 Utilization

The development of commercial uses for captured CO_2 can contribute to a net-zero economy in the US. While several climate and technology experts agree that CO_2 utilization can play a key role in the global transition to net-zero emissions[26], its exact contribution to the climate objective remains less clear in comparison to CCS or CDR. This is especially true given that the amount of CO_2 sequestration needed to achieve climate goals dwarfs the amount expected from CO_2 utilization.[27] The contribution of CO_2 utilization to net-zero economic transition is indirect and various, but is important nonetheless.

Firstly, CO_2 utilization and CO_2-based products may have profound decarbonization outcomes in hard-to-abate sectors, which face technical challenges in substituting fossil fuels with low-carbon electricity or hydrogen. For example, introducing synthetic liquid and gas from recovered CO_2 and substituting synthetic chemical products are likely to be essential options. Mineralization of CO_2 in concrete helps displace carbon-intensive products such as cement, improving material efficiency and resulting in relatively large potential for emissions reductions.[28] In addition, a combination of CCS and CO_2 utilization for CO_2-based sustainable aviation fuels (SAF) may be required to decarbonize the aviation sector.[29]

Secondly, mature CO_2 markets help catalyze broader industrial transformation by facilitating further market development for clean energy sources and inputs. Because CO_2 and hydrogen combine in many

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[20] Ozkan, Mihrimah, et al. "Current status and pillars of direct air capture technologies." *Iscience* (2022): 2.

[21] Sandalow, David, et al. "Direct air capture of carbon dioxide." *Innovation for Cool Earth Forum*. (2018); Ozkan, Mihrimah, et al. "Current status and pillars of direct air capture technologies" 2.

[22] Akimoto, Keigo, et al. "Climate change mitigation measures for global net-zero emissions and the roles of CO_2 capture and utilization and direct air capture." *Energy and Climate Change* 2 (2021): 16.

[23] Larsen et. al., Capturing Leadership: Policies for the US to Advance Direct Air Capture Technology, 16-17.

[24] Ibid: 16-17. (Larsen)

[25] Ibid: 16-17. (Larsen)

[26] Akimoto, Keigo, et al., Climate change mitigation measures for global net-zero emissions and the roles of CO_2 capture and utilization and direct air capture, 3.

[27] International Energy Agency (IEA). “Exploring Clean Energy Pathways: The role of CO2 storage.” (July 2019). Paris, France: 33.

[28] Akimoto, Keigo, et al., Climate change mitigation measures for global net-zero emissions and the roles of CO_2 capture and utilization and direct air capture, 3.

[29] Becattini, Viola, Paolo Gabrielli, and Marco Mazzotti. "Role of carbon capture, storage, and utilization to enable a net-zero-CO_2-emissions aviation sector." *Industrial & Engineering Chemistry Research* 60.18 (2021): 6859.

applications, such as low-carbon synthetic fuels, CO_2 utilization improves the ease and cost of using hydrogen, which in turn facilitates deep decarbonization and industrial transition. From this perspective, we can expect relatively large potential for CO_2 emission reductions.[30]

Thirdly, the development of markets for CO_2 outside of enhanced oil recovery (EOR) is important for maintaining “market pull” for CCS and CDR that is divorced from the market or price of fossil fuels. The global oil and gas sector uses approximately 70-80 Mt/y of 230 Mt/y of CO_2 for EOR[31], the largest market driver for carbon capture deployment in the US. Current deployment levels of EOR are unlikely to continue in the US given declining oil production and consumption forecasts.[32] Decline in demand for CO_2 for EOR therefore jeopardizes continued market pull for greater levels of carbon capture deployment. Further, market pull for alternative uses of CO_2 reduces the cost and increases the feasibility of carbon capture deployments in geographic locations where affordable transportation and storage is not possible or available. The US industry is not co-located with suitable storage geology in many cases. Assessments of the causes of prominent CCUS project failure finds that “market pull” factors, such as adoption and demand, are “effective tools for mitigating the increasing risks associated with upscaling” CCUS and CDR and that “business-driven market [approaches] are the most effective practice in mitigating project risk.”[33] Therefore, market-based substitutions for EOR are essential for continued improvements to carbon management business models and project economics given reducing demand for oil and gas.

1.2 CCUS Investments and Risks

Policy support for carbon management is important for the US to meet its net-zero objectives because of the existence of an array of political, cross-chain, technical, and economic risks at play across carbon management projects, shown in Figure 2 (particular to CCUS projects). Many risks are inherent in the carbon management system and are liable to cause deployment to deviate from a growth trajectory that remains aligned with net-zero outcomes. Empirical studies observe the inability of financial supports to adequately overcome key technology risks and high failure rates (capture performance, pipeline and storage quality, terrain, distance, and leakage concerns).[34] Unique technical and financial risks are not easily assessed by private financiers.[35] Moreover, many carbon management technologies are “pure climate technologies”, meaning that their sole purpose is to mitigate the effects of climate change and often do not come with significant monetizable co-benefits.[36] Common to carbon management projects, such dynamics result in a finance gap that is difficult to manage without government support.

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[30] Akimoto, Keigo, et al., Climate change mitigation measures for global net-zero emissions and the roles of CO_2 capture and utilization and direct air capture, 3.

[31] International Energy Agency (IEA), “Putting CO_2 to Use.” Paris, France.

[32] Larson, J. et.al., Net-Zero America: Potential Pathways, Infrastructure, and Impacts.

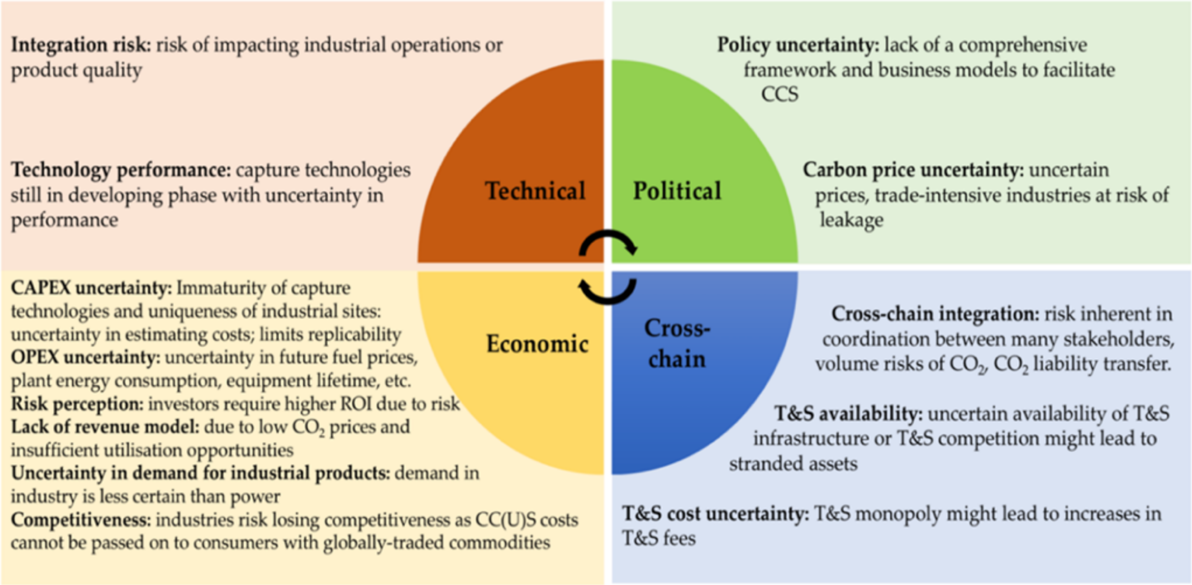
[33] Wang, Nan, Keigo Akimoto, and Gregory F. Nemet. "What went wrong? Learning from three decades of carbon capture, utilization and sequestration (CCUS) pilot and demonstration projects." *Energy Policy* 158 (2021): 6.

[34] Chen, Siyuan, et al. "A critical review on deployment planning and risk analysis of carbon capture, utilization, and storage (CCUS) toward carbon neutrality." *Renewable and Sustainable Energy Reviews* 167 (2022): 11-12.

[35] Ibid: 7 (Chen)

[36] Honegger, Matthias, et al. "Who is paying for carbon dioxide removal? Designing policy instruments for mobilizing negative emissions technologies." *Frontiers in climate* 3 (2021): 3.

Figure 2: Different types of risks inherent in CCUS projects[37]



Integration risk: risk of impacting industrial operations or product quality

Technology performance: capture technologies still in developing phase with uncertainty in performance

Policy uncertainty: lack of a comprehensive framework and business models to facilitate CCS

Carbon price uncertainty: uncertain prices, trade-intensive industries at risk of leakage

CAPEX uncertainty: Immaturity of capture technologies and uniqueness of industrial sites: uncertainty in estimating costs; limits replicability
OPEX uncertainty: uncertainty in future fuel prices, plant energy consumption, equipment lifetime, etc.
Risk perception: investors require higher ROI due to risk
Lack of revenue model: due to low CO_2 prices and insufficient utilisation opportunities
Uncertainty in demand for industrial products: demand in industry is less certain than power
Competitiveness: industries risk losing competitiveness as CC(U)S costs cannot be passed on to consumers with globally-traded commodities

Cross-chain integration: risk inherent in coordination between many stakeholders, volume risks of CO_2, CO_2 liability transfer.

T&S availability: uncertain availability of T&S infrastructure or T&S competition might lead to stranded assets

T&S cost uncertainty: T&S monopoly might lead to increases in T&S fees

Source: Muslemani et al. (2020)

2. The Inflation Reduction Act and 45Q

The IRA announced additional financial support and incentives for CCS, CDR and CO_2 utilization, most prominently through enhancements to Section 45Q of the *Internal Revenue Code*. Section 45Q provides a tax credit for CO_2 sequestration and CCUS deployment more broadly. The 45Q tax credit is widely considered to be one of the most influential government policies in support of CCUS globally.[38]

The 45Q tax credit was first introduced in 2008. The tax credit provided project owners with $10/t of CO_2 used for enhanced oil recovery (EOR)[39] and $20/t of CO_2 sequestered geologically. In 2018, the Bipartisan Budget Act (BBA) increased the credit value to $35/t for carbon captured and utilized for enhanced oil recovery (EOR) and $50/t if geologically sequestered. The BBA replaced a 75 Mt per project credit cap, replaced it with a 12-year crediting limit and allowed smaller facilities of less than 500,000 t/y to qualify for the credit. A broadened definition of those that qualify for the credit allowed smaller projects owners to monetize credits more flexibly by leveraging tax equity markets.

Following the IRA, the 45Q tax credit is further enhanced in its value, applicability, and flexibility. The credit enhancements are estimated to cost the US treasury almost $3.23 billion (cumulative) by 2031,[40] which is equivalent to an additional 37.9Mt of cumulative CO_2 sequestered geologically from point-source capture or 53.8Mt of CO_2 sequestered via EOR, or as low as 18.3Mt of CO_2 if captured via direct air capture (DAC) and stored geologically. Table 1 shows the evolution of the tax credit from its inception to the IRA. Most notably, the IRA increases the value of the 45Q tax credit value for CO_2 captured for utilization and EOR from $35/t to $60/t for point-source capture and $130/t for direct air capture. The

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[37] Muslemani, Hasan, et al. "Business models for carbon capture, utilization and storage technologies in the steel sector: a qualitative multi-method study." *Processes* 8.5 (2020): 576.

[38] Global CCS Institute, 2017-2022. Global Status of CCS: 2017-2022. Australia.

[39] Enhanced oil recovery is a process by which CO_2 is injected into existing oil wells to assist in extracting remaining crude product. Primary and secondary extraction often does not avail operators of the full extraction potential of a well and therefore CO_2 is used in tertiary extraction of remaining resources. A high proportion of CO_2 is permanently sequestered in the process of EOR. Currently, CO_2 captured for sale to oil operators represents one of the few reliable ways in which revenue can be generated through the capture of CO_2.

[40] Leggett, Jane and Ramseur, Jonathan. "Inflation Reduction Act of 202s (IRA): Provisions Related to Climate Change." *US Congressional Research Service* (October 2022).

credit value for CO_2 captured for dedicated geological storage increases from $50/t to $85/t for point-source capture and $180/t for direct air capture.[41]

Table 1: Evolution of the 45Q Tax Credit, 2008-2022[42,43]

Feature	**Qualifier**	**2008**	**2018**	**2022**	
				Point Source	**DAC**
Value ($/t)[44]	EOR/Utilization	10	35	60	130
	Storage	20	50	85	180
Commence Construction Date[45]	-	January 2024	January 2026	January 2033	
Term[46]	-	N/A (75 Mt cap)	12 years	12 years	
Transferability	-	Limited – the capturing party only	Broad with Limits – the capture party and owner	Broad – transferrable to an unrelated taxpayer for cash	
Qualified Size	Power Generation [47]	500,000 t/y	500,000 t/y	18,750 t/y	
	Industrial		100,000 t/y	12,500 t/y	
	Industrial Pilot	-	25,000 t/y	1,000 t/y	
	DAC	-	100,000 t/y	1,000 t/y	
Credit Eligibility	-	EOR, Storage	EOR, storage, utilization, DAC	EOR, storage, utilization, DAC	
Direct Pay	-	No	No	Yes[48]	
Size Cap	-	75 Mt total	N/A	N/A	

Source: Author's illustration

In addition to increases in the value of the credit, other material changes include: an extension of the commence construction window to January 2033; additional flexibility afforded to credit recipients to transfer all or a portion of the credit value to any third-party and tax-paying entity in exchange for a non-taxable cash payment during the 12-year period; reduced capacity thresholds for qualified credit-eligible facilities (power generation, industrial, and DAC facilities); and introduction of a "direct pay" option

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[41] Credit values under the Inflation Reduction Act (2022) are conditional upon Prevailing Wage and Apprenticeship compliance. Values listed in this table assume compliance with Guidance. For specific guidelines, see: *Prevailing Wage and Apprenticeship Initial Guidance Under Section 45(b)(6)(B)(ii) and Other Substantially Similar Provisions.*

[42] United States, Congress, Senate. Inflation Reduction Act of 2022. Congress.gov, https://www.congress.gov/bill/117th-congress/house-bill/5376. 117th Congress, H.R.5376, Introduced 27 Sept 2019.

[43] US Internal Revenue Code, Title 26, Section 45Q (2021): https://www.govinfo.gov/link/uscode/26/45Q.

[44] The credit in 2022 is inflation-adjusted beginning in 2027 and indexed to base year 2025.

[45] Commence construction date is defined as the date of substantial work completion of costs of 5% paid.

[46] At the time of writing, it is not yet clear based on current guidance if claimants can redeem 45V for the first 10 years of a project and 45Q for the remaining 2 years.

[47] Power generation facilities seeking to qualify for the credit must meet a capture design capacity requirement of not less than 75% of the CO_2 from an electricity generating unit that will install capture equipment.

[48] Direct pay is available for for-profit, tax-paying entities for 5 years only and for the full 12-year crediting period for tax-exempt entity.

where claimants may receive the credit as a fully refundable payment (for-profit, tax-paying entities can realize the direct pay option for five years after the carbon capture equipment is placed in service while tax-exempt entities can receive direct payment for the full 12-year period).[49]

The IRA also introduced other measures to supplement historical supports for clean energy more broadly, which may benefit the deployment of CCS, CDR, and CO_2 utilization technologies. The Advanced Industrial Facilities Deployment Program authorizes the Department of Energy's Office of Clean Energy Demonstrations to provide over $5.8 billion in financial assistance from 2022 to 2026.[50] This envelope adds to the existing $500 million Industrial Demonstrations Program. The program is available to owners and operators of non-power industrial or manufacturing facilities, such as iron, steel, cement, aluminum, concrete, glass, pulp, paper, chemicals, and other production facilities to reduce the greenhouse gas emissions. It supports the deployment of "advanced industrial technology", which includes "carbon capture technologies for industrial processes." [51] The Energy Infrastructure Reinvestment Financing Program under the DOE, the US Department of Agriculture's (USDA) Electric Infrastructure Loan and Loan Guarantee program for rural electric cooperatives, expansion of the Section 48C Advanced Energy Project Credit, and new loan and credit subsidy authority for innovative clean energy projects under Section 1703 of the Energy Policy Act may all support carbon management in the US.[52] Other tax credits will provide support to CCS in certain circumstances. These include the 45V production tax credit for clean hydrogen, which credits up to $60/kg (between 20% and 100% of this value) based on the lifecycle emissions of the product. In addition, 45Z is a production tax credit for clean fuels production, which may include fuels produced using captured CO_2. 45Q remains the most dedicated and substantial measure supporting CCS, CDR, and CO_2 utilization in the US as a result of the IRA.

3. Risks and Returns Under 45Q

3.1 Analytical Framework: Blended Finance

This section uses the theoretical foundations of *blended finance*, "the strategic use of concessional and non-concessional public and/or philanthropic capital to catalyze additional private capital that would otherwise not be available for climate investments in developing countries."[53] Blended finance is a practice of catalyzing (or 'attracting') private sector investment in climate projects and it can be particularly useful in explaining and anticipating the needs and preferences of investors in areas with an array of complex risks, like CCUS and CDR. Despite its historical use, the ultimate goal of *blended finance* is not necessarily linked to developing economies, but to creating self-sufficient markets and facilitating lasting sector development.[54]

Further, the perspective assumes: investors are motivated to **maximize return and minimize risk**[55]; investors **opt out** of investment opportunities if certain risks are unmitigated and returns are insufficient to compensate**;** uses of public capital should be **temporary** and facilitate self-sufficient sectoral and market development; public interventions are **necessary** for making projects happen, happen faster, or improve in design or impact; and investments must catalyze **impact** beyond economic gains (e.g.

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[49] Jones, Angela and Lawson, Ashley. "Carbon Capture and Sequestration (CCS) in the United States." *US Congressional Research Service* (October 2022).

[50] United States, Congress, Senate. Inflation Reduction Act of 2022.

[51] United States, Congress, Senate. Energy Security and Independence Act of 2007. Congress.gov, https://www.congress.gov/bill/110th-congress/house-bill/6. 110th Congress, H.R.6, Introduced 12 Jan. 2008: Section 17113(c).

[52] For more information, refer to: The White House. "Building a Clean Energy Economy: A Guidebook to the Inflation Reduction Act's Investments in Clean Energy and Climate Change." 2 (January 2023).

[53] OECD. "Blended Finance Principles for Unlocking Commercial Finance for the Sustainable Development Goals." (2018): 4.

[54] Choi, Esther, and Alicia Seiger. "Catalyzing capital for the transition toward decarbonization: Blended finance and its way forward." *Available at SSRN 3627858* (2020).

[55] Polzin, Friedemann, et al. "How do policies mobilize private finance for renewable energy?—A systematic review with an investor perspective." *Applied Energy* 236 (2019): 1249.

significant emission reductions). The perspective allows the analysis to account for investor preferences amid complex return and risk profiles, particularly at the intersection of climate and industrial policy.[56]

3.2 Financing CCS in Heavy Industry

The IRA's amendments to the 45Q tax credit may greatly increase the number of economic carbon capture projects. Any material change to carbon capture project economics is likely to result from the increase of the credit value, which increases the credit's effect in reducing revenue-related economic risks (Figure 1). The tax credit however may not be sufficient for carbon capture in the hardest-to-abate industrial applications, where returns and difficult-to-mitigate risks result in carbon capture investment opportunities that do not compete favourably against other carbon capture projects in the power sector or in other industrial sectors. Government support in addition to the enhanced 45Q tax credit is needed to drive down capital costs in hopes of attracting suitable levels of private investment.

3.2.1 Costs and Revenues

In increasing the 45Q credit value through the IRA, Congress responded to a body of research claiming that the rate of $50/t under the 2018 Bipartisan Budget Act was insufficient to spur meaningful investment in the "management of most industrial CO_2 emissions."[57] In one prominent study, Tarufelli et al. (2021) surveyed over 560 industrial facilities in the US across industrial processes with the most highly concentrated waste streams containing 99% CO_2 (natural gas processing, ethylene oxide production, ammonia production, and ethanol production).[58] These industrial processes are among those that are most conducive to economical CCUS,[59] yet the survey found that only a handful of projects would be economical at a CO_2 price of $50/t.[60] Importantly, these types of facilities are not considered 'hard-to-abate' relative to cement and iron/steel production. Therefore, some value above $50/t was deemed necessary to meaningfully drive carbon capture deployment for most emissions in heavy industrial sectors.

The study demonstrated a clear relationship between scale and breakeven CO_2 price. Where breakeven CO_2 price falls below $50/t, projects are considered uneconomical if a credit of that value is provided. Breakeven occurs only for surveyed facilities of sizes exceeding 500,000 and 750,000 t/y. Given the breakeven costs of these applications and the typical size of plants in the US, the survey found that only 4.2% (24 of 560) of studied industrial sites had sufficient scale to breakeven at $50/t assuming optimistic geology and a 50-mile transportation line.[61] Further, these calculations assume that the $50/t credit is redeemed over the life of the project, and not merely the 12 years permitted under 45Q.

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[56] Choi and Seiger, Catalyzing capital for the transition toward decarbonization: Blended finance and its way forward.

[57] Tarufelli, Brittany, Brian Snyder, and David Dismukes. "The Potential Impact of the US Carbon Capture and Storage Tax Credit Expansion on the Economic Feasibility of Industrial Carbon Capture and Storage." *Energy Policy* 149 (2021): 1.

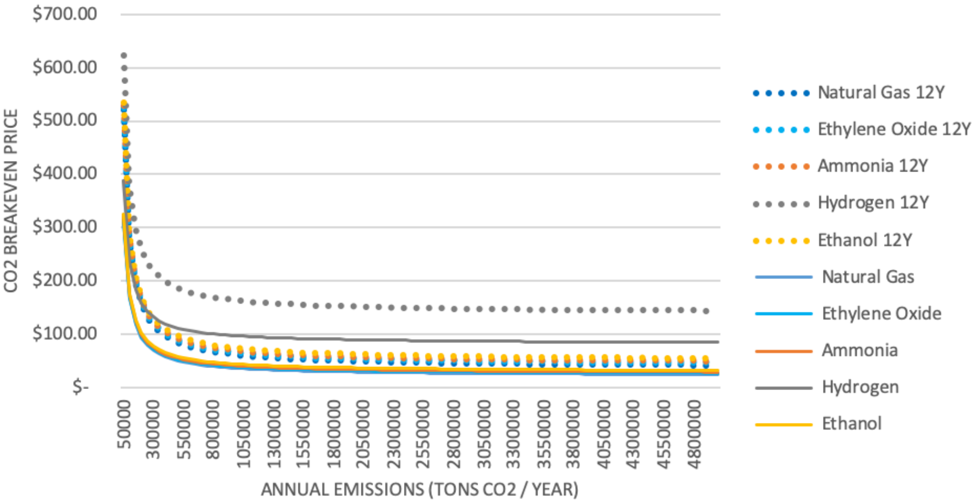
[58] Ibid: 2. (Tarufelli)

[59] Woodall, Caleb M., et al. "Technology options and policy design to facilitate decarbonization of chemical manufacturing." *Joule* (2022): 2-6

[60] Tarufelli, et. al., The Potential Impact of the US Carbon Capture and Storage Tax Credit Expansion on the Economic Feasibility of Industrial Carbon Capture and Storage, 5-6.

[61] Ibid: 8. (Tarufelli)

Figure 3: CO_2 Breakeven Price for Industrial Processes by Facility Size[62]



Source: Tarufelli et al. (2021)

Figure 3 demonstrates a comparison of facility breakeven CO_2 price by facility size (or CO_2 captured annually). Projects break even at $85/t at a lower facility size of approximately 250,000t/y presumably enabling substantially more economical projects. However, these gains are erased when a 12-year cap is placed on credit period (dotted lines in Figure 3). In sum, limiting 45Q redemption to 12 years translates each curve up such that a higher 45Q tax credit is needed to achieve breakeven for a given facility size. As a result, increases in project economics resulting from a credit value increase to $85/t is largely offset by the restricted crediting period, limited to 12 years (Table 2).

Table 2: Summary of results from Figure 3.

45Q value	Breakeven Volume (45Q for Project Life)	Facilities (% of 560)	Breakeven Volume (45Q for 12 years)	Facilities (% of 560)
$50/t (BBA 2019)	500,000-700,000 t/y	4.2%	>500,000-700,000t/y	<4.2%
$85/t (IRA 2022)	250,000 t/y	>4.2%	500,000-700,000t/y	4.2%

Source: Author's own illustration of data from Tarufelli et. al. (2021)

Cement plants are larger in contrast to chemicals plants considered in the survey and produce on average 838,000 t/y per facility. On one hand, larger average facilities could be expected to cause a higher proportion of carbon capture projects that can break even at $85/t. However, carbon capture in cement applications costs $78/t, an average across 93 cement facilities in the US.[63] Among those considered in the survey, carbon capture on ammonia costs approximately $57/t and on ethanol costs approximately $38/t. The cost of carbon capture in cement exceeds the new $85/t cost after $10/t cost of transportation and storage is added, in line with National Energy Technology Laboratory standard assumptions.[64] Speaking generally, it is therefore doubtful that carbon capture in cement would require

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[62] Tarufelli, et. al., The Potential Impact of the US Carbon Capture and Storage Tax Credit Expansion on the Economic Feasibility of Industrial Carbon Capture and Storage, Supplementary Figure 1. Note that data is based in 2021 costs, which are likely to have reduced in the time since the study. Hydrogen CCS (blue hydrogen) figures over 12 years may be much lower than pictured.

[63] Hughes, Sydney, et al. *Industrial CO_2 Capture Retrofit Database (IND CCRD)*. No. DOE/NETL-2022/3319. National Energy Technology Laboratory (NETL), Pittsburgh, PA, Morgantown, WV, and Albany, OR (United States), 2022.

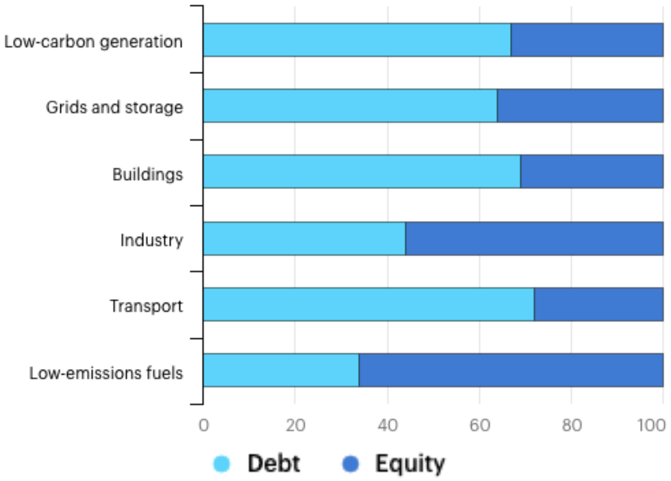
[64] Ibid. (Hughes)

a lower breakeven CO_2 price because of its increased capture volumes. It remains doubtful whether project economics will attract private investment to facilitate rapid carbon capture deployment in hard-to-abate industrial sectors. Financial investment decisions depend heavily on the individual economics of each plant and the preferences of the company making them. Cement producers may opt to make investment decisions due to their ability to pass costs onto customers.

Government support in addition to the 45Q tax credit is likely to be required to stimulate substantial amounts of private investment for carbon capture in hard-to-abate industrial sectors, like cement. Deployments are likely to require breakeven CO_2 prices that are higher than $85/t and for longer than the 12-year crediting period afforded under the incentive. The IRA introduced the Advanced Industrial Facilities Deployment Program under the US Department of Energy (DOE). However, this section finds that the 45Q tax credit remains a primary support for industrial emissions abatement.

Moreover, the cost of capital is generally higher for green, or low-carbon, investments in the industrial sector compared to green investments in other economic sectors. Also, the cost of capital is generally higher for carbon capture investments in the industrial sector compared to the power generation sector. This is indicated in Figure 4. Green investments typically require a greater share of equity, or lower debt-equity ratio. Equity is more expensive than debt, meaning that it requires a higher rate of return (hurdle rate) than debt (interest rate) because it is generally more difficult to repay in instances of project failure. The implication is that project capital is more accessible and easily repayable in competing green investment spaces – the low-carbon generation, grids and storage, buildings, and transport sectors than in the industrial sector. Moreover, Figure 5 illustrates how capital is generally more available to carbon capture in the power sector than in the industrial sector, across cases below. Data is currently insufficient to draw definitive conclusions in this area, though available cases of first-of-a-kind projects may provide early indications.[65] A small set of successfully financed CCUS projects in North America finds that industrial projects (Air Products Steam Methane Reformer, Illinois Industrial, and Shell's Quest) reflected a significantly higher proportion of grant funding – 60% compared to 25% in power CCS cases. While the power projects examined here required more equity, the high proportion of grant funding signals that anticipated project returns were likely too low to justify commitments of available equity (Shell and Air Products being well-capitalized companies that need to allocate development capital at a sufficiently high rate of return).

Figure 4: The Capital Structure of Clean Energy Investments in Advanced Economies[66]



Source: International Energy Agency (2022)

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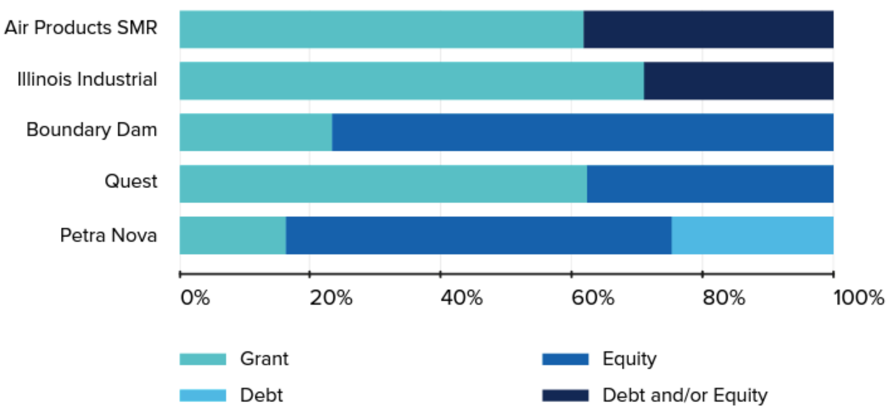
[65] Note that financing for first-of-a-kind projects is highly government-dependent and is designed in such a way to mitigate risks of failure. Future projects will be financed differently and may not reflect the early trend established in this section. Further, examined projects are financed across jurisdictions, policy environments, and credit schemes, which limit the explanatory strength of this early comparison. Further research is required in this area.

[66] International Energy Agency (IEA), "The Cost of Capital in Clean Energy Transitions." (December 2022). Paris, France. Accessible at: https://www.iea.org/articles/the-cost-of-capital-in-clean-energy-transitions

Figure 5: Capital Structure of Notable Large-Scale CCS Projects[67]

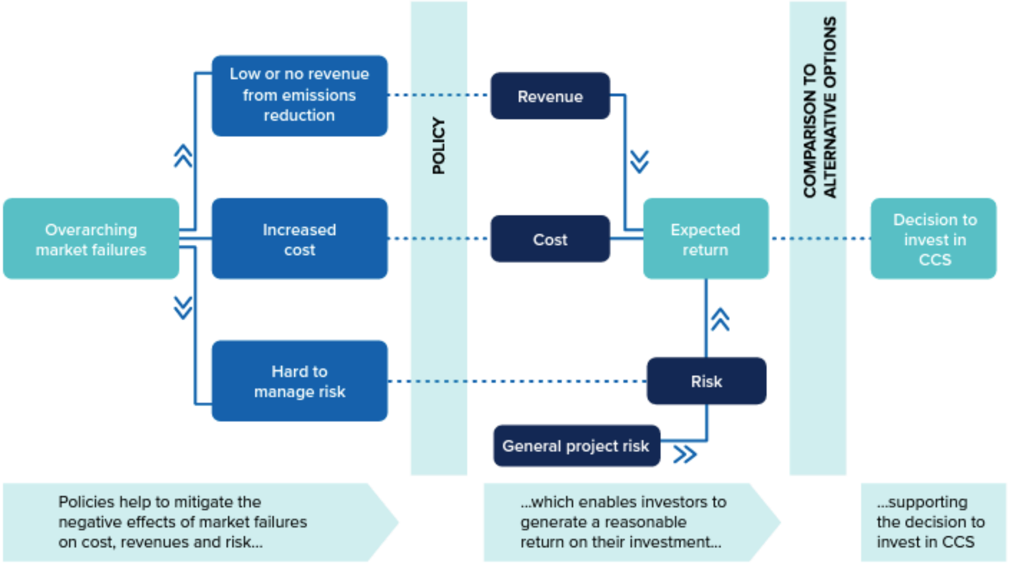


Source: Zapantis (2019)

3.2.2 “Cross-Chain” and Technical Risks

Investment decisions are clearly more complicated than a comparison of costs and revenues. Consider any marginal abatement cost curve and observe that, while several green options have attracted investment, many options requiring lesser investment have not. Key risks prevent private sector investment despite promising project economics. Figure 6 illustrates the relationship between costs, risks, and policies in influencing investment decisions in carbon capture. It delineates hard-to-manage risks from other market failures and shows that dedicated measures, aside from supports that provide cost reductions or revenue enhancements (e.g., tax credits), are needed to reduce such risks and enable projects to deliver expected returns.

Figure 6: CCUS Investment Decision-Making Model[68]



Source: Zapantis (2019)

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[67] Zapantis, Alex, Alex Townsend, and Dominic Rassool. "Policy priorities to incentivise large scale deployment of CCS." *Thought Leadership Report. Global CCS Institute* (2019): 12

[68] Ibid: 10. (Zapantis)

Carbon capture developers and financers face **"cross-sectoral" or "cross-chain" risks** because the capture, transportation, and sequestration or utilization of CO_2 relies on project execution across a value chain with many actors and components. Uncertainties are inherent in carbon capture deployment given the breadth and complexity of the value chain. Further, it requires an investment "decision sequence that includes decision-points around many areas outside of the developer's area of expertise – storage and transportation – before FID [final investment decision] can be reached (typically 3-8 years of parallel decisions)."[69] This may also be referred to as "counter-party risk" given the challenging reality that decisions rely on mutual confidence among multiple actors across different sectors and with limited visibility throughout the CO_2 chain. This risk may be borne by both project developers and project owner-operators and highlights a unique feature of the CCS supply chain.

Experts in cross-chain risk attest to the rarity that a single firm is capable of understanding and accounting for the range of uncertainties across the CO_2 chain.[70] For example, while industrial emitters might see a commercial opportunity in capturing CO_2, through 45Q tax credits for example, the investment is difficult without confidence that long-term affordable storage is available.[71] In an illustrative comparison of risks that influence CCS investment decisions, The Global CCS Institute (GCCSI) notes that cross-chain risk carries the highest probability, consequence, and resulting impact on the cost of debt – an additional 2.7% on a low-risk lending rate of 4% (although perhaps 2-3% higher since this data was developed).[72] The Global CCS Institute acknowledges that further research is needed to validate this specific figure. However, this risk is decisively the most influential hardest-to-mitigate risk in carbon capture project finance and development. As more projects develop and costs become more predictable, cross-chain risk is likely to decrease in importance relative to uncertainties and risks on the revenue side. This latter set of risks may persist longer than cross-chain risks and may outlive IRA supports. Still, cross-chain risk reflects a key factor delaying near-term deployment and specifically-designed supports are needed before it can be reduced. However, the IRA's enhancements to CCUS programming, including 45Q and the DOE's Energy Infrastructure Reinvestment Financing program does not significantly help to address it for industrial CCS developers and financers. Specifically, these programs do not backstop these risks for industrial carbon capture projects, an intervention that arguably has the largest impact on cost of capital.[73]

Technical risks associated with industrial carbon capture projects can exacerbate cross-chain risks. Generally, the result is persistently high capital costs and unavailability of commercial capital. Cost reductions of CCS have been observed primarily in the power sector – 35% reduction from first- to second-of-kind large-scale facilities.[74] Meanwhile, there have been very few operational commercial-scale carbon capture projects in hard-to-abate industries like cement and iron/steel. At first glance, the IRA's Advanced Industrial Facilities Deployment Program seems to be a promising development in favour of supporting industrial carbon capture development and deployment. However, the program allows a broad list of eligible technologies, specifically including "other technologies that achieve net-zero emissions in nonpower industrial sectors."[75] It remains unclear to what extent industrial carbon capture will be supported by the IRA's Advanced Industrial Facilities Deployment Program and what proportion of the authorized envelope will result in the commercialization and deployment of less mature capture technologies for cement and iron/steel applications. The initiative may not result in meaningful investments in these sectors because (a) most eligible technologies are lower on the cost curve than carbon capture, (b) investment in carbon capture is likely to flow to less expensive applications (e.g. chemicals production), and (c) investment in carbon capture is likely to flow to the most commercial and deployable solutions, which may disadvantage solutions best-suited to abate process emissions. A

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[69] Greig and Uden, The value of CCUS in transitions to net-zero emissions, 7.

[70] Ibid: 7. (Grieg and Uden)

[71] Ibid: 7. (Grieg and Uden)

[72] Zapantis, et. al., Policy priorities to incentivize large scale deployment of CCS, 25.

[73] Greig and Uden, The value of CCUS in transitions to net-zero emissions, 7.

[74] International Energy Agency, "Is carbon capture too expensive?" IEA. Paris (2021): https://www.iea.org/commentaries/is-carbon-capture-too-expensive.

[75] United States, Congress, Senate, Energy Security and Independence Act of 2007, Section 17113(c).

dedicated envelope for industrial carbon capture may help reduce the competition for capital disadvantaging hard-to-abate applications.

It is possible that investor apathy may be due to the difficulty of CCS to generate reliable revenues, effects that dwarf the effects of technology and cross-chain risks. If technology and cross-chain risks did not exist, incentives to increase revenue certainty would likely be sufficient to strengthen the economic case for CCS. 45Q has been well-positioned to provide such an incentive for over a decade. However, net-zero targets require more rapid deployment than observed in hard-to-abate industrial sectors, pointing to the need for supports to target mitigation of a broader set of risks. Further, technology and cross-chain risks are not only perceived by investors, but often materialize. Detailed analysis shows that carbon capture has been slow to reinforce investors that the above risks are reliably manageable, especially without government support to address them specifically: nearly half of announced CCUS projects globally were canceled over the past 30 years.[76] While causes vary, underperforming technology, few opportunities to draw on learnings, and disjointed development of key components account for most project failures.[77] Further, and most relevant to large-scale industrial projects, the risk of project failure increases by nearly 50% as capture capacity increases by 1 Mt/y, reducing the case for investment on the largest facilities with the most promise of economies of scale. These results further reinforce the necessity to address cross-chain risk and technology risks. While some risks may be sufficiently addressed with higher expected returns, these difficult-to-mitigate risks require intentional policy design consideration. Until deals are positioned for investors, leveraging offtake guarantees or other backstops, investors are not likely to increase in confidence that technology underperformance or execution failures prevent them from claiming the expected value of 45Q tax credits.

3.3 Financing Carbon Dioxide Removal: Direct Air Capture

Despite 45Q enhancements, consistently high capital and operational costs and persistent technology and demand risks associated with DAC are likely to divert capital away from near-term deployment. The US's net-zero objectives are at risk given the importance and reliance on scaling DAC technologies.

3.3.1 Costs and Revenues

Costs remain high, widely uncertain, and difficult to forecast across capital and operational requirements. Costs are highly dependent on the type of DAC technology under consideration. Broadly, there are two main DAC pathways: liquid solvent systems and solid sorbent systems. Consider liquid solvent systems first. Capital costs alone range from $80-150/t. These costs account for the cost of the contactor array, air separation unit and condenser, slaker, and calciner components, to varying degrees. Operating costs add $40-75/t to total levelized costs. Assuming that natural gas is the system's energy source, cost estimates of $147-264/t are currently reflected in technical literature, however estimates rely on early assumptions and likely represent long-term (up to 10 years) cost forecasts.[78] First large-scale plants may cost double.

Realistic capital costs for solid sorbent technologies can vary widely from $130-1000/t, the adsorbent comprising a vast majority of the cost, and of cost variability. Operating costs also vary widely from $5-50/t depending largely on the adsorption and the amount of steam required. Operating costs vary further when accounting for energy-related costs. DAC systems are energy intensive. Renewable energy may add substantially to operational costs while natural gas typically adds to a lesser extent. Therefore, costs of $135-1050/t may be technically feasible. This range is wide due to the nascence of the technology type and limited amount of available, commercial-scale project data. Leading technology developers corroborate these estimates. Climeworks, a leading solid sorbent developer, reports a cost of $600/t and Carbon Engineering, a leading liquid solvent developer, reports potential, at-scale costs between $94-232/t after further progress.[79] Occidental Petroleum is developing Carbon Engineering's

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[76] Chen, et al., A critical review on deployment planning and risk analysis of carbon capture, utilization, and storage (CCUS) toward carbon neutrality, 11.

[77] Ibid: 11. (Chen)

[78] Ozkan, M. et. al., Status and Pillars of Direct Air Capture Technologies, 11.

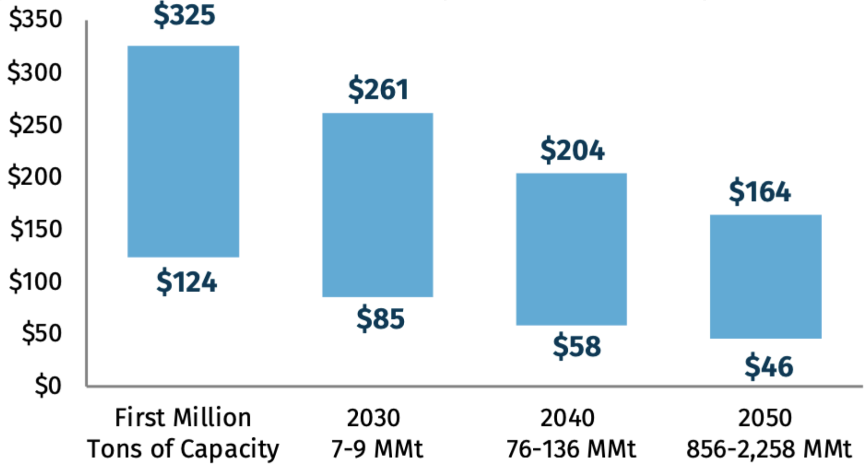
[79] Ibid: 7 (Ozkan)

first at-scale DAC facility – 0.5 Mt/y with potential to scale to 1 Mt/y. Reports suggest that Occidental expects DAC costs between $300-425/t over the next 5 years (from 2022), which is notably high considering their interest.[80]

Given the immaturity of the technology and lack of available project data, it is difficult at present to evaluate the volume of DAC, or number of projects, in the US that may move forward under current financial and policy conditions (i.e. 45Q at $180/t). Only early indications are available given the relatively small number of projects and the broadly defined ranges of costs. Therefore, consider the following based on ranges discussed above: the value of 45Q falls within the lowest 28% of the cost range for liquid systems and in the lowest 5.7% of the likely range for solid systems. This suggests, with caution, that most projects would not breakeven under 45Q alone. Consider in addition that the cost ranges above omit transportation and storage costs, which may account for an additional 5-20% of expense. Moreover, the lowest portions of the range of each cost likely depends on optimal environments at megaton scales, where project economics improve in theory. Many current and near-term deployments are unlikely to achieve these low-end cost estimates. The IRA's 45Q tax credit alone, without stacking with California's Low Carbon Fuel Standard (LCFS), is unlikely to have an immediate and direct impact on large-scale DAC investment. DAC projects vary greatly between them, so developers may be able to locate facilities to leverage CO_2 transportation and storage infrastructure networks to improve economics in the short- to medium-term.

However, positive trends may support the temporary provision (5-10 years) of a substantial tax credit or funding program for DAC. Any program would need to be designed specifically to catalyze near-term cost-compression because forecasting suggests that it is likely to leverage 'learning rates', leading to temporary and additional concessional finance. For instance, despite real technical challenges such as low CO_2 concentration and energy requirements, high costs may be most closely determined by the relative immaturity of the technology. Forecasts point to future capture costs between $100-200/t and even dropping below $60/t by 2040 or 2050.[81] Many new entrants, startups, and research laboratories globally are specifically focused on driving down costs in air contactors, sorbents, and regeneration methods. The role for public investment today is to accelerate "technology development and de-risking so that DAC can mature fast enough to meaningfully contribute to a portfolio of carbon removal approaches in the coming decades."[82]

Figure 7: Projected Cost-Compression for DAC ($2018 levelized cost)[83]



Source: Larsen et. al. (2019)

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[80] Evans, Carol. "Occidential All In on Carbon Capture." *Energy Intelligence.* (2022). https://www.energyintel.com/0000017f-d27b-de9b-a77f-d37f75310000.

[81] Ibid: 2 (Ozkan)

[82] Ibid: 3 (Ozkan)

[83] Larsen, John, et. al. "Capturing Leadership: Policies for the US to Advance Direct Air Capture Technology," Rhodium Group, LLC. (May 2019): 28.

Several studies[84] have documented the "learning effect", the mechanism by which learning-by-doing and leveraging shared information reduces the costs of capital-intensive technologies over time. Typically, learning is communicated as a cost reduction corresponding to a doubling in deployed capacity. Researchers find that, if a policy or measure is able to provide investors and developers with certainty of demand over a 30-year payout, typical for most DAC projects, then the need for capital support is expected to reduce after 7-9 megaton-scale plants are constructed, if learnings are shared broadly (approximately $10-15 billion in total project cost).[85,86] Shown in Figure 7, of these first nine projects most likely to get over the line – those leveraging both the Low-Carbon Fuel Standard (California) and EOR – the 45Q credit required for breakeven would reduce from $179/t for the first megaton of scaled capacity to $137/t for the ninth megaton-scale plant.[87,88] This data demonstrates that: (a) 45Q alone is insufficient to address costs and revenue constraints, (b) it can be designed and configured alongside other supports such that it provides additional benefit to catalyze project investment on a temporary basis, and (c) immediate investment should seek to maximize learning effects for rapid cost-compression. Government may leverage these mechanisms of cost-compression to design policy supports intended to create self-sustaining markets for hard-to-finance outputs.

3.3.2 Technology and Revenue Risks

The enhancements to the 45Q tax credit are the only provisions in the IRA that provide new support for DAC. The enhancements complement previous programming announced and funded through the 2021 Infrastructure Investment and Jobs Act (IIJA), which includes the DOE's Office of Clean Energy Demonstrations' delivery Regional Direct Air Capture Hubs ($3.5 billion until 2026). The program seeks to develop four hubs that facilitate the deployment of DAC at megaton-scale, demonstrate the value chain, and deliver networks of sequestration.[89] The analysis below demonstrates that the design of the tax credit falls short in addressing risks, and therefore likely to continue to discourage adequate private investment in rapid DAC development and expansion. Moreover, the outcomes of the Regional Direct Air Capture Hubs program, and considerations for future expansion of 45Q or other programming, should reflect the need to address technology risk and demand risk.

DAC requires additional development before **technology risks** can be reduced. A 2019 report by Rhodium Group examines options for a comprehensive program to advance DAC in the US It proposes that substantially more research, development, and demonstration (RD&D) programming is needed to contribute to the "take-off" of DAC to meet net-zero emissions. [90] In fact, the cumulative amount of government RD&D funding for DAC over the previous decade was just $11 million, while the National Academies of Sciences, Engineering, and Medicine (NASEM) recommends funding DAC research over the next decade at an average annual level of $240 million (or roughly $2.4 billion by 2030).[91] This recommendation points not just to high capital costs impeding private investment ("take-off"), but persistent technology risk that government support needs to direct investment toward.

As of April 2022, there were only 18 pilot-scale DAC plants across Canada, US, and Europe. They are capturing a total of almost 8,000 t/y and an average of just 430 t/y at the facility level.[92] Noted above, Carbon Engineering and Occidental Petroleum are currently developing the world's first plant capable of capturing up to an initial 0.5 Mt/y, in Texas, US. However, the facility is not yet in operation and is

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[84] Victor, Nadejda, and Christopher Nichols. "CCUS deployment under the US 45Q tax credit and adaptation by other North American Governments: MARKAL modeling results." *Computers & Industrial Engineering* 169 (2022): 108269.

[85] Assumes $1 billion to $1.5 billion per project capturing 1 Mt/y.

[86] Larsen, John, et. al., Capturing Leadership: Policies for the US to Advance Direct Air Capture Technology, 31.

[87] These estimates are in $USD 2018. The estimates also assume a 30-year credit payout and annual decrease in Low-Carbon Fuel Standard (LCFS) credit revenue after 2030 in accordance with the schedule implemented in 2019.

[88] Larsen, John, et. al., Capturing Leadership: Policies for the US to Advance Direct Air Capture Technology, 31.

[89] Office of Clean Energy Demonstration. "Regional Direct Air Capture Hubs." Energy.gov, www.energy.gov/oced/regional-direct-air-capture-hubs. Accessed on March 1, 2023.

[90] Larsen, John, et. al., Capturing Leadership: Policies for the US to Advance Direct Air Capture Technology, 5.

[91] Ibid: 5. (Larsen)

[92] International Energy Agency (IEA), "Direct Air Capture: A Technology for Net-Zero." (April 2022). Paris, France. Accessible at: https://www.iea.org/reports/direct-air-capture-2022.

likely to require additional optimization even once in-service.[93] Until further demonstration occurs at scales nearer to 1 Mt/y, DAC investments will carry substantial risk of underperformance, and financial structures seeking to mobilize finance will need to backstop or reduce these risks in the interim.

The 45Q tax credit alone is not intended or designed to address technology risk, despite the IRA lowering the eligible facility size requirements. To the contrary, the initiative ties access to the credit to the ability to capture CO_2. While this may be its objective, technology risks that materialize dramatically reduce the amount of revenue available to a project if that project relies on 45Q tax credits. A credit that rebates capital expenditure (e.g. investment tax credit) may more effectively attract co-investment because payback is not necessarily tied to performance (i.e. capital costs are rebated regardless of the volumes of CO_2 that is sequestered as is the case under 45Q, notwithstanding additional eligibility criteria).[94] On a related note, the capacity threshold for eligible DAC facilities was lowered from 100,000 t/y to 1,000 t/y. However, only 2 of the 18 existing facilities exceed this lower threshold, signifying that testing and demonstrating new processes often starts below 50-500 t/y and lasts for several years. Therefore, other mechanisms are needed to reduce the cost of finance associated with RD&D. Before an appropriate initiative can spur the deployment of the first 7-9 megaton-scale DAC facilities, dedicated RD&D support must complement capital support to reduce technology risks for investors that prefer to avoid early-stage technology altogether.

DAC suffers from acute **demand risks** or revenue uncertainties, which are not adequately addressed through existing measures. The importance of predictable or guaranteed demand for the output of nascent technologies is clear in comparison between DAC and the historical deployment pathways of key electric power sector technologies like natural gas combined-cycle power plants, wind and solar, which saw substantial federal action to catalyze rapid cost-compression and, in some cases, self-sufficiency in take-off.[95] In these cases, cost-compression is "largely attributable to the long-term outlook of output purchasing entities that inserted stability into the output purchase agreements and gave developers a certainty of return on investment over time."[96]

45Q credit revenue is capped at 12 years and this remains the duration of total revenue if EOR or additional regulatory credits are not also leveraged. Modeling of supports for DAC find that a credit of $180/t for 30 years, in addition to an eligibility threshold that includes facilities of 10,000 t/y capacity would allow just the first wave of DAC plants to break even, mainly due to the preference that investors receive predictable revenue for the useful lifetime of a facility – 30 years for a typical DAC facility. They are unlikely to be built and operated without revenue certainty for a comparable duration.[97] Importantly, the modeling referenced here assumes that 45Q is "stacked", or combined, with revenues from California's Low Carbon Fuel Standard (LCFS), which would afford projects and their investors with additional revenue and a reduction of demand risk.

In California, the LCFS provides credits for low-carbon-intensity fuels that users purchase. It is an important regulatory market creating demand for CO_2-based fuels. In 2020, 14 new CCUS projects entered development and 5 leveraged both 45Q and the LCFS to stabilize revenues.[98] California's Air Resource Board (CARB) has operated LCFS since 2011 and extended the program to 2030 requiring a 20% reduction in carbon intensity by that year. Most of the low-carbon fuel supplied has come from biofuels. In 2019, CARB also expanded the range of eligible technologies, active in 2021, to allow fuels produced using CO_2 from DAC to receive credit, depending on carbon intensity.[99] DAC-based fuels can have a carbon-intensity of 90% lower than gasoline if zero-emitting energy is used to power the DAC facility, and the product can directly replace fossil fuel products in existing vehicles.[100] As discussed in

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[93] Ozkan, M. et. al., Status and Pillars of Direct Air Capture Technologies, 2.

[94] Canada's Investment Tax Credit for CCUS is one example, pending final design.

[95] Larsen, John, et. al., Capturing Leadership: Policies for the US to Advance Direct Air Capture Technology, 5.

[96] Segel, Neil. "Direct Air Capture Facilities and Production of Carbon-Neutral Hydrocarbons." *Envtl. L. Rep.* 51 (2021): 18.

[97] Larsen, John, et. al., Capturing Leadership: Policies for the US to Advance Direct Air Capture Technology, 5.

[98] Global CCS Institute, Global Status of CCS: 2022.

[99] Larsen, John, et. al., Capturing Leadership: Policies for the US to Advance Direct Air Capture Technology, 23.

[100] Ibid: 23. (Larsen)

the sections following, utilization improves the business case for DAC by addressing demand risk. Stacking revenue supports has been an important tool to get projects "over the line" in the US given that CARB allows DAC projects located anywhere in the world to generate LCFS credits if they sequester captured CO2 permanently or sell low-carbon intensity fuels (from DAC processes) into California. However, rationale for this expansion is based on CARB's anticipation that few DAC plants will be built, and not enough to upset credit balances.[101]

In weighing the relative importance of 45Q changes under the IRA, higher credit value and longer payout period trump extended eligibility thresholds for improving project economics for potential investors. For example, consider a DAC facility that captures and sequesters 1 Mt/y of CO_2 and has a capex (capital expenditure) of $1.5 billion. With a credit price of $180/t adjusted for inflation starting in 2027 (in accordance with the IRA), a 30-year credit period would yield $7.3 billion over the operating life of the facility. Reduction of the crediting period to 20 years reduces this revenue to $4.37 billion and further reduction to 12 years reduces this revenue to just $2.4 billion. Breakeven of capex only occurs in year 8 in this example. Not only does this represent a limited return for investors ($900 million; 60% over 12 years, or 5% per year) that is unlikely to meet hurdle rates, but revenue ceases just 4 years after breakeven, leaving up to 18 years of remaining opex (operational expenditure) on the facility. While this data is not validated against real commercial-scale projects given they have not existed, it is a reasonable illustration of what may be expected.[102]

To some extent, the new "direct pay" provisions may help drive down the high cost of capital for CCS and DAC projects by helping developers overcome technology and revenue risks. Direct pay allows for-profit entities to receive the full value of the credit as a tax refund for the first 5 years, without needing to enter complex and often expensive tax equity structures with investors. Prior to the IRA, such structures supported between 30-60% of capex needs[103] but they were especially required for claimants without sufficient income tax against which to claim the full credit amount.

The impact of direct pay measures on project economics has been documented. Through leveraging direct pay rather than tax equity structures, developers save capital by avoiding associated expenses and interest. As a result, developers improve direct revenues and may accelerate debt repayment, reducing risks to creditors and associated interest rates. Further, greater access to debt financing is likely to reduce the project need for dilutive and expensive equity investment, which would increase the cost of capital. Projects are more likely to qualify for public loan guarantees, which further result in reduced capital costs.[104] Highlighted here is an important complementarity between tax credits and loan guarantees with concessional benefits.

Assessments of public financing policies in the space of CCS and CDR find that loan guarantees may reduce WACC by up to 2%, translating to a decrease in the levelized cost of the first DAC plant by 9%.[105] By comparison, other tax advantageous structures or public finance measures, such as Master Limited Partnerships and Private Activity Bonds (PAB) can reduce WACC by 1% and 0.5%, respectively. Most notably, an Investment Tax Credit (ITC) of 30% is the most effective strategy due to its direct reduction in capital costs, rather than operational costs.[106] Estimates suggest that a "30% ITC to the capital cost of the first DAC plant could cut the median breakeven cost by 25%, a significantly larger cost reduction" than alternative policies. A 30% ITC coupled with a similar design of the 45Q credit under the IRA could bring down the necessary credit value to $125/t, or a 30% reduction.[107] The

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[101] Stillwater Associates. "California Low Carbon Fuel Standard (LCFS): Monthly Newsletter." *Stillwater Associates LLC* (November 2020).

[102] Calculations in this section are done by the author and are illustrative.

[103] Segel, Direct Air Capture Facilities and Production of Carbon-Neutral Hydrocarbons, 27-28.

[104] Friedmann, S. Julio, Emeka R. Ochu, and Jeffrey D. Brown. "Capturing investment: Policy design to finance CCUS Projects in the US power sector." *NY Columbia SIPA Cent Glob Energy Policy Accessed April* 1 (2020): 5.

[105] Larsen, John, et. al., Capturing Leadership: Policies for the US to Advance Direct Air Capture Technology, 6.

[106] Ibid: 6. (Larsen)

[107] Ibid: 33. (Larsen)

utility of stacking ITCs with other public finance policy offering is well-proven, having been used to drive the rapid rise of solar PV deployment.[108]

In conclusion, costs are likely to persist in preventing substantial private investment to catalyze rapid deployment with the 45Q tax credit alone. This is despite the increased tax credit value following the IRA. In addition, specific risks are likely to exacerbate the difficulties in attracting investment at favourable terms. However, dramatic cost reductions are possible if learnings are leveraged throughout the first 7-9 megaton-scale facilities. Policy initiatives that are designed to mitigate key risks, while providing capital to first deployments may have the potential to catalyze substantial private investment ahead of 2050.

3.4 Financing CO_2 Utilization and Market Development

One of the most prominent prescriptions of blended finance are that public investments should be leveraged in such a way that contributes to the development of robust markets with self-sufficiency without the ongoing need for public investment. In the US this is likely to be achieved when a mature market for CO_2 utilization and CO_2-based products emerges. Despite the IRA, and enhancements to the 45Q tax credit particularly, more intentional policy support is needed to develop economical and attractive CO_2 utilization opportunities. Policy supports are needed to address key risks associated with investment in CO_2 utilization and associated technologies, which remain insufficiently addressed by the IRA.

3.4.1 Costs and Revenues

The costs associated with CO_2 utilization technologies, and the revenues associated with resulting CO_2-based products, are highly various and dependent on the specific technology and market sector – fuels, chemicals, food and beverage, polymers, and building materials. For example, production costs of CO_2-based fuels depend on the production cost of hydrogen, and consequently, the cost of renewables.[109] In other sectors like building materials, relatively low energy costs to produce CO_2-based products result in more rapid technology commercialization.[110] The cost of CO_2 utilization depends largely on the high cost of captured CO_2.

However, economics may be improved given the value and potential revenue attributed to CO_2-based products for industrial processes and consumer goods. For example, mineral carbonation technologies for concrete building materials seem particularly promising in the short term due to the combined advantage of increasing material strength while sequestering CO_2 for a considerable length of time.[111] While some early assessments argue that the enhanced 45Q tax credit value for CO_2 utilization may lead to cost-competitive CO_2-based products,[112] evaluating the ability of the tax credit to direct private finance to CO_2 market development is complicated by a variety of factors. This section focuses on evaluating the case for investment in CO_2 utilization for building materials, given that CO_2-based cement and concrete represent one of the most advanced technology options.

Generally undertaken by start-up companies and pre-commercial entities, initiatives in this group include: production of concrete through CO_2 curing of cement-based materials (e.g., CarbonCure, Solidia Technologies and CO_2-SUOCOM), and preparation of concrete with carbonated minerals (e.g., Calera Corporation). In most approaches, existing industrial equipment is usually sufficient, without necessitating major alterations.[113] Leading firm CarbonCure, illustrates the business case and potential

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[108] Ibid: 6. (Larsen)

[109] Akimoto, et. al., Climate change mitigation measures for global net-zero emissions and the roles of CO_2 capture and utilization and direct air capture, 4.

[110] CO_2 Sciences The Global CO_2 Initiative. "Global Roadmap for Implementing CO_2 Utilization." *Ann Arbor, MI: University of Michigan (2016).*

[111] Valluri, Sriram, Victor Claremboux, and Surendra Kawatra. "Opportunities and challenges in CO_2 utilization." *journal of environmental sciences* 113 (2022): 340.

[112] Thielges, Sonja, et al. "Committed to implementing CCU? A comparison of the policy mix in the US and the EU." *Frontiers in climate* (2022): 200-201.

[113] Li, Ning, Liwu Mo, and Cise Unluer. "Emerging CO_2 utilization technologies for construction materials: A review." *Journal of CO_2 Utilization* 65 (2022): 102237.

emissions reduction effects of utilization. Specifically, introduction of a precise amount of “recycled [(CO_2)] into fresh concrete [improves] the concrete’s compressive strength and [optimizes] mix designs [achieving] up to a 7% reduction in cementitious content, which results in significant cost savings” and emission reductions.[114]

To determine the effects of the 45Q tax credit, as the main federal financial policy in the space currently, compare its effects across CO_2 utilization in the cement and concrete sector with alternative CO_2 destinations, especially considering that these alternatives compete for private capital. For comparison purposes, consider available options for CO_2 utilization in cement: mineral carbonation, where waste CO_2 is injected into cement and concrete; and carbonation (curing) of cement-based materials. Both are methods of permanent CO_2 sequestration.

Table 3 shows the relative costs of CO_2 utilization options and demonstrates the relative disadvantage of CO_2 utilization in attracting investment. First, CO_2 utilization receives the same credit value as EOR. EOR is a mature process (TRL 10) and requires a breakeven of approximately \$45-60/t of CO_2.[115] Carbonation of cement-based products and mineral carbonation are less mature (TRL 7-8) and require breakeven cost of approximately \$25-56/t and \$30-81/t respectively.[116,117] Presumably, lower relative TRL forces CO_2 utilization costs to the top end of the noted ranges. Investors are therefore expected to be more attracted to EOR after also bearing lower technology risk and other uncertainties that are often associated with less mature technology. EOR does not sequester all injected CO_2 and results in additional scope 3 emissions. Given this, a credit rewarding both methods equally directs private capital toward EOR and away from continued demonstration and commercialization of other CO_2 utilization routes. Note that the assumed cost of capture for estimating the CO_2 utilization costs is far lower than typical carbon capture systems (\$15/t) and therefore upward pressure on these figures further disadvantages CO_2 utilization in this comparison. Interestingly, US Senators (Whitehouse and Cassidy) introduced a bipartisan bill in February 2023 that would make the 45Q credit for sequestration and utilization equal.[118] The bill does not address the competitive imbalance between EOR and CO_2 utilization, however.

While EOR results in permanent sequestration of a proportion of the injected CO_2, any oil field operator is incentivized to minimize the amount of CO_2 that is “lost” to permanent sequestration and maximize the recovery of used CO_2 for recycling. Since the 45Q tax credit has become the US’s primary method of deploying CCUS to meet into net-zero ambitions, it is important that it avoids moral hazards and align incentives to maximum emission reductions and industrial transition.[119] The lower 45Q credit for utilization may be due to its lower cost relative to CCS and DAC. However, utilization competes for capital against policies that do not resist the ongoing decline of demand for CO_2-EOR and help incentivize alternative uses of CO_2 that will be more aligned with net-zero objectives.

Second, compare CO_2 utilization methods presented here with sequestration costs. Here, \$15/t is likewise assumed as the capture cost. Even with ancillary income – cost savings resulting from increases in material quality and efficiency after carbonation – the CO_2 utilization methods are further disadvantaged. The 45Q tax credit provides substantially greater support for this activity, despite both resulting in permanent CO_2 sequestration. Until a commercial market is established, tax credits that are more proportional to the lifecycle emissions profile of the sequestration method is likely to yield more investment to CO_2 utilization technologies and market development.

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[114] CarbonCure (2017).

[115] Valluri, et. al., Opportunities and challenges in CO_2 utilization, 340.

[116] Ibid: 340. (Valluri)

[117] Jang, Jeong Gook, et al. "Review on recent advances in CO_2 utilization and sequestration technologies in cement-based materials." *Construction and Building Materials* 127 (2016): 769; Li, et. al., Emerging CO_2 utilization technologies for construction materials: A review, 14.

[118] Senator Sheldon Whitehouse. Press Release (February 28, 2023). Available at: https://www.whitehouse.senate.gov/news/release/

[119] Ibid: 330. (Valluri)

Table 3: Technology Readiness Levels of CO_2 Utilization Technologies.[120,121]

Division	**Application**	**Impact**	**Technology Readiness Level (TRL)**	**Breakeven Costs (US$/t)**
Chemicals and Materials Processing	Iron and Steelmaking; Steel slag carbonation, others	Medium	6-8	20 to 50
Oil and Gas	Enhanced Oil Recovery	Very High	10	40 to 60
Mineral Carbonation	Concrete Building Materials	Medium	7-8	30-81
Carbonation of Cement-Based Materials	Cement Curing	Unknown	7-8	25-56
Fuels and Chemicals	Fuels (methanol, ethanol, syngas, methane); urea	High	5-6	Unknown
Geological Sequestration	CO_2 Storage	Extremely High	10	15

Source: Author's reproduction from Valluri (2022), Jang (2016) and Li (2022)

CO_2 utilization in the cement and concrete sector is among the technologies that are nearest to commercialization (i.e. chemical intermediates, liquid fuels, and polymers were also considered), but government investment is still needed to capitalize on recent development, growth, and potential marketization in the US. The University of Michigan's Global CO_2 Initiative measured the growth of the CO_2 utilization market landscape between 2011 and 2016. Considering technology, commercial, and emissions reduction potential, the study found that CO_2 utilization in building materials, particularly concrete curing, and carbonate aggregates in the sector, showed significant progress and immediate potential.[122] The CO_2-based concrete curing market may grow between $6.5 billion and $10.5 billion by 2030 globally, driven by increased performance and reduce cost. The CO_2-sourced carbonate aggregates market is forecast to grow to between 1,000 and 3,500 Mt by 2030, for use in concrete, asphalt, and construction fill.[123]

Data from IEA demonstrates the continued growth in CO_2 utilization since the close of the initial period for the study conducted by the University of Michigan. Global venture capital investment in CO_2-utilization start-ups (Figure 8) reflects consistent interest in CO_2-based polymer firms, moderately growing interest in algae-based proteins/chemicals/fuels firms, and the highest degree of growing interest in CO_2-based fuels and chemicals firms. Investor interest in building materials has been relatively negligible, in contradiction to implied academic prediction. Importantly, this data broadly supports the notion that many of these technologies are still at relatively low TRL levels and are still pre-commercial in nature. Venture capital investment represents investment at the corporate level, rather than investment in deployed projects, and is important for early-stage companies seeking to scale.

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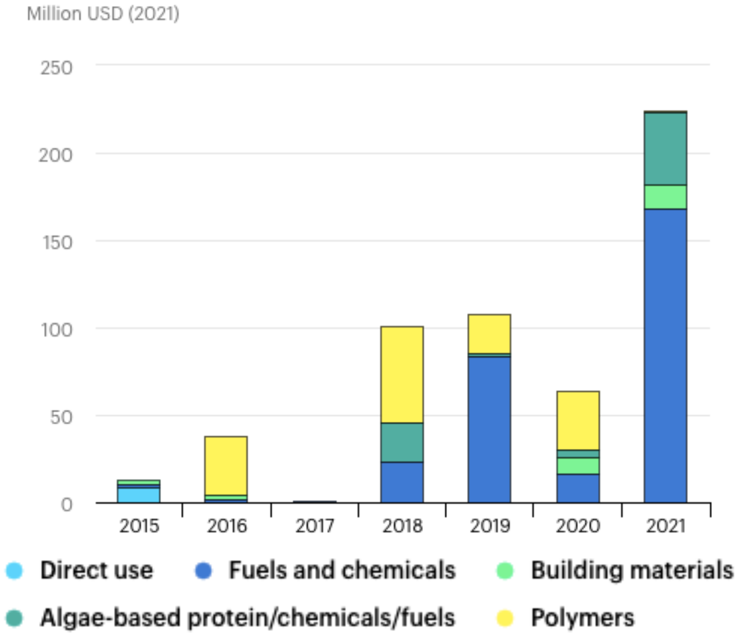
[120] Ibid: 340. (Valluri)

[121] Jang et al., Review on recent advances in CO_2 utilization and sequestration technologies in cement-based materials, 14.

[122] CO_2 Sciences The Global CO_2 Initiative, Global Roadmap for Implementing CO_2 Utilization, *19.*

[123] Ibid: 19. (UofM)

Figure 8: Venture Capital Investments in CO_2 Utilization Start-ups, 2015-2021.[124]



Source: International Energy Agency (2022)

3.4.2 Political Risk: Policy Uncertainty

Policy risk – the potential for priorities, practices, and supports to change or subside through the course on an investment – is acute among emerging climate-friendly technologies like CO_2 utilization. Active support from policies and regulations is often important to "overcome lock-ins in incumbent technologies and create an enabling environment for the development and diffusion of new technologies and related business models."[125] Policy mixes are most likely to be successful in reducing policy risk when they are consistent with credible and comprehensive strategic commitments that are clearly communicated, especially to capital markets.[126] An OECD study emphasizes the importance that policies provide certainty and predictability over periods of time that are aligned with investment horizons to help create "investment grade" policy.[127] Without clear strategic commitments that signal a requirement for CO_2 utilization and CO_2-based products, technologies are not likely to attract invest to their fullest potential.

CO_2 utilization is absent with very few exceptions from US climate and net-zero strategy. Support for CO_2 utilization has consequently suffered from the absence of a "comprehensive, legislation-based climate strategy at the federal level."[128] This is true despite the broad climate support provided under the IRA. Specifically, across the main sources of US climate strategy – Executive Orders[129], the 2021 report from The Council on Environmental Quality, the 2022 Strategic Vision, the 2022 Long-Term Strategy of the United States, and the US Nationally Defined Commitment under the Paris Agreement – CO_2 utilization is often excluded, or addressed implicitly as part of a larger group of "carbon management solutions", including CO_2 conversion and CDR. Strategic documents often omit specific mention of CO_2 utilization technologies beyond those associated with CDR. Supports for CO_2 utilization has been provided in piecemeal throughout an array of legislative and regulatory orders, including the

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[124] International Energy Agency (IEA). "CO_2 Capture and Utilisation." IEA, Paris, License: CC BY 4.0

[125] Thielges, et al, Committed to implementing CCU? A comparison of the policy mix in the US and the EU, 197.

[126] Ibid: 206-207. (Thielges)

[127] Della Croce, Raffaele, Christopher Kaminker, and Fiona Stewart. "The role of pension funds in financing green growth initiatives." (2011): 18.

[128] Thielges, et al, Committed to implementing CCU? A comparison of the policy mix in the US and the EU, 198

[129] The Executive Order on Protecting Public Health and the Environment and Restoring Science to Tackle the Climate Crisis, The Executive Order on Tackling the Climate Crisis at Home and Abroad, The Executive Order on Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability, and The Executive Order on America's Supply Chains.

IRA, USE IT Act, the Energy Act of 2020, and the SCALE Act. Still, federal support for CO_2 utilization technologies has been highly dependent on the respective executive branch and has not been clearly part of evolving climate strategy.[130]

Moreover, the IRA has not addressed uncertainties regarding the treatment of CO_2 utilization under the 45Q tax credit. Section 45Q(f)(5)(A) is likely to qualify many eligible uses of “carbon oxide” as “a process where the qualified carbon oxide is used for any other purpose for which a commercial market exists.” From 2018, investors and developers, including signatories to a public letter[131], have sought critical clarification of what is precisely eligible under this definition.[132] Neither the Final Regulations (2021) or the IRA address this issue as they fail to sufficiently confirm an interpretation of “commercial market” or provide a clear list of CO_2-based products and uses to guide investment decisions. Signatories to the public letter sought specific clarification of the eligibility of DAC-based CO_2 synthesized fuels and a process by which claimants may demonstrate the “commercial” profitability or competitiveness of their product.[133, 134] Clearer confirmation is needed to address these issues, which represent a significant policy risk to FID.

Despite clear increases in the value of the 45Q tax credit for CO_2 utilization, the costs of many of the most advanced CO_2-based products and technologies are likely to remain at a disadvantage in their competition for private capital against projects leveraging EOR. These include CO_2 utilization products and technologies with significant potential to contribute meaningfully to net-zero emissions both in providing “market pull” for rapid carbon capture and CDR deployment and in reducing the carbon intensity of industrial processes and products. Disadvantages of CO_2 utilization are likely to be exacerbated by a continuation of policy risks, left unaddressed by the IRA and previous US climate and decarbonization strategies.

4. Key Considerations

The paper has examined how the IRA, and the 45Q tax credit in particular, affects the ability of certain carbon management solutions to attract investment in the US. As it leverages the theory of “blended finance” to account for the impacts of particular risk and return dynamics on investor behaviour, the study considers some of the concepts below to an extent. However, future research on the topic may valuably integrate a more fulsome perspective of “transition finance”, or considerations that ensure carbon management project investments align more closely with a transition to a net-zero economy in the US. The following concepts may inform additional analysis.

4.1 Locking in Fossil Fuel Use

The 45Q tax credit rewards higher volumes of CO_2 captured and sequestered/used. Its structure incentivizes the retention and preservation of large sources of CO_2 emissions that are available to capture. In other words, emitters are incentivized to preserve their source of CO_2 rather than eliminate it through other means, such as switching to cleaner fuels, electrifying operations, and shutting in. The risk in this slight difference is that emitters will be incentivized to (a) keep combusting fossil fuels, (b) avoid investments that reduce emissions outside of CCS, which may be less expensive or essential to reduce facility emissions to zero, and/or (c) grow emitting operations where scope 3 emissions are not

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[130] Thielges, et al, Committed to implementing CCU? A comparison of the policy mix in the US and the EU, 199-200.

[131] Letter from Presidents/Chief Executive Officers of Carbon Engineering et al. cmt. 39 (Aug. 1, 2020), Notice of Proposed Rulemaking on Section 45Q Credit for Carbon Oxide Sequestration (Docket IRS-20200013) (in response to IRS NPRM for the Credit for Carbon Oxide Sequestration, 85 Fed. Reg. 34050 (June 2, 2020)) (on file with Baker Botts L.L.P. at https://www.bakerbotts.com/thoughtleadership/publications/2020/august/finding-tool-for-public-comment-letters-carbon-capture-tax-creditproposed-regulations-section-45q).

[132] Thielges, et al, Committed to implementing CCU? A comparison of the policy mix in the US and the EU, 199-200.

[133] Segel, Direct Air Capture Facilities and Production of Carbon-Neutral Hydrocarbons, 23.

[134] Baker McKenzie. “United States: Treasury and the IRS Release Long-Anticipated Section 45Q Final Regulations.” Baker McKenzie InsightPlus, 29 Jan. 2021, insightplus.bakermckenzie.com/bm/tax/united-states-treasury-and-the-irs-release-long-anticipated-section-45q-final-regulations.

reduced.[135] This would not just apply for CO_2-EOR, but supports that accrue long-term benefit to CO_2 sources, rather than capture and sequestration more specifically, may result in behaviours that lock-in fossil fuel use. Further, some consider this incentive to be a moral hazard from the extension of fossil fuel use. Particularly regarding power CCS, experts agree that there is a need for firm (natural gas or low-carbon hydrogen generation) capacity technologies until long-duration, grid-scale energy storage costs reduce sufficiently to enable greater intermittent renewable generation.[136] Clean and renewable electrification is important to help facilitate a net-zero economy. The investment case for CCUS may strengthen relative to alternative decarbonization pathways as policy and financial supports for CCUS increase and costs reduce. As this occurs, the incentive structure of such supports should be examined alongside net-zero objectives.

4.2 Trade Risk and Scope 3 Emissions

According to the US Environmental Protection Agency, Scope 3 emissions are “the result of activities from assets not owned or controlled by the reporting organization, but that the organization indirectly affects in its value chain.” They include all sources of emissions, typically indirect, that are not within an organization’s scope 1 and 2 boundary. If Scope 1 emissions are “direct emissions that occur from sources that are controlled or owned by an organization (e.g., emissions associated with fuel combustion in boilers, furnaces, vehicles), [and] Scope 2 emissions are indirect emissions associated with the purchase of electricity, steam, heat, or cooling”[137], then Scope 3 emissions include all other emissions that an organization “indirectly affects in its value chain”.[138] This consideration pertains most pertinently to CO_2-EOR, which uses captured CO_2. In any lifecycle assessment of the carbon capture technology, the emissions reductions would be discounted by the existing Scope 3 emissions affected by the combustion of fossil fuels. The IEA forecasts steady reductions in global oil demand both in current policy scenarios and net-zero scenarios, as oil demand for road transport declines.[139] With reduced demand for oil, CO_2-EOR operations may face increased risk of shut-in, especially as CCS projects near the end of their useful life. Investment in CCS with CO_2 destinations that are at risk of shutting in before the useful life of the CCS reduces the attractiveness of investments. It is important to note that forecasts noting reductions in oil demand do not claim that it will be eliminated altogether. EOR may play an important role in servicing future, reduce oil demand with lower-carbon-intensity product (before combustion). Future analysis that considers Scope 3 emissions should reflect further research needed to evaluate the role of EOR in a net-zero world.

4.3 Levelized Cost of Carbon Abatement

Traditional ‘levelized cost’ allows for a comparison of the costs associated with marginal abatement (1 ton of CO_2) across sectors. Friedmann et al. (2020) notes the limitations in this approach given that it does not consider the volumes of emissions reductions that a certain measure can achieve. While a measure may be relatively inexpensive (low $/t of marginal CO_2 abatement), it may only be able to reduce a small proportion of facility emissions. The researchers’ levelized cost of carbon abatement (LCCA) concept[140] allows for a comparison of both marginal cost of abatement and emissions reduction potential, which would yield different investment results for those looking to allocate capital for large-scale decarbonization in alignment with net-zero objectives. For example, retrofitting blast furnaces is the main opportunity for CCS in the US steel sector and it is available to only around 30% of US steel

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[135] Gross, The challenge of decarbonizing heavy industry.

[136] Anderson, Jeffrey J., et al. "Fossil-Fuel Options for Power Sector Net-Zero Emissions with Sequestration Tax Credits." *Environmental Science & Technology* 56.16 (2022): 11164.

[137] Environmental Protection Agency (EPA). “Scope 1 and Scope 2 Inventory Guidance.” 9 Sept. 2022, www.epa.gov/climateleadership/scope-1-and-scope-2-inventory-guidance.

[138] Environmental Protection Agency (EPA). “Scope 3 Inventory Guidance.” 14 Feb. 2023, https://www.epa.gov/climateleadership/scope-3-inventory-guidance.

[139] International Energy Agency (IEA), “World Energy Outlook 2022.” (2022). Paris, France.

[140] Friedmann, Julio, et al. "Levelized cost of carbon abatement: An improved cost-assessment methodology for a net-zero emissions world." *Columbia University SIPA Center on Global Energy Policy: New York, NY, USA* (2020).

production. The remaining 70% of production occurs through electric arc furnaces (EAFs), where other decarbonization avenues are more technically and economically feasible.[141] An increase in 45Q tax credit value from $50/t to $85/t may make CCS retrofits of blast furnaces in steel production economical, given that this cost is currently $60/t at many potential facilities.[142] However, only 34-40% of facility emissions are accessible through this pathway and integration of zero-carbon electricity or green or blue hydrogen would be needed to bring these facilities to zero emissions, all of which carry higher LCCA than CCS.[143] Alternative measures needed to decarbonize EAFs (Direct Reduced Iron and zero-carbon electricity or hydrogen) can decarbonize over 55-85% of facility emissions.[144]

4.4 Alternative Decarbonization Incentives

The study discusses policy supports, and specifically financial measures that alter incentives associated with CC(U)S investment. Additional analysis is necessary to integrate alternative incentives that may drive investment behaviour instead of, or further than, policy measures. Corporate net-zero objectives, most likely to drive Environmental, Social, Governance (ESG) appeal among participants in capital markets, have already started influencing the allocation of capital in CC(U)S. Prominent corporates like Stripe, Alphabet, Meta, Shopify, and McKinsey launched Frontier Climate in 2022 to accelerate the development of permanent carbon removal technologies by developing future demand. It targets over $1 billion in "advance market commitments" for carbon removal and has a portfolio of almost $60 million and 112,000t across areas of technical and natural carbon removal.[145] Other industries may be motivated to invest in costly CCS to take advantage of nascent markets for low carbon-intensity product, where a premium can be charged. This motivator may drive investment in cement production, where public procurement represents a notable portion of demand. In these cases, demand is driven by buyers that are interested in or obliged to reduce Scope 3 emissions or "embodied emissions" (emissions represented by the carbon-intensity of materials used in the buildings sector, for example). Further work to elucidate these motivations will strengthen the literature and analysis on the relative strength and importance of policy measures.

Conclusions

Substantial private investment is needed to facilitate the deployment of carbon capture at sufficient levels to reach net-zero by 2050 in the US. This is particularly important for CCS in heavy industry, DAC, and CO_2 utilization. Unique and difficult-to-mitigate risks are likely to persist despite the IRA and strengthened 45Q tax credit.

The analysis supports an extension of the crediting period from 12 years to 30 years. While a rapid decline in costs comparable to those in the solar industry would likely present substantial downside risk to the US treasury, this or alternative measures to lengthen periods of predictable revenue-generation are important for reducing revenue risks associated with CCS in heavy industry. Further analysis may explore the feasibility of a gradual credit value decrease in later years, given that long-term certainty is of primary value to investors. Amendments should distinguish the different lifecycle emissions (scope 1, 2, and 3) impacts of CO_2 utilization and EOR by amending credit values awarded to each activity accordingly. The intended result is to improve the competitiveness of CO_2 utilization against EOR in attracting financial investment.

In the US context specifically, where the 45Q tax credit provides opex support, an ITC that is made available to industrial CCS and CDR, specifically DAC, can combine to dramatically and immediately reduce capital costs for project developers. The 48E Clean Energy Investment Tax Credit is not

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[141] Perpinan, Jorge, et al. "Integration of carbon capture technologies in blast furnace based steelmaking: A comprehensive and systematic review." *Fuel.* 336 (2023): 3.

[142] Ibid. (Friedmann)

[143] Ibid. (Friedmann)

[144] Ibid. (Friedmann)

[145] Frontier Climate, available at: https://frontierclimate.com/portfolio.

currently stackable with the 45Q. In addition, while claimants of 48E may use CCUS, they are available only to existing emitters, and not to DAC facilities. The other credits applying to CCUS, 45Q and 45V (blue hydrogen), have not been made stackable. An ITC reflecting a 30% refundable credit of eligible capital expenditures, in addition to 45Q for DAC alone, could create promising conditions to support an acceleration of two types of critical investment. First, investment in pre-commercial and demonstration-scale projects that contribute to technological improvements and reductions in technology risk. Second, investment in capital-intensive projects near or at scale, which are required before replication and cost-compression (documented by Larsen et. al., 2019) can be catalyzed and revenues from the 45Q and LCFS measures can become appealing.

To supplement existing loan programs that benefit the development of CCS for the power sector, analysis supports the need for a dedicated authorization to issue loans and loan guarantees to support specific policy objectives. Firstly, provision of capex support for industrial CCS deployment, where the measure would seek to coordinate and support 'value-chain' projects (capture, transportation, sequestration/utilization) to reduce cross-chain risk, and present coordinated deals to the market for private sector participation. Secondly, provision of capex support for technology RD&D, with emphasis on DAC and next-generation industrial CCS technologies. The measure would specifically emphasize rapid cost reduction.

Amendments to central strategic documents should provide a clear market signal that CO_2 utilization is a long-term priority for the net-zero transition of certain industrial sectors – cement, steel, fuels, and transportation. Policy measures to action this commitment should reflect compliance criteria given this clear statement of priority sectors. Amendments to 45Q credit values for utilization can favour investment in non-EOR utilization over EOR, with a view to correcting for risks and costs that disadvantage uses for CO_2 in net-zero-aligned industrial sectors like cement and concrete. Revised credit values for these activities would need to account for relative differences in TRL and current and future costs.

The above does not suggest additional credit value enhancements to those afforded under the IRA necessarily. Analysis finds that, for applications where capex and opex exceed current credit values, credit values may be refined to correct undesirable competitiveness issues (e.g., EOR and CO_2 utilization), or where additional RD&D is needed to support cost-compression. This also does not propose additional funding support for CO_2 utilization technologies. Clearer public policy objectives and market signals may be sufficient to attract investment as carbon capture costs decline.