EFI FOUNDATION

ENERGY FUTURES FINANCE FORUM

Unlocking Private Capital for Carbon Capture and Storage Projects in Industry and Power

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About the EFI Foundation

The EFI Foundation (EFIF) advances technically grounded solutions to climate change through evidence-based analysis, thought leadership, and coalition-building. Under the leadership of Ernest J. Moniz, the 13th U.S. Secretary of Energy, EFIF conducts rigorous research to accelerate the transition to a low-carbon economy through innovation in technology, policy, and business models. EFIF maintains editorial independence from its public and private sponsors.

About the Energy Futures Finance Forum

The Energy Futures Finance Forum (EF^3) is a program within the EFI Foundation that examines barriers to the flow of private capital to clean energy and industrial decarbonization opportunities. By reflecting the investor perspective, its primary focus is enhancing the bankability of projects and business models essential for the energy transition. Through rigorous analysis, thought leadership, stakeholder convening, and public education, EF^3 develops actionable policy and financial sector recommendations to address challenges and drive at-scale capital deployment.

Report Sponsors

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Acronyms and Abbreviations

ATR –auto-thermal reforming
BIL – Bipartisan Infrastructure Law
CCS – carbon capture and storage
CCUS – carbon capture, utilization, and storage
CDR – carbon dioxide removal
CEPCI – Chemical Engineering Plant Cost Index
CI – carbon intensity
DAC – direct air capture
DOE – Department of Energy
EOR – enhanced oil recovery
EPA – Environmental Protection Agency
EPC – engineering, procurement, and construction
EPS – emissions performance standard
FECM – Office of Fossil Energy and Carbon Management
FEED – front-end engineering and design
FID – final investment decision
FOAK – first-of-a-kind
GCCSI – Global CCS Institute
GHG – greenhouse gas
IRA – Inflation Reduction Act
LCFS – low carbon fuel standard
Mtpa – million metric tons per annum
MW – megawatts
MWh – megawatt-hour
NGCC – natural gas combined cycle
NOAK – nth-of-a-kind
RD&D – research, development, and demonstration
RDD&D – research, development, demonstration, and deployment
SMR – steam methane reforming
TRL – technology readiness level
UIC – underground injection control
VCM – voluntary carbon market

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Executive Summary

This report presents an updated analysis of the demonstration and deployment of carbon capture and storage (CCS) technology across the power sector and industrial sectors. The analysis focuses on early implementation of the new CCS funding programs and increased tax incentives provided in the Bipartisan Infrastructure Law (BIL) and the Inflation Reduction Act (IRA).

The principal findings from the new analysis include:

- The increased level of the Section 45Q ("45Q") tax credit for carbon storage in the IRA has not provided additional incentive value because the increase has been fully offset by COVID-era inflation and higher interest rates for CCS in most sectors, negating additional benefits.
- The new credit is adequate to facilitate bankable free-standing CCS projects in only four of the 11 industrial and power sectors that were studied. These include natural gas processing, auto-thermal reforming of natural gas in greenfield facilities, carbon capture from ethanol fermentation, and steam methane reforming (SMR) of natural gas. These sectors comprise only 2.5% of total stationary emissions.
- For higher-emitting industrial and power sector applications, such as cement, steel, and natural gas combined cycle power plants, the cost of capturing and storing carbon dioxide (CO_2) exceeds the value of the 45Q tax credit by up to \$58/metric ton CO_2. The cost gap tops out at \$90/metric ton for natural gas boilers. The shortfall for pioneering "first-of-a-kind" (FOAK) projects is even larger.
- While there has been some forward movement in FOAK commercial-scale demonstration projects in the heavier-emitting and harder-to-abate industry sectors, this progress is being facilitated by a combination of the 45Q credit with three other policy measures, principally U.S. Department of Energy (DOE) cost-sharing for early commercial-scale demonstration projects, as well as state government incentives and corporate voluntary decarbonization commitments. Layered support for more pioneering projects in more industries will be necessary to bring down costs.
- While cost issues are central for the carbon capture process, which accounts for about 80% of total CCS costs for new applications in higher-emitting sectors, the primary impediment to investment in CO_2 transport and storage is the permitting of infrastructure development. To date, EPA has issued permits for only eight Class VI wells for geologic storage since the inception of the Class VI rules in 2010. Applications for more than 160 wells are still pending review. Four states have been approved to implement permitting at the state level, while eight others are currently seeking DOE delegation approval. One key project awaiting permit approvals is the Summit CO_2 pipeline, a planned 2,500-mile pipeline to transport captured CO2 from as many as 57 Midwest ethanol plants across five states to permanent storage in North Dakota. If successful, the project could lead to the capture and geologic storage of about 18 million metric tons of CO_2 per year.

The report reaffirms the recommendations in the original 2023 EFI Foundation report and highlights several new recommendations, including that:

- Congress amend 45Q to eliminate the current restrictions on indexing the credit for inflation and consider additional bonus credits for early movers.
- The National Energy Dominance Council consider measures to coordinate and expedite federal permitting actions for CO_2 pipelines across agencies and work with the U.S. Environmental Protection Agency (EPA) to clarify the criteria and process for approvals of state permitting programs for underground CO_2 geologic storage. The Trump administration should also work with Congress if additional legislative authority is needed to achieve this objective.
- DOE fully implement current BIL and IRA research, development, and demonstration (RD&D) funding authorities, enable more flexible public-private partnerships, and increase information sharing from commercial-scale demonstration projects to facilitate the learning benefits of federally funded projects. DOE should also consider additional targeted CCS demonstration projects in other industrial sectors where cost reductions appear feasible.
- States consider expanding existing clean energy portfolio goals, requirements, and financial incentives to include CCS.

Introduction

This analysis provides an update to the EFI Foundation's February 2023 report *Turning CCS Projects in Heavy Industry & Power into Blue Chip Financial Investments*. That report, issued shortly after the enactment of the new carbon capture and storage (CCS) tax credits in the Inflation Reduction Act (IRA), identified a suite of complementary policy actions to jump-start U.S. CCS deployment across all the major sectors of heavy industry and across various power applications.

CCS is a central element in a future low-carbon energy economy in the U.S. and globally. It's the only technology that can address the carbon dioxide (CO_2) emissions from all forms of fossil fuels across all types of facilities (i.e., stationary sources) for power generation and industrial process heat. In the United States, these sectors currently make up almost half of total annual greenhouse gas (GHG) emissions.[1]

The purpose of this report is to update the analysis, findings, and recommendations in the 2023 report. This update reflects upon the initial implementation of the new IRA provisions as well as experience with the CCS programs authorized and funded in the Bipartisan Infrastructure Law (BIL).

The 2023 report identified 27 recommendations organized into six major themes. The complete list of recommendations is provided in Appendix A. The key recommendations are summarized in **Box 1** below.

This report provides further insights into the early phase of CCS implementation efforts. It draws from more than 15 interviews with government experts, developers, and nonprofit organizations, and participation in five expert-level working group meetings. The paper additionally draws from detailed reviews of U.S. Department of Energy (DOE) documents, filings from CCS projects in development, recent CCS reports, and cost data from projects in the demonstration or operation stage.

The study concludes with pragmatic, actionable recommendations for addressing new and existing financial and nonfinancial hurdles to attracting private financing for CCS deployment at scale.

Box 1. *Turning CCS Projects in Heavy Industry & Power into Blue Chip Financial Investments*: 2023 report recommendations

Complementary Incentives for Carbon Capture in New Power and Heavy Industry Sectors: Provide BIL grant funding for new applications of CCS where the expected costs and risks still exceed the 45Q tax credit; allow stacking of federal grants, loans, and tax credits; adopt provisions for expanding baseload power generation with CCS in organized markets; encourage state and local government incentives for CCS similar to other pollution control projects.

Improving the Effectiveness and Efficiency of the Section 45Q ("45Q") Tax Credit: Facilitate monetization of the 45Q credit through direct pay and transferability to a larger pool of investors.

Maximizing Information Value: Encourage DOE to make available more complete engineering and performance technical data from DOE-funded demonstration projects to accelerate the pace of market diffusion of CCS technologies.

Permitting Reform: Work with the EPA to streamline procedures for permitting geologic storage wells and promote delegation of permitting programs to states. Encourage states to create coordinating bodies to manage all CCS regulatory interfaces.

Comprehensive Environmental Disclosure: Provide comprehensive public reports on the environmental impact of CCS retrofit projects, incorporating impacts on criteria air pollutants, hazardous air pollutants, and CO_2 emissions.

COVID-era inflation and higher interest rates have offset the increased value of the 45Q tax credit.

Policy context: Over the past half-century, every major new pollution control technology or low-emissions energy technology deployed in the United States benefited from strong policy support. That support has been composed of various permutations of (i) mandatory regimes of pollution control, such as the sulfur dioxide (SO_2)/acid rain rules under the Clean Air Act; (ii) mandatory purchases, including state renewable portfolio standards and federal biofuel blending requirements; and (iii) incentive systems to mitigate costs to current polluters, such as renewable energy federal tax credits/loans and corn ethanol tax credits.

In the absence of any meaningful mandatory CO_2 emissions or purchase regimes, the business case for CCS scale-up—moving from a handful of operating commercial demonstrations to capturing hundreds of millions of metric tons of CO_2 per year—inevitably relies solely upon incentives.

The principal financial incentive for commercial application of CCS is the 45Q tax credit for the capture of CO_2 emissions from the industrial and power sectors and disposition of the captured CO_2 for use in enhanced oil recovery, storage in deep geological formations, or the creation of new products utilizing CO_2. The IRA increased the value of the 45Q tax credit for geologic carbon storage from $50/metric ton to $85/metric ton, an increase of $35/metric ton. The IRA also increased the value of the 45Q tax credit for carbon utilization for enhanced oil recovery or other allowable forms of utilization from $35/metric ton to $60/metric ton. Qualified projects that start construction by 2033 are eligible for the credit over the initial 12 years of operation.

The expansion of the 45Q credits in the IRA was intended to bridge the cost gap for CCS projects in sectors that were otherwise uneconomical even after the costs and risks of applying carbon capture technologies to new sectors were sufficiently reduced through early mover projects. Put simply, 45Q was supposed to bridge early cost gaps until CCS applications reach nth-of-a-kind (NOAK) cost levels.

To further offset the financial risk of FOAK projects, the BIL provided over $12 billion in funding for CCS and carbon dioxide removal (CDR) programs. The CCS support expanded research and development (R&D) programs to include funding for front-end engineering and design, programs for CO_2 transport infrastructure, a new credit support called the Carbon Dioxide Infrastructure Finance and Innovation program, and a new grant program to facilitate state programs for permitting Class VI wells for the injection of carbon dioxide.[a][2]

Methodology and assumptions for CCS cost estimates: The 2023 EFI Foundation report presented cost estimates for CCS deployment in various power and industrial sectors for FOAK and NOAK projects with and without the 45Q tax credit. These estimates have been updated to reflect current economic factors.

The cost estimates represent a set of conservative assumptions. They were developed on a business model that assumed a CCS project needs to compete on a free-standing return-on-investment hurdle rate with other capital projects within a company's overall capital budget. To address this, the cost estimates represent a midpoint between an entity with a large tax appetite and ready access to relatively low-cost capital (such as a major oil and gas company) and a standalone developer who might have to rely on a tax equity transaction to monetize the tax credits. For coal- and natural gas-fired power plants, the estimates include a third estimate for utilities whose rates of return on investments for large capital projects are regulated by state commissions.

[a] The EPA's Class VI well program, part of the Underground injection Control (UIC) program, regulates the injection of carbon dioxide for permanent geological storage under the Safe Drinking Water Act.

Using this business model as the framework, the key data inputs and assumptions that informed the cost estimates included the following:

- The capital cost estimates were based on the capital cost for deployment of established commercial CO_2 capture using amine scrubbing technology. The cost reduction potential of advanced sorbents or innovative scrubber designs was not considered in the analysis.
- The price index considered most applicable to CCS, the Chemical Engineering Plant Cost Index (CEPCI), soared. For relevant heavy industry producers, price indexes increased by anywhere from 30%-43%.[b] Capital-intensive industries, like CCS, were particularly hit by inflation.
- Interviews with developers and other industry experts have made clear that most planned CCS projects are retrofits for existing facilities. Retrofit application can be more costly than adding CCS to brand new ("greenfield") facilities because adding carbon capture equipment often requires modifications to existing energy systems, steps to address space and infrastructure constraints, and extensive pretreatment of flue gases, and may trigger the need for new or revised permits.
- Taking the applicable interest rates from year-end 2020 to end of 2024 (with the main rate spike beginning in 2022), rates started at 2.06% and had risen to 5.55% by the end of 2024.[3]
- Capital providers' required return on equity for CCS projects also increased, meaning the project must deliver greater returns to satisfy investors, whether they be internal corporate financial managers or third-party equity investors. The hurdle rate for corporate return on equity increased from 10.1% (year-end 2020) to 13.6% in Q3 2024.[c]
- Furthermore, if the initial investment costs of carbon capture systems increase, there is typically a proportional increase in the carbon capture plant's annual operational and maintenance (fixed and semi-fixed) costs. These annual fixed costs are typically 5% of the original plant cost, with a range of 4%-7% depending on the application of CCS.[d,4]

Since the industry has very little "as-constructed" experience, the estimates are based upon extensive engagement with developers along with reviews of the best available data. To address this data gap, FOAK commercial-scale demonstration projects that receive public support should share detailed information. These federally funded projects can then help create reliable estimates of FOAK costs and inform future investment decisions to drive faster commercialization. In this way, federal cost-sharing for FOAK commercial-scale demonstration projects is critical to reducing perceived and real risk.

The updated estimates for both FOAK and NOAK deployments, and comparison with the new 45Q tax credit levels, are shown in **Figure 1**.

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[b] This analysis evaluated CEPCI costs for electrical contractors, alloy steel castings, industrial pumps, concrete contractors, industrial construction inputs, and the chemical engineering plant cost index from Q4 2020 through Q3 2024.

[c] Companies' targets are not public, but the formula is based on a small premium for CCS (here, 2%) above the Capital Asset Pricing Model public equity target returns (which are up ~3.5% since Q4 2020).

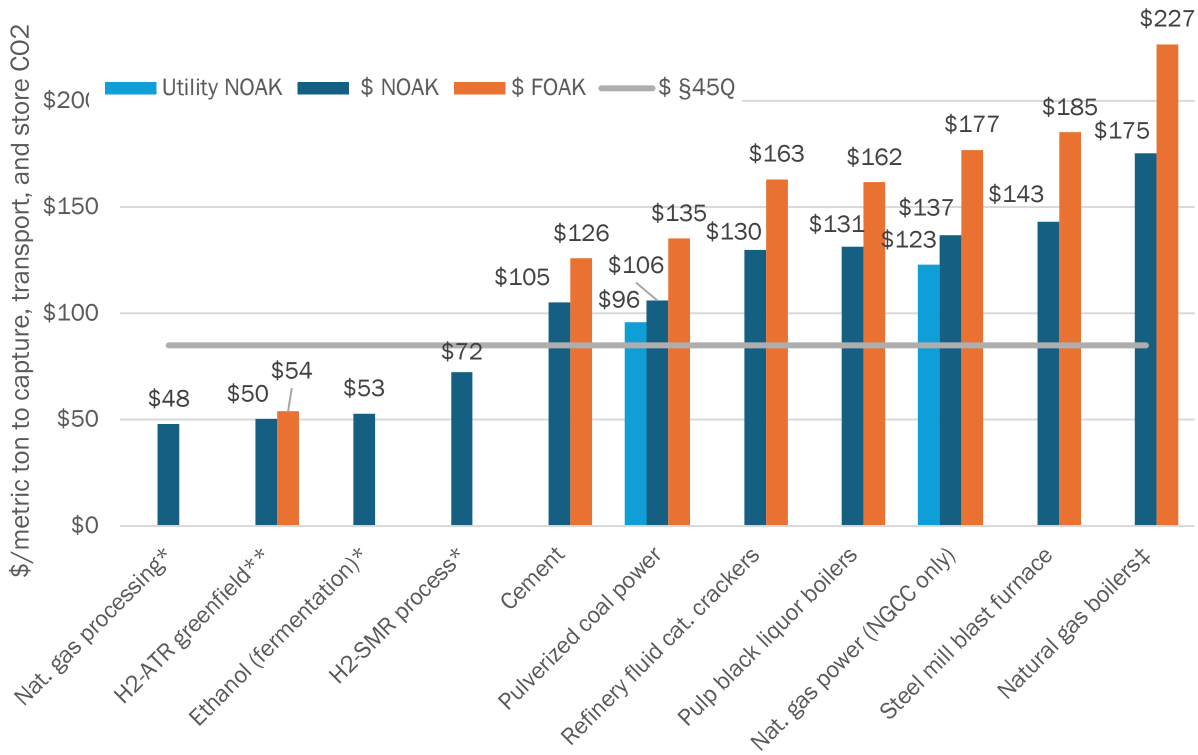
[d] This variance is due to changes in the cost of tax, insurance, and replacement parts based on the original plant cost.

The results show that new IRA tax credits can currently support blue chip investments in only four of the 11 industrial and power applications that were studied: natural gas processing, auto-thermal reforming (ATR) of natural gas in greenfield facilities, carbon capture from ethanol fermentation, and steam methane reforming (SMR) of natural gas.

The other industrial and power applications have a net cost gap after accounting for revenues from the 45Q credit. CCS deployments in these industrial sectors are only economical when other business factors are considered, such as voluntary decarbonization commitments or the sale of carbon credits into voluntary carbon markets. The 45Q tax credit can also play a powerful role in reducing the net cost of compliance with state or local government requirements for reduced CO_2 emissions.

Generally, the benefits of the new 45Q credits provided in the IRA were counteracted by a 35%-40% increase in heavy industry construction costs during the COVID era, compounded by an increase in interest rates of approximately 3 percentage points as the Federal Reserve combated that inflation.

Figure 1. FOAK vs. NOAK cost estimates ($/metric ton) for application of CCS to power and heavy industry sectors



Applications marked with one asterisk (*) have no FOAK bar because these industries have been selling captured CO_2 to industry and enhanced oil recovery fields for more than a decade. The source marked with a double cross (‡) is poorly studied, with few or confusing reference publications; thus, we primarily based these estimates upon well-studied pulverized coal plant costs, adjusting upward for the complexity of emissions streams, typically poor emissions control on criteria pollutants, and physical layout difficulties within existing *plants. The chart does not include figures for industrial heat and power boilers because CCS has not been adequately studied for that application.*

Estimates based on industry and DOE sources for NOAK new builds in 2018 dollars, adjusted for construction inflation costs from dates of engineering estimates to 2024 (1.34x) and including higher financing costs post-COVID pandemic. NOAK figures include a 20% factor for retrofit complexity (except ATR) and a 10.2% capital recovery factor. FOAK figures include the same retrofit factor, a 1.25x capital cost multiplier for FOAK vs. NOAK, and a 12.2% capital recovery factor. All figures include capture, compression, and transport/geologic storage ($30 combined).
Source: EFI Foundation

In short, the $35/metric ton increase in the value of the 45Q tax credit was counteracted by an increase in equipment and financing costs of more than $35/metric ton in most applications. An illustrative NOAK CCS retrofit project that uses midrange values for capacity costs, fixed costs, and energy consumption is now worse off economically relative to the pre-COVID era, even after accounting for the increased value of the 45Q tax credit (**Table 1**).

Table 1. 2020 feasibility vs. 2024 feasibility after 45Q $35/metric ton increase given rising costs

		2020		2024
Fixed costs for CCS	Plant capital cost $/metric ton at 1.0x 2019 level	$310	Plant capital cost $/metric ton annual capture capacity at 1.34x 2019 level and 1.2x for retrofit	$498
	Midpoint capital recovery factor	8.48%	Midpoint capital recovery factor	10.20%
	Return of and on capital	$26.29	Return of and on capital	$50.80
	Non-energy fixed cost	$15.50	Non-energy fixed cost	$24.90
	Total financing and fixed cost	**$41.79**	**Total financing and fixed cost**	**$75.70**
Energy costs to industrial customers	Electricity	$10.77	Electricity	$12.24
	Natural gas	$9.96	Natural gas	$11.40
		$20.73		**$23.64**
Storage	Transport and Class VI storage	**$15.00**	Transport and Class VI storage	**$30.00**
Cost vs. 45Q	Total cost	$77.52	Total cost	$129.34
	Less 45Q	($50.00)	Less 45Q	($85.00)
	Cost in excess of incentive	**$27.52**	Cost in excess of incentive	**$44.34**

Source: EFI Foundation

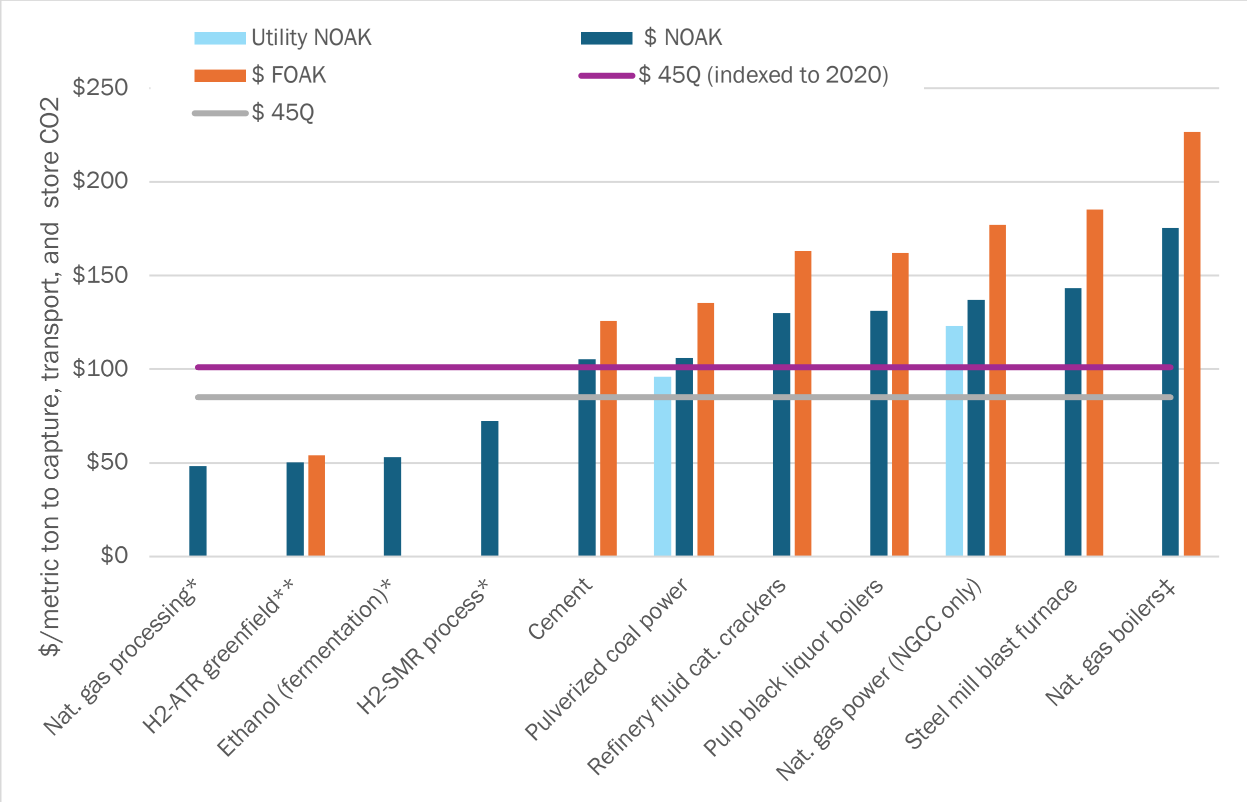
A principal factor creating the gap between the value of the 45Q credit and the escalation of costs for CCS projects is the restrictions on indexing the value of the 45Q credit. The credit was indexed for inflation under a complex formula that provided an adjustment for inflation after 2026 from a 2025 base year. The first inflation adjustment will take place in 2027. This complex formula causes two problems for investors:

I. Setting 2025 as the base year does not compensate for the inflation that took place in the early part of the decade.

II. Moving back the starting date for applying the indexing credit creates a lag in the indexed value. It also causes uncertainty and delays in reaching final investment decision (FID) until the indexed values take effect.

As seen in **Figure 2**, indexing 45Q to 2020 as the base year would increase the value of the credit to $101/metric ton.[e] While such an increase does not alone create the business case to apply CCS across new applications, it would dramatically reduce the cost gap that must be covered. Indeed, NOAK applications of CCS in cement and coal are nearly covered at the higher level, with the cost of adding CCS to coal-fired power plants fully covered if a utility receives regulated rates of return on equity. The fact that inflation indexing does not fully close the cost gap reinforces the need for public financial support to be combined with voluntary commitments from the private sector and/or regulatory mandates.

Figure 2. Comparison of FOAK and NOAK cost estimates ($/metric ton), if inflation is indexed to 2020 as the base year for 45Q



Applications marked with an asterisk (*) have no FOAK bar because these industries have been selling captured CO_2 to industry and enhanced oil recovery fields for more than a decade. The application marked with a double asterisk (**), i.e., auto-thermal reforming of methane to manufacture hydrogen (H_2), has only

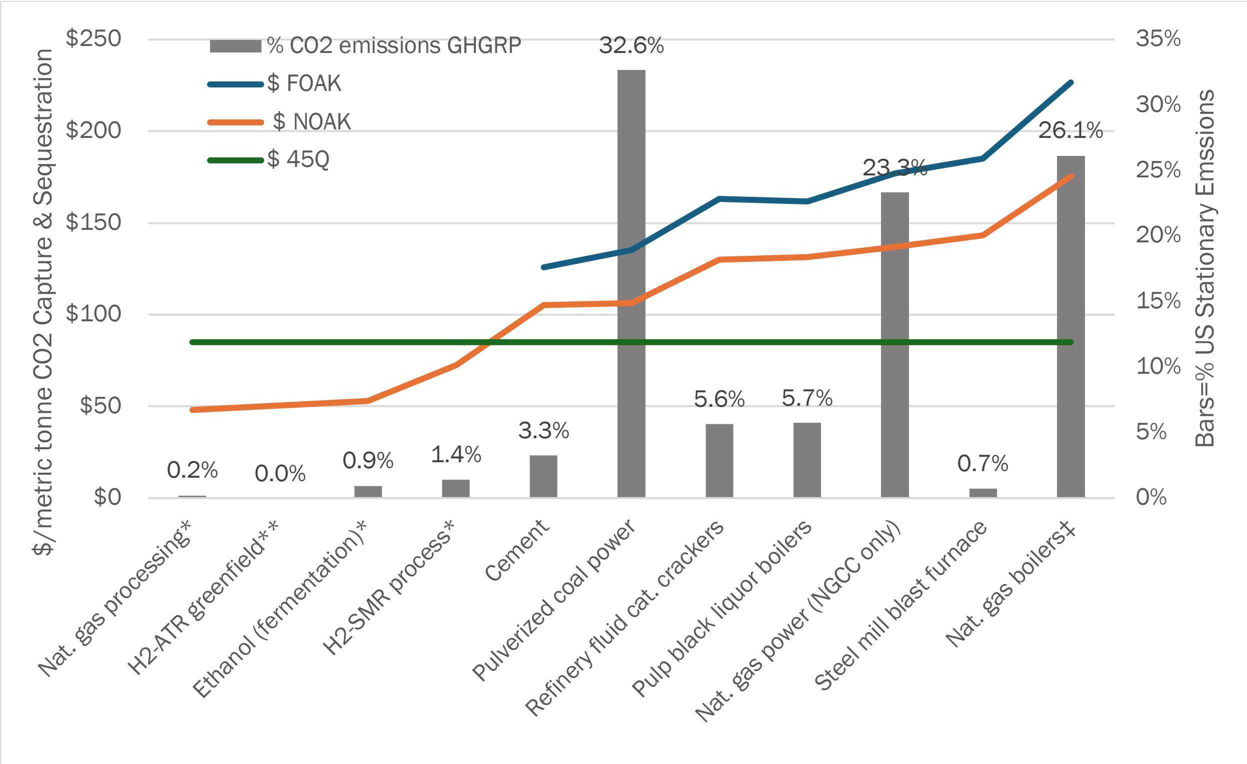
[e] Using the inflation adjustment formula stipulated in section 45Q(b)(1)(A)(ii) of the Inflation Reduction Act. The inflation adjustment factor calculated, 1.192, was based on data through Q3 of 2020, as that was the latest available data from the Federal Reserve Bank of St. Louis.

greenfield plants under development so currently has no emissions. The *source marked with a double cross (‡) is poorly studied, with few or confusing reference publications; thus, we primarily based these estimates upon well-studied pulverized coal plant costs, adjusting upward for the complexity of emissions streams, typically poor emissions control on criteria pollutants, and physical layout difficulties within existing plants. Source: EFI Foundation*

CCS costs vary greatly when applied to easier-to-abate or harder-to-abate sectors. Harder-to-abate sectors are not currently bankable with the 45Q credit alone.

Some heavy industry sectors are more costly to abate than others. This variance was identified in the 2023 EFI Foundation (EFIF) report and was reaffirmed in the updated cost estimates. **Figure 3** shows the variance of costs across industry sectors, along with estimates of the potential levels of CO_2 that could be captured in each.

Figure 3. Variation in CCS costs across industry sectors compared to CO_2 capture potential



Applications marked with an asterisk (*) have no FOAK bar because these industries have been selling captured CO_2 to industry and enhanced oil recovery fields for more than a decade. The application marked with a double asterisk (**), i.e., auto-thermal reforming of methane to manufacture hydrogen (H_2), has only greenfield plants under development so currently has no emissions. The source marked with a double cross (‡) is poorly studied, with few or confusing reference publications; thus, we primarily based these estimates upon well-studied pulverized coal plant costs, adjusting upward for the complexity of emissions streams, typically poor emissions control on criteria pollutants, and physical layout difficulties within existing plants. Source: EFI Foundation

Figure 3 illustrates that the principal dividing line between “easier” and “harder” is whether CCS in that sector requires the purchase and operation of expensive capital equipment to separate CO_2 from other gases and pollutants in a mixed flue gas stream. The harder-to-abate sectors need expensive CO_2 separation equipment, driving their per-metric-ton cost of CO_2 capture to levels three times higher than costs for the easier-to-abate sectors that do not.

The easier-to-abate sectors start out emitting near-pure streams of 100% CO_2 from their vent stacks, which makes capturing that CO_2 a relatively straightforward process. These easier-to-abate sectors are: (i) natural gas processing plants, where CO_2 is removed to meet pipeline requirements; (ii) methane-splitting hydrogen plants, which produce a CO_2 byproduct; and (iii) ethanol fermentation, in which microorganisms in alcohol fermentation tanks excrete CO_2. These sectors require modest cleanup to remove water vapor and excess oxygen, compression to reach pipeline pressures, transport, and underground injection (totaling \$30-\$40/metric ton of CO_2 abated).[f] The current \$85/metric ton federal 45Q tax credit is sufficient. However, the tonnage of CO_2 that can be captured from medium- to large-sized plants that have not already applied CCS is in the range of 2% of reported U.S. stationary CO_2 emissions (**Figure 3**).

The harder-to-abate sectors are industries whose vent stacks emit a mixed stream of waste flue gases that contain 3% to 20% concentrations of CO_2 mixed with a host of other nonproblematic gases such as nitrogen, oxygen, water vapor, etc. NOAK projects requiring CO_2 separation are expected to have costs of variable energy, maintenance, and annual financing payments of \$60-\$100 per metric ton separated. The wide cost range results from differing flue gas contaminants (cleaner = cheaper), CO_2 concentrations (higher concentration = cheaper), and size (bigger = cheaper on a per-unit basis). Compression, transport, and underground injection amount to an extra ~\$30/metric ton.

The harder-to-abate sectors have total costs in the \$105-\$175/metric ton range for NOAK CCS retrofits (**Figure 1**). For them, the \$85/metric ton 45Q tax credit falls short of the level needed to incentivize voluntary investments in CCS.

The updated analysis also found that the cost impacts of COVID-era inflation and higher interest rates were greater for the more capital-intensive, harder-to-abate sectors than for the lower-cost CCS applications. This impact is illustrated in **Figure 4**.

Figure 4 shows that, for example:

- The cost of deploying a FOAK CCS project differed by industry: Cement and pulverized coal plant costs increased by an average of ~\$25.50/metric ton; refineries and pulp and paper black liquor boilers increased by an average of ~\$39.50/metric ton; natural gas combined cycle (NGCC) plants and steel mill blast furnaces increased by an average of ~\$61.50/metric ton.

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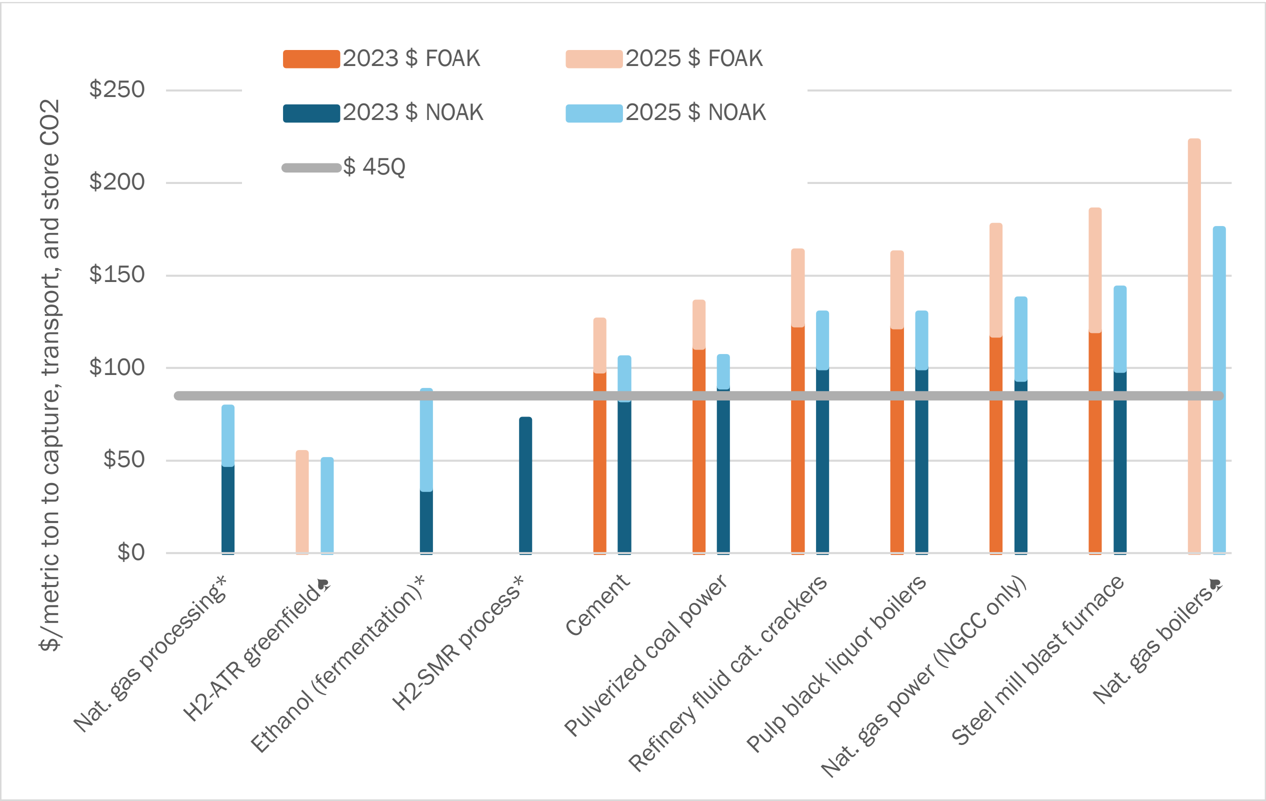
[f] The case of hydrogen production via steam methane reformers (SMRs) is oversimplified here. SMRs in fertilizer plants separate roughly 100% of process CO_2, whereas SMRs for oil refineries may combine the high purity/high pressure process CO_2 with low purity/low pressure combustion CO_2. The latter case requires additional modifications to capture process CO_2, but these additional modifications are still relatively cheap compared with sectors such as power or industrial steam furnaces.

- The dollar impact on NOAK projects is lower. For example, the cost of CCS projects for NGCCs or steel mill blast furnaces increased by ~$43/metric ton.

Given the high-cost environment, driving down costs and risks to NOAK levels can reduce how much the tax incentive needs to adjust for inflation while spurring CCS deployment.

Figure 4. Cost increases impact FOAK and NOAK applications of CCS across all sectors, especially the higher-cost, harder-to-abate industry sectors ($/metric ton)

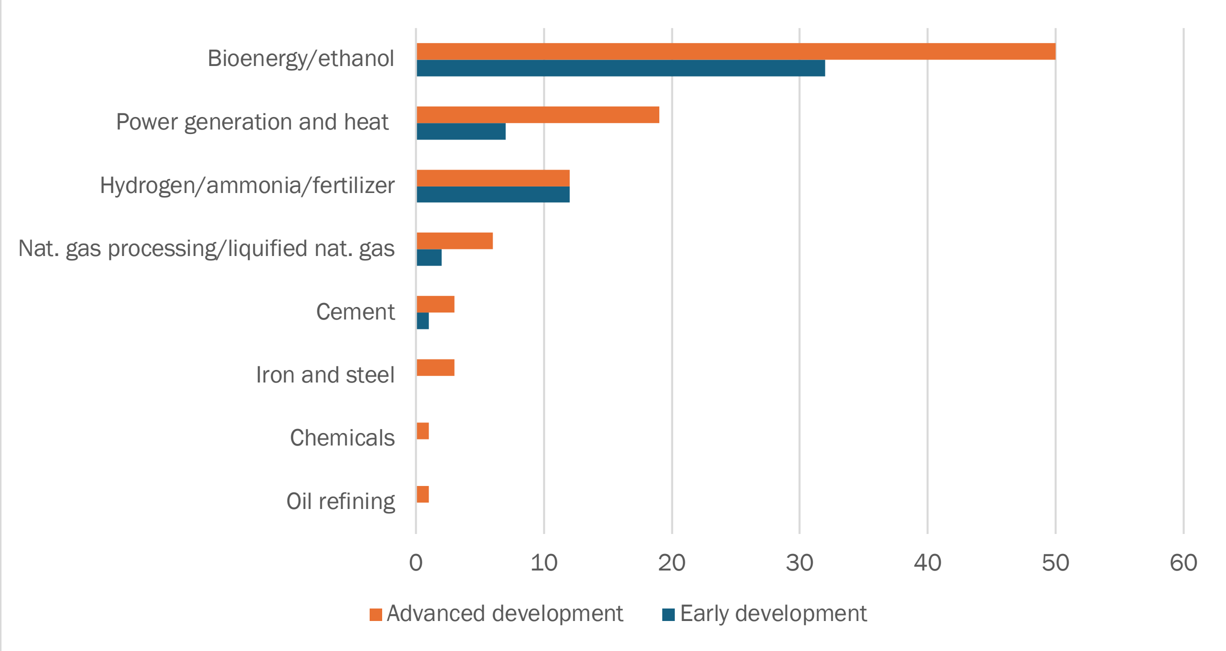


Applications marked with an asterisk (*) have no FOAK bar because these industries have been selling captured CO_2 to industry and enhanced oil recovery fields for more than a decade. Sources marked with a spade (♠) were not studied in 2023, so we only have 2025 estimates. Note that the costs of natural gas boilers are poorly studied, with few or confusing reference publications; thus, we based these estimates primarily on well-studied pulverized coal plant costs, adjusting upward for the complexity of emissions streams, typically poor emissions control on criteria pollutants, and physical layout difficulties within existing plants. The chart does not include figures for industrial heat and power boilers because CCS has not been adequately studied for that application. The 2023 numbers are sourced from EFIF's earlier report, Turning CCS Projects in Heavy Industry & Power into Blue Chip Financial Investments. *Source: EFI Foundation*

Only a small subset of reported CCS projects in development appears to be moving toward final investment decision (FID), with most in partnership with DOE cost-shared commercial-scale demonstration project grants.

Overview: The Global CCS Institute (GCCSI) has tracked 152 CCS projects—excluding direct air capture and carbon removal projects—that have announced preliminary planning. Of those, 95 projects are reported to be in advanced development. Of note, 82 of those projects are for ethanol plants. The distribution of these projects is illustrated in **Figure 5.**

Figure 5. Carbon capture projects in advanced and early development across the U.S.



Data from: Global CCS Institute, Global Status of CCS 2024: Collaborating for a Net-Zero Future, *November 2024, https://www.globalccsinstitute.com/wp-content/uploads/2024/11/Global-Status-Report-6-November.pdf. EFIF only included carbon capture or vertically integrated CCS projects in the early and advanced stages of development (i.e., excluding projects for direct air capture, carbon dioxide removal, and CO_2 transport/storage).*

The development pipelines of CCS projects, as illustrated in **Figure 5**, are typically tracked based on whether the developer has started pre-feasibility or front-end engineering and design (FEED) studies.[5] Although FEED studies are necessary to determine whether a carbon capture project is a viable option from an economical and technical perspective to reduce a plant's emissions, the commencement of a FEED study does not alone signal a developer's intent to pursue CCS. Further analysis is needed to fully understand the status and pace of project development.

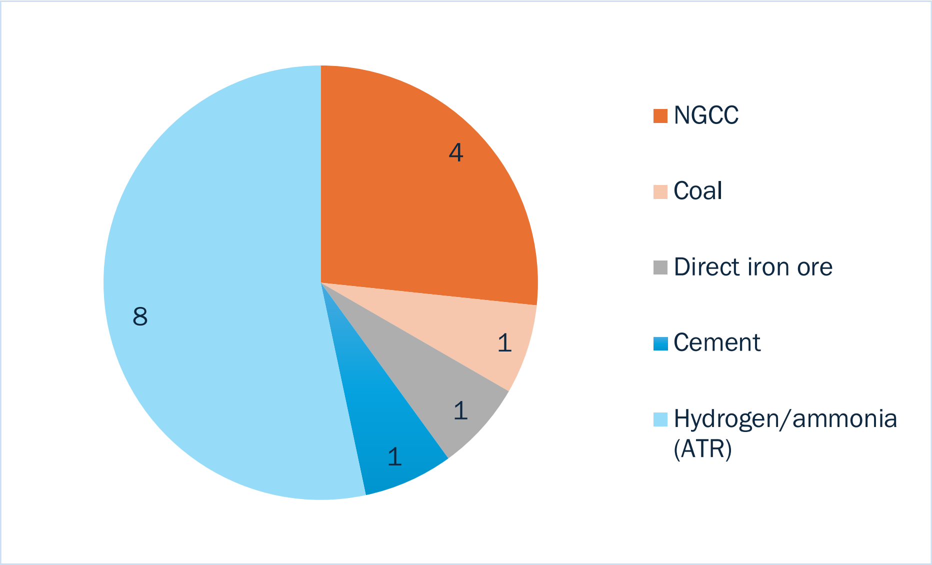
EFIF conducted an in-depth screening analysis of the reported projects in development to highlight the subset of projects that appear to be making material progress toward FID. The screening analysis incorporated factors that included:

- Positive movement on permits for CO_2 pipeline and Class VI storage.
- Hydrogen offtake or power offtake agreements.
- The completion (or at least funding and commencement) of FEED studies.
- The completion of negotiations on engineering, procurement, and construction (EPC) contracts.
- Selection of a carbon capture technology vendor.

Although some additional projects in early or advanced stages of development, according to GCCSI's database, may be constructed in the intermediate term, these projects will require significant efforts to get there. For example, if a project has not made progress on permits for pipelines and/or a Class VI well application, it is, at minimum, several years from a final investment decision.

The results of the screening analysis identified 15 commercial-scale CCS projects that appear to be making material progress toward start of construction in the harder-to-abate sectors. The distribution of CCS projects by industry sector is shown in **Figure 6**.

Figure 6. CCS projects making material progress toward start of construction



The 15 projects mentioned in Figure 6 are described and cited in the text below. Source: EFI Foundation

Of the 15 CCS projects identified, eight are for hydrogen/ammonia production using auto-thermal reforming, a CCS technology area that is economically viable with the current 45Q credit and thus bankable. The other projects are not bankable with the 45Q credit alone and are dependent upon complementary incentives, either DOE cost-shared demonstration project grants or special offtake agreements (or both).

Five of these projects received DOE cost-shared grant awards, underscoring the importance of the de-risking capital provided through the department's commercial-scale demonstration program funding for harder-to-abate sectors.

Although important steps for these projects remain to be completed, including final technical and business case analyses and permitting decisions, these projects could generate the FOAK cost data necessary to inform and improve the feasibility and economics of scaled deployment. The status of these projects is described below.

Hydrogen/ammonia (eight projects): CCS projects in the hydrogen/ammonia sector make up more than half of all the projects that appear to be making serious progress toward deployment. The concentration of hydrogen projects may be driven in part by growing demand and policy support for low-carbon hydrogen. A complementary explanation is economic: Carbon can be profitably captured, transported, and stored from hydrogen ATR plants with just the value of the 45Q tax credit (as shown in **Figure 1**).

Seven of the eight projects in **Figure 6** are new ammonia production facilities for export.[g,6,7,8,9,10,11,12] These projects are mostly designed to convert hydrogen to ammonia for export to countries that will co-fire the ammonia in coal power plants. While the initial round of projects will be focused on impacting CO_2 emissions globally, the learning experience will set the stage for additional deployments in the future to decarbonize the U.S. fertilizer supply chain.

The ExxonMobil project to replace carbon-intensive fuels at its Baytown Olefins Plant in Texas with hydrogen produced from ATR with CCS would have a significant impact on U.S. CO_2 emissions. The Baytown plant is the sixth-most polluting plant in the United States, contributing 12.6 million tons of GHG emissions in 2022.[13] The plant was awarded the first phase of its federal cost-share award (up to $331.9 million) through the IRA and BIL Industrial Demonstrations Programs.[14]

Cement (one project): CCS is expected to play a major role in reducing the emissions of the cement sector, where few other transformative decarbonization options are currently commercialized, though alternatives are in the R&D stage.[15] The International Energy Agency expects that CCS will contribute to an average of 60% of 2050 emissions reductions for the sector.[16]

In August 2024, Heidelberg Materials' Mitchell Cement Plant in Indiana—the second-largest cement plant in the U.S.—finalized a cost-share agreement with DOE totaling $500 million. The project has two years of design work prior to the commencement of construction, which would take an additional three years. In parallel, the Illinois Geological Survey is investigating the feasibility of on-site Class VI geologic CO_2 storage, for which the site has received federal funding through DOE's CarbonSAFE initiative.[17] If the project can be permitted and does not face unexpected costs or other hurdles, it could receive FID from Heidelberg and be operational by 2030.[18,19]

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[g] The Linde Beaumont hydrogen plant in Texas, a hydrogen/ammonia project using the ATR process, is the only project to add CCS in a new industry to reach FID since the passage of the IRA and recently began construction. The Air Products and Chemical Louisiana Clean Energy Complex is currently seeking an equity partner but plans to proceed with the project. Five more have yet to announce FID: Copenhagen Infrastructure Partners' St. Charles Clean Fuel Plant; Clean Hydrogen Works' Ascension Clean Energy; 8 Rivers' Cormorant Clean Energy; CF Industries' Donaldsonville; and Lake Charles Methanol II.

Another project is still too early in development to be included in **Figure 6** but could result in nearly a million metric tons of CO_2 captured per year if it advances. DOE awarded the first phase of up to $500 million for the Lebec Net-Zero Project at National Cement's plant in California through the Industrial Demonstrations Program. The project is using CCS as one of three methods to decarbonize its operation. The first phase of the project, which will run through Q1 2026, will include preliminary development activities, including carrying out a pre-FEED study and setting up a community advisory body.[20]

Direct iron ore (one project): CCS could be applied to reduce CO_2 emissions associated with producing steel and iron, including direct reduced iron (DRI). Recently, Nucor announced plans to adapt CCS to a DRI plant in Louisiana and has signed EPC contracts and a contract with ExxonMobil to capture, transport, and store carbon from the project.[21,22] Although this project could advance CCS use in DRI plants, blast furnace manufacturing remains the primary and more emissions-intensive method to produce steel and iron. Adapting CCS to this setting is more difficult and has, therefore, been limited to pilot-scale studies.[23,24]

Natural gas combined cycle (four projects): DOE has entered cost-sharing partnerships with Calpine for two NGCC CCS projects (Baytown in Texas and Sutter Energy in California) that would be the first commercial-scale NGCC CCS applications in the United States. Both plants have finalized negotiations over federal grant terms with DOE and are now completing FEED studies, community benefits negotiations, project permitting, and other technical assessments.[25,26]

In addition, the California Resources Corporation's Elk Hills NGCC Power Plant recently reached FID. Calpine is also looking at another NGCC with CCS project at Deer Park, in Texas. The Calpine Deer Park project completed a federally supported FEED study in 2023, showing reasonable costs, and has obtained air permits.[27,28] Although FID has not yet been achieved, the FEED study award criteria outline that construction should begin no later than January 2026.[29]

The Shay Energy Center in West Virginia would also be an important contribution to CCS deployment: The capture facility is on a large-scale, greenfield NGCC plant rather than a retrofit. The project has obtained a siting certificate.[30] It is not known, however, if the project sponsors have begun a FEED study and, therefore, it's too early-stage to be included in **Figure 6**.

Coal (one project): DOE is engaged in a cost-sharing partnership to support CCS deployment at Project Tundra in North Dakota. The project appears to be progressing toward construction but faces several potentially deal-killing hurdles. Although the project received funding for the first phase of activities, it has delayed its FID, citing cost inflation.

Box 2. Case study: Making gas processing with CCS profitable with Class II wells

The analysis above focuses on projects intending to pursue geologic storage via Class VI wells. This focus is partly because Class VI is regulated by the EPA and often considered the "gold standard" for long-term geologic storage of captured CO_2, but also because DOE made Class VI storage a criterion for funding demonstration projects under the Carbon Capture Demonstration Projects Program.

Another pathway available to entities seeking to capture and store CO_2 is Class II wells, which are regulated at the state level. Class II wells are most often associated with enhanced oil recovery, which earns a lower $60/metric ton under §45Q. However, when paired with a long-term plan for monitoring, reporting, and verification, storage via Class II wells can earn the full $85/metric ton.

BKV Corp. has demonstrated the viability of including Class II storage as part of a CCS strategy. Its first project, Barnett Zero in Texas, which captures and stores carbon from natural gas processing operations, launched in 2023 and is expected to capture 210,000 tons of CO_2 each year. Since Barnett Zero launched, BKV has announced FID for two additional projects that use Class II storage and existing pipeline networks. BKV executives noted that while they are pursuing projects with both Class II and Class VI storage, Class II wells are often permitted more quickly, which enables projects to come online faster.

While BKV's projects are relatively small, they demonstrate that commercial-scale CCS can be profitable in certain applications. BKV reported that it expected its Barnett Zero project to earn $18 million annually from the 45Q tax credit, which will be sufficient to pay back its investment.

While the distinctions between Class II and Class VI wells are outside the scope of this update analysis, EFIF addressed them in detail in the 2023 study, *Turning CCS Projects in Heavy Industry & Power into Blue Chip Financial Investments.*

Sources: U.S. Department of Energy, "Carbon Capture Demonstration Projects Program Funding Opportunity Announcement Number: DE-FOA-0002962," Office of Clean Energy Demonstrations, February 23, 2023, https://oced-exchange.energy.gov/FileContent.aspx?FileID=86c47d5d-835c-4343-86e8-2ba27d9dc119

Energy Intelligence, "Cash-Poor BKV Eyes Barnett Drilling Pullback, CCS Ramp-Up" (Natural Gas Week, December 8, 2023), https://read.bkv.com/pdfs/BKV-ng231208.pdf.

Moving from demonstration to broad-scale deployment: DOE cost-shared partnerships have been crucial in moving FOAK commercial-scale demonstration projects forward. As noted earlier, BIL provided $12 billion for a range of CCS and CDR technology RD&D and supporting programs for CO_2 infrastructure and permitting.

The DOE-funded commercial-scale demonstration projects (details in **Appendix B**) are critical for validating FOAK costs for various CCS applications. They also provide key engineering data to identify both the challenges and opportunities for further learning and cost reduction. Moving down this cost curve to NOAK projects, however, requires another four to five follow-on commercial demonstration projects. And because applying CCS to each sector is different, those follow-on demonstration projects are needed in each sector.

The BIL and IRA programs do not provide the funding resources to move beyond initial FOAK demonstrations on a path to NOAK. Absent appropriate incentives, including public-private partnerships, the NOAK technologies face a potential "valley of death."[h] Policy measures that could overcome this potential barrier include:

- Additional federal funding for follow-on commercial-scale demonstration projects.
- A bonus 45Q tax credit for early adopters in the harder-to-abate sectors that could be phased out commensurate with learning experience.
- Various forms of demand support, such as purchase agreements or market incentives, could provide market certainty for early deployments of CCS beyond the FOAK stage.

A liftoff at scale for a commercial CCS industry requires that CCS technologies be well-proven on a technical basis and clearly viable on a financial basis for their intended market applications. The types of measures identified above could bridge the gap. CCS projects would then have straightforward access to conventional capital markets under typical commercial funding terms. Once CCS projects demonstrate attractive risk-adjusted returns, such projects are considered bankable.

Pilot projects and front-end feasibility and design studies for future deployment: In addition to supporting FOAK commercial-scale demonstration projects, DOE is also currently supporting several pilot-scale demonstration projects and FEED studies for future commercial-scale projects. Pilot-scale projects are crucial for validating and de-risking the technologies that progress to commercial-scale demonstration (**Box 3**).

Box 3. DOE program criteria and objectives for commercial-scale vs. large pilot-scale demonstration projects

Commercial-scale demonstration: TRL (technology readiness level) 7+

- Objective: Increase investor confidence by demonstrating the operational viability to advance the development, deployment, and commercialization of CCS technologies.
- *Note that FEED study funding is used to test the viability of potential commercial-scale CCS projects to increase the number of investment-ready CCS projects.*

Large-scale pilots: TRL 5-6

- Objective: Validate scaling factors of a new and transformational carbon capture technology or application to enable the large-scale pilot project to proceed to commercial-scale demonstration or application (TRL 7).
- *These projects should have already completed a small pilot-scale prototype of the technology.*

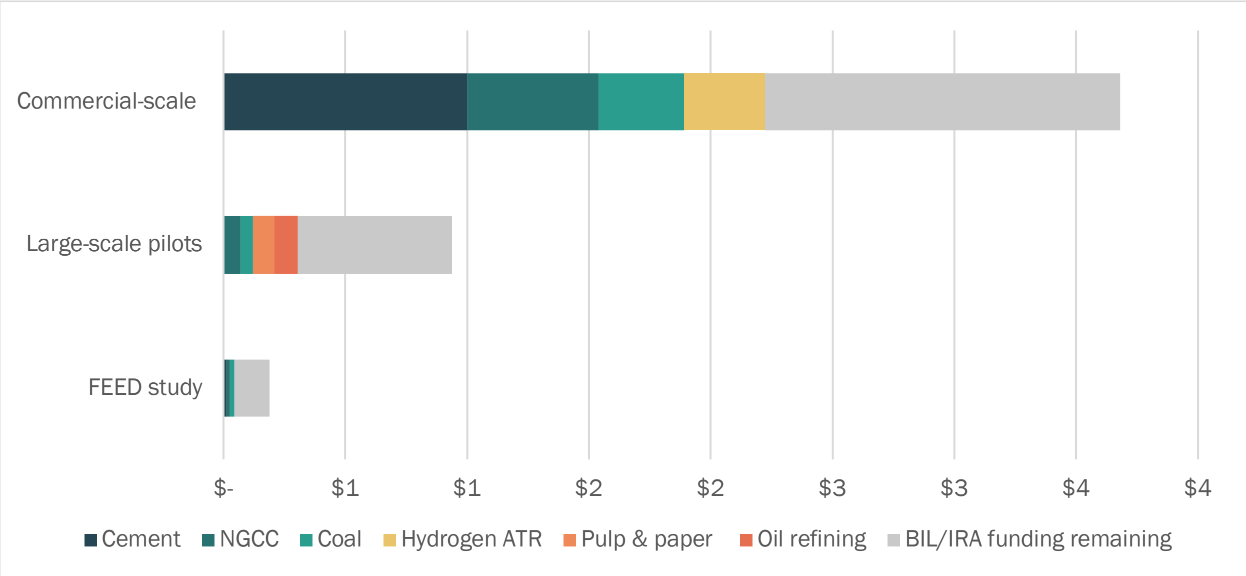
Source: U.S. Department of Energy, "Point Source Carbon Capture Large-Scale Pilots, Commercial Demonstrations, and Networked Demonstration Commercialization Funding Opportunity Number: DE-FOA-0003473," Office of Clean Energy Demonstrations, December 2024, accessed March 2025, https://oced-exchange.energy.gov/FileContent.aspx?FileID=c50d6b04-37bf-4ff5-9fab-9c547cec9731

DOE has supported FEED studies for 34 projects through annual Office of Fossil Energy and

[h] The "valley of death" is a period when promising technologies face technical, financial, and market uncertainties that can prevent the technologies from reaching commercialization.

Carbon Management (FECM) appropriations and BIL funding.[31] **Figure 7** illustrates the allocation of DOE funds across the various forms of CCS project support and accounts for the funds still available to be obligated.

Figure 7. Status of DOE funding for CCS projects in BIL and IRA programs (in $ billions)



The "commercial-scale" funding bar includes the $2,537 million authorized through the BIL §41004(b) for the Large-Scale Demonstration Projects Program, minus the $189 million DOE allocated for FEED studies. Of the authorized $2,348 million for the large-scale demonstration projects program, $810 million has been awarded for CCS on three power plants, with $1,458 million remaining. The "commercial-scale" bar additionally includes the $1,331.9 million awarded to three commercial-scale demonstrations for three industrial plants authorized through IRA §50161 and BIL §41008 for the Industrial Decarbonization Program. Further information on the six commercial-scale demonstration projects with federal cost shares through these two programs is included in Appendix B.

The "large-scale pilots" funding bar includes the $937 million authorized through BIL §41004(a), with $304 million awarded to four projects and $633 million remaining.[32]

The "FEED study" funding bar includes the $189 million authorized through BIL §41004(b) for FEED studies, with $45.27 million awarded to seven projects and almost $144 million remaining.[33]

Source: EFIF Foundation

DOE is funding pilot-scale projects at a paper mill waste-wood boiler in Minnesota and another pulp and paper mill in Mississippi through the DOE Office of Clean Energy Demonstrations' Carbon Capture Large-Scale Pilot Projects Program. The program is also providing funding for a refinery CCS project on a fluidized catalytic cracking unit (FCCU) at the Big Spring Refinery in Texas. FCCUs are the single biggest source of process emissions at refineries, although it is important to note that combustion is the predominant source of emissions.[34] Although such projects are too early in the planning process to be included in

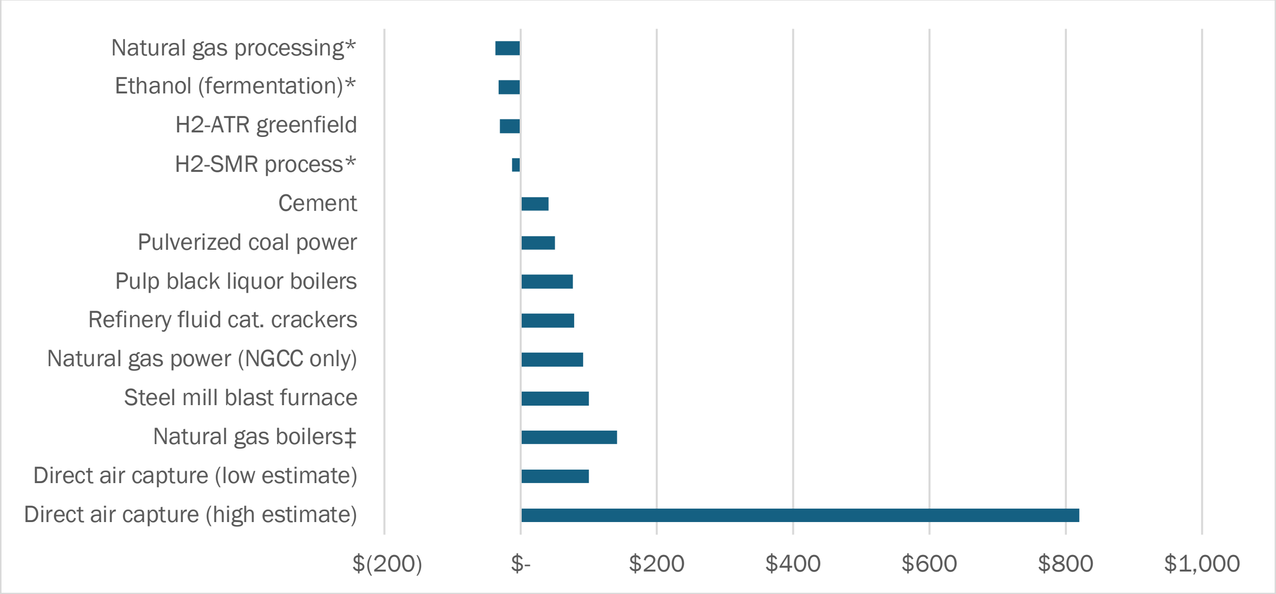
Figure 6, the lessons learned could contribute to cost and risk reductions at the FOAK stage. Expanding the level of support for pilot-scale projects and FEED studies can accelerate the pace of commercialization by incorporating the learning from FOAK demonstration projects as well as other innovations into the next generation of CCS technologies.

Various voluntary and compliance pathways are available to privately finance early CCS deployment.

The cost gap for CCS deployment could also be addressed through other market and policy tools, including emerging voluntary carbon markets and state-level policy initiatives. These are discussed in more detail below.

Voluntary decarbonization commitments: Companies with comprehensive voluntary commitments could consider CCS projects as part of a portfolio of options to meet decarbonization goals. For example, major tech companies have provided early commitments to scale direct air capture (DAC). When compared against DAC costs, CCS costs can be quite competitive (**Figure 8**). Indeed, in September 2024, Google signed a deal to buy DAC credits at $100/metric ton, net of the more generous $180/metric ton 45Q incentive for DAC, which is the lowest price on record for DAC.[35,36]

Figure 8. Current estimated costs of capturing carbon directly from the air vs. applications in power and industrial plants through CCS, net of 45Q ($/metric ton)



Negative costs indicate that carbon emissions could be captured profitably. Current estimated costs of CCS applications use FOAK numbers, except for applications marked with an asterisk (*). Those industries have been selling captured CO_2 to industry and enhanced oil recovery fields for over a decade. The source marked with a double cross (‡) is poorly studied, with few or confusing reference publications; thus, we based these estimates primarily on well-studied pulverized coal plant costs, adjusting upward for the complexity of emissions streams, typically poor emissions control on criteria pollutants, and physical layout difficulties within existing plants. Current cost estimates for DAC range from $200/metric ton of CO_2 to $1,000/metric ton of CO_2. Source: EFI Foundation

One example of how CCS can be an important tool is the Calpine-Covestro partnership. Calpine is retrofitting CCS to a natural gas combined cycle facility that it owns and operates, serving a Covestro chemical facility in the United States. The project will support Covestro's voluntary commitment to 30% CO_2 emissions reductions by 2035 across its global operations.[37] The project is also being supported by a DOE cost-sharing partnership.

Participation in voluntary carbon markets: Voluntary carbon markets provide an opportunity for companies to implement CO_2 reduction projects and monetize the value of those reductions by selling the emissions reduction credits to other companies seeking to offset their emissions as part of a voluntary decarbonization program. Voluntary credits are a separate market from the compliance credit market, such as the Regional Greenhouse Gas Initiative, where companies buy and sell credits to meet mandatory CO_2 emissions caps.

CCS for emissions reductions in the power and heavy industry sectors have not yet garnered much success in the voluntary carbon market (VCM), except for BECCS (bioenergy with CCS).[38] One barrier is the lack of CCS crediting pathways (i.e., standards and methodology). California's Air Resources Board is one of the few entities that has set protocols for verifying carbon intensity (CI) reduction at CCS plants, although this is limited to plants that produce fuel (e.g., ethanol).[39] Another impediment is price volatility of VCMs. Currently, VCMs have widely varying prices for captured CO_2 that are often negotiated on a case-by-case basis, creating uncertainty for would-be CCS project developers.[40]

Low-carbon electricity premiums: Companies may choose to purchase low-carbon electricity and fuels to meet their energy needs. For example, the largest data center owners (hyperscalers) have expressed strong interest in contracting for large quantities of carbon-free baseload power. Several have entered initial collaborations with nuclear power technology vendors.

Natural gas power plants with CCS could be a viable option, especially since they can be deployed more quickly than new nuclear power. The cost premium for adding CCS technology to current commercially available NGCC plant technology would have a relatively small impact on the overall cost structure of a data center. For example, a 1-megawatt (MW) NGCC power generation facility would emit about one-third of a metric ton of CO_2. Installing CCS technology at an NGCC facility would have a net cost of about $45/metric ton for CCS (net of the $85/metric ton 45Q incentive). This translates into approximately 1.5 cents per kilowatt-hour for the cost of power (assuming the NGCC operates at a high capacity factor, at least 85%, needed for data center operation).

Compliance markets: States have also established power sector portfolio standards for low-carbon power generation. While some portfolio standards programs restrict eligibility to renewable electricity or select other carbon-free generating technologies, others have adopted eligibility criteria that would include CCS. In such cases, NGCC with CCS is a viable compliance option. For example:

- The Virginia Clean Economy Act requires state utilities to meet a 100% renewable portfolio standard but does not allow CCS to qualify as an eligible resource.[41]

- By comparison, Michigan provides a strong template for technology-neutral approaches to decarbonizing the power sector. Senate Bill 271, passed in 2023, requires utilities to achieve 100% clean energy portfolios but is flexible in what resources can be used to meet that goal.[42] The bill explicitly includes natural gas with CCS as a viable compliance pathway.

Another potential mechanism states could employ is a carbon-intensity standard, commonly referred to as an emissions performance standard. For example, Washington state established an emissions performance standard (EPS) of 1,100 pounds (lb) of CO_2/megawatt-hour (MWh) for natural gas-fired plants in 2007. Since then, the EPS has regularly been revised lower; the current EPS is 876 lb/MWh.[43] While the standard is currently aligned to the best-performing unabated gas plants, future reductions in the level of the standard could make CCS a feasible compliance pathway.

Some states have also developed low carbon fuel standards (LCFSs), which have helped create bankable revenue streams for a few CCS applications (e.g., ethanol).[44] Expansion of compliance markets to include harder-to-abate sectors can incentivize broader CCS applications and commercialization.

State-level demand mechanisms: Several states have enacted policies increasing demand for industrial products produced with lower-carbon-emissions technologies, indirectly or directly increasing demand for the application of decarbonization technologies like carbon capture, utilization, and storage (CCUS) in the harder-to-abate sectors.

- New Jersey's low-carbon concrete tax incentive: Enacted in January 2023, New Jersey's S287 bill creates a tax credit of up to 8% of a project's total concrete cost if it uses concrete made with CCUS technology.[45]

- Washington's cap-and-invest program implements a statewide cap on emissions from large emitters, which encourages the production of industrial products with lower carbon intensity. Emissions trading can encourage plants to install technologies like CCS to decarbonize and gain further revenues by trading allowances with plants that do not.[46]

- California, Washington, and Colorado all have "Buy Clean" laws directing state agencies to consider embedded carbon emissions when purchasing materials (e.g., steel and cement). The Buy Clean laws in California and Colorado also set procurement standards for materials used in public infrastructure projects.[47,48,49]

Near-term efforts to commercialize and scale CCS for harder-to-abate sectors will require additional forms of policy support.

While CCS technology has the potential to decarbonize all forms of fossil fuels used in power generation and across all industrial heat and power generation, opportunities for commercialization and scaling could vary significantly by industry sector based on sector-specific circumstances.

As illustrated in Figures 1 and 3, variations in the cost of abatement are a key factor but not the only one that will affect the relative pace of deployment across sectors. Other factors that will affect the relative feasibility of deployment include access to CO_2 pipeline and storage infrastructure; availability of other low-carbon solutions, such as hydrogen fuels; electrification from carbon-free generation sources; and innovation in alternative process technologies.

Future CCS policies and programs may be more impactful if they focus on the sectors where CCS appears to be the most viable or where it offers the sole approach to deep decarbonization. Examples of industry-specific challenges and opportunities for CCS deployment are summarized below.

Ethanol with CCS is bankable today but faces other risks. The ethanol sector has a long history of capturing CO_2 for utilization in various industries. Yet, efforts to scale up CCS have faced regulatory challenges prompted in part by community concerns. One such interstate CO_2 pipeline project is Summit, a planned 2,500-mile CO_2 pipeline to transport captured CO_2 from 57 Midwest ethanol plants across five states to permanent storage in a North Dakota Class VI well. Summit has taken more than three years to permit.

Thus far, Minnesota, Iowa, and North Dakota have approved permits for their sections of the pipeline, and North Dakota approved the Class VI well application.[50,51,52] However, Summit Carbon is still awaiting permit decisions from Nebraska and South Dakota, both of which denied original applications, requiring Summit to reapply.[53,54] Furthermore, South Dakota recently approved legislation that would prohibit carbon pipeline companies from using eminent domain—which is commonly used to permit infrastructure projects—to acquire land.[55] As a result, Summit must gain approval from 100% of landowners to build the pipeline.

Meanwhile, CCS retrofits on heavier-emitting plants often do not face the same permitting delays as they can capture enough CO_2 to justify co-locating a Class VI well with the plant, reducing transportation needs.

NGCC with CCS could become a viable option with price premiums. Hyperscalers seeking to build new data centers to support AI have very few options for servicing their rapidly growing electricity demand in the near term while also advancing low-carbon solutions. Natural gas-fired generation appears to be the leading option among planned new generation projects to meet surging load growth, and as many as 80 new plants are planned by 2030.[56] Despite commitments from large tech companies to not only reduce their emissions but also reverse historical emissions, none of the projects is currently planned to include carbon capture, though a handful will be “CCS ready.” Data center developers have demonstrated that they are largely price-insensitive when it comes to building new generation—and thus may be willing to pay a premium for zero-carbon firm electricity. But they cannot afford delays. As such, efforts to accelerate CCS for gas-fired generators will largely depend on the ability to site, permit, and build the necessary infrastructure as quickly as possible. These efforts are likely to be region-specific.

Cement production with CCS could coexist with emerging alternatives to decarbonize the sector. A common concern about CCS is whether alternative technologies will ultimately be more competitive. For example, cement produced without limestone shows promise in reducing carbon intensity. However, the U.S. has 96 active cement kilns, including 10 that were built after 2000 and account for 22% of national production. Even if newer technologies begin to earn market share in the coming years, it is imperative that existing facilities have a pathway to decarbonize.[57]

CCS deployment and scaling are heavily dependent on the availability of CO_2 pipeline, storage, and utilization infrastructure.

The cost of infrastructure for transport and ultimate storage or utilization of captured CO_2 is relatively modest compared to the cost of capture technology, but it is highly dependent on location. Sites for geologic storage can be far from power plants and industrial capture sites and, in some cases, across state borders (as illustrated by the Summit pipeline example described earlier). Once an attractive site has been identified for CO_2 geologic storage or for CO_2 utilization—such as in enhanced oil recovery (EOR)—the key challenge is permitting. For project developers, one benefit of pursuing EOR is that many pipelines with connections to permitted Class II wells already exist, allowing more projects to use existing rights of way.

Geologic storage of CO_2 and utilization of CO_2 for EOR are both subject to federal permitting authority under the Safe Drinking Water Act underground injection control (UIC) program. While permitting CO_2 utilization for EOR is well-established under the federal Class II permitting program, federal Class VI well permitting for CO_2 geologic storage is not.

Table 2 summarizes the current application data, showing a significant backlog in the U.S. Environmental Protection Agency (EPA) Class VI permit program. Since the inception of the Class VI rules in 2010, the EPA has issued permits for only eight Class VI wells, excluding those for the canceled FutureGen project.[58] The technical review stage of the application process is the major holdup, with 95% of applications in this phase as of April 7, 2025.[59] This backlog is contributing to the lag in schedules for CCS projects in development. It also serves as a disincentive for new project planning.

Table 2. EPA backlog of wells in Class VI application process as of April 7, 2025

Current phase of work	Number of projects	Number of wells	% of wells
Completeness review phase or applicant hold	1	4	2%
Technical review phase	52	154	95%
Prepare draft permit phase	1	1	1%
Public comment on issued draft permit	0	0	0%
Final permits being prepared	1	3	2%
Totals	55	162	100%

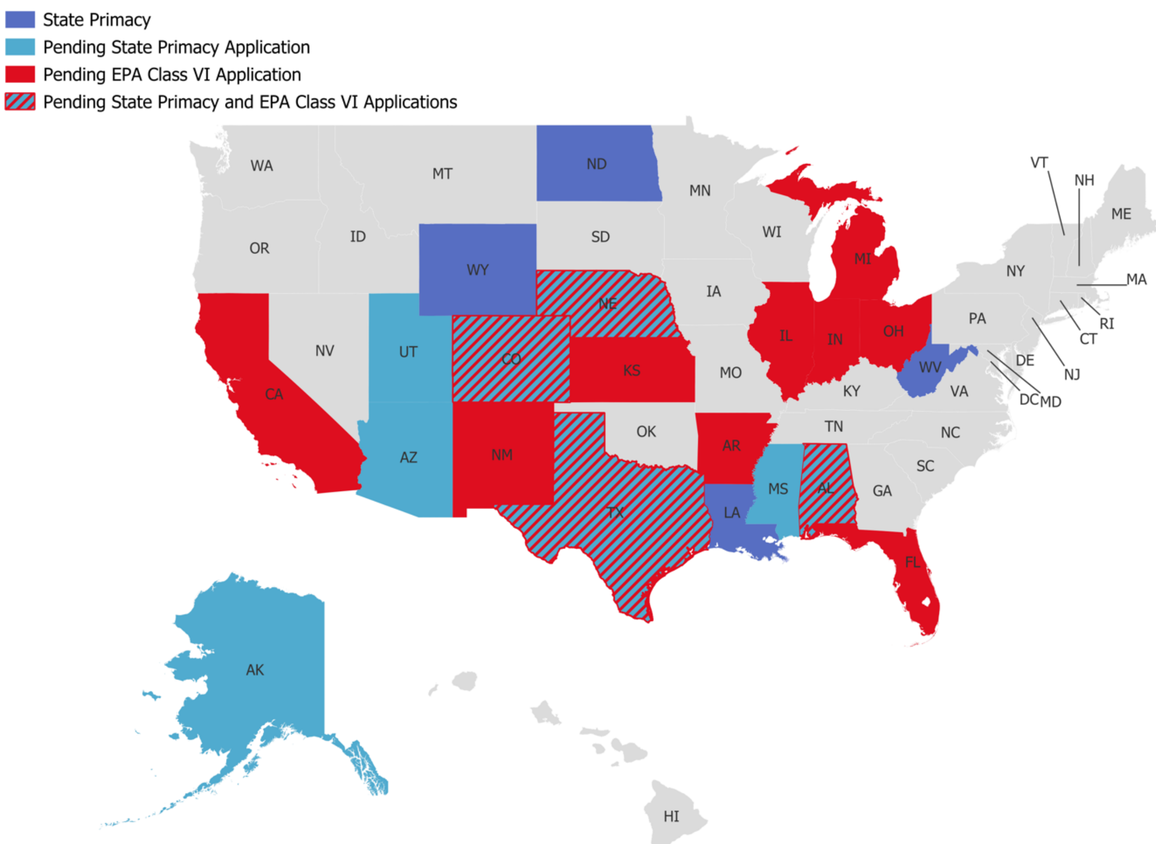
Transferring permitting responsibility to state agencies experienced in storing CO_2 underground would help resolve the backlog.[i] North Dakota and Wyoming—the first two

[i] The oil and gas industry has long been storing CO_2 in enhanced oil reserves (Class II wells), which is technically similar to storing CO_2 from CCS projects but is far simpler from a regulatory perspective.

states to be granted "Class VI primacy"—have processed Class VI applications in a year or less. Class VI primacy grants states the ability to permit and enforce CO_2 injection permits themselves rather than rely on the EPA once a state demonstrates that (i) state rules and regulations are at least as stringent as federal requirements and (ii) the state has sufficient procedures and resources to enforce those rules and regulations.

Since the passage of the BIL and IRA, Louisiana and West Virginia have been granted primacy. Other states are in various stages of preparation to seek EPA primacy determinations. For example, 56 of the 162 Class VI well permit applications currently under EPA review are for projects in Texas, but Texas does not have primacy to issue Class VI permits.[60] The EPA could reduce the Class VI backlog in the near term by prioritizing primacy applications for the states with the most pending Class VI applications. (**Figure 9**).

Figure 9. Status of state primacy for Class VI well permitting and states with pending EPA Class VI well applications



Source: Data on Class VI well applications from the [EPA's Class VI Well Permit Tracker Dashboard](#) (updated as of April 7, 2025). Data on state primacy also from the [EPA](#) (as of April 7, 2025). Note that most of the state primacy applications are still in the pre-application phase. Only Arizona has progressed to the proposed rulemaking stage.

The Utilizing Significant Emissions with Innovative Technologies (USE IT) Act included new provisions to expedite the Class VI UIC permitting program, but it is not clear whether those provisions have had an impact yet. In addition, the BIL appropriated $50 million to the EPA to provide grants to the states to build state-level Class VI permitting programs. Although the EPA has announced[61] the availability of funding, no funds have been disbursed.

Landowners continue to have major concerns regarding the safety and environmental risks of geologic storage of CO_2, a factor that must be properly addressed to approve Class VI wells. According to interviewees, a priority consideration for states to gain primacy for Class VI permits will be how they address safety and environmental risks. For example, Louisiana and the EPA signed a memorandum of agreement outlining the state's commitments to environmental justice considerations.[62] However, environmental groups filed a lawsuit arguing that the state's plans were less stringent than the EPA's, and the decision now lies with the 5th Circuit.[63] Despite these tensions, the hope is that the EPA can use lessons learned from the first few states granted primacy to develop model state-level policies and practices to accompany state primacy, accelerating future primacy application timelines.

Conclusion

Fossil fuels are and will remain a central part of the U.S. and global energy economy for a long time. The United States is the world's largest producer of petroleum and natural gas, and domestic production levels reached all-time highs in 2023. The expansion of global trade in liquefied natural gas, as well as near-term investments in new gas-fired generating capacity to meet growing domestic electricity demand, will continue this momentum.

Carbon capture and storage is the only readily available emissions abatement technology that is applicable across the power sector and all subsectors of the industrial heat and power markets. Direct CO_2 emissions from large stationary sources alone total 2.5 billion metric tons/year, or 39% of total U.S. emissions.[j, 64]

The 45Q tax credit, as currently constituted, is insufficient to support standalone, bankable projects for the CO_2 emissions-heavy, harder-to-abate industry sectors. Additional stackable policy measures to supplement the credit will be needed to achieve meaningful scale-up in these sectors. Consequently, additional CCS policy measures may need to be developed within the context of a broader national industrial innovation strategy—one that considers economic competitiveness, trade, and workforce development objectives along with carbon management.

Recommendations

The EFI Foundation's 2023 CCS report contained a comprehensive set of recommendations for how to make CCS projects bankable in the absence of a federal mandate for decarbonization. These recommendations appear in their entirety in Appendix A. Limited progress has been made on several of these recommendations, but overall, they remain pertinent to the current political and business environment.

[j] The sum of Subpart C, Subpart D, and biogenic CO_2 emissions in U.S. EPA FLIGHT summary data for reporting stationary emitters. Primary exclusions are non-CO_2 GHGs and CO_2 process emissions from various industries.

The major shortcoming in recent years has been the inability of the revised 45Q tax credit in the IRA to provide additional incentive for investments in CCS. This is due in large part to the design of the credit, which allowed the increased value of the credit to be offset by COVID-era inflation.

The following recommendations are intended to reinforce and augment the 2023 recommendations to offer near-term, pragmatic steps that decision-makers can take to advance CCS at the federal and state levels and in the private sector.

Recommendations to Congress

Congress should consider strengthening the current 45Q tax credit. At a minimum, the indexing provisions could be modified to remove restrictions that have prevented the credit from keeping up with inflation. Congress also could consider adding a bonus credit for early mover commercialization projects.

Congress should include provisions for CO_2 pipelines in any new permitting reform legislation.

Congress should provide additional funding to expand the DOE CCS demonstration program and remove restrictions on the ability to stack multiple incentives such as grants and loans.

Recommendations to the Executive Branch

The National Energy Dominance Council should make CCS an early priority for additional policy actions that could include the following measures:

- Conducting a detailed process flow analysis of the EPA Underground Injection Program for Class VI permits to identify opportunities to significantly reduce permitting schedules without compromising the quality of decision-making.

- Establishing interagency technical assistance teams to advise and assist large multi-state CCS pipeline and storage projects of national significance through data sharing and schedule coordination of federal, state, and local government permitting processes.

- Working with the EPA to clarify and update its criteria to be used in approving state requests for Class VI permitting authorization, including applying the current $50 million of EPA funding to support seed grants to facilitate the startup of state programs.

- Working with the EPA and DOE to develop methodologies for determining CO_2 credits from power sector and industrial CCS projects that could be eligible for participation in voluntary carbon markets and state-level portfolio mandates.

DOE should fully use all available funding from the BIL, IRA, and annual appropriations to support a robust, end-to-end CCS Technology Innovation Program that encompasses:

- Early-stage research on new concepts and technologies for carbon capture and utilization.
- Rapid prototyping of next-generation technologies at pilot scales.
- FEED studies to better understand the technical and cost challenges for commercial-scale deployments.
- Continued funding for a suite of first-of-a-kind demonstrations of CCS retrofits in various use cases where cost reductions appear feasible.
- Greater sharing of information learned from government-supported research, development, demonstration, and deployment (RDD&D) projects by limiting the scope of "restricted data" requirements in DOE Funding Opportunity Announcements (FOAs) and cost-share partnership agreements.
- Use of Other Transaction Authority (OTA) as the basis for developing more durable public-private partnerships. DOE should work with the Office of Management and Budget and Congress to improve the flexibility of OTA agreements to allow "stacking" of multiple federal and state incentives, including direct funding, loans, loan guarantees, and tax credits.

Recommendations to the States

States should take a more active role in advancing demand for CCS and enabling associated infrastructure buildout by:

- Expanding existing clean energy targets and portfolio standards to allow any generation resources that meet certain performance standards to qualify (e.g., carbon intensity, dispatchability, etc.).
- Establishing markets for carbon credits that can be used to meet compliance requirements and voluntary commitments that include CCS as an approved source of credits.
- Incentivizing projects to sign binding agreements with host communities to facilitate permitting action for such projects.
- Developing legislative packages to streamline siting and permitting to provide developers with certainty regarding issues like pore space ownership, surface rights, unitization, financial assurance, community engagement, and long-term monitoring and liability.

Appendix A: Summary of Recommendations from 2023 EF^3 Analysis *Turning CCS Projects in Heavy Industry & Power into Blue Chip Financial Investments*

The 2023 analysis identified six themes that pose risks to CCS bankability in the heaviest-emitting sectors. The themes and associated recommendations are below:

Theme 1: There must be light at the end of the deployment tunnel – supply & demand incentives

Recommendation 1A: DOE should update the threshold of deployed projects to five projects from the current three projects by administratively amending the definition of “Commercial Technology” in the regulations governing eligibility for loans under Section 1703.

Recommendation 1B: Considering the industry-specific commercialization trajectories of CCS as a pollution control technology, DOE should prioritize BIL grant funding to those FOAK applications that are still out-of-the-money even after taking into account IRA’s 45Q bonus tax credit value.

Recommendation 1C: Congress should allow, once appropriated, the stacking of grants and loans for CCS projects.

Recommendation 1D: Funding from the BIL and/or the IRA should be made available for FOAK applications that are currently out-of-the-money given the current value of 45Q to cover ongoing operating costs from year 13 onward.

Recommendation 1E: All state governments should include CCS as an eligible compliance option for state-level decarbonization mandates. Further, CCS projects should be treated as pollution control projects and receive the same state tax and local property tax treatment as pollution control projects for criteria air pollutants.

Recommendation 1F: The Federal Energy Regulatory Commission (FERC) (for ISO/RTO electricity markets) and state Public Utility Commissions (PUCs) (for non-ISO electricity markets) should develop rules and incentives, respectively, for clean baseload electricity, which would materially improve the economics of CCS applied to electricity generation.

Recommendation 1G: The Department of Transportation, through the BIL, should support the market for low-carbon industrial products by mandating requirements tied to funding.

Recommendation 1H: To enable the implementation of Recommendation 1G, DOE should establish rigorous and transparent life-cycle emissions standards for industrial products and a certification program for low-carbon industrial products.

Theme 2: Tax credits need to become more efficient and accessible

Recommendation 2A: The Internal Revenue Service (IRS) should ensure that the new regulations required to implement the 45Q direct pay and transferability provisions of IRA are designed in a manner that will be conducive to bringing a broader range of new buyers into the market.

Recommendation 2B: Congress should consider expanding the pool of eligible entities able to make use of all clean energy tax credits.

Theme 3: Critical data and knowledge exist on capture and geologic storage; increasing its availability and accessibility would accelerate commercialization

Recommendation 3A: OIRA should initiate efforts to harmonize federal emissions databases.

Recommendation 3B: DOE should require all key engineering performance data be disclosed by the funding recipient to DOE, as a condition of awarding competitively procured cost-sharing agreements.

Recommendation 3C: DOE should form a joint industry and national laboratory committee to examine the collection and dissemination of technical data as part of federally funded projects.

Recommendation 3D: DOE should collaborate with DOI and other authoritative sources of GS data to expand the National Energy Technology Lab's (NETL's) EDX database and identify commercially relevant data gaps.

Recommendation 3E: DOE should collaborate with an expanded set of EDX information users such as commercial developers, local communities, and policymakers to identify, prioritize, and fund functionality beyond current EDX development plans.

Theme 4: Streamline federal and state regulatory requirements across the CCS value chain of capture, transportation, storage, and long-term monitoring

Recommendation 4A: The Environmental Protection Agency (EPA) should release a detailed workflow for UIC VI permitting and promulgate best practices developed from past UIC II and VI experiences.

Recommendation 4B: EPA should provide certainty on rules and pathways by which an existing Class II permit can be converted to a Class VI permit, thereby taking advantage of existing oil industry investments in infrastructure, surface facilities, and site characterization.

Recommendation 4C: State governors should each create one empowered coordinating body to manage all state-level CCS regulatory interfaces.

Recommendation 4D: State coordinating bodies and legislatures each need to develop clear, workable regulations, and statutes concerning pore space unitization, post-closure liability, and pipeline eminent domain.

Recommendation 4E: For first-of-a-kind projects, the federal government should consider a project-specific developer financial responsibility cap.

Recommendation 4F: Based upon scientific analysis of the risks involved, EPA should harmonize financial assurance requirements across UIC I Hazardous Waste, UIC II, and UIC VI.

Theme 5: Siting analysis for a carbon capture project needs to address fenceline community health issues

Recommendation 5A: State environmental quality authorities should require carbon capture project proponents to perform and comprehensively disclose an analysis of the combined impact on emissions of CO_2, criteria air pollutants, and hazardous air pollutants of the host facility and the new capture plant.

Recommendation 5B: DOE should fund and undertake research examining the net changes of CAP and HAP that result from carbon capture installation applied in industries characterized by host facilities that produce both high quantities of CO_2 and conventional pollutants.

Recommendation 5C: The findings of the studies from Recommendation 5B should be incorporated into federal policy development, including into National Environmental Policy Act (NEPA) proceedings.

Recommendation 5D: DOE should encourage project owners who are the beneficiaries of federal cost-sharing grant agreements to engage in best practices in community disclosure of comprehensively considered environmental costs and benefits of carbon capture projects.

Theme 6: Harness community benefits given the energy transition

Recommendation 6A: Federal agencies should initiate community-based, collaborative research and community engagement programs for CCS technologies and infrastructure, with the goal of developing engagement guidance for agencies.

Recommendation 6B: DOE, working with states and local governments, should provide direct funding for the capacity building of communities to lead the negotiation of CBA with CCS developers.

Appendix B: DOE-Supported Commercial Demonstration Projects Supported Through BIL and IRA

Industry	FOAK cost gap (net of $85/metric ton 45Q)	DOE-supported commercial demonstration project	Million metric tons per annum (Mtpa) CO_2 emissions reduction	Federal spending status	Program
Cement	$41/ton	Heidelberg Materials' Mitchell Cement Plant	2 Mtpa[65]	Obligated $500M; will receive $300k for first-phase activities; $0 in outlays.	Industrial Demonstrations Program
Cement	$41/ton	National Cement's Lebec Cement Plant	0.95 Mtpa[66]	Obligated $500M; $0 in outlays.	Industrial Demonstrations Program
Coal-fired power plant	$50/ton	Minnkota's Project Tundra	4 Mtpa[67]	Finalized $350M award; obligated $4.2M for first-phase activities.	Carbon Capture Demonstration Projects Program
NGCC	$92/ton	Calpine's Baytown Carbon Capture and Storage Project	2 Mtpa[68]	Finalized $270M award; obligated $12.5M for first-phase activities; $421k in outlays.	Carbon Capture Demonstration Projects Program
NGCC	$92/ton	Calpine's Sutter Decarbonization Project	1.75 Mtpa[69]	Finalized $270M award; obligated $8.6M for first-phase activities.	Carbon Capture Demonstration Projects Program

				$0 in outlays.	
Hydrogen	$54/ton	Exxon's Baytown Olefins Plant	2.7 Mtpa[70]	$331.89M obligated; will receive for first-phase activities; $0 in outlays.	Industrial Demonstrations Program

Appendix C: States Leading in CCS-Specific Policies

Given that CCS deployment is likely to be highly state- and region-specific, the tables below group states by the level of interest that state governments have demonstrated in setting up an enabling environment for deployment. Interest level is determined by the major state-level CCS-specific policies in addition to industry interest in CCS, which here is gauged by the number of Class VI well applications in the state.

This analysis largely focuses on state regulatory and policy frameworks for Class VI well permits. Use of Class VI wells is the most common pathway project developers pursue to obtain the $85/metric ton 45Q tax credit. The tables below provide an overview of state-level actions to create the policy and regulatory frameworks necessary to enable CCS deployment. Comprehensive state policies governing CCS (particularly around eminent domain, unitization, pore space, long-term monitoring, and liabilities of CCS) are critical to mitigate regulatory uncertainty for would-be developers.

The tables also note which states have experience in enhanced oil recovery (EOR). Such states will have more experience and familiarity with storing and sequestering CO_2, which is applicable to the development of Class VI well permitting programs. CCS projects using Class II wells for storage may also be more viable in the near term given the slow pace of Class VI well permitting in states without Class VI primacy. Captured carbon stored through EOR is eligible for a $60/metric ton 45Q tax credit, though developers can obtain the full $85/metric ton with a Class II well if certain requirements are met, e.g., the EPA approves the project's monitoring, reporting, and verification plan.

Additionally, some states have CCS-specific funds or market-based incentives that could spur CCS deployment (e.g., a Low Carbon Fuel Standard), which are noted below. Note that state governments also have economic development funding and tax incentives that may apply to proposed CCS capital investments, although these incentives were not studied here.

High interest: These states have financial incentives and/or policy and regulatory frameworks demonstrating strong state-level interest in CCS deployment. Additionally, these states have a decent number of CCS projects seeking permits (indicating commercial interest).

	Class VI policies	Class II primacy	Incentives	Additional notes
Wyoming	Class VI state primacy and has approved multiple permits. Storage fund for monitoring and liability of CO_2 storage.[71]	Yes	Recently enacted a CO_2-EOR stimulus.[72]	Launched a CO_2 Pipeline Corridor Initiative.

California		Yes, with a significant number of Class II wells. EOR tax credit.[73]	Market-based incentives: • Low Carbon Fuel Standard (LCFS) (high recent market prices around $200/metric ton CO_2 but varies considerably). • Cap-and-trade awards offset credits for verified geologic storage of CO_2 from industrial sources. • Proposed Buy Clean bills to incentivize low-carbon cement and steel.	Significant number of pending Class VI applications; one recent CCS project approval (CRC).
Louisiana	Class VI state primacy and strong regulatory framework.[74] Geologic Storage Trust Fund for monitoring and liability of CO_2 storage.[75]	Yes		Strong commercial interest in CCS and ammonia/ hydrogen (for international export).
North Dakota	Class VI state primacy and has successfully permitted multiple sites. Carbon Dioxide Storage Facility Trust Fund for monitoring and liability of CO_2 storage.[76]	Yes	Low-interest loans: • Clean Sustainable Energy Authority, Industrial Commission (loan/grant authority) can provide loans to carbon capture sites and matching grants for feasibility studies and site characterization. State severance tax for CCS with coal power plants.	Significant familiarity with CCS, and Red Trail Energy biofuel CCS plant recently went into operation. Considering a low-carbon fuels fund to cover up to 50% of project costs for ethanol with CCS.

Illinois	Recently passed comprehensive Class VI legislation (the Illinois SAFE Act).[77]	Yes	Sustainable aviation fuel tax credit at $1.50/gallon.[78]	Pending Class VI applications. Successfully permitted an ethanol-CCS project.
Texas	Class VI state primacy expected in near term.	Yes, with a significant number of Class II wells.	Tax incentives for EOR.[79]	Significant number of pending CCS projects.
Alabama	Applying for Class VI state primacy. Recently enacted CCS legislation.[80]	Yes		Pending Class VI applications.
West Virginia	Recently obtained Class VI state primacy.	Yes		Significant state-level support for coal with CCS.

Medium interest: These states are setting up the policy frameworks necessary for CCS deployment.				
	Class VI policies	Class II primacy	Incentives	Notes
Indiana		Yes		Pending Class VI applications. Notably, a cement-CCS plant is progressing toward FID.
Pennsylvania	Recently passed CCS legislation.[81]	No	Appropriated EPA funds for decarbonization.	
Ohio	Proposed bills to regulate CCS in the legislature.[82]	Yes		Pending Class VI applications.
Michigan		Yes		Pending Class VI applications.
Nebraska		Yes		Pending Class VI applications.

Colorado	Applying for Class VI state primacy. Recently enacted CCS legislation.[83]	Yes	Buy Clean Act encourages state procurement of materials with lower-embodied carbon.	Pending Class VI applications.
New Mexico		Yes		Pending Class VI applications.

Lower interest: These states have some policies or incentives to encourage CCS.				
	Class VI policies	Class II primacy	Incentives	Notes
Washington		Yes	LCFS. Cap-and-invest program encourages the production of industrial products with lower carbon intensity. Buy Clean Act encourages state procurement of materials with lower embodied carbon.	
Kansas	Storage fund for monitoring and liability of CO_2 storage.[84]	Yes	Property tax exemption and income tax accelerated appropriation deduction for CCUS machinery and equipment.[85,86]	Pending Class VI applications.
Montana	Comprehensive CCS legislation.[87] Geologic Storage Reservoir Program for monitoring and liability of CO_2 storage.[88]	Yes	Carbon capture equipment may be eligible for property tax abatements.[89]	

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