Carbon Capture in the Industrial Sector: Addressing Training, Startups, and Risk

Katerina Graf

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Summary

Decarbonizing our energy system is a major priority for slowing and eventually reversing climate change. Federal policies supporting industrial-scale solutions for carbon capture, utilization, and sequestration (CCUS) have significantly decreased costs for large-scale technologies, yet these costs are still high enough to create considerable investment risks. Multiple companies and laboratories have developed smaller-scale, modular technologies to decrease the risk and cost of point-source carbon capture and storage (CCS). Additional federal support is needed to help these flexible, broadly implementable technologies meet the scope of necessary decarbonization in the highly complex industrial sector. Accordingly, the Department of Energy (DOE) should launch an innovation initiative comprising the following three pillars:

1) Launch a vocational CCS training program to grow the pool of workers equipped with the skills to install, operate, and maintain CCS infrastructure.

2) Develop an accelerator to develop and commercialize modular CCS for the industrial sector.

3) Create a private-facing CCS Innovation Connector (CIC) to increase stability and investment.

These activities will target underfunded areas and complement existing DOE policies for CCS technologies.

Challenge and Opportunity

Carbon dioxide (CO_2) is the largest driver of human-induced climate change. Tackling the climate crisis requires the United States to significantly decarbonize; however, CCS and CCUS are still too costly. CCUS costs must drop to $100 per ton of CO_2 captured to incentivize industry uptake. U.S. policymakers have paved the way for CCUS by funding breakthrough research, increasing demand for captured CO_2 through market-shaping, improving technologies for point-source CCS, and building large-scale plants for direct-air capture (DAC). DAC has great promise for remediating CO_2 in the atmosphere despite its higher cost (up to $600/ton of CO_2 sequestered), so the Biden Administration and DOE have recently focused on DAC via policies such as the Carbon Negative Shot (CNS) and the 2021 Infrastructure Investment and Jobs Act (IIJA). By comparison, point-source CCS has been described as an "orphan technology" due to a recent lack of innovation.

Part of the problem is that few long-term mechanisms exist to make CCS economical. Industrial CO_2 demand is rising, but without a set carbon price, emissions standard, or national carbon market, the cost of carbon capture technology outweighs demand. The Biden Administration is increasing demand for captured carbon through government purchasing and market-shaping, but this process is slow and does not address the root problems of high technology and infrastructure costs. Therefore,

targeting the issue from the innovation side holds the most promise for improving industry uptake. DOE grants for technology research and demonstration are common, while public opinion and the 45Q tax credit have led to increased funding for CCS from companies like ExxonMobil. These efforts have allowed large-scale projects like the $1 billion Petra Nova plant to be developed; however, concerns about carbon capture pipelines, the high-cost, high-risk technology, and years needed for permitting mean that large-scale projects are few and far between. Right now, there are only 26 operating CCUS plants globally. Therefore, a solution is to pursue smaller-scale technologies to fill this gap and provide lower-cost and smaller-scale — but much more widespread — CCS installations.

Modular CCS technologies, like those created by the startups Carbon Clean and Carbon Capture, have shown promise for industrial plants. Carbon Clean has serviced 44 facilities that have collectively captured over 1.4 million metric tons of carbon. Mitsubishi is also trialing smaller CCS plants based on successful larger facilities like Orca or Petra Nova. Increasing federal support for modular innovation with lower risks and installation costs could attract additional entrants to the CCS market. Most research focuses on breakthrough innovation to significantly decrease carbon capture costs. However, there are many existing CCS technologies — like amine-based solvents or porous membranes — that can be improved and specialized to cut costs as well. In particular, modular CCS systems could effectively target the U.S. industrial sector, given that industrial subsectors such as steel or plastics manufacturing receive less pressure and have fewer decarbonization options than oil and gas enterprises. The industrial sector accounts for 30% of U.S. greenhouse gas emissions through a variety of small point sources, which makes it a prime area for smaller-scale CCS technologies.

Plan of Action

DOE should launch an initiative designed to dramatically advance technological options for and use of small-scale, modular CCS in the United States. The program would comprise three major pillars, detailed in **Table 1**.

Pillar	Purpose	Champion	Cost	Funding	Time Frame
Vocational Training	Increase CCS workforce	DOE OCED	$5 million	IIJA	2–4 years
Modular CSS Innovation Program	Develop modular CCS technology for industry subsectors	DOE OCED or FECM	$10 million	IIJA, DOE grants	1 year
CCS Innovator Connector	Encourage private CCS investment	DOE OCED	$750,000/ year	IIJA	2 years

Table 1. Three complementary efforts to increase industrial uptake of CCS technologies.

Pillar 1. Launch a vocational CCS training program to grow the pool of workers equipped with the skills to install, operate, and maintain CCS infrastructure.

DOE should leverage IIJA and the new DOE Office of Clean Energy Demonstration (OCED) to create a vocational CCS training program. DOE has in the past supported — and is currently supporting — a suite of regional carbon capture training. However, DOE's 2012 program was geared toward scientists and workers already in the CCS field, and its 2022 program is specialized for 20–30 specific scientists and projects. DOE should build on this work with a new vocational CCS training program that will:

- Offer a free, 2- to 3-hour online course designed to raise private-sector awareness about CCS technologies, benefits, and prospects for future projects and employment. DOE should advertise this new program alongside existing grant programs and industry connections.

- Work with community colleges, four-year institutions, and workers' unions to disseminate the online course and create aligned vocational training programs specifically for CCS jobs. In this effort, DOE should target states like Texas and Louisiana that have carbon-rich economies and low public approval of CCS.

- Partner with DOE-sponsored public university programs and private issue groups like ConservAmerica, American Conservation Coalition, and the Center for Climate and Energy Solutions to advertise and update the course.

This educational program would be cost-effective: the online course would require little upkeep, and the vocational training programs could be largely developed with financial and technical support from external partners. Initial funding of $5 million would cover course development and organization of the vocational training programs.

Pillar 2. Create an accelerator for the development and commercialization of modular CCS technologies.

The DOE Office of Fossil Energy and Carbon Management (FECM) or OCED should continue to lead global innovation by creating the Modular CCS Innovation Program (MCIP). This accelerator would provide financial and technical support for U.S. research and development (R&D) startups working on smaller-scale, flexible CCS for industrial plants (e.g., bulk chemical, cement, and steel manufacturing plants). The MCIP should prioritize technology that can be implemented widely with lower costs for installation and upkeep. For example, MCIP projects could focus on improving the resistance of amine-based systems to specialty chemicals, or on developing a modular system like Carbon Clean that can be adopted by different industrial plants. Projects like these have been proposed by different U.S. companies and laboratories, yet to date they have received comparatively less support from government loans or tax credits.

Figure 1. Proposed timeline of the MCIP accelerator for U.S. startups.

As illustrated in Figure 1, the MCIP would be launched with a Request for Proposals (RFP), awarding an initial $1 million each to the top 10 proposals received. In the first 100 days after receiving funding, each participating startup would be required to submit a finalized design and market analysis for its proposed product. The startup would then have an additional 200 days to produce a working prototype of the product. Then, the startup would move into the implementation and commercialization stages, with the goal to have its product market-ready within the next year. Launching the MCIP could therefore be achieved with approximately $10 million in grant funding plus additional funding to cover administrative costs and overhead — amounts commensurate with recent DOE funding for large-scale CCUS projects. This funding could come from the $96 million recently allocated by DOE to advance carbon capture technology and/or from funding allocated in the IIJA allocation. Implementation funding could be secured in part or in whole from private investors or other external industry partners.

Pillar 3. Create a private-facing CCS Innovation Connector (CIC) to increase stability and investment.

The uncertainty and risk that discourages private investment in CCS must be addressed. Many oil and gas companies such as ExxonMobil have called for a more predictable policy landscape and increased funding for CCS projects. Creating a framework for a CCS Innovation Connector (CIC) within the DOE OCED based on a similar fund in the European Union would decrease the perceived risks of CCS technologies emerging from MCIP. The CIC would work as follows: first, a company would submit a proposal relating to point-source carbon capture. DOE technical experts would perform an initial quality-check screening and share proposals that pass to relevant corporate investors. Once funding from investors is secured, the project would begin. CIC staff (likely two to three full-time employees) would monitor projects to ensure they are meeting sponsor goals and offer technical assistance as necessary. The CIC would serve as a liaison between CCS project developers and industrial sponsors or investors to increase investment in and implementation of nascent CCS technologies. While stability in the CCS sector will require policies such as increasing carbon tax credits or creating a global carbon price, the CIC will help advance such policies by funding important American CCS projects.

Conclusion

CO_2 emissions will continue to rise as U.S. energy demand grows. Many existing federal policies target these emissions through clean energy or DAC projects, but more can and should be done to incentivize U.S. innovation in point-source CCS. In particular, increased federal support is needed for small-scale and modular carbon

capture technologies that target complex areas of U.S. industry and avoid the high costs and risks of large-scale infrastructure installations. This federal support should involve improving CCS education and training, accelerating the development and commercialization of modular CCS technologies for the industrial sector, and connecting startup CCS projects to private funding. Biden Administration policies — coupled with growing public and industrial support for climate action — make this the ideal time to expand the reach of our climate strategy into an "all of the above" solution that includes CCS as a core component.

Frequently Asked Questions

1. Why should the federal government focus on smaller-scale, modular CCS systems when we need large-scale CO_2 removal to reach the goals of the Paris Climate Agreement?

Experts generally agree that CCS infrastructure is needed to fully decarbonize the U.S. energy system and that large-scale DAC has the greatest potential to reduce atmospheric CO_2 levels. But the impacts of DAC will be most significant if we also strive to prevent *more* CO_2 from reaching the atmosphere — i.e., through CCS. Large-scale CCS is also very challenging due to its costs and complexity, so it makes sense to promote and fund smaller systems that can be deployed widely and advance proof-of-concept for technologies needed to enable more economical large-scale CCS projects. Finally, many industrial point sources are small and specialized, so meeting the needs of these point sources through modular CCS technology is a priority.

2. What is the current opinion in the private sector about CCS technologies?

Opinions vary widely based on the field and the company, but some large companies, such as ExxonMobil, are starting to allocate large funds to CCS projects. Academic research around CCS is also well-funded and productive, leading to more and more startups developing novel CCS technologies. The interest has been demonstrated, but the economics are proving to be the main roadblock for CCS.

3. What existing CCS education and training courses exist already, and how would the course proposed in this memo build on these past curricula?

DOE, along with many other independent actors, has launched trainings about CCS. The vocational training proposed in this memo will strive to link these existing resources into one accessible, introductory course for new and interested CCS workers. The successful SunShot Initiative and surrounding trainings about solar energy can also be used as a model for the proposed CCS course, as the goals are very similar.

4. What is different about MCIP, compared to a normal grant program?

MCIP is envisioned as an innovation accelerator — it would operate on a short time scale and emphasize collaborations to achieve modular systems. MCIP would also

provide startups with technical support through connections to experts and external financial support for the implementation of final products.

5. Have any companies shown interest in partnering to support CCS projects?

Yes, especially given existing markets for trading carbon emissions. Companies like Microsoft and BP buy carbon offsets in voluntary trade markets, yet these markets are not regulated and do little to verify that carbon is actually being captured. The CIC will help link companies interested in CCS with startups that promise to provide CCS in more effective, validated, and stable ways.

6. The DOE recently launched a new office specifically for clean energy demonstrations (OCED). How does this new office's mandate align with CCS?

OCED has a mandate to tackle issues with carbon capture implementation and commercial development. Therefore, the initiative proposed herein will fit neatly within OCED's scope as the office establishes and grows.

7. Could increasing public awareness and training about CCS negatively impact stakeholder views of federal spending on carbon capture?

CCS is a controversial issue, as committing to carbon capture is also committing to the continued use of fossil fuels. Yet given that 65% of Americans believe that the federal government is doing too little to reduce the effects of climate change, it is unlikely that public opinion writ large will turn against CCS. Supporting more accessible and commercialized CCS solutions will also improve private-sector views of CCS. Finally, many of DOE's current CCS projects use participatory-technology techniques to involve local communities and target environmental racism. The DOE should continue using these approaches to boost support for its continued and expanded involvement in CCS.

About the Author

Katerina Graf received her B.S. in Chemistry from the University of Minnesota in 2021. She was the Editor-in-Chief of the interdisciplinary Minnesota Undergraduate Research & Academic Journal and helped publish over 20 articles. She is currently a graduate student at the University of California – Berkeley in the Long Group working on porous materials for gas storage and separation applications. Her group was promoted by ExxonMobil for its important contributions to CO_2 capture using porous materials.

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