Free Market Carbon Capture: Aligning market demands, regulation, and research innovation towards reducing global CO_2 emissions

Matthew Hollingham[1*], Jack Hughes[2*], Hanna C. Leapaldt[3*]
[1]Department of Architectural Engineering, The Pennsylvania State University, University Park, PA 16802, USA
[2]Department of Energy and Mineral Engineering, The Pennsylvania State University, University Park, PA 16802, USA
[3]Department of Geosciences, The Pennsylvania State University, University Park, PA 16802, USA
*Authors contributed equally
https://doi.org/10.38126/JSPG270106
Corresponding author: hcl5089@psu.edu
Keywords: Carbon Capture and Storage; Emissions Abatement; Primacy;

Executive Summary: Carbon capture and storage (CCS) technology presents an opportunity to mitigate climate change. In the past, CCS has been researched for both its use in the oil and gas industry and as a primary storage for the greenhouse gas CO_2. CCS policy has maintained bipartisan support, and consecutive administrations continue to update and utilize CCS. Despite continued relevance, policy has failed to sufficiently commodify CO_2 and incentivize technological innovation. Here, we present three policy recommendations aimed at commodifying CO_2, accelerating CCS permitting, and producing competitive CCS technology. The first policy recommendation provides economic incentive for industry to develop and utilize CCS technology through a two-phase solution that begins with a market-price government subsidy for CCS and ends with a carbon cap-and-trade model. The second recommendation delegates underground injection control to the states, otherwise known as state primacy, leading to faster adoption of and expanded CCS infrastructure. Lastly, we suggest the development of CCS grant funding that targets academia-industry partnerships. The implementation of the three policy recommendations would allow the United States to be a global leader in CCS.

I. Introduction

The Intergovernmental Panel on Climate Change has shown that to prevent major catastrophe due to climate change, we must both decrease the amount of human-produced carbon dioxide (CO_2) emissions entering the atmosphere and remove carbon dioxide gas from the atmosphere (Calvin et al. 2023). Decreasing CO_2 emissions in the U.S. has resulted from regulating CO_2 emissions from fossil-fuel based power plants and motorized vehicles, as well as policies that foster a transition to renewable energy sources and electric vehicles (e.g., US EPA 2021). However, changes to non-fossil fuel sources of energy take time to implement, and in some cases not all fossil fuel usage can yet be eliminated entirely. This is why removing CO_2 from the atmosphere is also necessary. Carbon capture and storage (CCS) is the act of obtaining CO_2 from the atmosphere and storing it somewhere that is not the atmosphere. For most CCS methods, this means injecting the CO_2 underground with the goal of storing it permanently.

CCS lies at a political intersection of seemingly contradicting environmental philosophies: it aims to reduce global CO_2 emissions in line with environmentalist goals (e.g., Paris Agreement, 2015) while some CCS methods help oil and gas recovery and are supported by the fossil fuel industry (ExxonMobil 2025). This duality has been reflected in bipartisan support of CCS related bills. For example, in 2020, President Trump offered support for the carbon capture advancing bill "Utilizing Significant Emissions with Innovative Technologies Act" in 2020 (U.S. Senate Committee on Environment and Public Works 2020), and President Biden furthered carbon storage efforts within the Inflation Reduction Act in 2022 (Rep. Yarmuth 2022).

The cross-party backing for CCS presents an opportunity for growth in the legislating of CCS, but it also raises ethical questions for both sides about how best to advance carbon capture in the United States. For example: should large CO_2 emitters profit from removing the CO_2 emissions they produced? The current legislation in place to support CCS – the 45Q tax credit – provides a tax credit to companies based on tonnage of CO_2 sequestered permanently (Congressional Research Service 2023). It attempts to compromise so that both the environment and major CO_2 emitters can benefit together. However, like most compromises, it has its flaws.

i. Statement of issue

In order to incentivize removal of CO_2 from the atmosphere in the United States, the 45Q tax credit provides a fixed, government-set credit per ton of CO_2 stored, contingent on meeting a minimum CO_2 storage threshold. To qualify, companies must capture a minimum amount of CO_2 based on the type of storage facility. While the tax credit amount and eligibility storage threshold have changed with new iterations of legislation (Congressional Research Service 2023; Congressional Research Services 2022), one issue has remained the same: the tax credit does not reflect the real cost of implementing CCS technologies, especially with the requirement of a certain tonnage stored before the tax credit can be received (Smith 2023; Harker Steele et al. 2021). The high upfront costs of implementing CCS can exceed benefits of the tax credit, especially for smaller companies attempting to employ CCS (Congressional Budget Office 2023; Rubin et al. 2015). The high up-front cost is one of the main reasons cited to explain why an estimated 80% of CCS projects in the U.S. have failed (Abdulla et al. 2020), suggesting that the 45Q tax credit is not enough to support successful CCS.

Thus comes the fundamental flaw with the 45Q tax credit—the 45Q tax credit is not a free market, but a market with government set pricing. Such markets often do not reflect the real cost of services determined through supply and demand, also known as "the pricing mechanism" (Coase 1937). The pricing mechanism incentivizes both cost reductions to meet a demand, and innovation to achieve these reductions (Naldi 2013). If the CCS system were to utilize the pricing mechanism (instead of an arbitrary government set price), companies could compete to sequester X tons of CO_2 and be incentivized to lower their cost to sequester CO_2 over time, seeking the cheapest capture technology, while costing the government less. Over time, this process optimizes and selects for low-cost CCS systems, which could represent a global panacea for reducing atmospheric CO_2 emissions. This would both help prevent climate catastrophe and position the U.S. as a leader in the growing global CCS market.

Additionally, the current tax credit limits the CO_2 capture market's long-term compatibility with policies that have had success in other places like the European Union, such as emissions trading schemes (often called "cap-and-trade systems") (e.g., Wettestad 2011). Cap-and-trade policies create a limit on an emission or pollutant within a geographic area, where individual entities are free to exchange emissions or pollutants between themselves to meet the overall cap. If a given company emits more than the emissions they have been allotted within the cap, they pay a financial penalty. These systems are typically successful as they follow the free market exchange of a commodity. Carbon credits can blend into this system as business entities can offset their emissions by purchasing carbon removal credits instead of CO_2 emissions permits. However, if the cost of the carbon removal credit is not sufficiently below the cost of the permit or financial punishment, entities would opt to pay for the permit of financial punishment instead of employing CCS.

In order to effectively decrease total CO_2 emissions over time, a cap-and-trade system must lower the CO_2 cap through time. As the CO_2 emissions cap lowers, CO_2 producing industries must decide whether to (1) pay financial penalties/fines for exceeding the cap, (2) invest in low or no emission technology, or (3) adopt a carbon capture and storage method. Importantly, only options (2) and (3) result in lowering CO_2 emissions through time, and option (2) is not yet an option for certain industries with "hard to abate emissions" like the cement production industry (Kumar et al. 2024). This leaves option (3), CCS, as a key method for reducing total CO_2 emissions (Kumar et al. 2024). However, if adopting carbon capture is not sufficiently low cost, companies would instead pay the financial penalty of exceeding the cap, leading to no net decrease of CO_2 emissions. To prevent this, the cost of CCS must decrease over time.

There are also geological hurdles to CCS implementation. Permanently storing CO_2 underground requires specific geologic conditions not available in each state, and transporting CO_2 to such locations can be dangerous. Underground CO_2 storage is further complicated by limited regulation surrounding who owns and is responsible for space underground (Menefee et al. 2025). Under the Safe Drinking Water Act, the EPA regulates underground CO_2 fluid injection by requiring permits for various types of injection wells (GovTrack.Us, n.d.); however, the permitting process has proven to be a major bottleneck in storing CO_2. While the EPA estimates that Class VI well permits - the type of well needed for CO_2 in deep geologic reservoirs below drinking water resources - should take only two years to be reviewed, only 4% of all Class VI well projects have met this review deadline (Environmental Protection Agency 2022; Figure 1). To help alleviate this delay, the EPA has given some states the authority to review and issue permits for underground well injection if the state codifies EPA standards onto their own state laws, also known as "state primacy" (US EPA 2022). But, as of April 2025, only four states have primacy for Class VI well permits (West Virginia, North Dakota, Wyoming, and Louisiana) (US EPA 2023). Granting more states primacy over injection wells has the potential for faster permitting without compromising safety.

To tackle the major hurdles facing a full implementation of CCS in the United States, we put forth three major policy recommendations for legislating CCS markets, permits, and research and development. Each has the overall goal of decreasing barriers to industry implementation of CCS.

II. Policy recommendations:

i. Free market carbon capture

"Economics points to one inconvenient truth about climate-change policy: for any policy to be effective, it must raise the market price of CO_2 and other GHG emissions." - Nordhaus, 2019

To increase CCS, greenhouse gases must have an associated value (Nordhaus 2019; Committee on Carbon Utilization Infrastructure, Markets, Research and Development et al. 2023). In other words, producing CO_2 must cost something. This is currently set as a tax credit with amounts set under the Inflation Reduction Act (IRA) as the 45Q tax credit. However, this arbitrary pricing, set by the government, does not reflect the real cost of CCS. Under Free Market Carbon Capture, the IRA would allow the purchase of a pre-determined amount of CO_2 stored per year from industry at the lowest prices, leading the industry to compete to lower the cost of their CO2 storage and carbon price. This pre-determined amount would be based upon the sum of 45Q tax credits the government would be willing to distribute. Due to this free market effect, the cost of CO_2 per ton may rise above the current \$85/ton, or drop below \$85/ton. Regardless, CCS projects would be forced overtime to compete with each other to go below \$85/ton, something they currently do not have to do.

However, this free market pricing opens the possibility for price fixing by industry, if companies conspire on a higher \$/ton price. Although, the diversity of companies investing in CCS provides a barrier to this collusion.

Additionally, some may take issue with rewarding the industries that are producing the most CO2 emissions for sequestering them. An alternative option is a CO_2 emissions trading scheme (penalty), colloquially known as carbon cap-and-trade (described above) (e.g., Stavins 2020). However, this model alone does not provide funding necessary to support industry in developing and implementing CCS technologies.

To address this, we propose a two-phase policy solution that merges these incentive and penalty models. The first phase includes a market-determined price on stored CO_2, purchased by the IRS. The second phase occurs when CCS technology is cost effective enough for incorporation into a cap-and-trade model, when the price to sequester CO_2 is lower than the price to not emit CO_2.

Phase I: Free market support of carbon capture (short-term)

This phase requires the removal of government set pricing by the Internal Revenue Service (IRS), and instead requires the IRS to pool the total amount it would allocate to the 45Q tax credits and would sell fractions of that fund to the lowest bidding firm per ton CO_2. The IRS would sell its credits at market price, forcing competition between firms to reduce the price to sequester CO_2, enabling, over time, the cost of CO_2 capture to become lower than the current 45Q tax credit.

Phase II: Carbon cap-and-trade incorporation (long-term)

As carbon capture becomes more cost-effective over time, it can be implemented into a cap-and-trade system long-term. As emissions are lowered through renewable energy technology, eventually they will reach a plateau where their low-CO_2 footprint cannot be reduced further. However, as the cap-and-trade system pushes the minimal cost of this CO_2 up, and the emissions goals become costly to meet, carbon storage could become a more cost-effective solution for industry than purchasing the CO_2 permits of a cap-and-trade model. This could potentially cause the cap on CO_2 emissions to decrease below the number of permits needed by industry. Thus, the adoption of CCS inline with the cap-and-trade results in a low-cost permit for industry, allowing industry to maintain its productivity without suffering large financial penalties.

ii. Primacy

To achieve permanent storage of CO_2 (the "S" in CCS), sufficient infrastructure must be scalable. Currently, to inject CO_2 into the subsurface, an individual or company must obtain a Class VI well permit through the EPA, which aims to approve permits within 24 months. As of April 2025, the EPA's public tracker shows that 52 out of 54 Class VI project reviews are running behind this schedule, 22 of which only started in 2024 (US EPA 2023). Having 96% of projects behind schedule (Figure 1) indicates gross inefficiency in the permitting process and will delay the CCS needed to avoid climate catastrophe.

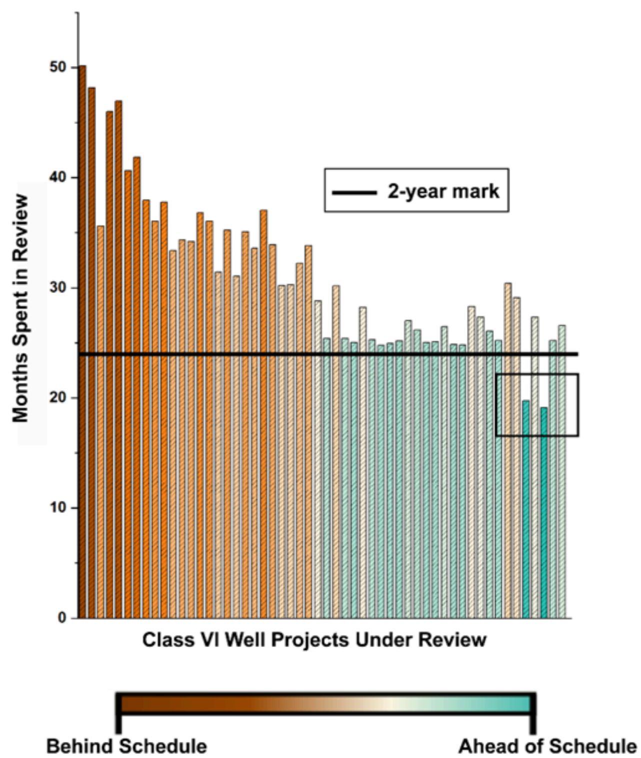

Figure 1: The 54 current Class VI well projects under review as of April 2025 via the EPA. Each bar represents one project, with the vertical black line representing two years (24 months) of review time. If a bar exceeds this line, it means that the project under review has exceeded the expected two-year time-period for review. The box surrounds only two permits that are anticipated to meet the expected two-year review time. Data obtained from the EPA (US EPA 2023).

43 states have individual control over Class II well permits to inject waste water/brine underground, yet only four states have the authority to grant Class VI permits to inject waste CO_2 underground (US EPA 2022). These four states have received 42% of all Class VI well applications to date (Hunt 2023). State primacy has been known to speed up Class VI permitting. The State of Wyoming issued its first 3 Class VI permits within 10 months of receiving primacy ("Unlocking Carbon Storage Wells in 2024 | ClearPath," 2024). It is plausible that some companies may see state regulated

permitting as less resource intensive and more attractive when considering developing. Nonetheless, most applications still fall under the purview of the EPA.

Across all ten EPA regional offices, as of April 2025, there are 162 individual well applications under review across the 54 projects ("SPeCS Public Element Dashboard | EPA@Work," n.d.; US EPA 2023). The largest CO_2 emission producing corridors are in EPA region 5, encompassing the Ohio River Valley, and region 6, encompassing Texas and Louisiana (Meckel et al. 2021). Louisiana, having gained primacy in February of 2024, is the only state throughout region 5 and 6 with Class VI primacy. The two regions account for 58% of well applications under review. The only other EPA region that rivals 5 and 6 for number of well applications is region 9, which includes California, Nevada, and Arizona (34% of well applications under review). The remaining EPA regions combined make up only 8% of all well applications under review ("Unlocking Carbon Storage Wells in 2024 | ClearPath," 2024; Federal Register 2024). If the state of Texas currently had primacy, it would be capable of taking on 56 well applications currently in review by the EPA, which could reduce the time it would take to be granted Class VI permits and allow the EPA to focus on other regions' applications. Granting states primacy in Class VI injection permits would expedite scalable CCS infrastructure. Policy recommendation I outlines a financial model to stimulate the implementation of CCS, but if states are unable to distribute Class VI well permits, the regional CCS industry will not grow.

It is possible that the financial incentives for states to rapidly approve Class VI well permits could cause dishonesty in the rigor of the permit application review process. Lack of rigorous enforcement of the environmental standards required by the permits could create cause for potential contamination to underground sources of drinking water via issues such as injection well leaks. However, while there is not enough data for a definitive conclusion, the only current Class VI injection well leak that exists is in a state without state primacy (US EPA, 2024), suggesting that primacy has not led to negligence. Additionally, state approval boards have a closer relationship with local demography compared to the federal level officials due to their collective sharing of land, which may disincentivize leaks. Overall, we recommend that the EPA expedite state primacy.

ii. Research and development

Cutting the cost of CCS technologies will be crucial to CCS implementation by lowering the cost of the market price for stored CO_2. However, to make CCS more efficient and less costly to implement, more research and development is needed (NASEM Committee on Carbon Utilization Infrastructure, Markets, Research and Development et al. 2023). Currently, CCS technology research tends to be siloed into industry, government, or academia, despite collaborations among sectors driving innovation and adoption (NASEM Committee on Carbon Utilization Infrastructure, Markets, Research and Development et al. 2023). This can make academic progress of CCS research seem disconnected and difficult to use in industrial applications.

More academia-industry collaborations are needed to accelerate the R&D for CCS. National government science agencies, largely the Department of Energy, fund most current academic and government research on CCS (Congressional Research Services 2024), but these projects tend to happen within either academic, government, or industry labs alone. To incentivize partnerships between industries and academia, funding agencies could create specific grant categories that require industry partnership. Perhaps the best example of government support of academia-industry partnered R&D in the decarbonization and energy space is that done by the Energy wing of the Advanced Research Projects Agency (ARPA-E) at the DOE. They currently fund four ongoing CCS projects at research universities that all have industry partnerships ("FLECCS | ARPA-E," 2025). Strong investment in academia-industry R&D partnerships will be needed to accelerate the cost-effectiveness and implementation of CCS technologies required to transition from an incentives model to a penalties model for the carbon capture economy.

Due to recent decreases in federal investment in scientific research (Harvey and E&E News 2025; Science News Staff 2025), private and/or philanthropic efforts to fund R&D in CCS will become increasingly important. An example is Frontier, an LLC that connects companies wanting to purchase CCS to the researchers performing innovative CCS methods that have the potential to become cheaper (Frontier, 2025). These purchasing companies are acting in lieu of federal investment, buying carbon credits to claim lower carbon emissions (or even carbon neutrality) but receiving no direct financial return. To continue this private support that aligns with IRA CCS goals, a company must be convinced that the positive public relations and technological investments from purchasing carbon storage will materialize as an eventual profit increase. Continued private support and public acceptance for combatting climate change through carbon storage is paramount to this model functioning.

Implementation and feasibility

An ideal scenario would follow the tandem implementation of our three policy recommendations: Research and Development, State Primacy, and Free Market Carbon Capture with Carbon Cap and Trade. The initial increase in available federal funding for academia-industry partnerships would lead to a surge in innovative technologies which could then efficiently scale in states where primacy enabled expedient class VI permitting would be available. The later implementation of Free Market Carbon Capture followed by Carbon Cap and Trade would commodify CO_2 and incentivize industry competition eventually decreasing CO_2 emissions.

One potential disadvantage of implementation exists when removing the limitations of government set pricing and control alongside state primacy: you open the possibility for industry price fixing and industry-state collusion, along with greater control on CCS by the oil and gas industry. Furthermore, implementation could also foster a closer relationship between industry and academia, potentially resulting in conflicts of interest and hampering the objectivity academia should possess from industry (e.g., Taylor 2013). In fact, most research has shown that instead, industry-academia collaboration has been an extremely important source of technological innovation and derisking of new technologies (O'Dwyer et al. 2023; Petruzzelli 2011; Philpott et al. 2011). In the carbon capture enterprise, increased funding and fundamental research in academia has been cited as the reason for an increase in innovation, diversification of carbon capture methods, and influx of carbon capture start-ups (Dalla Fontana and Nanda, 2023). Steering the CCS enterprise away from a sole mechanism of carbon capture (direct injection wells) and sole controlling industry (oil and gas) would make harder, if not possibly even prevent, market corruption such as industry price-fixing.

We propose that all three of our policy recommendations, when working in conjunction, would spur a more efficient and diverse CCS enterprise helping to prevent climate catastrophe. However, we suggest that first and most important to be prioritized at present is to increase funding for fundamental research and academia-industry partnerships in carbon capture knowledge and technology. Optimally, advancing and derisking technology via academic research would lead to a need for more robust CCS pricing markets (free market carbon capture) and require higher efficiency in implementing CCS (state primacy of Class IV injection wells).

III. Conclusions

Carbon capture and storage is necessary to achieve reduced greenhouse gas emissions while simultaneously preventing economic stunting of major U.S. industries. Despite its importance, major hurdles still exist to widescale adoption of CCS technologies, such as (1) lack of economic incentive to implement CCS, (2) high price of implementing CCS, and (3) extremely long regulatory wait times when implementing new CCS technologies. We provided three policy recommendations that could help to address these major hurdles:

1. Implement a two-phase carbon market policy that starts with free market carbon pricing (incentive) and ends with carbon cap and trade carbon (penalty) during which intensive federal investment is put into research and development to lower the cost of CCS technologies; the goal is the dissolution of the fixed and arbitrary carbon market pricing system in favor of free market CCS implementation.
2. Give state primacy to the Class VI permitting process, such that states still must comply with minimum (or stronger) EPA requirements for the injection wells, but states are the evaluators and eventual granters of Class VI injection well permits.
3. Accelerate the adoption of CCS technologies and reduction in price of CCS through

CCS-focused R&D grants that require academic institutions to partner with industry.

The bipartisan nature of CCS presents a foreground for environmental and industry goals to coexist. Our recommendations strengthen current CCS policies cultivating large-scale success for CCS in the United States.

References

Abdulla, Ahmed, Ryan Hanna, Kristen R Schell, Oytun Babacan, and David G Victor. 2020. "Explaining Successful and Failed Investments in U.S. Carbon Capture and Storage Using Empirical and Expert Assessments." Environmental Research Letters 16 (1): 014036. https://doi.org/10.1088/1748-9326/abd19e

Calvin, Katherine, Dipak Dasgupta, Gerhard Krinner, et al. 2023. IPCC, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (Eds.)]. IPCC, Geneva, Switzerland. First. With Hoesung Lee. Intergovernmental Panel on Climate Change (IPCC). https://doi.org/10.59327/IPCC/AR6-9789291691647.

"Carbon Capture and Storage in the United States | Congressional Budget Office." 2023. December 13. https://www.cbo.gov/publication/59832.

Coase, R. H. 1937. "The Nature of the Firm." Economica 4 (16): 16. https://doi.org/10.1111/j.1468-0335.1937.tb00002.x.

Committee on Carbon Utilization Infrastructure, Markets, Research and Development, Board on Energy and Environmental Systems, Board on Chemical Sciences and Technology, Division on Engineering and Physical Sciences, Division on Earth and Life Studies, and National Academies of Sciences, Engineering, and Medicine. 2023. Carbon Dioxide Utilization Markets and Infrastructure: Status and Opportunities: A First Report. National Academies Press. https://doi.org/10.17226/26703.

Congressional Research Service. 2023. "The Section 45Q Tax Credit for Carbon Sequestration." Legislation. August 25. https://www.congress.gov/crs-product/IF11455.

Congressional Research Services. 2022. "Carbon Capture and Sequestration (CCS) in the United States." Legislation. October 5. https://www.congress.gov/crs-product/R44902.

Congressional Research Services. 2024. "DOE's Carbon Capture and Storage (CCS) and Carbon Removal Programs." Legislation. November 29. https://www.congress.gov/crs-product/IF1186.

Dalla Fontana, Silvia, and Ramana Nanda. 2023. "Innovating to Net Zero: Can Venture Capital and Start-Ups Play a Meaningful Role?" Entrepreneurship and Innovation Policy and the Economy 2 (January): 79–105. https://doi.org/10.1086/723236.

Environmental Protection Agency. 2022. Class VI Permitting Report to Congress. https://www.epa.gov/system/files/documents/2022-11/EPA%20Class%20VI%20Permitting%20Report%20to%20Congress.pdf.

ExxonMobil. 2025. "Why We're Investing $15 Billion in a Lower-Carbon Future." March 27. https://corporate.exxonmobil.com/news/news-releases/2021/1109_why-we-are-investing-15-billion-in-a-lower-carbon-future.

Federal Register. 2024. "State of Louisiana Underground Injection Control Program; Class VI Primacy." January 5. https://www.federalregister.gov/documents/2024/01/05/2024-00044/state-of-louisiana-underground-injection-control-program-class-vi-primacy.

"FLECCS | ARPA-E." n.d. Accessed May 6, 2025. https://arpa-e.energy.gov/programs-and-initiatives/view-all-programs/fleccs.

Frontier. n.d. "An Advance Market Commitment to Accelerate Carbon Removal." Accessed May 6, 2025. https://frontierclimate.com/.

GovTrack.Us. n.d. "S. 433 - 93rd Congress: Safe Drinking Water Act." Accessed June 6, 2025. https://www.govtrack.us/congress/bills/93/s433.

Harker Steele, Amanda, Travis Warner, Derek Vikara, Allison Guinan, and Peter Balash. 2021. "Comparative Analysis of Carbon Capture and Storage Finance Gaps and the Social Cost of Carbon." Energies 14 (11): 11. https://doi.org/10.3390/en14112987.

Harvey, Chelsea, and E&E News. 2025. "Government Agencies, Universities, Nonprofits Pause Critical Work Over Trump Administration Executive Orders." Scientific American, February 18. https://www.scientificamerican.com/article/trump-takes-a-giant-wrecking-ball-to-u-s-research/.

Hunt, Kara. 2023. "Interactive Map of Class VI Wells for Geologic Storage of Carbon Dioxide." Clean Air Task Force, November 16. https://www.catf.us/2023/11/interactive-map-class-vi-wells-geologic-storage-carbon-dioxide/.

Kumar, Amit, Arun Kumar Tiwari, and Dia Milani. 2024. "Decarbonizing Hard-to-Abate Heavy Industries: Current Status and Pathways towards Net-Zero Future." Process Safety and Environmental Protection 187 (July): 408–30. https://doi.org/10.1016/j.psep.2024.04.107.

Meckel, T.a., A.p. Bump, S.d. Hovorka, and R.h. Trevino. 2021. "Carbon Capture, Utilization, and Storage Hub Development on the Gulf Coast." Greenhouse Gases: Science and Technology 11 (4): 619–32. https://doi.org/10.1002/ghg.2082.

Menefee, Anne, Hannah Wiseman, Seth Blumsack, and Michael Helbing. 2025. "For Geological Carbon Sequestration to Work, We Need a Geospatial Planning Policy." Proceedings of the National Academy of Sciences 122 (11): e2403020122. https://doi.org/10.1073/pnas.2403020122.

Naldi, Nerio. 2013. "Adam Smith on Value and Prices." In The Oxford Handbook of Adam Smith, edited by Christopher J. Berry, Maria Pia Paganelli, and Craig Smith. Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199605064.013.0015.

Nordhaus, William. 2019. "Climate Change: The Ultimate Challenge for Economics." The American Economic Review 109 (6): 1991–2014.

O'Dwyer, Michele, Raffaele Filieri, and Lisa O'Malley. 2023. "Establishing Successful University–Industry Collaborations: Barriers and Enablers Deconstructed." The Journal of Technology Transfer 48 (3): 900–931. https://doi.org/10.1007/s10961-022-09932-2.

Paris Agreement. Dec. 12, 2015. U.N.T.S. v. 3146 p. 79 No. 54113. https://treaties.un.org/Pages/showDetails.aspx?objid=0800000280458f37.

Petruzzelli, Antonio Messeni. 2011. "The Impact of Technological Relatedness, Prior Ties, and Geographical Distance on University–Industry Collaborations: A Joint-Patent Analysis." Technovation 31 (7): 309–19. https://doi.org/10.1016/j.technovation.2011.01.008.

Philpott, Kevin, Lawrence Dooley, Caroline O'Reilly, and Gary Lupton. 2011. "The Entrepreneurial University: Examining the Underlying Academic Tensions." Technovation, Managing Technology, vol. 31 (4): 161–70. https://doi.org/10.1016/j.technovation.2010.12.003.

Rep. Yarmuth, John A. [D-KY-3. 2022. "H.R.5376 - 117th Congress (2021-2022): Inflation Reduction Act of 2022." Legislation. August 16. 2021-09-27. https://www.congress.gov/bill/117th-congress/house-bill/5376.

Rubin, Edward S., John E. Davison, and Howard J. Herzog. 2015. "The Cost of CO2 Capture and Storage." International Journal of Greenhouse Gas Control, Special Issue commemorating the 10th year anniversary of the publication of the Intergovernmental Panel on Climate Change Special Report on CO2 Capture and Storage, vol. 40 (September): 378–400. https://doi.org/10.1016/j.ijggc.2015.05.018.

Science News Staff. 2025. "Trump's Proposed Budget Would Mean 'Disastrous' Cuts to Science." May 2. https://www.science.org/content/article/trump-s-proposed-budget-would-mean-disastrous-cuts-science.

Smith, Alden. 2023. "Buried Hope: Assessing the Future of Carbon Sequestration in the U.S. under the Updated 45Q Tax Credit." Business, Entrepreneurship & Tax Law Review 7: 143.

"SPeCS Public Element Dashboard | EPA@Work." n.d. Accessed June 6, 2025. https://awsedap.epa.gov/public/extensions/specs-element-dashboard/index.html.

Stavins, Robert N. 2020. "The Future of US Carbon-Pricing Policy." Environmental and Energy Policy and the Economy, ahead of print, January 1. Chicago, IL. https://doi.org/10.1086/706792.

"Unlocking Carbon Storage Wells in 2024 | ClearPath." n.d. Accessed June 6, 2025. https://clearpath.org/our-take/unlocking-carbon-storage-wells-in-2024/.

US EPA, OAR. 2021. "Climate Change Regulatory Actions and Initiatives." Overviews and Factsheets. June 11. https://www.epa.gov/climate-change/climate-change-regulatory-actions-and-initiatives.

US EPA, OA. 2024. "EPA Announces Proposed Order Requiring Archer Daniels Midland Co. to Take Actions to Ensure Safe Operation of Its Carbon Sequestration Well in Decatur, Illinois." News Release. September 19. Illinois. https://www.epa.gov/newsreleases/epa-announces-proposed-order-requiring-archer-daniels-midland-co-take-actions-ensure.

US EPA, OW. 2022. "Primary Enforcement Authority for the Underground Injection Control Program." Overviews and Factsheets. June 9. https://www.epa.gov/uic/primary-enforcement-authority-underground-injection-control-program-0.

US EPA, OW. 2023. "Current Class VI Projects under Review at EPA." Data and Tools. April 27. United States. https://www.epa.gov/uic/current-class-vi-projects-under-review-epa.

U.S. Senate Committee on Environment and Public Works. 2020. "President Trump Signs Barrasso's Bipartisan Carbon Capture Bill into Law." December 28. https://www.epw.senate.gov/public/index.cfm/2020/12/president-trump-signs-barrasso-s-bipartisan-carbon-capture-bill-into-law.

Wettestad, Jørgen. 2011. "EU Emissions Trading: Achievements and Challenges." In Toward a Common European Union Energy Policy. Palgrave Macmillan, New York. https://doi.org/10.1057/9780230119819_5.

Matthew Hollingham is a PhD candidate in Architectural Engineering at The Pennsylvania State University. Through his fellowship he studies Carbon Capture Policy and Ex-situ Carbon Capture in Mafic and Ultra-Mafic rocks for use in concrete structures. He is currently leading the implementation of a patented novel CCS unit that will capture Penn State's natural gas CO_2 emissions and to produce cementitious materials.

Jack Hughes is a PhD candidate at the Pennsylvania State University in the John and Willie Leone Family Department of Energy and Mineral Engineering. Jack studies the geochemical processes related to the geologic storage of CO_2 both in traditional sedimentary reservoirs, and ultramafic and mafic reservoirs.

Hanna C. Leapaldt is a PhD candidate in the Department of Geosciences at The Pennsylvania State University. She studies how carbon cycles between microbial communities and carbonate rocks/sediment. She has been a Christine Mirzayan Science and Technology Policy Fellow on the Board of Earth Science and Resources at the National Academies of Science, Engineering, and Medicine, and the President of the Science Policy Society at Penn State.

Acknowledgments

The authors would like to acknowledge Hannah Wiseman and Anne Menefee for their help with CCS policy, and the Science Policy Society at Penn State.