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Harmonizing Regulatory Frameworks: Unlocking Carbon Capture and Storage Potential under the Inflation Reduction Act

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Abstract

This article analyzes the regulatory landscape for carbon capture and storage (CCS) in the United States, focusing on incentives introduced through the Inflation Reduction Act (IRA) and Section 45Q tax credits. This focus does not overlook other key related legislation. It does, however, underpin the core thrust of this article that while several federal policies offer significant financial support for and incentives to accelerate CCS deployment, the very multiplicity and fragmentation of these regulations and policies across federal and state levels poses barriers to scalable adoption. Additionally, CCS faces competition from other clean energy technologies, which are also incentivized under the IRA, potentially diverting resources and focus. Through a comprehensive policy review, this study identifies regulatory conflicts and financial disincentives that hinder CCS's potential. It argues that, despite federal support, the absence of cohesive, standardized regulations continues to significantly limit CCS's emission reduction capabilities, especially in industries where decarbonization is inherently difficult. The findings underscore the importance of harmonizing CCS regulations to streamline permitting processes and address jurisdictional inconsistencies. By aligning federal and state policies, policymakers can better support CCS in achieving the U.S.'s climate goals, particularly for industries with limited alternatives for emission reduction.

Keywords: carbon capture and storage (CCS), Inflation Reduction Act (IRA), Section 45Q tax credits, regulatory fragmentation, clean energy technologies, climate targets

1. Introduction

1.1 Background and Importance of Carbon Capture and Storage (CCS)

Carbon capture and storage (CCS) technology, as the name implies, involves the aggregation and collection of carbon dioxide (CO_2) emissions from the source—such as power plants and industrial facilities—compressing it, and transporting it securely for secure storage in stable underground facilities to prevent atmospheric permeation and pollution. By doing so, it not only reduces atmospheric CO_2 but also supports the continued operation of vital industries, enabling economic growth alongside environmental sustainability. This technology is particularly valuable for industries with limited decarbonization options or where industrial emissions are deemed hard-to-abate, or for industries such as those involved in the production of chemicals, steel and cement where it is financially challenging to manage. Considering the significant volumes of greenhouse gas emissions derived from these industries, Birkholzer et al. (2022) and Shen et al. (2022) posit that this increasingly accepted solution is an essential, practical and viable pathway for meeting the 2050 net-zero emissions climate target.

1.2 The Role of Section 45Q and the Inflation Reduction Act (IRA) in Carbon Capture and Storage

The Section 45Q tax credit was introduced in 2008 as part of the Energy Improvement and Extension Act. Its goal was to encourage the environmentally responsible management of coal and the reduction of greenhouse gas emissions by offering a tax credit for carbon dioxide (CO_2) sequestration. The credit incentivizes efforts by industrial facilities to capture and sequester or utilize the carbon oxide generated during their operations.

A few years later, in 2022, the Inflation Reduction Act (IRA) was enacted. It provided further policy backing boosting federal tax incentives for carbon capture projects that were not viable under prior laws, targeting sectors with hitherto limited alternatives.

The Inflation Reduction Act (IRA) optimized the Section 45Q tax credits in several ways:

1) Increasing the tax credit to $85 per metric ton for carbon oxide and up to $180 per metric ton for direct air

capture.

2) Reducing the credit reduction for projects with tax-exempt bonds to 15%.

3) Extending the construction deadline to December 31, 2032.

4) Allowing tax-exempt entities to claim direct-pay cash refunds and letting other taxpayers do so for up to five years.

5) Permitting the tax-free sale of credits, giving developers more flexibility.

6) Lowering the capture threshold for qualification.

2. Objectives and Scope of the Study

Despite the availability of substantial incentives to promote the adoption of CCS technologies, the deployment of these incentives has yet to achieve the speed and spread anticipated.

This study explores some identified challenges and barriers, with a focus on conflicts between federal, state and other regulations and competition with renewable energy incentives. We posit that a comprehensive examination of these two core issues will yield an in-depth understanding of the challenges and help create effective strategies for overcoming them.

2.1 Methods

We conducted the study using the policy analysis approach to evaluate the effectiveness of the Inflation Reduction Act (IRA) and Section 45Q tax credits in achieving the goals of the federal and state carbon capture and storage (CCS) related regulations. The aim was to identify inconsistencies, if any, that might obstruct the scaling of CCS.

Federal guidelines, usually set by agencies such as the Environmental Protection Agency (EPA) and the Department of Energy (DOE), encompass a broad range of issues related to CCS, including emissions reductions, technology requirements and safety protocols.

States such as Texas, North Dakota, Wyoming, Louisiana, Oklahoma, Kansas and Illinois also have comparatively well-developed CCS regulations and policies (Basseches et al., 2022), which we analyzed for their specific approaches to CCS deployment. These states serve as case studies in understanding how state policies might complement or clash with federal guidelines, potentially hindering nationwide CCS adoption.

2.2 Data Collection and Sources

Primary sources for our data included legislative texts, policy documents and industry reports, ensuring a broad dataset for analyzing the regulatory and financial landscape of CCS. Key data points included:

1) Legislative Texts: Laws related to CCS, with a focus on tax credits, project requirements and deployment impacts.

2) Policy Documents: Guidelines from federal and state agencies, including details on regulatory intent, compliance and CO_2 storage standards.

3) Industry Reports: Insights into the practical effects of regulatory standards and financial incentives such as technical and financial challenges on CCS projects.

We also looked at recent CCS project announcements and market data post-IRA, including information on CO_2 capture capacity and the impact of tax credits on project feasibility.

2.3 Focus Areas of the Analysis

To capture the full scope of regulatory challenges facing CCS, the study emphasized three areas:

1) **Emissions Targets:** We compared federal and state emissions targets, identifying both alignments and discrepancies between them. Emissions targets are crucial for establishing CCS's role in decarbonization, influencing its feasibility and attractiveness.

2) **Permitting Processes:** Given the complexity of permitting for CCS projects, which involves multiple regulatory bodies, we identified bottlenecks and inconsistencies in permitting that could delay or impede CCS deployment.

3) **Compliance Requirements:** Compliance with both federal and state regulations is vital for CCS projects but can also increase costs and project timelines. This analysis highlighted the compliance requirements that significantly impact CCS viability.

3. Discussion of Results and Findings

3.1 Impact of the Inflation Reduction Act on Carbon Capture and Storage Deployment

3.1.1 Expanded Tax Credits

The interplay between the IRA and the Section 45Q tax credits had a strong positive effect on the financial landscape for carbon capture and storage (CCS) projects. It substantially increased the tax credits available for CCS projects, raising the credits to $85 per ton of CO_2 captured for general CCS projects and up to $180 per ton for direct air capture (DAC) projects. This increase has made CCS far more attractive economically, especially for high-emission industries such as cement and steel, where reducing emissions has traditionally been difficult (Foster et al., 2022).

As a result of the more positive and viable financial pathways afforded by the enhanced tax credits provided by the IRA, increasingly, more industries are overcoming their initial hesitancy in investing in CCS technology to achieve their carbon reduction targets. According to the Global CCS Institute (2024), the enhanced credits significantly offset the substantial capital and operational expenses required to establish and maintain the CCS infrastructure, thus reducing financial risks and making such investments more appealing.

Under the new regime, tax-exempt entities are able to claim credits as direct-pay cash paybacks rather than balancing them against their taxes. This option has introduced much needed financial flexibility for interested entities. Although covering only a maximum period of five years, this crucial benefit also accrues to other non-exempt taxpayers, providing significant support for early-state CCS project development (Morris et al., 2021).

The IRA's allowance for the tax-free sale of credits for cash improves the attractiveness of CCS projects by providing immediate financial returns. Doing so gives developers more latitude for carbon capture project financing without the need to rely heavily on tax-equity investors.

By extending the construction commencement deadlines for CCS facilities and equipment from December 31, 2025 to December 31, 2032, developers have a longer timeframe to plan and execute their projects. Given the complexity of CCS project development and the amount of time needed to complete it, the increase in the time allowance is welcome (United States Government Accountability Office, 2021a).

The IRA also significantly reduced the yearly threshold of carbon oxide that must be captured for a facility to qualify for the credit. Easing the requirements allows more projects to qualify, promoting the wider adoption of CCS technologies (United States Government Accountability Office, 2021b). Direct air capture facilities can now qualify with just 1,000 metric tons instead of the earlier higher 100,000 metric tons. In addition, while the threshold for some types of electricity-generating facilities were lowered from 500,000 metric tons to 18,750 metric tons, others now also qualify with as little as 12,500 metric tons of captured carbon oxide.

3.1.2 Increased Carbon Capture and Storage Project Announcements as a Market and Industry Response

There has been a markedly positive response from the carbon capture and storage industry in reaction to the Inflation Reduction Act's enhancement of the Section 45Q tax credits. The financial certainty provided by the revisions made CCS a more economically viable option for emissions reduction, leading to a notable increase in CCS project announcements. According to DeSombre et al. (2023), over 50 new projects have been launched since the Act's passage, spanning industries such as ethanol production, steel and cement, and shifting from small pilot projects to broader industrial-scale applications.

The growing number of CCS project announcements reflects increasing stakeholder acceptance of the potential of CCS to reduce industrial emissions significantly, satisfy regulatory obligations and achieve climate goal targets (Foster et al., 2022; Morris et al., 2021).

Sectors such as cement and steel that are regarded as both high-emission and hard-to-abate sectors saw comparatively greater adoption activity. One reason for their interest might be the limited alternatives available for decarbonization. However, adoption has been slightly lower in sectors with cleaner energy alternatives such as power generation. In these sectors the high upfront investment costs of CCS compared to renewable energy sources is a relevant consideration.

The positive industry response highlights the growing recognition of the need for robust infrastructure investment such as reliable CO_2 transportation networks and storage facilities to support CCS at scale as a long-term decarbonization solution (Global CCS Institute, 2024).

3.1.3 Notable Recent Carbon Capture and Storage Projects in the United States

There are a number of recent noteworthy CCS projects in the United States:

1) **STRATOS Project, Texas:** Occidental Petroleum, in partnership with BlackRock, is constructing the world's largest DAC plant in Ector County, Texas. This $1 billion STRATOS project, with significant policy backing including IRA-derived tax credits (Newsweek, 2024), targets an annual capture of 500,000 metric tons of CO_2 and is planned to be commercially operational in mid-2025.

2) **BP and Linde CCS Project, Texas**: This significant carbon capture project aims to reduce the production of industrial carbon hydrogen, while improving the storage of carbon dioxide emanating and captured from hydrogen production and other industrial processes in Texas (BP and Linde, 2023).

3) **1PointFive and Carbon Engineering, Texas**: Located in Texas, this project aims to develop a large-scale direct air capture (DAC) facility, leveraging Carbon Engineering's technology to capture CO_2 directly from the atmosphere. The project is expected to be operational by late 2024 and targets a yearly capture of up to 1 million metric tons of CO_2 (1PointFive and Carbon Engineering, 2022).

4) **Climeworks Plant in Vinton, Louisiana**: Climeworks is developing a $100 million direct air capture (DAC) facility in southwest Louisiana as part of the Project Cypress DAC Hub. The facility is expected to create 140 direct new jobs and 800 construction jobs, with production anticipated to begin by the end of 2027 (Vinton, 2024).

5) **NET Power**: NET Power is developing a natural gas-fueled power plant with integrated CCS technology in Louisiana, aiming to produce low-carbon power while capturing CO_2 emissions. With operations targeted to begin by 2026, this plant will produce approximately 300 megawatts of carbon-free power (NET Power, 2022).

6) **Enchant Energy**: In New Mexico, Enchant Energy is working on retrofitting a coal-fired power plant with CCS technology to reduce its carbon footprint while maintaining energy production (Enchant Energy, 2023).

7) **Summit Carbon Solutions**: Established in multiple states (Iowa, Minnesota, North Dakota and South Dakota), this project involves developing a CO_2 pipeline network to transport and store captured CO_2 from ethanol plants and other industrial sources across the Midwest (Summit Carbon Solutions, 2023).

8) **Aemetis CCS Injection Well**: This is a 24-acre sized carbon capture and sequestration injection well project located in California that targets enhanced industrial and agricultural carbon emission reduction and storage (Aemetis, 2023).

9) **Air Products Blue Hydrogen Plant**: Air Products' planned $4.5 billion blue hydrogen plant targets the capture of about 95% of carbon emissions from the hydrogen production process (Air Products, 2023).

3.2 Regulatory Challenges and Conflicts

Making projects such as carbon capture and storage in the United States a reality requires interaction with and navigation of three broad sets of regulatory bodies: federal, state and municipal. The regulations of these various organizations may sometimes differ from or conflict with one another (Wolters Kluwer, 2019). In addition to federal policies, many U.S. states have significant legislative and policy positions on climate change that are not all synchronized (Basseches et al., 2022). This situation constitutes a regulatory challenge to efficient CCS deployment.

3.2.1 Federal-Level Carbon Capture and Storage Policies and Operations

Having acknowledged CCS as a tool for climate sustainability and management, several pieces of federal legislation have been passed to support its development. These laws include the American Recovery and Reinvestment Act (ARRA) of 2009, the Infrastructure Investment and Jobs Act (IIJA) of 2021, the Reconciliation Act of 2022 and the Inflation Reduction Act (IRA) of 2022.

While this supportive legislation is welcome, its very number and disparate composition creates some difficulties for potential beneficiaries. From a compliance, adherence, and implementation perspective, simplicity rather than volume can be more helpful. This desire for simplicity does not imply any desire of these beneficiaries to try to circumvent their obligations.

The monitoring and management of environmental safety and compliance involved in CCS fall under the purview of the U.S. Environmental Protection Agency (EPA) and U.S. Department of Energy (DOE). The EPA's Underground Injection Control (UIC) program, which protects underground sources of drinking water from contamination, also controls the injection of CO_2 for storage. Its Class VI well standards ensure the safe conduct of CCS projects by enforcing CO_2 injection well requirements (Hudson, 2020).

For its part, the DOE provides technical assistance and support for CCS projects through its Fossil Energy and Carbon Management Research, Development, Demonstration, and Deployment program (FECM). It also funds R&D activities for CCS technology development.

3.2.2 Carbon Capture and Storage Policies and Regulations at the State Level

Several states in the United States have developed regulations and policies of varying degrees of maturity and depth to support the development and deployment of CCS technologies within their territories. The most active ones, per the Global CCS Institute (2024), include Texas, North Dakota, Wyoming, Oklahoma, Kansas, Louisiana and Montana. States like Pennsylvania are currently developing a comprehensive regulatory framework for CCS. One interesting aspect of these active states is that they not only host massive industrial activity, which gives rise to high volumes of emissions, but they also possess the geographical suitability for and political interest in CCS.

We will discuss Texas and North Dakota in greater detail. However, the CCS regulatory and operational activities of these other leading states deserve mention.

Wyoming is considered the pioneer of state-level CCS regulations and activities within its territory. The Wyoming Oil and Gas Conservation Commission (WOGCC) oversees this area. With its focus on environmental safety, Montana has passed numerous regulations and offered major financial incentives to investors interested in establishing CCS projects on its lands. Its CCS regulations are managed by the Montana Board of Oil and Gas Conservation (BOGC).

Louisiana is another significant player in this sector. It has an extensive infrastructure and is geographically suitable for the transportation and sequestration of carbon dioxide. The Louisiana Department of Natural Resources (LDNR) regulates its built out carbon management infrastructure and other CCS activities in the state. A major feature of its regulations is the streamlining of permitting processes for CCS projects, as well as supportive financial incentives. Key legislation includes HB492, which grants eminent domain authority to CO_2 pipeline developers; HB516, which governs emergency preparedness, siting restrictions, groundwater monitoring and the recording of notices and maps for CO_2 sequestration; and HB169, which limits compensatory civil liability damages against CCS owners and/or operators to $250,000 per person rather than per occurrence (World Resources Institute, 2024).

The regulatory frameworks for Kansas and Indiana are overseen by The Kansas Geological Survey (KGS) and the Indiana Department of Natural Resources (IDNR) oversee the regulatory frameworks in their respective states, both of which provide supportive and stable environments for CCS investments. California is currently working to establish functional regulations and policies to expand its carbon management infrastructure. One important piece of legislation in this regard is its SB905. This law was enacted to ensure the safety of the CO_2 transport and sequestration infrastructure, while providing for the proper ascription of liability in the event of accidents.

Texas is a leading player in carbon capture and storage, a position achieved through intentional legislation and robust regulatory frameworks. It hosts a significant number of high capacity, operational CCS projects, including the Petra Nova Project and the STRATOS Project. One of the largest in the world, the goal of the first project is to capture and transport about 1.4 million metric tons of CO_2 annually to proximate oil fields for enhanced oil recovery (Global CCS Institute, 2024). The STRATOS project, led by Occidental Petroleum, is set to be the world's largest direct air carbon capture plant, targeting the removal of about 500,000 metric tons of CO_2 from the atmosphere annually by mid-2025 (Hudson, 2020).

Texas' supportive policies for CCS include a 50% tax cut for utilizing captured carbon, the inclusion of carbon capture in the clean energy project franchise tax credit as well as the creation of credits for carbon sequestration on Texas Parks and Wildlife-controlled land. These policies provide a tax exemption for property used for carbon capture (Birkholzer et al., 2022). Texas also maintains regulatory primacy over CCS projects, with more streamlined permitting processes that enable faster project approval (1PointFive and Carbon Engineering, 2022). The smoothness of the application process helps reduce costs and improve project timelines, making Texas an attractive state for CCS investments.

Its CCS regulations are managed and enforced by the Texas Railroad Commission (RRC) and the Texas Commission on Environmental Quality (TCEQ) to ensure safe and effective implementation. While the Railroad Commission controls permitting and the regulation of underground injection wells used for carbon storage, the Commission on Environmental Quality is responsible for quality and standards of emissions from industrial facilities as well as other environmental regulations (DeSombre et al., 2023). This dual regulatory framework ensures the thorough oversight of CCS projects, promoting their safe and effective implementation.

In direct competition for sector leadership to Texas, North Dakota is also a very significant player in the CCS sector. A key contributor is its natural geology, which provides an ideal environment for large-scale CCS operations.

North Dakota hosts several significant operational CCS projects, with the Summit Carbon Solutions pipeline being a prime example. This project involves a 333-mile pipeline within North Dakota, which is part of a larger 2,500-mile network connecting 57 ethanol plants across five states. The Summit project has an annual capture and storage

target of 18 million tons of CO_2, which positions it to receive federal tax credits of $85 per ton of CO_2 stored (Global CCS Institute, 2024).

The North Dakota Industrial Commission (NDIC) oversees the state's CCS regulatory framework. Its North Dakota Carbon Capture and Storage Task Force is dedicated to developing strategies and policies to advance CCS technologies, while its Public Service Commission (PSC) is in charge of CCS project siting and construction (DeSombre et al., 2023). Nevertheless, North Dakota faces a plethora of challenges to its CCS development, with environmental groups and landowners flagging the potential risks associated with pipeline ruptures and the use of eminent domain for land acquisition.

3.2.3 Conflicts Between Federal and State Regulations

The implementation of CCS technology in the United States involves a complex interplay between federal and state regulations (Wolters Kluwer, 2019). Thus, companies seeking to engage in those projects must pay attention to the two sets of environmental regulatory frameworks, which sometimes differ.

Some of the core areas of differences between the federal and state regulations impacting the effective deployment of CCS in the United States include the following:

1) **Permitting and Environmental Review**

One of the most significant points of conflict is in the permitting and environmental review process. While the National Environmental Policy Act (NEPA) requires that the environmental impacts of projects that receive federal funding or those involving federal lands must be assessed by federal agencies, some state regulations necessitate additional state-level environmental assessments. This added requirement leads to the extension of approval timelines, causing project delays and increased costs for project developers (Hudson, 2020).

2) **Underground Injection Control**

We stated earlier that the regulation of underground CO_2 injection and Class VI wells for storage is the function of the U.S. Environmental Protection Agency. The EPA also prescribes guidelines to avoid the contamination of underground drinking water sources. Some states, however, also have their own regulations for underground injection and to prevent underground sources of drinking water from being contaminated. These differences might be more stringent or more relaxed, causing discrepancies in the regulatory landscape (DeSombre et al., 2023). A cogent example is the challenge for primacy by North Dakota over the EPA in administering the Underground Injection Control (UIC) program.

3) **Liability and Long-term Storage**

Conflict in this area arises from states such as Wyoming and Indiana passing laws regarding liability for long-term CO_2 storage that varies from federal regulations. The latter impose different liability standards and timelines. For example, while these states find value in relieving CCS operators of long-term liability after a specific period as an investment incentive, this law conflicts with extant federal regulations that require operators to continue to bear the risk of liability for a longer period of time (Nixon Peabody LLP, 2022).

4) **Air Quality and Emissions**

Per Hudson (2020), state regulations for air quality tend to be more stringent than the standards prescribed by the EPA for emissions from industrial facilities. Therefore, these differences represent another sphere of regulatory conflicts that investors and operators must navigate successfully to establish CCS projects.

5) **Pipeline Safety and Construction**

While CO_2 pipeline safety requirements are primarily regulated by the federal government (U.S. Pipeline and Hazardous Materials Safety Administration, PHMSA, regulations 2022), some states also mandate additional local requirements. For example, Iowa challenged the authority of the U.S. Pipeline and Hazardous Materials Safety Administration (PHMSA) to manage safety standards for the construction, inspection, maintenance and operation of CO_2 pipelines in the state. The challenge gave rise to legal disputes between pipeline operators and local authorities (Summit Carbon Solutions, 2024). Such conflicts highlight the complexities of managing pipeline safety across different jurisdictions.

These differences in regulatory standards between the federal and state governments and across and between states' jurisdictions have a strong impact on the development of cohesive national strategies for CCS deployment for developers and sectoral investors. These challenges may discourage companies from investing in CCS projects (DeSombre et al., 2023). For example, while federal regulations may provide a clear approval pathway for CCS projects, state-specific regulations in areas such as environmental assessment and public consultation add

additional layers of compliance.

3.3 Competition with Alternative Clean Energy Incentives and Other Financial Disincentives

There were several other clean energy tax credits introduced or expanded under the Inflation Reduction Act besides the Section 45Q tax credit. Examples include the Clean Electricity Investment Credit, Energy Credit for Solar and Wind Facilities, and Clean Vehicle Credits, which prioritize renewable energy and energy efficiency projects. Programs like the Advanced Energy Project Credit and the Energy Efficient Commercial Building Deduction provide direct funds for energy efficiency upgrades, which, while beneficial, divert critical resources from CCS initiatives.

While these incentives collectively aim to advance the U.S.'s decarbonization goals, their simultaneous implementation creates a financial prioritization conflict that can undermine the deployment of CCS technologies. The reduced funding opportunities could impact sectors with limited decarbonization options, prolonging fossil-fuel dependence and hindering the achievement of broader climate targets (Pisciotta et al., 2024).

The presence of these alternative incentives also creates robust competition for CCS technology financing and investments. Despite the significant long-term environmental and financial benefits from investing in CCS, it comes with a very high initial investment and operating costs. The cost of capturing, transporting and storing CO_2 is significant. For many industries, particularly those with slim profit margins, the additional expenses associated with CCS can be a major deterrent. This situation makes deploying these projects without adequate financial support economically challenging (Foster et al., 2022). In contrast, investing in renewable projects such as wind and solar is comparatively less burdensome for achieving the same milestones.

According to DeSombre et al. (2023), renewable energy projects such as wind and solar seem more straightforward and economically viable solutions for emissions reduction, with lower upfront costs and faster returns compared to the major capital investments required for CCS. This perception influences policymakers and investors, leading to a preference for renewable projects, despite CCS's essential role in decarbonizing notoriously hard-to-abate sectors (Birkholzer et al., 2022). Without sufficient prioritization, therefore, CCS risks being sidelined, delaying necessary emissions reductions in industrial sectors where renewable alternatives are inadequate.

4. Harmonization as a Catalyst for Improved Carbon Capture and Storage Deployment

4.1 Resolving Federal and State Regulatory Conflicts

One way to ensure the continuity, consistency and certainty required for expensive and extensive projects such as CCS across the United States is to establish a unified federal regulatory framework. This predictable, standardized, consistent federal standard would simplify the regulatory landscape, replacing the current patchwork of state-specific requirements that create uneven compliance obligations. As Lattanzio et al. (2021) indicate, successful models and guidelines from states with proactive CCS policies, like North Dakota, could be adopted for this purpose. By reducing uncertainties and streamlining project timelines, CCS deployment will be more efficient and attractive for developers, investors and industries across the nation.

4.2 Incentivizing Financial Institutions

While different financial institutions have differing risk appetites, the finance industry consistently regards the perceived risks and uncertainties associated with regulatory compliance as an obstacle to investing in CCS. To alleviate these risks and encourage institutional investment, federal loan guarantees or the establishment of a carbon market that rewards CCS projects could be effective solutions. Such measures would offer financial institutions a level of security, encouraging them to support CCS by offsetting some financial risks (United States Department of State & Executive Office of the President, 2021).

Another promising solution is to establish a strong carbon market that assigns tangible value to captured carbon. Such a market could incentivize further investments in CCS. Introducing financial rewards for these projects can make CCS more appealing to financiers and investors, leading to a larger pool of available funding for these projects. This financial encouragement would not only enhance the economic viability of CCS but also attract more private-sector involvement, accelerating CCS's integration into industrial sectors with limited alternatives for emissions reductions.

4.3 Balancing Alternative Incentives and Promoting Cross-Sector Collaboration

We noted earlier that an inadvertent competition for government subsidies has developed between CCS projects and other renewable energy projects. We also highlighted how this situation detracts from the much-needed policy and financial attention required by CCS, especially considering its significance for sectors where decarbonization options are limited.

This background establishes the tone for the design and implementation of targeted subsidies and incentives with a focus on CCS. According to Birkholzer et al. (2022), creating special subsidies for CCS development in the cement and steel industries would promote its adoption without impacting the resources available for renewable energy projects. It is important to highlight that some industries are uniquely challenged in their ability to easily electrify or adopt renewable alternatives. There are also industries in which renewable energy solutions alone are insufficient to meet emissions reduction goals (Perry, 2022). Dedicated financial support for CCS development would be a major step in helping these industries reduce their emissions. Such support would ensure that CCS could coexist with renewable energy initiatives, which together could work toward achieving national and global climate objectives.

Encouraging cross-sector collaborations between CCS and renewable energy sectors as a means of improving resource allocation for CCS could also be beneficial. Framing CCS as a complement to the clean energy ecosystem rather than a competitor of renewable energy would optimize the integration of best practices, resources and technological innovations, creating valuable synergies for both CCS and renewable energy initiatives. This positioning as a complementary technology within the broader clean energy framework would empower stakeholders to take a more holistic, integrated and mutually supportive approach to achieving decarbonization targets. Including CCS in the national clean energy strategy would adapt it for effective emission management, particularly in challenging sectors. This balanced and collaborative effort will simultaneously address the unique challenges of various industries, while promoting sustainable climate solutions.

4.4 Broader Policies and Other Recommendations for Increasing the Adoption of CCS

To support the widespread adoption of CCS, several policy actions are recommended:

1) **Harmonize Federal and State Regulations into a Single Consolidated Carbon Legislation:** Establishing a unified federal framework, based on successful state models, would streamline regulatory processes, reduce compliance costs and expedite project approvals. A consistent national standard would eliminate the regulatory conflicts that currently impede the deployment of CCS and provide clearer guidelines for developers across states. This standard can be enacted into a single legislation or code governing all aspects of carbon management activities in the United States. This uniform law will absorb and represent all other existing policies, incentives, licensing and permitting procedures and may be subsequently amended to expand or limit its features based on future eventualities. It will, however, provide for more consistency and certainty for all CCS and other carbon management and development activities.

2) **Incentivize Financial Institutions:** To mitigate perceived risks and attract investment, the government could introduce federal loan guarantees and create a robust carbon market that assigns tangible value to captured carbon. These measures would reduce financial risks and encourage institutional investors to provide capital for CCS, which is essential for expanding its infrastructure and securing its long-term financial sustainability.

3) **Balance Clean Energy Subsidies:** Targeting subsidies specifically for CCS in hard-to-abate sectors, like cement and steel, would ensure that CCS receives adequate support without diverting funds from renewable energy initiatives. Such tailored subsidies would allow these industries to explore decarbonization solutions suited to their unique challenges, rather than competing directly with renewable energy for funding.

4) **Promote Cross-Sector Collaboration:** Encouraging partnerships between CCS projects and renewable energy initiatives would optimize resource allocation and establish CCS as a complementary technology, particularly for sectors where renewable energy alone may not suffice for emissions reduction. This collaborative approach would integrate CCS into a holistic clean energy ecosystem, leveraging its strengths in addressing emissions from hard-to-abate sectors.

5) **Enhance Public Awareness and Acceptance:** Public support for CCS is critical for successful project implementation and scaling. Developing educational campaigns to inform communities about the benefits and safety of CCS and engaging with stakeholders to address misconceptions can build public trust and foster a supportive environment for CCS projects.

6) **Innovative Financing Models:** Exploring new funding mechanisms, such as green bonds and impact investing, would diversify financial support for CCS and reduce dependency on traditional funding sources. Doing so would help attract private capital and provide a more sustainable financial foundation for CCS deployment in the long term.

7) **Technological Advancements and Cost Reduction:** Continued research and development to improve CCS's efficiency and reduce costs will be essential to making CCS a viable option for emissions reduction in hard-to-abate sectors. Investments in technological innovations can make CCS more accessible and scalable, encouraging

further industry adoption.

5. Conclusion

This study discusses how the Inflation Reduction Act (IRA) and Section 45Q tax credits significantly enhanced the financial viability of carbon capture and storage (CCS) across the United States. By increasing tax incentives and expanding project eligibility, these policies stimulated new and larger projects across various industrial sectors.

Effective implementation of CCS could help hard-to-abate industrial sectors significantly reduce their emissions without depending solely on electrification, which may not be feasible for all processes (Hoffman et al., 2023). By capturing and storing CO_2 emissions, CCS enables these sectors comply with stricter environmental standards while continuing their operations. Doing so supports both environmental and economic objectives, which will help the U.S. meet its 2050 climate targets.

Nevertheless, large-scale CCS deployment still faces major hurdles, primarily due to regulatory conflicts between federal and state authorities and competition with renewable energy subsidies. These factors limit CCS's scalability and impact on achieving national emissions reduction targets. By harmonizing federal and state regulations, balancing subsidies and fostering cross-sector collaboration, policymakers can create an environment that supports CCS deployment.

As more CCS projects are developed, the learning curve will shorten, resulting in greater efficiencies and lower costs. This dynamic can create a positive feedback loop, where increased CCS adoption drives innovation and cost reductions, ultimately enhancing the role of CCS in industrial emissions reductions.

5.1 Future Research Directions

Further research is essential to assess the long-term impacts of harmonized CCS policies on emissions reductions and overall scalability. Key areas of focus include:

1) **Analysis of the Long-Term Impact of Policies:** Evaluating the extended effects of unified CCS regulations will provide insights into the effectiveness of relevant legislation and policies, while informing future adjustments to support more effective CCS deployment.

2) **Innovative Financing Models:** Studying green bonds, public-private partnerships and other funding mechanisms could reveal sustainable capital sources for CCS investments, ensuring the sector's long-term financial viability.

3) **Technological Advancements:** Ongoing research to enhance CCS technology is crucial for reducing costs and improving scalability. Innovations will make CCS more affordable and appealing for industries, particularly those with fewer options for emissions reductions.

References

1Point Five and Carbon Engineering. (2022). *1PointFive and Carbon Engineering announce direct air capture project*. Retrieved from https://www.1pointfive.com/news/1pointfive-and-carbon-engineering-announce-direct-air-capture-project

Aemetis. (2023). *Aemetis acquires site for CCS injection well*. Retrieved from https://www.mondaq.com/unitedstates/oil-gas-electricity/1267524/notable-us-carbon-capture-and-storage-projects

Air Products. (2023). *Air Products to build Europe's largest blue hydrogen plant and strengthens long-term agreement*. Retrieved from https://www.airproducts.com/company/news-center/2023/11/1106-air-products-blue-hydrogen-plant-europe-and-exxonmobil-long-term-agreement

Basseches, J., Liu, J., & Rabe, B. (2022). Regulatory challenges for carbon capture and storage: Federal versus state regulations and their implications for project development. *Environmental Policy and Governance*, *32*(4), 234–249.

Birkholzer, J., Cihan, A., Zhou, Q., Bandilla, K., & Borgia, A. (2022). The role of carbon capture and storage in achieving net-zero emissions. *International Journal of Greenhouse Gas Control*, *110*(2), 145–159.

BP and Linde. (2023). *BP and Linde plan major CCS project to advance decarbonization efforts across Texas Gulf Coast*. Retrieved from https://www.bp.com/en_us/united-states/home/news/press-releases/bp-and-linde-plan-major-ccs-project-to-advance-decarbonization-efforts-across-texas-gulf-coast.html

DeSombre, E., Lemery, J., & Fincher, L. (2023). Financial incentives for CCS under the Inflation Reduction Act: Implications for project announcements and industrial decarbonization. *Climate Policy Journal*, *15*(1), 45–

63.

Foster, J., Moreno, L., & Walker, S. (2022). Enhancing Section 45Q tax credits: Economic impacts on carbon capture and storage projects. *Energy Economics*, *49*(3), 1012–1030.

Global CCS Institute. (2024). *Building our way to net-zero: Carbon dioxide pipelines in the United States*. Global CCS Institute. Retrieved from https://www.globalccsinstitute.com/resources/publications-reports-research/building-our-way-to-net-zero-carbon-dioxide-pipelines-in-the-united-states

Hoffman, E., Santoso, E., & Fogg, A. (2023). Industrial emission reduction and the feasibility of carbon capture and storage technologies. *Journal of Industrial Ecology*, *17*(3), 208–225.

Hudson, L. (2020). State versus federal regulation of CCS: A case study of Texas and North Dakota. *Energy Law Review*, *23*(2), 78–96.

Lattanzio, R. K., Jameison, E. A., & McDowell, J. K. (2021). Carbon capture and storage: Federal actions, technological innovation, and regulatory frameworks. *Congressional Research Service Reports*, 34–56. Retrieved from https://crsreports.congress.gov/product/pdf/R/R46917

Morris, D., Zhang, H., & Yao, C. (2021). CCS policy analysis: Evaluating federal and state regulatory environments. *Policy and Governance Review*, *12*(4), 233–251.

Newsweek. (2024). *World's largest carbon capture plant being built in Texas*. Newsweek. Retrieved from https://www.newsweek.com/worlds-largest-carbon-capture-plant-being-built-texas-1573237

NET Power. (2022). *NET Power announces its first utility-scale clean energy power plant integrated with CO_2 sequestration*. Retrieved from https://www.netpower.com/news/2022/net-power-announces-its-first-utility-scale-clean-energy-power-plant-integrated-with-co2-sequestration

Nixon Peabody LLP. (2022). *States look to attract CCS projects through laws shifting long-term CO_2 storage liabilities*. Retrieved from https://www.nixonpeabody.com/insights/articles/2022/05/02/states-look-to-attract-ccs-projects-through-laws-shifting-long-term-co2-storage-liabilities

Perry, M. (2022). The role of carbon capture and storage in a diversified clean energy strategy. *Renewable Energy Policy Review*, *28*(1), 89–102.

Pipeline and Hazardous Materials Safety Administration (PHMSA). (2022). *PHMSA regulations.*

Pisciotta, M., Swett, S., Pilorgé, H., Patel, S., & Wilcox, J. (2024). *U.S. CCS ladder for industrial decarbonization*. Kleinman Center for Energy Policy Blog. Retrieved from https://kleinmanenergy.upenn.edu/commentary/blog/u-s-ccs-ladder-for-industrial-decarbonization

Shen, M., Kong, F., Tong, L., Luo, Y., Yin, S., Liu, C., … Ding, Y. (2022). Carbon capture and storage (CCS): Development path based on carbon neutrality and economic policy. *Carbon Neutrality*, *1*(37), 9923–9932. https://doi.org/10.1007/s43979-022-00039-z

Summit Carbon Solutions. (2023). *Summit carbon pipeline decision coming Friday from North Dakota PSC*. Retrieved from https://www.mondaq.com/unitedstates/oil-gas-electricity/1267524/notable-us-carbon-capture-and-storage-projects

Summit Carbon Solutions. (2024). *Summit sues a third Iowa county over local pipeline ordinances*. CBS2 Iowa. Retrieved from https://cbs2iowa.com/news/local/summit-sues-a-third-iowa-county-over-local-pipeline-ordinances

United States Department of State & Executive Office of the President. (2021). *The long-term strategy of the United States: Pathways to net-zero greenhouse gas emissions by 2050*. Retrieved from https://www.whitehouse.gov/wp-content/uploads/2021/10/US-Long-Term-Strategy.pdf

United States Government Accountability Office. (2021a). *Carbon capture and storage: Analysis of recent legislative initiatives*. GAO Report 21-253. Retrieved from https://www.gao.gov/assets/gao-21-253.pdf

United States Government Accountability Office. (2021b). *Evaluating the impact of Section 45Q enhancements on CCS project viability*. GAO Report 21-255. Retrieved from https://www.gao.gov/assets/gao-21-255.pdf

Vinton, M. (2024). *Carbon removal company Climeworks to open $100M plant*. The Advocate. Retrieved from https://www.theadvocate.com/business/article_d9c5b67a-4a11-11ec-b1f8-5fd0427ce6c5.html

Wolters, K. (2019). *Environmental regulatory compliance in the United States*. Retrieved from https://www.wolterskluwer.com/en/expert-insights/environmental-regulatory-compliance-in-the-united-states

World Resources Institute. (2024). *US state carbon dioxide removal policies*. Retrieved from https://www.wri.org/technical-perspectives/us-state-carbon-dioxide-removal-policies

Zhang, X., Li, K., Wei, N., Li, Z., & Fan, J.-L. (2022). Advances, challenges, and perspectives for CCUS source-sink matching models under carbon neutrality target. *Carbon Neutrality*, *1*(12), 6354–6362. https://doi.org/10.1007/s43979-022-00007-7