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The State of the Carbon Capture and Sequestration Industry in California in 2024: Challenges and Policy Solutions

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A Capstone Project required for the award of Master of Public Policy

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Executive Summary

Carbon Capture and Sequestration (CCS) is the process of capturing CO_2 from an above ground carbon source, transporting it to a sequestration well, and permanently sinking it deep underground. Despite the state of California depending on CCS to reach carbon neutrality, not one CCS project is operational yet in the state. Due to the recent creation and expansion of state LCFS credits and the federal 45Q credits, CCS projects are beginning to be developed. Between 2021 and 2023 twelve Class VI applications were submitted to the US Environmental Protection Agency (EPA) in California.

This paper looks at the history and development of the CCS industry. It then uses interviews from six industry experts through a qualitative data method to gain perspective on how permitting, financing, CO_2 transportation, and property rights are affecting the industry, and whether any policy changes need to be made to improve the industry. After an analysis of twelve policy options, policy recommendations are identified, and include: updating the Class VI application process in three specific ways, expanding certified options for CO_2 transportation to include carbon reinforced polymer containers, expanding grant funds available to CCS developers, and educating property owners on the value of their pour space to encourage informed decisions on participating in CCS projects.

I. Introduction

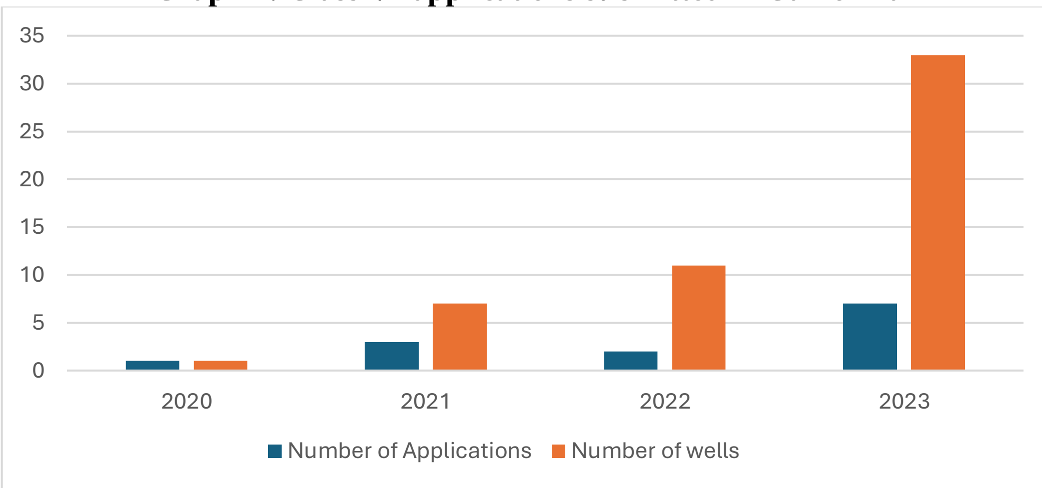
The state of California has set the goal of reaching carbon neutrality by 2045. Many industries in the state are nearly impossible to decarbonize, meaning that California’s effort to decarbonize must include carbon dioxide removal (CDR) projects, not just carbon reduction projects. At this time, very few technologies permanently remove carbon dioxide from the atmosphere, and none do so as permanently as Carbon Capture and Sequestration (CCS).[1] For this reason, state and federal governments have been researching CCS since 1997 and incentivizing CCS beginning in 2008 with the creation of the 45Q tax credit. Even with growing incentivization, to date California has not permitted any Class VI wells to geologically sequester carbon, despite having ample geological capacity. Based off this issue, the research questions this paper seeks to addresses are: How does permitting, financing, CO_2 transportation, and property rights affect the pace and scale of carbon capture and sequestration (CCS) development as a carbon dioxide removal (CDR) solution? and what policy changes are necessary as the industry develops?

To set the stage, there has been an influx in project applications for Class VI wells since 2021, as shown in Graph 1, Class VI permits being the EPA permit required to develop a CCS project. This influx is due to the establishment and expansion of both the Low Carbon Fuel Standard (LCFS) state environmental credit and the 45Q federal environmental credit. These permit applications add up to a total annual sequestration capacity of eighteen million metric tons per year. To set this in perspective, California Air Resources Board's (CARB) targets for CDR are to be sequestering thirteen tons annually by 2030, and 93 tons annually by 2045 (California Air Resources Board, 2022). Creating a trendline based on pour space applied for to date, if the pace of applications continues, California can permit enough wells to achieve its CCS goals by 2045, which is shown in Graph 2. This is assuming these projects receive permits, are financed,

[1] While CCS is sometimes defined to include biological and other forms of less permanent carbon storage, in this paper CCS refers specifically to geological sequestration deep underground.

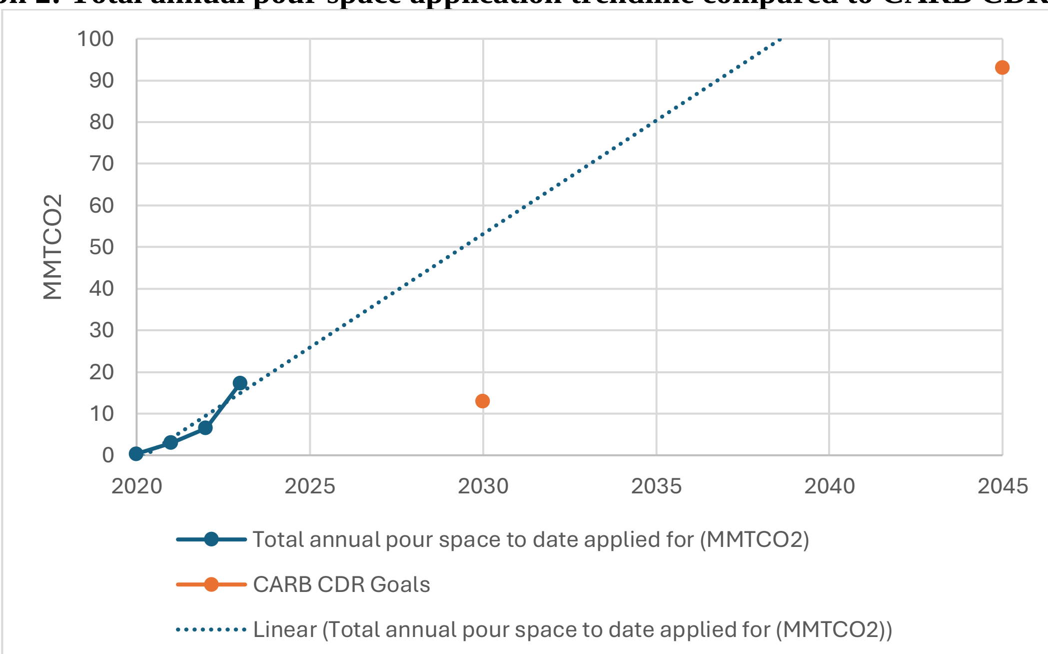
developed, and ultimately have the ability to transport CO_2 from capture points to sequestration wells.

Graph 1: Class VI applications submitted in California



Source: United States Environmental Protection Agency. "UIC Permits in EPA's Pacific Southwest (Region 9)".

Graph 2: Total annual pour space application trendline compared to CARB CDR goals



Source: California Air Resources Board. 2022. "2022 Scoping Plan for Achieving Carbon Neutrality."

The paper structure is broken down into a literature review, a description of methodology, empirical results, policy analysis, and conclusion. The paper summarizes six expert interviews conducted in March and April 2024; experts include public and private sector executives and researchers working directly in the CCS industry. The paper provides a policy analysis of the solutions brought up during and in response to the interview process. The conclusion provides policy recommendations to continue developing the CCS industry so that California can achieve its carbon neutrality goals.

II. Literature Review

The literature exploring CCS is relatively young because the industry as a whole is new. In the past decade, it has grown in popularity due to CCS's environmental benefits, and so the literature has grown rapidly with the industry. This literature review begins with a breakdown of the CCS process and history of CCS in the US. It then explains why CCS is critical to achieving a carbon neutral society. The next Subsection explains the nuts and bolts of federal EPA permitting, and the final section gives an overview of the industry specifically in California.

A. Overview and History of CCS in the US

CCS is the process by which CO_2 is captured from a carbon source, transported to a well, and pumped underground. Varnäs, et. al. (2012) studied the technology development of CCS, and found that even in 2012, CCS was not a new technology, but was a developed technology that is being improved and employed for new purposes. The process is as follows.

CO_2 can be captured from sources that create CO_2 streams, such as bioenergy plants (BECCS), electricity generation plants, cement plants, or direct air capture (DAC) facilities.

Transportation from the source to the well takes place either by pipeline, rail, truck, or ship depending on infrastructure and distance of travel (Varnäs, et. al. 2012). Transportation occurs while the carbon dioxide is either in liquid, gaseous, or supercritical phase (a cold, high pressure physical state in between liquid and gas). Geological sequestration is the process of sequestering carbon dioxide in geological formations deep underground through sequestration wells. The CO_2 is pumped into the wells in a supercritical phase, which allows high volumes of fluid to flow freely deep below the earth's surface. The wells are typically over a mile deep, and are required not to leak for at least 100 years, but most will likely store carbon for thousands of years.

The US government has supported CCS development since 1997 when it first invested in CCS research and development. In the early 2000s, CCS as a US industry was inhibited by a lack of unified climate policy, but pushed forward by the development of Enhanced Oil Recovery (EOR) and the need for clean coal. EOR is the process of injecting CO_2 into the ground below spent oil fields to push oil up and make it accessible. EOR played the role in the U.S. that carbon markets played in the EU during the early 2000s, as it provided an economic incentive for geological sequestration (Varnäs, et. al., 2012). Because EOR extends the life of oilfields and reduces the carbon emissions of fossil fuels, the early association between EOR and CCS brought about most of the opposition by environmental groups in California seen today.

Beyond having no viable economic profit apart from EOR, another thing that makes CCS economically unviable is the transportation cost of CO_2. Large scale CCS associated with Carbon from ethanol would not be viable apart from government assistance (Edwards, R. & Celia, M., 2018). One of the challenges the article found is that often the location of sources of CO_2 are not geographically located near plausible sequestration sites. Thus, CCS development will require significant infrastructure development, and transporting CO_2 at large scales is expensive apart from pipelines (Edwards & Celia, 2018). CO_2 emitters considering CCS must factor in either the capital cost of building a pipeline (which could cost over two million dollars a mile), or the operating costs of filling trucks or rail cars, driving the CO_2 to the site, and offloading.

Governments have acknowledged the benefits of CCS and are responding by incentivizing it through research and development, tax credits, and carbon markets. The US government has supported CCS development since 1997, when the US Department of Energy (DOE) began funding CCS through R&D in the Fossil Energy and Carbon Management (FECM) office (Jones, A. C., Lawson, A. C., 2022). In 2009, CCS became a priority of the U.S. government when DOE announced investment of 3.4 billion dollars in CCS R&D, recognizing it as critical to decarbonization (Chu, 2009). The Congressional Research Service also outlines the government involvement in CCS since 1997 (Jones, A. C., Lawson, A. C., 2022). At a federal level, the U.S. has established the 45Q tax credit, which provides up to 180 dollars per ton (as of the passage of the IRA in 2022) to capture and sequester carbon.

B. Environmental Benefits of CCS

Numerous industries in the US are hard if not impossible to decarbonize. While reducing the carbon intensity of industries is critical, identifying technologies that can actually remove carbon from the atmosphere are essential to carbon neutrality. In 2020 Lawrence Livermore National Laboratories ("LLNL") came out with an extensive report on how California could get to carbon neutrality (Baker, S. E. et. al., 2020). This study accentuated the need for CCS in California, and came from a well-respected institution. The report provided an in-depth analysis of California's "toolbox" to get to neutral, which included natural solutions such as soils and forest management, waste biomass conversion to energy, and direct air capture. Sequestration is required for the last two to be carbon neutral or carbon negative. Thus, two of the three most significant pathways to carbon neutrality in California require sequestration. Two other CDR processes are actively being considered: carbon storage in oceans and enhanced weathering. Both of these processes are less developed and not ready for large scale implementation, but they could lessen dependence on CCS in the medium to long term.

Both the federal and California state government have identified CCS as necessary to reaching federal and state climate goals. In its 2022 Scoping Plan, California set the target of carbon neutrality by 2045. This plan requires the state to sequester100 million metric tons of CO_2 (MMTCO2) per year by 2045 (California Air Resources Board, 2022). The US White House released a document in 2021 laying out the US commitment and strategy to reach carbon neutrality by 2050 (United States Executive Office of the President, 2021). This goal is closely aligned with the state goal established the following year.

The scale of reaching carbon neutrality is so large that experts are skeptical that it can be done. One estimate suggests that 30 gigatons per year must be removed from the atmosphere to bring the US to carbon neutrality. This would require the development of around 30,000 large scale direct air capture (DAC) facilities. For comparison, 10,000 coal power plants have been developed in the US (Smith, D. C., 2023). At a state scale, the average Class VI permit application is for 1.336 MMTCO2 per year. At this scale, the US would need 22,455 Class VI CCS wells by 2050 to sequester enough carbon to reach carbon neutrality. The Smith article goes on to address the feasibility of scaling sequestration as well as CDR broadly, to reach carbon neutrality. The rise of the feasibility and popularity of the Bioenergy with Carbon Capture and Storage (BECCS) industry in California, featured in the LLNL Report as well as additional articles (Mayor, B. 2018), also highlighted the need for CCS if the bioenergy industry were to be carbon negative in California. On every account, CCS is a critical component of the state and federal goals to reach carbon neutrality.

C. The Federal Permitting Process

The EPA regulates all types of wells in the US, and does so under its authority to protect water sources. Up until 2013, CCS injection was regulated as a Class II well, which is specifically for EOR (Steincamp, 2021). Because the amount of carbon sequestered is so different between EOR and general CCS, and because CCS for carbon reduction served a completely different purpose, it started to make sense to separate carbon wells for EOR from carbon wells for CDR projects.

In order to respond to the heightened demand for CCS projects, in 2013 the U.S. EPA developed a new class of permit specifically for these projects – Class VI permits. There are currently 187 CCS projects that are either in the Class VI permitting process or that have been permitted as of November 2023. Currently, only two projects have been granted full permits and two projects granted draft permits (Grove, 2023). The EPA has been swamped by permits since the passage of the Inflation Reduction Act ("IRA") in 2022, and there is much uncertainty around the pace at which EPA can process these permits. The IRA expanded 45Q tax credits for CCS projects from fifty dollars per ton of carbon sequestered to eighty-five dollars per ton of carbon sequestered (or 180 dollars if sequestered from DAC). It also had numerous other incentives for renewable energy and related facilities, including a project construction tax credit. The IRA set off a major boom of renewable energy and related projects, including CCS.

The Class VI permitting process is clunky and not well known. Steincamp, et al. provide a legal background and framework for EPA's Class VI wells (2021). The purpose behind the article is that there had been very little use of Class VI wells in the first 8 years of its existence, and investors and developers were hesitant to develop these projects because of the uncertainty around the regulation of CCS. The problem was so significant that Congress created a task force for improving the process in December 2020.

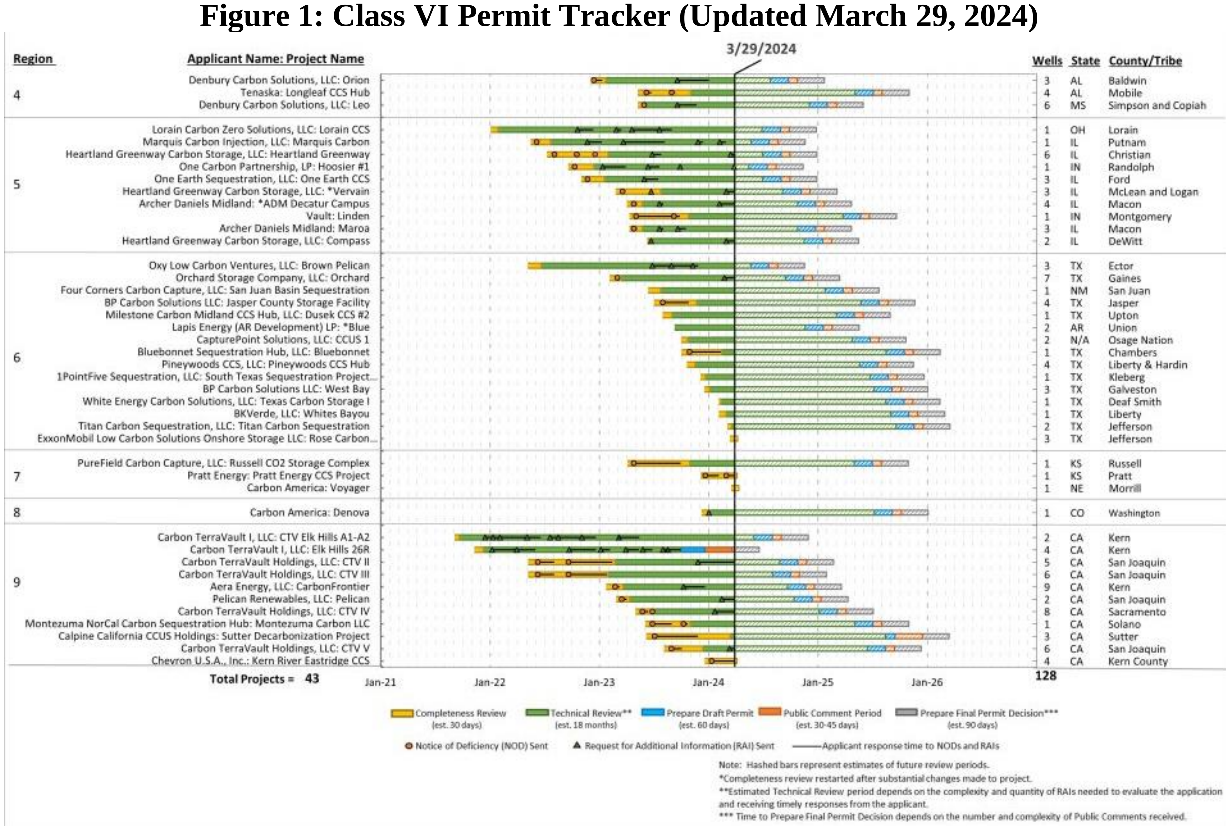
There are nine required plans in a Class VI application, as well as the four requirements for a project to be eligible for a Class VI permit (Steincamp, et al., 2021). The nine plans include: Summary of Operating and Reporting Requirements, Area of Review (AoR) and Corrective Action Plan, Testing and Monitoring Plan, Injection Well Plugging Plan, Post-Injection Site Care and Site Closure Plan, Emergency and Remedial Response Plan, Construction Details, Financial Assurance Demonstration, and Stimulation Plan. The AoR is the most difficult part of the plan in that it requires a comprehensive study of all the geology in the surrounding area with the purpose of proving that there is room for the carbon, but that it will not leak. The four requirements for eligibility are: (1) a suitable injection zone where the carbon can be stored, (2) a confining zone that will not allow seepage, (3) identification of all sources of underground drinking water to ensure carbon does not enter the water source, and (4) maintenance of the pressure in the injection zone.

D. CCS in California

Much of the information regarding CCS development in California comes from the EPA’s website “UIC [Underground Injection Control] Permits in EPA's Pacific Southwest (Region 9).” This official government site provides updated information on all UIC wells, including Class VI wells (13 permits). Data includes name, date of submission, location, number of injection wells, project description, injection volume, and application status/materials. The first application to be administratively complete was the Carbon Terra Vault Elk Hills project, which has been in technical review since September 20, 2021.

The EPA provides a very user-friendly chart of all of the projects being permitted in Region 9, and their past and future timelines. This will help the reader understand the length of these permitting processes, and contrast them to the EPA's stated goal of completing each permit in two years (See Figure 1). In order to expedite CCS permitting, the California state government has attempted to streamline permitting, yet environmental interests have opposed the governor's efforts, claiming that CCS is perpetuating the use of fossil fuels (Smith, D. C., 2023). The ultimate language passed by the California legislature was so watered down that it made the expedited process optional at the discretion of both the local government and the developer (California Health and Safety Code § 39741).

Figure 1: Class VI Permit Tracker (Updated March 29, 2024)



Source: United States Environmental Protection Agency, "Current Class VI Projects under Review at EPA."

Regarding incentives in California, the state government has incentivized CCS through the Low Carbon Fuel Standard (“LCFS”), which requires energy importers and producers whose fuel is above a specific emissions threshold to purchase credits from energy producers who are below the emissions threshold. CCS is one way producers can lower their lifecycle emissions or carbon intensity (CI) and earn more credits. For example, a biofuels producer who is producing carbon neutral fuel, can make its fuel carbon negative by capturing and sequestering CO_2 from the production process. The lower the CI of a fuel, the more credits it is eligible for, economically incentivizing CCS. Because of its access to both the federal 45Q credits and the state LCFS credits, California is one of the most lucrative locations to develop CCS projects.

Another benefit of developing CCS in California is that there are prime locations for sequestration throughout the state, meaning that industrial projects that capture carbon should in theory have the potential for access to Class VI wells within a close proximity. Yet even transportation within close proximity would add significant costs.

Two unresolved legal issues that are complicating CCS permitting and development in California are the legal uncertainty around pour space ownership and unitization of sequestration fields. Pour space ownership is difficult in that even if mineral rights were transferred, sequestration rights are not transferred unless expressly mentioned in the agreement (Smith, D. C., 2023). This means that rights to sequester are gray under land of which mineral rights had been separated from surface rights without mentioning CCS. This issue needs to be clarified by the state government. Regarding unitization, at this point, one landowner can delay a sequestration project indefinitely even if all other landowners agree to allow sequestration under their land (Smith, D. C., 2023). Other states have resolved this issue through unitization, and

California is considering this option. Unitization is the process of aggregating the below surface rights within an area so that aquifers, mines, etc. can be operated by a single entity.

Another significant barrier to development of the industry is the cost of transportation. Even in California, most sites that could benefit from CCS are over fifty miles from the Class VI wells being permitted. CO2 must be transported either by pipeline, rail, or truck. While pipelines have almost zero operating costs compared to trucks or rail, they are extremely capital intensive and require lead time to permit and develop. Trucks and rail are readily accessible, but are extremely expensive. CCS networks are being developed to create economies of scale, and allow smaller carbon producers to participate in sequestration (Smith, D. C., 2023). Without developments in the affordability of transporting carbon, projects that otherwise could sequester carbon will choose not to sequester.

Based on a comprehensive review of CDR in California, Smith (2023) recommends the following policy options: federal funding, state primacy of Class VI wells, integrated federal and state environmental review, national backbone pipeline infrastructure, consolidated federal permit review, consolidated state and local review, and finite timelines for all stakeholders, regulators, and applicants. Some of these policy recommendations or their corresponding problems were brought up in the expert interviews for this paper as well. They will be explored further throughout the remainder of this paper.

III. Description of Methodology

The research questions for the paper are: How does permitting, financing, CO_2 transportation, and property rights effect the pace and scale of carbon capture and sequestration (CCS) development as a carbon dioxide removal (CDR) solution? and what policy changes are necessary as the industry develops? A qualitative approach is necessary to answering this question because to date, no Class VI permits have been approved in California, and thus no permanent CCS is taking place. Because of this, there is very little data on the CCS industry and process. Only a handful of Class VI wells have been permitted nationally, making a quantitative study even at a national level difficult. Because the field is in such an early stage, the best understanding of what is going on is through expert interviews.

The sampling approach for this paper consists of *convenience sampling* targeted at a very specific subset of industry experts, and *network sampling* based on recommendations from each expert interviewed. Ultimately thirty-five industry experts were identified. Due to not finding everyone's email address, twenty-five were emailed requesting an expert interview (for email draft, see Appendix I). The twenty-five industry experts consist of government officials, CCS project developers, BECCS developers, non-profit industry experts, and national lab researchers. Many were identified through official correspondence between the EPA and developers regarding their Class VI permit applications. Others were identified through personal connections, or through network sampling. Of the twenty-five emailed, six responded in the affirmative willing to interview. The six interviewees include a CCS developer, a high-level federal employee, a high-level state employee, a non-profit expert, a national lab researcher, and a BECCS developer.

The structure of the data collection for the paper is semi-structured interviews. The interviews began by identifying whether the expert has experience in (1) permitting, (2) financing, (3) transportation, and/or (4) property rights. Based on the expert's answers, I asked initial questions regarding one, two, three, or all four of the topics. Appendix II includes the discussion guide for the interviews. I asked follow-up questions to the initial questions based on the expert's answers, leading to a constructive and semi-structured conversation. My interviews were between thirty and forty-five minutes, and transcripts included between 3,000 and 8,000 words.

The interviews were conducted over Zoom and the sessions were recorded. Using Zoom allowed for the use of the automatic transcribe function, and the transcriptions were automatically saved in the cloud. The RADaR methodology was then used to enter the transcript into excel. RADaR stands for rigorous and accelerated data reduction and is a methodology introduced by D. C. Watkins (2017) to more effectively organize and analyze data. The first step in the RADaR process is to compile the entire transcript in one Word or Excel document. Then in a new tab the researcher culls the data and cuts out unnecessary commentary. This step is repeated until the data includes concise comments directly relating to the research questions. Each line is given a code based on a codebook of topics and subtopics so that the data can be organized by topic and subtopic. The information organized using the RADaR methodology was used to draft the following section, Empirical Results of Expert Interviews.

IV. Empirical Results of Expert Interviews

As noted before, the six expert interviewees included a CCS developer, a high-level federal employee, a high-level state employee, a non-profit expert, a national lab researcher, and a BECCS developer. Due to the wide variety of experts, each of the interviews were very different. This meant that there was very little duplication of comments. A summary of the findings from the interviews follows organized by the four issues affecting CCS development. Each introduction paragraph gives a summary of the interviews, and each concluding paragraph gives policy considerations based off the interviews as well as additional interviews that should be conducted. All ideas discussed in the body paragraphs are ideas raised by the interviewees.

A. Permitting

Experts on both sides of the permitting process, regulators, and developers, raised issues they have experienced with the permitting process, although from a government standpoint the process is developing smoothly, and not much information was received from the development side regarding permitting. The following are the main ideas raised by the interviewees.

Both government officials signaled that there were very few inefficiencies identified in the Class VI permitting process itself. The main message from both of them was that it is a new process so the kinks are still being worked out, but the more applications they complete, the more issues will become standard and easily addressable. One of the challenges of the Class VI permitting process is the significant amount of claimed Confidential Business Information (CBI). Most well permits have a few pages of information that is claimed CBI, but some of the Class VI applications are seventy-five percent CBI. This has made it very challenging for EPA to be transparent with the public about the projects, and has forced EPA to reevaluate what qualifies as CBI and how to handle CBI. Some projects claim the location itself as CBI, making it difficult to work with the communities on soliciting feedback or discovering local issues.

Another challenge identified by both government officials is that unlike most well permit applications, the Class VI applications include a whole ecosystem of tangential projects such as DAC, hydrogen production facilities, ethanol plants, oil refineries, pipelines, etc. This has made discerning what the EPA must get involved in and can get involved in more challenging. Under the Biden administration, federal regulators are encouraged to get involved in the tangential aspects of the project even though the EPA's primary responsibility is to permit for ground-water protection. California has CEQA permitting requirements, but many other states do not, so the federal government under the Biden administration is getting involved in the tangential aspects of projects to ensure environmental protection and environmental justice.

While the EPA manages the Class VI permitting process, the California Water Board also plays a critical role. The role of the Water Board is to work with both the EPA and with the local government to review how the project will affect surface water and ground water. The California Water Board is governed by the Porter Cologne Act, which is stricter than the Safe Drinking Water Act that governs the EPA. Thus, there may be points when the Water Board has to implement stricter parameters for Class VI than the EPA, although none have been identified yet as EPA has covered all the issues the Water Board would want to cover. The Water Board is still very uncertain about the Class VI process in general because the first project in Elk Hills has no effect on beneficial water use, and future projects will be much more complex from a water standpoint. Other issues that the Water Board is going to have to deal with are regulating pipelines and carbon capture facilities and their effect on surface water.

One challenge identified by one of the interviewees is that the California Water Board does not have review access for the Class VI permit until the permit is essentially complete. This adds additional time to the process as opposed to having the Water Board involved throughout the process. While the Elk Hills project did not have significant water related issues, in the future if the Water Board does not see the application until the public review period, it could cause significant delays as opposed to running parallel reviews.

Based on expert interviews, potential policy solutions to be considered are standardizing what qualifies as CBI, running a parallel review of Class VI permits with the state so applicants do not have to wait until the public comment period to address issues raised by the state, and requiring EPA to stay within its jurisdiction of groundwater protection. Additional interviews that would be beneficial include an interview directly with a CARB official as CARB is the lead agency for state permitting, and another interview with a developer focused more on permitting.

B. Transportation

Numerous experts had input specifically on CO_2 transportation, and raised numerous policy solutions. The general opinion is that little energy has been spent on innovated transportation solutions, and that as is, California's transportation infrastructure will be a significant hinderance to the CCS industry.

Two interviewees pointed out that pipelines are the golden ticket for CO_2 transport because they can move a tremendous volume at little cost. They are especially successful when there are large capture projects near sequestration sites. The problem is that due to the regulatory environment in California and the population density, it is nearly impossible to develop a large-scale pipeline system in the state. Further, even though they are safer than truck and rail, they have a strong negative public opinion. Even though trucks cause much more damage to life and property, people feel much more comfortable with trucks than with pipelines. Further, one of the interviewee's organizations found that at smaller scales, moving CO_2 by truck or rail is much cheaper than pipeline because of the infrastructure required for pipelines. Thus, the state must shift its focus to truck, rail, and barge.

Because there has been a demand for CO_2 in California for a century, there is significant technology development in truck and rail transportation of CO_2. CO_2 has primarily been transported for food grade use so transportation is not optimized for large scale injection, and little energy has been exerted in recent years to innovate. The baseline for transporting via truck or rail is transporting it in liquid phase. There are three problems with liquid state transportation. The first is that it takes significant energy to liquify CO_2, and then additional energy to convert it to supercritical phase at the injection site. Second, liquid CO_2 is extremely cold, and as it warms, pressure increases and some of the CO_2 must be released from the container. This ultimately leads to less CO_2 stored. Third, if a pipeline is ever installed from the CO_2 capture facility, all the capital to convert CO_2 to liquid becomes stranded assets because CO_2 must be in supercritical state to be transported via pipeline.

Two interviewees identified that the solution to this problem is to transport CO_2 in supercritical state. Doing so would allow it to be transferred to a pipeline, or directly to the injection facility without having to change the state from liquid to supercritical. This would also deem pipeline hubs more feasible as numerous small projects could truck CO_2 over short distance and inject into a pipeline. The policy problem is that CO_2 cannot efficiently be transported via truck in supercritical state because the only DOT certified trailer is a thick steel container that is too heavy. There is a fiber reenforced polymer container that is much lighter, but it is not certified by DOT to transport CO_2. The certification would take five to ten years, and to the interviewees' knowledge, no one is going through this process at the time. The DOT certification time may also depend on the political party in power at the federal level. If the administration is prioritizing solutions to get to carbon neutral, it could be permitted much faster than if its not a priority. Further, the barge should be a lot easier to permit than the same containers for truck or rail due to the dangers of on-road travel as well as potential risks associated with transporting fluid at high pressures.

Another policy solution raised by one interviewee to provide ample truck transportation is to create a seamless certification transition between gasoline truck drivers and CO_2 truck drivers. As California shifts away from gasoline, an order of magnitude more trucks will be coming off the road than are needed to transport CO_2, so if the state could develop a easy transition program from gasoline driving to CO_2 driving, that could be effective.

Transportation by barge is another low cost and technologically ready option that three interviewees identified. Developers are working with the world's largest marine transportation companies on solutions. The primary issue with barge is that the sequestration sites must be near deep water ports, making them effective in the Delta and along the coast, but nowhere else. Still there is significant pour space as well as a limited number of property owners and usable land, making the Delta a prime location for CCS, and barge a viable transportation option. The other benefit is that CO_2 can be brought in from around the world. Conversations are being had by interviewees with Japan about bringing CO_2 in to sequester. Japan is an interesting participant in that they have significant CO_2 but do not have the geology to sequester it.

Two interviewees pointed out that the largest problem with transportation is that no one is focusing on developing the industry. One policy solution raised is to provide grants for innovative transportation solutions, something that is not happening right now. Another solution is simply meeting with state legislators to raise awareness of the transportation challenges that must be overcome if California is to scale CCS. There also needs to be communication with transportation companies about why it would be worth their time to invest in infrastructure, paired with government support for infrastructure to kickstart the industry.

Based on the expert interviews, policy solutions in the CO_2 transportation space include (1) permitting carbon reinforced polymer containers to transport CO_2 through the US DOT, (2) developing a pipeline network, (3) creating a simple transition process for fossil fuel drivers to become CO_2 drivers, and (4) developing grants for innovative transportation solutions.

C. Financing

Overall, interviewees believe these projects will continue to be financed, especially biofuels and oil refinery-based projects, with DAC projects not yet penciling. There are also grant opportunities for developers, including DOE's CarbonSAFE grant. The greatest concern is that the market for CCS is entirely government dependent, vulnerable to political decisions, and unpredictable, causing financers to hesitate when considering whether to enter the market.

One cost estimate for a CCS project was between 150 million dollars and 200 million dollars. An interviewee directly involved in project development noted that the ethanol-based projects and the oil projects at this cost pencil great. What is not penciling yet are the DAC projects, but as the industry develops and costs drop, DAC will pencil. There is also expectation that incentives will only increase for CCS projects, which is already being seen by a floor for the LCFS.

Some developers in California are applying for the CarbonSAFE grant provided by the US Department of Energy (DOE), which provides tens of millions of dollars available for CCS projects and requires a twenty percent match. Even without this grant, developers believe financing will come through since the projects pencil and private equity want these projects for DEI reasons. Yet some developers would prefer not to use private equity because then the developers lose control of their project.

One of the primary issues with financing is that the LCFS market is so unstable. Because the credits are market driven, when the market is saturated, the LCFS price drops drastically.

CARB can fix this issue by setting a floor for the LCFS price. The floor can be driven by tightening emissions standards if the price drops below a certain point. One interviewee added that the RINs market is also highly unstable, and a conservative administration can easily tank RIN price as was done in the last administration through exempting small oil refineries from having to participate in the RIN market.

The permitting process is also risky and the outcome uncertain, leading one of the interviewees to believe CCS developers are spending hundreds of millions of dollars on the permitting process. Because developers are spending so much money to get these projects developed, they have to be hyper-aware of the political climate, and chance of permitting success.

Another obstacle to financing raised by one interviewee is cheap electricity. Almost all of the operating cost for CO_2 capture projects comes from cost of electricity. California is in a situation where electricity production is a couple cents, but distribution costs are seventeen to forty cents due to the complexity of selling or transferring electricity on the grid. This strongly incentivizes owning electricity production, but even if a company has their own electricity production but it is in a different location, it is very difficult to transfer. One solution to this problem is utilizing the grid through low-cost battery storage. If low-cost battery storage were available, then the grid could transfer twice the electricity it does today because it can be moving at peak load 24 hours a day.

The LCFS incentive encourages as much CCS as possible because the lower the carbon intensity (CI), the higher the credit, but the federal credit is the main incentive, and it is not pinned directly to CI. Thus BECCS developers are incentivized by 45V credits to get to a zero CI, then sell the rest of their CO_2 for utilization. One interviewee also commented that CCS is an artificial market, and many would prefer to use their CO_2 to produce other fuels. Because there are incentives for this as well, BECCS developers are considering producing methanol, or other high value fuels, instead of sequestering.

Based on issues raised by the interviewees, policy solutions in the financing space include (1) providing additional grants for development, (2) stabilizing the LCFS price floor, (3) extending the life of 45Q credits, (4) developing battery storage to reduce the cost of electricity, and (5) deregulating the electricity market to make using cheap electricity easier.

D. Property Rights

Property rights is one of the trickiest issues to deal with in the CCS industry. There is significant pressure to either unitize mineral rights or require remaining landowners to participate in CCS if owners of seventy-five percent of the land agree to move forward with a CCS project. While only one interviewee discussed property rights in depth, the interviewee raised numerous important points.

Property rights play a critical part in financing. When the big developers first started talking with landowners, they were offering one-hundred dollars per acre one-time payment to sequester under their land. Within a few years, that price had gone up to five-thousand dollars per acre plus a four dollar per ton tipping fee for each ton sequestered. Yet for uneducated landowners, developers are still offering low prices. The goal of the oil and gas companies in the game is to grab as much land for sequestration at the lowest price. For this reason, individuals are trying to educate landowners on the true value of their pour space.

The establishment of regulations under SB905 will play a critical role in defining property rights in relation to CCS. Large developers are thought to have had influence on these regulations, as in their current form they would force land owners of the last twenty-five percent of land to comply with the CCS project once seventy-five percent of land in an area agrees to develop. This can be used as a tool by large landowners and companies to strong-arm smaller landowners into participating against their will. If these landowners were offered the true value of their pour space, the eminent domain provision in SB905 would not be needed, but the provision allows large developers to get away with paying less than market price for pour space.

Once CO2 is injected, the underground plume can never again be pierced, as it would cause CO_2 to leak. Thus, when landowners agree, or are forced to participate in CCS, they are permanently giving up almost all of their mineral rights. For this reason, efforts are being made to show CARB and the California Department of Conservation (CA DOC) that as written, the SB905 regulations are illegal in that they cause forced takings of property without just compensation. These efforts have delayed the release of the text of the regulations as the state tries to address these issues. In the meantime, both Bloomberg and Lawrence Livermore National Labs have come out with papers on the true cost of CCS. Knowledge is power, and this is giving power to the landowners to receive just compensation for their land. This is going to push the CA DOC to include a royalty structure for landowners in its release of regulations.

The oil and gas developers want California to believe that these essential projects are never going to be developed apart from forced participation, but if landowners are justly compensated, there is ample pour space. Other developers are working directly with landowners to cooperatively stand-up projects, and when landowners can see the benefits and participate directly, they are eager to participate.

Based on comments from the one expert interview addressing property rights, one policy solution to expedite CCS development is to establish the regulation included in SB 905 that would require that if landowners of seventy-five percent of the land agree to sequester, the final twenty-five percent of landowners would be forced to participate, making it easier to develop CCS projects. An alternative option would be to provide equal access to information for property owners so that they can make informed decisions about the value of pour space.

V. Policy Analysis

The questions being addressed in the paper are: How does permitting, financing, CO_2 transportation, and property rights affect the pace and scale of carbon capture and sequestration (CCS) development as a carbon dioxide removal (CDR) solution? And what policy changes are necessary as the industry develops? Fourteen potential policy solutions arose in response to the expert interviews across the four categories identified in the research question. Two of the solutions will not be addressed as they have to do with lowering cost of electricity in California, which is outside the scope of this paper but would have significant impact on the industry.

The twelve remaining policy solutions are analyzed and ranked on a scale of one to five under three separate criteria (see Table 1). The top solutions in each category are identified, as well as the top solutions over-all, leading to the final policy recommendation. The three criteria used to weigh each option include **affordability**, **effectiveness**, and **legal/political feasibility**. Affordability refers to the cost to both the government and the population as a whole. Costs range from estimated hundreds of thousands of dollars to implement Policy 1, which is given a five for affordability, to billions of dollars for Policies 5 and 10. Effectiveness refers to how effective the policy would be in scaling the CCS industry. Effectiveness ranges from Policies 1 and 2, which save permittees a few months of time and were given a two, and Policy 5, which would give pipeline access to the state, and was given a five. Legal/political feasibility refers to how plausible the policy is from either a legal or political standpoint (whichever is lower). Feasibility ranges from Policy 11, which would forcefully take property rights away from landowners below cost and was given a zero, to Policy 1, which is a simple update to the Class VI permitting process by EPA and was given a five.

Table 1: Policy Solution Rankings

#	Policy Solution	Affordability	Effectiveness	Legal/ political Feasibility	**Total**
	Permitting				
1	Streamline CBI definition and integrate into application process	5	2	5	**12**
2	Run parallel review for state agencies so they do not wait until public comment to review for the first time	5	2	4	**11**
3	Require EPA to stay in its regulatory jurisdiction by focusing on drinking water protection	5	3	3	**11**
	Transportation				
4	Permit carbon reinforced polymer containers to transport CO_2 through the US DOT	4	4	4	**12**
5	Develop a pipeline network in California	1	5	2	**8**
6	Create a simple transition process for fossil fuel drivers to become CO_2 drivers	4	1	4	**9**
7	Develop grants for innovative transportation solutions	3	2	4	**9**
	Financing				
8	Provide additional grants for project development	2	4	4	**10**
9	stabilize the LCFS price floor	1	4	3	**8**
10	Extend the life of 45Q credits	0	4	2	**6**
	Property Rights				
11	Implement 75% unitization rule in the SB905 regulations	2	4	3	**8**
12	Educate landowners on value of pour space	5	2	4	**11**

Regarding the permitting policy solutions, Policy 1 is to streamline the definition of Confidential Business Information (CBI) in Class VI permits and integrate the definition into the application process. The costs are minimal and would include the staff time to come up with a unified definition, and integrate the requirements into the application process. Applications that did not comply with the definition of CBI would be returned to the applicant to be updated and resubmitted. It ranked low in effectiveness in that it would simply cut application times by a matter of months. It scored high on feasibility because it is non-controversial and is identified as a need by regional offices. Over all Policy 1 scored a twelve and is recommended.

Policy 2 would require EPA to run a parallel review process to give states the ability to view the Class VI applications before public comment. It Scored high in affordability because the only costs would be the staff time to provide state and local governments access to drafts of the Class VI permits. It scored low in effectiveness because like Policy 1, it would simply shave a few months off the application process. It scored a four out of five in feasibility because while it is legal, the EPA regional offices may push back against the requirement due to the complicating factors associated with parallel review. Overall, Policy 2 scored an eleven and is recommended.

Policy 3 would require the EPA to narrow the scope of its Class VI permit review to consider only the effects on potentially drinkable ground water as is provided in the Safe Drinking Water Act. It is proposed due to finds from the expert interviews that under this administration, through the Class VI process the EPA was getting involved in all aspects of CCS project development. It scored high in affordability in that it should save the EPA money by narrowing the staff time required for review of Class VI applications. It scored relatively average in effectiveness because it should simplify the Class VI permitting process and reduce duplicative work already being done by CARB in its permitting process, but will not have a significant effect on permits granted and permit processing time. It scored a three on feasibility because under the current administration it is impossible since the administration prioritizes environmental justice and the climate crisis over regulatory overreach, but if a conservative administration were to be elected in November, it would be very feasible due to the new administration's opposition to regulatory overreach at the EPA. Overall, Policy 3 scored an eleven, and is recommended.

Policy 4 is a permitting solution that would qualify carbon reinforced polymer containers to transport CO_2. The permit would be processed by the US DOT. It scored high on affordability in that it would consist of going through the permitting process for one type of container, a process that is occurring regularly for different technological advancements in transportation solutions. It scored high on effectiveness because if it were to become an option, it would allow seamless transitions between CO_2 capture facilities, trucks, rail, pipelines, and sequestration facilities. This solution saves money and energy, further reducing emissions. It also scored high on feasibility because there should be little legal or political concern. The only identified concern is that it is operating at very high pressure. Another factor not considered by the metrics is the timeline of five to ten years that it could take. Even considering the long timeline, Policy 4 scored a twelve, and is recommended.

Policy 5 would develop a comprehensive CO_2 pipeline network throughout California so that all projects from Bakersfield to Sacramento would have easy access to an injection site. While this would be a significant boost for the industry, and thus scored high in effectiveness, it faces serious hurdles. First, conservatively it would cost over two million dollars per mile (Wallace, M. et al., 2015). This means that a five-hundred-mile pipeline network would cost over a billion dollars. The even greater dilemma for this policy would be the political feasibility. The public opinion regarding pipelines is extremely negative, and projects even in rural prodevelopment states have gotten shut down due to public opposition. The legal challenges with running a new pipeline down the center of the state would be extremely complex and would take years to develop. For the above reasons, Policy 5 scores an eight, and is not recommended.

Policy 6 would create a streamlined transition process for truck drivers certified to transport petroleum products to become certified to transport CO_2. This solution scored high in affordability due to it simply being a coordination effort to help drivers become certified in transporting similarly hazardous products. It scores low in effectiveness because finding the truck drivers to transport CO_2 is a minor issue that is seldom raised. It scored high in feasibility because it should be a straightforward administrative process that would not raise public concern or legal concern. Overall, Policy 6 scored a nine, and is not recommended.

Policy 7 would create a grant program to incentivize innovation in CO_2 transportation technology. This grant would most likely be housed in NSF, DOE, or CARB, and could be in the ballpark of fifty million dollars (the size of the SMART Grants Program awards announced in March 2024) (United States Department of Transportation, March 14, 2024). It is given a score of three in affordability due to this cost. It is also given a three in effectiveness due to the long lead time until any results are seen at a commercial scale, as well as the uncertainty of return on investment. It scores high in feasibility because grant programs like this are one of the standard services provided by these agencies. Overall, Policy 7 scores a nine, and is not recommended as a policy priority.

Policy 8 would create a grant program to subsidize project development for CCS, and would be very similar to Policy 7. This grant would most likely be housed in DOE or in CARB, or could simply provide additional funds to the already established CarbonSAFE Grant housed in the DOE. The cost is flexible, but could be in the ballpark of an additional one-hundred to two-hundred million dollars. It scores low in cost due to the significant expense. It scores high in effectiveness, in that it could kick-start an additional four to eight CCS projects in California if each project received twenty-five million dollars. Like Policy 7, it also scored high in feasibility in that it is a standard function of these agencies, and a similar grant program already exists. Overall, Policy 8 scores a ten, higher than Policy 7 due to its effectiveness, and is recommended as a policy priority.

Policy 9 would stabilize the LCFS floor be automatically lowering the carbon emissions threshold for emitters in California. The size of the LCFS market in 2021 was roughly 4.6 billion dollars, trading over twenty-five million credits at roughly eighty dollars per credit (PG&E, 2022). If the price floor were raised even twenty dollars above the market price, it would cost emitters over a billion dollars per year. Because of this price tag, it scores low in affordability. It scores high in effectiveness, because LCFS market certainty would bring financers to the table, as long as they are certain the floor is set long-term. The policy scores three in feasibility in that it is being considered in the legislature, but there may be opposition to ratcheting emissions standards even lower than companies are already having to deal with. Overall, Policy 9 scores an eight, and is not recommended as a policy priority.

Policy 10 would extend the life of the 45Q credit. The cost of the 45Q is estimated to be at thirty-two billion dollars between 2022 and 2032, extending the life of these credits would have significant costs to the American taxpayer beginning ten years from now, in the amount of billions of dollars per year for each year extended. Thus is scores very low on affordability. It scores very high on effectiveness, as longer life of these credits could allow the credits to last the span of the loans needed to finance these projects, guaranteeing financing. The policy scores very low in political feasibility as the House is controlled by the Republicans, and there is no appetite for additional renewable energy spending after the IRA and in a presidential election year. Overall, Policy 10 scores a six, and is not recommended as a policy priority.

Policy 11 would implement the SB905 provision that allows owners of seventy-five percent of the land to begin the process of unitization, given reasonable compensation to the remaining twenty-five percent of landowners. This policy scores low on affordability because without equal access to information, landowners will end up being forced to settle for compensation below their true value. If 100,000 acres worth of landowners settled for two-thousand dollars less per acre than their true value, that is two-hundred million dollars in lost revenue to California property owners, pocketed by oil corporations such as CRC or Chevron. It scores high on effectiveness as it would allow a mechanism by which CCS projects only need seventy-five percent approval as opposed to one-hundred percent approval to move forward. The policy scores a three on feasibility due to the realization that as written, the regulations may be considered a taking without just compensation. Overall, Policy 11 scores an eight, and is not recommended as a policy priority. Note that if it were implemented after Policy 12, which would give landowners equal access to information, then its affordability rating would rise, and it could be recommended as a policy priority.

Policy 12 would provide landowners with equal access to information regarding costs and true value of their pour space. It would do so through working with willing developers to distribute actual costs and profits from CCS projects. At this point the landowners are largely in the dark as to the value of their pour space, giving CCS developers the opportunity to take advantage of them. This policy is high in affordability as it would simply be an information campaign to reach landowners throughout the Sacramento and San Joaquin Valleys and the Delta region. It scores low on effectiveness in that it does not do much to directly expand the CCS industry in California, and in some cases may limit it through making negotiations between CCS developers and landowners more challenging. It scores high in feasibility in that it should be generally non-controversial and legal. The only major political opposition would come from major CCS developers who are currently trying to tie up pour space in California. Overall, Policy 12 scores an eleven, and is recommended as a policy priority.

VI. Conclusion

The analysis of the policy options considering affordability, effectiveness in improving the CCS industry, and legal/political feasibility, recommends that policy makers and industry advocates prioritize Policies 1, 2, 3, 4, 8, and 12. The selections were made by taking the top half of the scores, policies that scored ten or higher. The lowest hanging fruit are the permitting related policies, 1 through 3, which are all affordable and feasible. Implementing these policies should reduce Class VI permitting by a matter of months to a year, and keep EPA from veering into review of issues it does not have regulatory authority over. Policy 4 would allow for a more coordinated and agile transportation infrastructure that avoids the energy and capital required to change the physical state of CO_2 numerous times between capture and sequestration. Policy 8 would build off the current grants for project development, getting four to eight additional CCS projects into development in the next couple years. Policy 12 would level the playing field between developers and landowners, paving the way for an equitable unitization policy that would accurately compensate landowners who are forced into permanently giving up their mineral rights.

There are numerous strengths and weaknesses to this analysis. The first strength is the broad scope of expertise interviewed. Interviews were evenly split between private sector, public sector, and non-profit experts. This led to a broad range of perspectives and proposed policy solutions. Another strength of this analysis is that it provides policy solutions at every cost level and at both state and federal government level, meaning that state and federal policy makers with limited resources can make educated decisions about where to focus their limited energy and resources. A third strength of this analysis is that most of the proposed policy solutions are low-cost, other than the grant for CCS development.

One of the weaknesses of this analysis is the limited number of experts interviewed in the process. Interviewing additional project developers, landowners, and government officials specifically from CARB would make the interview findings more credible and less bias. A second weakness of this paper is the limited depth of analysis of each policy solution. Because of the number of proposals, the paper could not dive deeply into each one, even though each policy deserves its own paper. A final weakness is that the paper did not get much information from the private sector about challenges with the permitting process. Topics for further study include a deep dive into the regulations being drafted to comply with SB905. This process is ongoing by CA DOC, and will have significant impact on the industry. While the bill is mentioned numerous times throughout the paper, it is not analyzed in depth. Another topic for further study is the feasibility of short pipelines between carbon capture sites and sequestration sites. While state-wide pipeline infrastructure would be expensive and politically impractical, pipelines may still play a critical role in the development of the CCS industry.

Overall, CCS is a critical component of reaching carbon neutrality both in the state, and in the country. All aspects of the industry need to be closely analyzed over the coming years so that the industry can develop in a way that makes CCS economically feasible without coercing landowners into the industry without fair compensation. Both additional government funding for private development and simple fixes to the permitting process can go a long way in kickstarting the industry, and this analysis provides some low-hanging fruit that can be implemented quickly. As the industry develops, CCS has the opportunity to be a beacon of hope amongst the despair so often heard in climate conversations, and it is worth making CCS a policy priority both at the state and federal level.

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VIII. Appendices

E. Appendix 1: Email sent to expert interviewees

Good Morning,

My name is Noah Jackson and I am a Master of Public Policy candidate at Pepperdine University, originally from Central California. My background is in biofuels project development in California, as well as public service at the US Department of Agriculture.

I am doing a research project on Carbon Dioxide Removal (CDR), and specifically geological sequestration in the state. My plan is to use my research to analyze the current status of the CCS industry in California, including strengths weaknesses, development since the establishment of Class VI permits, and any bottlenecks that may exist.

Would you be willing to participate in a 20-minute expert interview on the topic of carbon sequestration (specifically permitting, financing, and/or CO2 transportation)? All responses will be anonymous and aggregated into general summaries, and interviewees will not be identified by name or organization. Your contribution would be greatly appreciated due to your extensive expertise in the field.

Please respond by **Tuesday, March 12** if you are able to participate. Thank you for your consideration, I look forward to hearing from you!

Sincerely,

Noah Jackson
MPP Candidate, Class of 2024
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(559)790-5155

F. Appendix 2: Discussion Guide

*Note that while these questions were used as a guide to stimulate conversation, most of the interviews did not follow the questions strictly.

1. Interview directing question: Which aspects of geological sequestration do you have experience in? Permitting, Finance, Transportation
2. Project permitting
    a. How have you been involved in the Class VI permitting process?
    b. In your experience, are there bottlenecks in the permitting process? If so, what are they?
    c. Regarding project permitting (Class VI or state/local), are there aspects of the permitting process that are not thorough enough or too thorough? If so, which aspects?
    d. Are there specific policy solutions that should be implemented to address any of the above concerns?
3. Finance
    a. Is CCS economically viable after receiving 45Q and LCFS credits? Why or why not?
    b. What are potential financers' greatest concerns or hesitations when considering investment?
    c. If you are developing a project, which credits is your project eligible for?
    d. Are there regulatory issues that are obstructing projects from receiving credits? If so, do you have ideas about policy changes?
4. CO2 Transportation
    a. How is CO2 transportation infrastructure helping or hindering development of CCS projects?
    b. Is cost effective CO2 transportation available? Which form of transportation is most cost effective?
    c. What would make CO2 transportation more cost effective?
    d. Are there policy solutions needed to develop transportation infrastructure?
5. Property Rights
    a. How are property rights affecting the development of CCS in California?
    b. What are the challenges regarding the interface of property rights and CCS?
    c. Are there recommended policy solutions to clarify property rights in relation to CCS?
6. Closing question: Do you have any other recommended industry experts I should reach out to or that you would be willing to connect me with?

G. Appendix 3: Excel with data and graphs used in descriptive analysis

See attached excel titled “Jackson, Capstone Dataset FINAL.”