An Action Plan for Carbon Capture and Storage in California: Opportunities, Challenges, and Solutions

SUMMARY FOR POLICYMAKERS

A joint study by:

ENERGY FUTURES INITIATIVE

Stanford | Precourt Institute for Energy

Stanford EARTH | Stanford Center for Carbon Storage

October 2020

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Suggested Citation: Energy Futures Initiative and Stanford University. "An Action Plan for Carbon Capture and Storage in California: Opportunities, Challenges, and Solutions." October 2020.

Revision 2, December 11, 2020

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The Energy Futures Initiative and Stanford University would like to thank the following organizations for sponsoring this report.

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Summary for Policymakers

California is a leader in addressing climate change. With some of the strongest decarbonization targets in the country—40 percent emission reductions by 2030, carbon neutrality by 2045, and net-negative emissions thereafter—California continues to pursue innovative policies to achieve ambitious emissions reductions.

At the same time, the impacts of climate change are becoming increasingly clear and common, and have had devastating impacts on the state: wildfires that have burned over four million acres; droughts; and heatwaves, like those that precipitated rolling electricity blackouts across California in August 2020. Average temperatures across the state are increasing, with Southern California warming by about 3 degrees Fahrenheit (°F) in the last century.[1] In comparison, California warmed approximately 1.5°F over the course of the previous century.[2]

Successful policy pathways for achieving California's ambitious emission reduction targets are critical. Additional and accelerated actions are needed to ensure that the state successfully transitions to a carbon-neutral economy both economically and equitably. With the world's fifth-largest economy, California's success in meeting its statewide targets has significant implications for the global climate.

California has a strong economic base, skilled workforce, and robust innovation capacity at its laboratories, universities, and technology companies. California must rely on these strengths and foundations while building powerful coalitions of policymakers, citizens, environmental and social justice advocates, industry leaders, and scientists to achieve its climate goals. California's leadership and citizenry are focused on the core objective—a net-zero greenhouse gas (GHG) emissions economy—using the full range of options to help meet this difficult but critical goal. California cannot afford to limit its flexibility by eliminating technology options or pursuing unfocused or suboptimal policies that may hinder, rather than accelerate, decarbonization.

This study, *An Action Plan for Carbon Capture and Storage in California: Opportunities, Challenges, and Solutions*, provides policymakers with options for near-term actions to deploy carbon capture and storage (CCS), a clean technology pathway well suited for rapidly reducing emissions from economically vital sectors in California that have few other options to decarbonize. This analysis builds on previous work, including the Energy Futures Initiative's (EFI) 2019 report *Optionality, Flexibility, and Innovation: Pathways for Deep Decarbonization in California,* which concluded that the targeted use of CCS could be one of the largest single contributors to California's decarbonization by 2030, and contribute to deep decarbonization by midcentury as well.[3]

CCS, like all other emission reduction technologies, is not a "silver bullet" technology for decarbonization. Carbon capture paired with permanent geologic storage (e.g. deep saline reservoir) offers a viable and important option for reducing emissions from the industrial and electricity sectors that are key contributors to California's economy and the reliability of its grid. Several industries—chemicals, transportation fuels, cement, plastics, and rubber products—rely on facilities that are large sources of emissions. With CCS, these facilities and sectors could be rapidly decarbonized and continue to make major contributions to the state's economy while helping it meet its near-term and midcentury climate targets.

Forty-three percent of California's in-state electricity generation in 2019 was natural gas-fired.[4] In addition to being the largest fuel source for in-state power generation, natural gas remains a prominent source of firm generation for California. In the power sector, CCS can be paired with natural gas combined cycle (NGCC) power plants to create a "clean firm" resource, which multiple studies identify as critical for maintaining grid reliability and managing energy system costs as California continues to build out its renewable resources. An analysis of California's pathways for achieving its Senate Bill (SB) 100 goals indicated that California will need approximately 30 gigawatts (GW) of clean firm generation resources[a,5] to cost-effectively decarbonize its grid.[6] The value of clean firm generation should not be underestimated through the clean energy transition.

Technoeconomic analysis done for this study identified 76 existing electricity generation and industrial facilities in California as candidates for CCS, representing close to 15 percent of the state's current GHG emissions. To put this in perspective, in 2017, California's buildings sector was responsible for 10 percent of its emissions and its power sector emitted 15 percent of the total.[7]

CCS is a strong complement to other decarbonization strategies. For California's cement industry, CCS is considered one of the most cost-effective carbon reduction options and supports other strategies like increased energy efficiency, clinker substitution, and fuel switching.[8]

CO_2 storage is a critical enabler of prominent carbon dioxide removal (CDR) pathways, including: direct air capture (DAC) and conversion of waste biomass to zero- or negative-carbon transportation fuels and electricity.

As of September 2020, there were five announced CCS projects in varying stages of planning and development in California.[b] These projects will provide valuable lessons learned for future project developers, policymakers, and regulators. The design of these early projects provides insight into the opportunities and challenges of pursuing CCS in California today. For example, the two projects closest to becoming operational leverage existing infrastructure and brownfield sites to manage total project costs, are designed to generate revenues in addition to those provided by policy incentives, and are co-located with CO_2 storage resources, eliminating the need to permit and build CO_2 pipeline infrastructure.

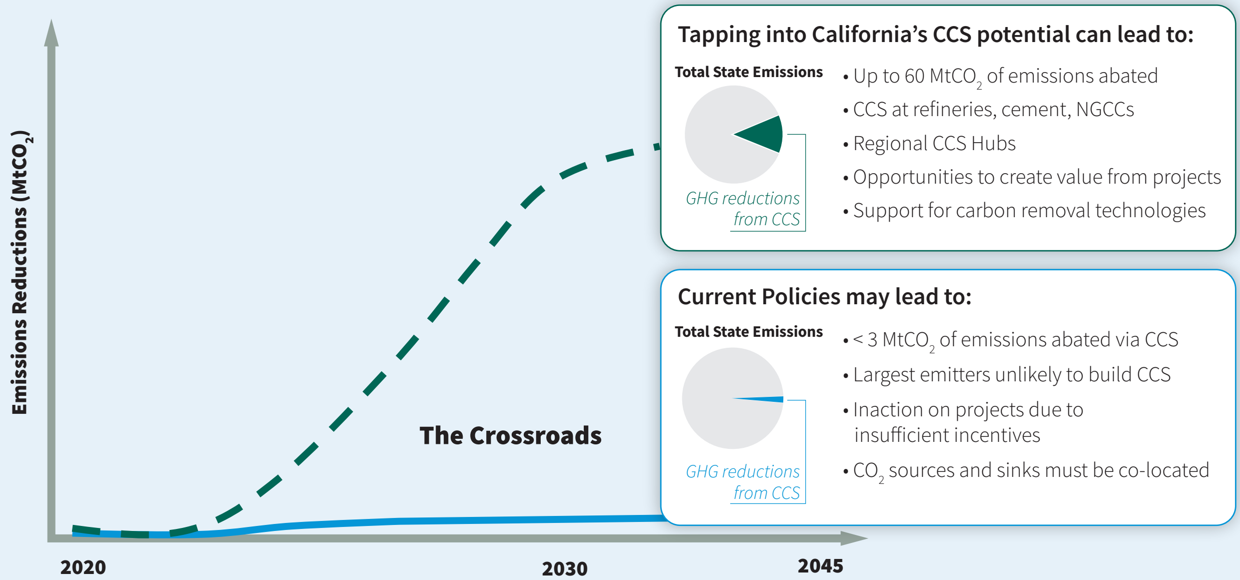
Today, California is at a crossroads in CCS development (Figure S-1). Despite a strong foundation of climate policy support, sizeable technical potential to rapidly decarbonize, and natural resources that could enable the state to become a leader in CCS, it has no CCS projects that are operational. If CCS is to play a meaningful role in meeting the state's 2030 emission reduction targets and 2045 carbon neutrality ambitions, California policymakers should consider additional and immediate actions to promote targeted deployment of CCS today.

a The U.S. EIA defines firm power as "power or power-producing capacity, intended to be available at all times during the period covered by a guaranteed commitment to deliver, even under adverse conditions." Clean firm generation includes firm power resources that are low- or zero-emissions, including nuclear, geothermal, biomass, hydro, NGCC-CCS, hydrogen and other carbon free fuels using net-zero processes.

b This includes Clean Energy Systems (CES) biomass to hydrogen with permanent geologic storage; California Resources Corporation (CRC) NGCC capture used for EOR; DTE Energy's transport and storage hub concept; Chevron's NGCC capture pilot, and a carbon capture pilot on the Los Medanos NGCC owned by Calpine Corporation. Note: only the CRC project is included in the Global CCS Institute CO2RE Database utilized in Chapter 1 to profile Global and US CCS development.

FIGURE S-1

CALIFORNIA IS AT A CROSSROADS FOR CCS TO CONTRIBUTE TO GREENHOUSE GAS REDUCTION BY MIDCENTURY



California is at a crossroads for CCS. In the current policy environment, there will likely be few projects with very limited emission reductions potential. With affirmative policy support, CCS could play a major role in enabling the state to meet its climate goals by midcentury. *Source: Energy Futures Initiative and Stanford University, 2020.*

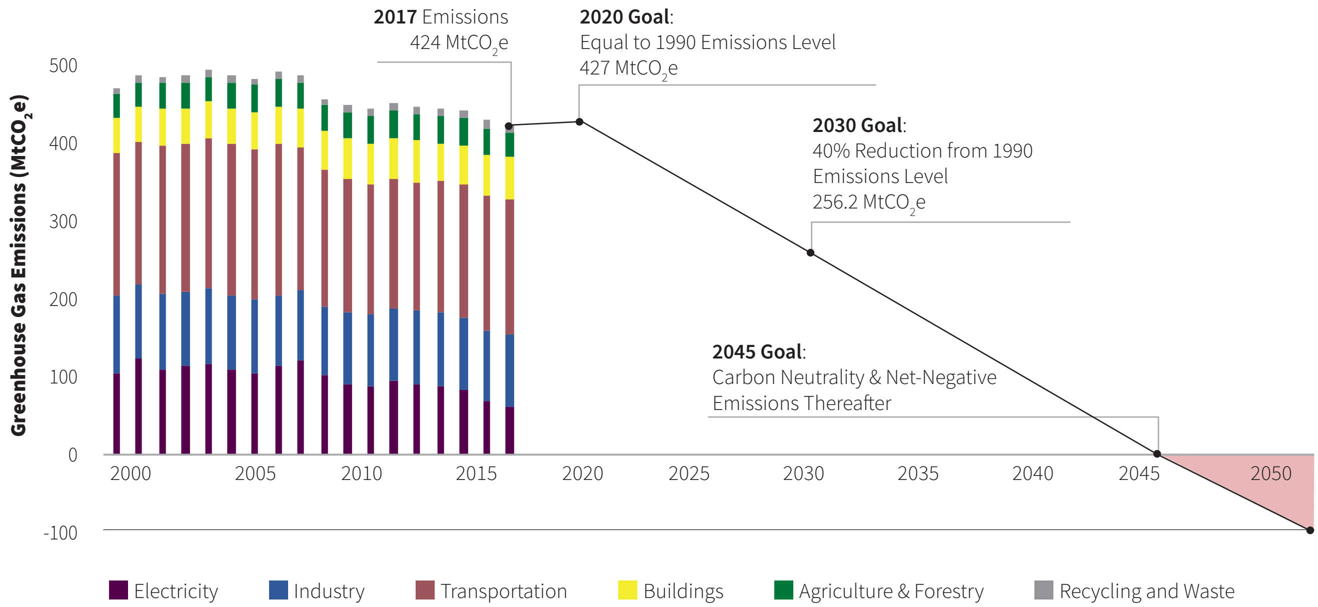
MAJOR ENABLERS OF CCS IN CALIFORNIA TODAY

There are strong drivers for CCS in California today. These include: the urgent need for early emission reductions to achieve 2030 targets and economywide carbon neutrality by midcentury; policy support from the Low Carbon Fuel Standard (LCFS) CCS Protocol; the commercial readiness of CCS; CCS as one of few options to reduce emissions from industry, one of the most difficult sectors to decarbonize; and the opportunities provided by CCS to transition the existing traditional energy workforce to clean energy jobs.

California has a strong foundation for supporting CCS projects. California's industrial and electricity sectors have sizeable technical potential to incorporate CCS technologies—this study identified 76 facilities that are suitable for carbon capture, with the capacity to remove 59 million metric tons of carbon dioxide ($MtCO_2$) annually by 2030. California's policy goals to reach economywide carbon neutrality by 2045 and net-negative emissions thereafter (Figure S-2) will likely require CCS: many studies including the Intergovernmental Panel on Climate Change (IPCC) *Special Report on Global Warming of 1.5 °C,*[9] and the International Energy Agency (IEA) *World Energy Outlook 2019,*[10] find that reaching net negative emissions will require a significant amount of carbon removal.

FIGURE S-2

CALIFORNIA'S HISTORIC EMISSIONS & FUTURE EMISSION REDUCTION TARGETS



California has already met its 2020 emission reduction target; however, it has increasingly stringent goals in 2030 and by midcentury that require additional technologies, policies, and decarbonization solutions. *Source: Energy Futures Initiative and Stanford University, 2020.*

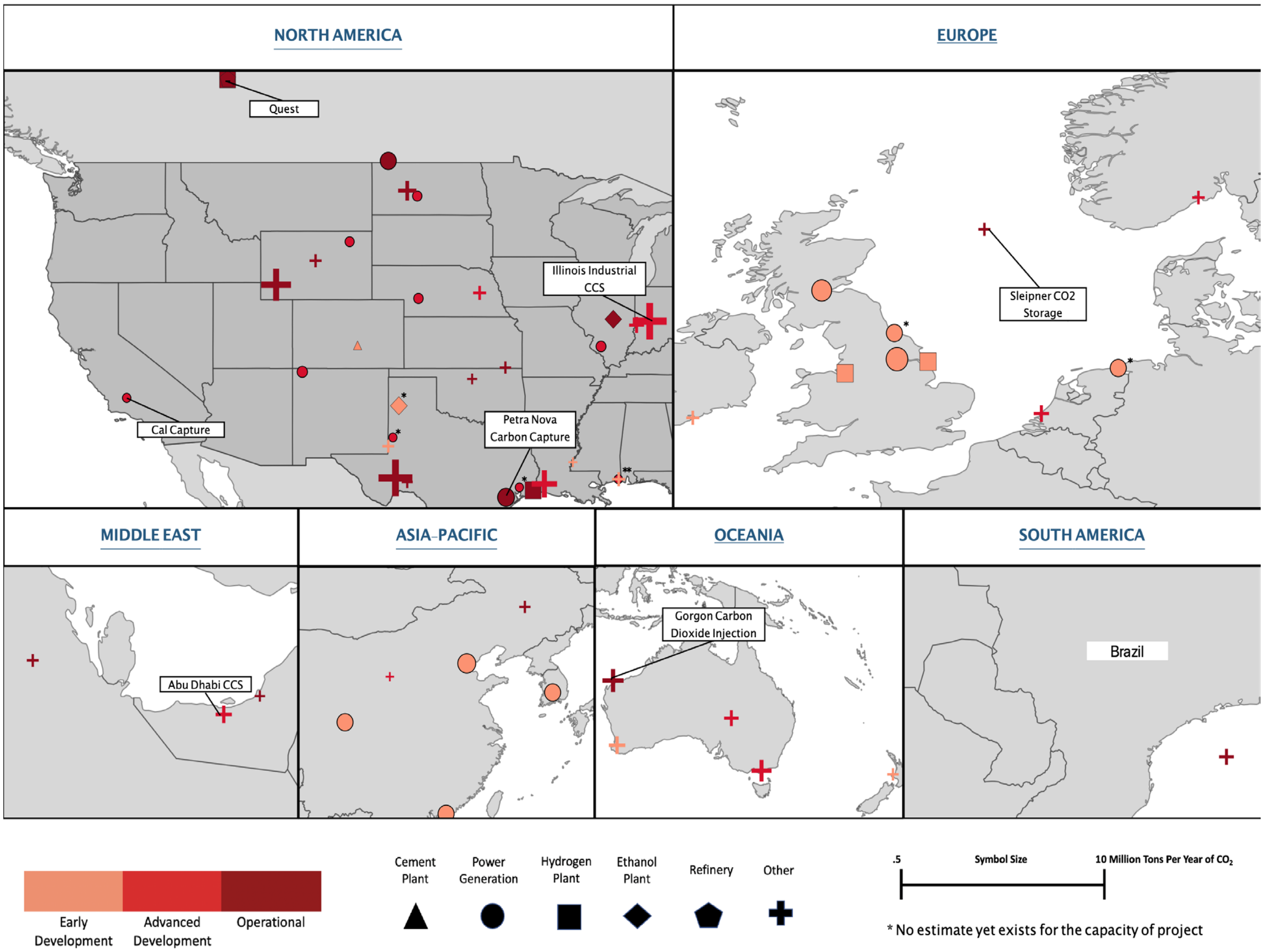
California's economy would see rapid near-term emission reduction benefits from CCS. A major motivation for deploying CCS in California is that it can be applied to multiple sectors of the economy, including those with large workforces and few decarbonization options: petroleum refining; hydrogen production; combined heat and power (CHP); cement production; and ethanol production. These industries are difficult to decarbonize without CCS due to a combination of factors, including high temperature requirements that cannot be practically met with electrification, and high levels of systems integration at many facilities, which make major changes highly disruptive to facility operations. Also, emissions from cement production, for example, are 60 percent from the process itself rather than from fuel combustion, which makes it especially difficult to decarbonize.[11] CCS, a post-combustion bolt-on option, can address these emissions sources with relatively little disruption in normal functions (assuming sufficient space is available at the site).

CCS activities would provide jobs for Californians with skillsets that may become obsolete in the clean energy transition. There are skillsets in the traditional energy sector, such as geologists, petroleum engineers, chemical engineers, process technicians, pipeline workers, and other related construction skills that could be re-deployed to support CCS. In 2019, there were 412,000 traditional energy jobs in California.[12] As conventional energy sector jobs decline, these workers could transition to jobs in the CCS industry that require similar knowledge and skills. Importantly, supporting a CCS and hydrogen production industry that allows for the transfer of skills and experience of today's workforce is aligned with the state's commitment to an equitable and just clean energy transition as CCS creates opportunities for new industries and jobs.

CCS is a commercially ready, clean energy technology that is growing globally. Globally, as of September 2020, there were 61 large-scale CCS facilities that were either operational, in advanced development (i.e. under construction or in an advanced planning stage), or in early development (i.e. early planning) (Figure S-3). California could become a global leader in CCS development and deployment to achieve its climate goals as it has with other clean energy technologies, but to do so, it needs to act quickly and comprehensively.

FIGURE S-3

GLOBAL CCS PROJECTS BY REGION, STATUS, AND SOURCE TYPE



Globally, CCS projects have operated since the 1990s with 21 large-scale projects in operation as of September 2020, and 40 in various stages of development. *Source: Energy Futures Initiative and Stanford University, 2020. Compiled using data from Global CCS Institute, 2020.*

OPPORTUNITIES TO RAPIDLY DECARBONIZE AND CREATE NEW CLEAN INDUSTRIES AND JOBS

California has opportunities to advance its decarbonization and economic goals by leveraging CCS due to its sizeable geologic storage resources; the suitability of its emissions sources for carbon capture; its need for clean firm electricity generation as the renewable energy profile grows; the need for decarbonized transportation fuels, such as hydrogen; and its experience advancing strong climate policies and innovative industries.

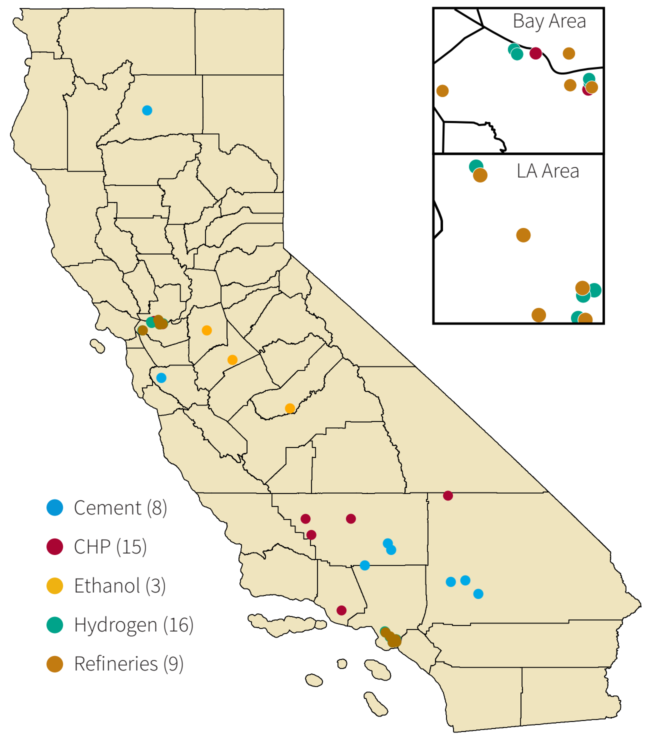
California's geology makes it well suited for safe, permanent CO_2 storage. As noted, multiple studies[13,14] have concluded that California has an enormous capacity and high-quality resources for storing CO_2.[15] One study done by the WESTCARB Regional CCS partnership, an organization led by the California Energy Commission (CEC) and the U.S. Department of Energy (DOE), estimated the CO_2 storage capacity of saline formations in the ten largest basins in California ranged from 150 to 500 gigatons (Gt), depending on assumptions about the fraction of the formations used and the fraction of the pore volume filled with supercritical-phase CO_2. Several factors in key regions make California particularly well suited for CO_2 storage. Layers of thick alternating sands and shales and broad structural closures, the same elements that are useful for trapping large quantities of oil and gas, are present in both the Central Valley and Ventura Basins. The state has the potential to store 60 $MtCO_2$/yr—the equivalent of total electricity sector emissions in 2017—for 1,000 years.

There are important policy incentives that make CCS attractive. California established the LCFS in 2009 with the goal of reducing GHG emissions from its transportation sector and increasing the range of availability of transportation fuels in California to reduce petroleum dependency and improve air quality.[16] In 2018, the California Air Resources Board (CARB) adopted a CCS Protocol, which enables new and existing CCS projects to generate LCFS credits and participate in the credit market.[17] LCFS credits have traded at all-time highs of nearly $200/$tCO_2$, providing a significant financial incentive for eligible CCS projects. The federal 45Q tax credit also provides incentives for dedicated geological CO_2 storage, CO_2 stored through enhanced oil recovery (EOR), or CO_2 utilization. Both LCFS credits and 45Q credits can be used by project developers, creating significant financial incentives; however, the 45Q credit requires that projects commence construction by January 1, 2024,[18] necessitating immediate action by project developers.

CCS offers a robust pathway for deeply decarbonizing several industrial subsectors in California. This analysis identified 51 industrial emitters in California as candidates for CCS, including 16 hydrogen facilities, 15 CHPs, nine petroleum refineries, eight cement plants, and three ethanol production facilities (Figure S-4). These facilities emitted nearly 36 $MtCO_2$ in 2018, of which approximately 27 $MtCO_2$ could be abated by CCS. The three ethanol plants are situated above suitable geologic storage in the Central Valley. The hydrogen and refining facilities benefit from eligibility for both LCFS and 45Q tax credits, though their location in the Los Angeles and San Francisco Bay metro areas necessitate new CO_2 transportation infrastructure to access suitable geologic storage. Some of the CHP facilities are associated with refining operations, making them suitable for CCS "hubs" in which capture operations located close together can share CO_2 transport and storage infrastructure, greatly reducing costs and infrastructure buildout. Finally, the cement plants have relatively low capture costs, while being a significant contributor to the state's economy; however, cement is not eligible for LCFS credits and will require CO_2 transport, making it more challenging from a project development perspective.

FIGURE S-4

CO_2 CAPTURE OPPORTUNITIES IN THE INDUSTRIAL SECTOR



This analysis identified 51 industrial facilities across five subsectors that are candidates for CCS retrofit in California. Note: Upper inset map is the San Francisco Bay Area. Lower inset map is the Los Angeles area. *Source: Energy Futures Initiative and Stanford University, 2020. Compiled using data from U.S. EPA, 2020.*

CCS on NGCC power plants provides a cost-competitive pathway for providing clean, firm—and essential—power. California's electricity sector currently has one of the lowest emission intensities in the U.S. because of its lack of coal-fired generation, high penetration of renewables, and relatively newer and more efficient natural gas generation fleet.[19] As the grid continues to decarbonize, especially through the deployment of intermittent renewable resources, the value of clean firm resources will grow. In 2017, California had 90 days with little to no wind generation, for as many as 10 days in a row; battery storage is typically four hours duration. There is also significant seasonal variation. Solar production was 1.5 terawatt-hours (TWh) in January 2017 but 3.2 TWh in June.[20] California currently has about six GW of clean firm resources, including nuclear, geothermal, and biomass power, which in 2018 were responsible for approximately 16 percent of total system generation. This analysis found that a 2030 scenario with NGCC-CCS saved $750 million per year in total electricity system costs compared to a system without CCS that relied heavily on renewables and battery storage. A separate study estimates that by 2045, California will need approximately 30 GW of clean firm resources to ensure sufficient supply all year long.[21] Another recent study of California's electric grid under deep decarbonization scenarios found: "Some form of firm generation capacity is needed to ensure reliable electric load service on a deeply decarbonized electricity system."[22]

Ten candidate facilities for CCS are co-located with high-quality CO_2 storage resources. This study identified three ethanol plants, two CHPs, and five NGCCs that are located directly above potential CO_2 storage reservoirs. CCS for these facilities could reduce emissions 5.6 $MtCO_2$/yr. These facilities should be considered for initial demonstration projects because they do not require new CO_2 transportation infrastructure, which can add significant cost, potentially require engagement of many landowners, and involve lengthy and complex permitting processes. As noted, the two projects closest to operation in California today both have an emissions source co-located with CO_2 storage. This study also identified an additional 4.1 $MtCO_2$/yr from two CHPs and three NGCCs that are close to suitable CO_2 storage, and would require minimal infrastructure development.

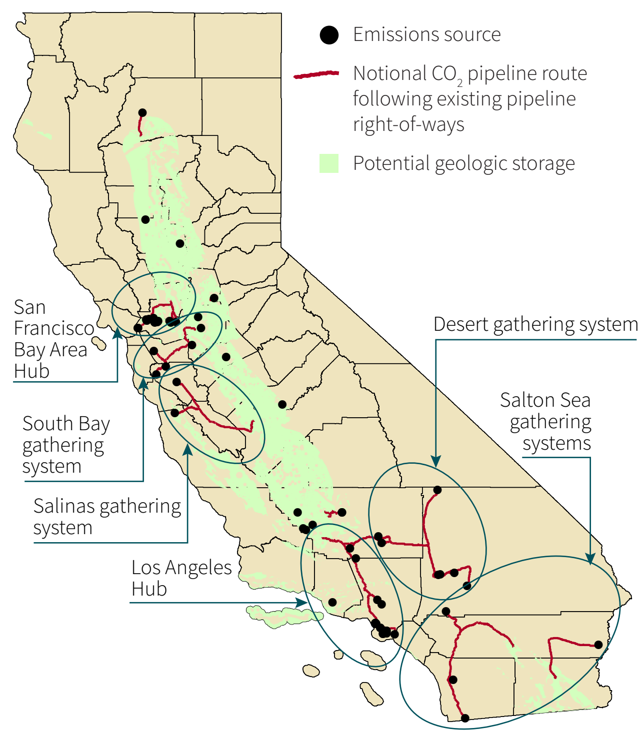
Deployment of CCS infrastructure can enable the emergence of new, potentially multi-billion-dollar clean energy industries, creating new jobs and value for the state's economy. Building out a CCS infrastructure can support the ultimate development of clean hydrogen, which has significant economic potential. Many studies show significant promise for using hydrogen to deeply decarbonize industry, heavy-duty transportation, electric power, and home energy needs. The least expensive method for producing clean hydrogen today uses a process called steam methane reforming with carbon capture; using this method could enable the development of a broader hydrogen infrastructure, while investing in ways to lower the costs of "green hydrogen" from electrolysis, which is currently 4-5 times more expensive than so-called "blue hydrogen" produced using natural gas. One study estimated that, by 2050, the hydrogen economy in the United States could generate $750 billion per year in revenue and support a cumulative 3.4 million jobs.[23]

Another emerging pathway to carbon neutrality is DAC, which removes CO_2 directly from the atmosphere and may be essential for achieving net-zero goals.[24] Similar to clean hydrogen, DAC relies on carbon storage or utilization after it is captured.[25] DAC has a significant carbon removal potential and can be co-located with suitable storage or utilization sites, eliminating the need for long-distance CO_2 transport.

California is well suited to develop carbon capture hubs where there is a high concentration of CO_2-emitting facilities and access to permanent storage capacity via shared pipeline. Hubs offer "economy of effort," where the economics of project design studies, permitting, and construction would be more favorable due to co-location of emissions sources. Pursuing CCS hubs can also ensure a targeted development of a CCS industry compared to many potential point-to-point projects. This study identified potential CCS hubs aimed at drastically reducing pollution from the large source clusters in the Los Angeles and San Francisco Bay areas, which could result in emissions reductions of 25 $MtCO_2$/yr and 14 $MtCO_2$/yr, respectively (Figure S-5). Project costs could also be managed using centralized storage facilities that accommodate multiple sources of CO_2.

FIGURE S-5

CCS PROJECT DEVELOPMENT OPPORTUNITIES



Map illustrates potential project development opportunities that together abate 59 $MtCO_2$/yr. Pipeline routings are 'notional' and follow existing pipeline right-of-ways. Sink locations are not intended to be exact locations for geologic storage. *Source: Energy Futures Initiative and Stanford University, 2020.*

CHALLENGES FOR DEVELOPING A ROBUST CCS INDUSTRY IN CALIFORNIA

Informed by interviews with project developers, financiers, and industry stakeholders, this analysis identified existing barriers to CCS project development, including: ambiguous state support for CCS, complex and untested regulatory process, revenue and cost uncertainty, and lack of public awareness and support.

Despite the strong project economics provided by federal and state incentives and California's foundational resources, there are, as noted, currently no operational CCS projects in the state. There are, however, a small number of CCS projects in active development. Their developers plan to take advantage of the 45Q tax credit and the state's LCFS program with supplemental revenues coming from selling electricity or fuels, and they are also taking advantage of existing infrastructure and close proximity to quality CO_2 storage resources. These first movers are very valuable, but many more projects are needed to maximize the potential CCS holds for helping to meet the state's ambitious climate targets. If CCS is to play a meaningful role in meeting California's 2030 and 2045 emissions reduction targets, California needs to address the regulatory and financial barriers to CCS deployment to enable the state's largest emitters to rapidly develop CCS projects.

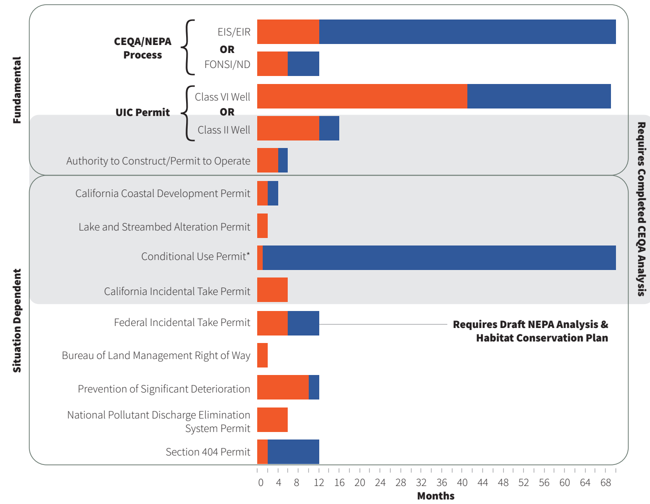
California policies and policy studies paint an ambiguous picture of the future role of CCS for some project developers and investors. California has issued major policy studies that describe the potential value of CCS to the state's decarbonization. In 2011, California Council on Science and Technology (CCST) issued its *"California's Energy Future—The View to 2050 Summary Report"* that found CCS to be an important strategy for achieving the state's GHG reduction targets under several scenarios.[26] In 2017, CARB's *"California's 2017 Climate Change Scoping Plan"* found that CCS "offers a potential new, long-term path for reducing GHGs for large stationary sources."[27] In 2018, CARB issued the CCS Protocol, making it possible for CCS projects to receive credits under the

LCFS program.[28] CCS is, however, ineligible for Cap-and-Trade and is not currently included in the analysis for SB100, the California Public Utility Commission's (CPUC) Integrated Resource Plan, and CEC's Integrated Energy Planning Report.

CCS projects have unique and relatively new planning and permitting requirements compared to other energy infrastructures in California. Permitting CCS projects can be a significant undertaking, as agencies involved may not be familiar with CCS, developers may not be familiar with the myriad of permits required for a complex CCS project, and the timelines for certain key permitting steps—namely the California Environmental Quality Act (CEQA) review and the Underground Injection Control (UIC) program Class VI application—are uncertain and potentially lengthy (Figure S-6). Because CCS projects involve at least two processes (capture and storage), and sometimes transport as well, they can cross multiple regulatory jurisdictions. This makes permitting very complex to navigate, especially considering the relative newness of the CCS technologies. For example, at least three different California agencies may be involved in CCS at an industrial facility at the outset of a project: the local air district for Clean Air Act permitting (Authority to Construct/Permit to Operate), EPA Region 9 or the California Geologic Energy Management Division (CalGEM) for UIC injection well permitting, and another agency (typically a local agency) to serve as the "lead agency" for CEQA.

FIGURE S-6

ESTIMATED CCS PROJECT PERMITTING TIMELINES



**Conditional Use Permits (CUPs) must be in accordance with the city or county's general plan (i.e. meet the development objectives) to be approved. General plans are not updated often, so this should be taken into careful consideration by a developer.*[29]

This figure illustrates timelines of permitting processes that may be required to develop a CCS project in California. The timelines are notional estimates based on federal and state guidelines, project case studies, and agency reports. The orange bars are a minimum estimated permitting duration from application to permit issuance, while the blue bars indicate how long the process could potentially take. Blue bars that extend to the end of the graph represent processes that could have an indefinite timeframe. Permits shaded in grey require a completed CEQA (either an ND or EIR) to commence. *Source: Energy Futures Initiative and Stanford* University, 2020.

CCS projects rely heavily on policy incentives (some relatively new), creating revenue and cost uncertainty. Absent public policy support mechanisms, there are few incentives to capture CO_2 emitted from facilities. As noted, two policies—the LCFS and 45Q—provide needed cash flows for eligible projects to justify the capital and operational expenses required to design, build, and operate CCS facilities. However, there are challenges related to the duration and value of these incentives, that can limit developer and investor interest in CCS. There are also cost-related uncertainties that add pressure to the overall project economics. In addition to the construction and operating costs, there are issues related to the costs of financial responsibility associated with UIC Class VI wells, the time needed to acquire necessary permitting, and establishing the feasibility of projects (e.g. obtaining the necessary permits and social license). Taken together, these revenue and cost challenges have contributed to a general lack of investor capital to fund CCS projects, especially those sources that contribute most significantly to CO_2 emissions that currently have access to fewer financial incentives than some of the smaller sources.

Public understanding and support of CCS vary, potentially impacting developer and investor interest. CCS technologies and their value are unknown to many in the public, and among those who are familiar with the technology, public attitudes are highly variable.[30] Public acceptance is a cross-cutting issue, potentially affecting each category of challenges to project development. Analysis suggests that individuals are influenced by relationships with their communities; better community relationships translate into greater individual support for CCS.[31] It is important for California as it considers the role CCS will play in its zero-carbon future, to prioritize outreach and education to all Californians, but especially those in affected communities. It is critical that these communities and stakeholders participate in decision-making to ensure CCS will promote a just transition to a zero-carbon California.

ACTION PLAN FOR POLICYMAKERS TO UNLOCK CALIFORNIA'S CCS POTENTIAL

A combination of policy actions supported by broad coalitions can maximize the value of CCS for meeting the state's economywide decarbonization goals, motivating the private sector to decarbonize, enabling economic and reliability benefits from existing industries and power generation, and unlocking new clean energy industries and jobs.

CCS is a critical decarbonization pathway for helping California meet its 2045 carbon neutrality goal, while also supporting related goals that are fundamental enablers of the clean energy transition and key to building the necessary coalitions. The goals are:

1) Maximizing options for meeting 2030 and 2045 GHG targets to reduce overall abatement costs, improve the likelihood of achieving the targets, and foster innovation.

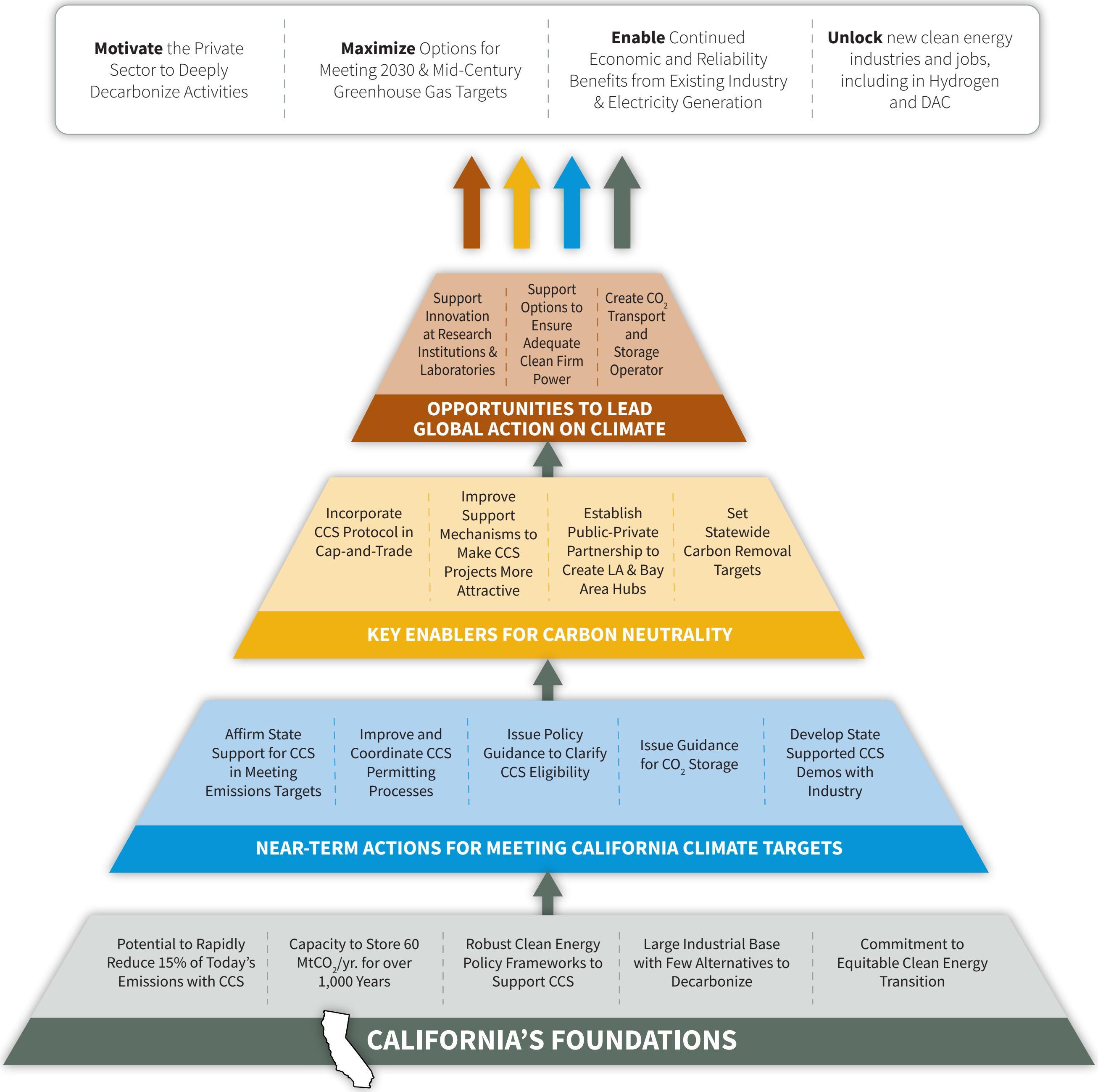
2) Motivating the private sector to deeply decarbonize its activities and products.

3) Enabling continued economic and reliability benefits from existing industries and power generation.

4) Unlocking new, potentially multi-billion-dollar, clean energy industries—such as hydrogen, CO_2 utilization, DAC, and fuels from biomass waste—creating new jobs in the process. Figure S-7 shows more detail.

FIGURE S-7

A POLICY ACTION PLAN FOR CCS IN CALIFORNIA TO MEET THE HIGH-LEVEL GOALS



The analysis in this report informed the establishment of high-level goals for CCS in California at the top of the figure. California has a strong foundation for CCS development. Key drivers—near-term actions for meeting climate targets, enablers of carbon neutrality, and opportunities to lead global action—inform and increase CCS project development in specific areas of recommended actions.
Source: Energy Futures Initiative and Stanford University, 2020.

California should take near-term actions to leverage its CCS potential for meeting its climate targets of 40 percent emissions reduction by 2030 and to pave the way for carbon neutrality by 2045.

- ***Affirm state support for CCS in meeting emissions targets.*** CCS projects can have immediate and long-lasting environmental, economic, and jobs benefits to nearby communities. The state should issue policy guidance, such as an executive order, affirming the conclusions of CARB and CEC about the need for and value of CCS. Policy guidance should also direct all relevant state agencies to align their respective CCS regulatory activities with the high-level goals discussed above. This would provide policy certainty and help align perspectives across the stakeholder landscape. Project developers, local governments, and community representatives could work collaboratively to provide input that would maximize the benefits of CCS projects and articulate these benefits to the public.
- ***Improve and coordinate CCS permitting processes.*** Building new infrastructure to support the emerging CCS industry requires strong financial, policy, and regulatory support. The regulatory environment for CCS in California is relatively untested, which makes it difficult to acquire the permits and financing necessary to move projects forward. Improved coordination could be achieved by California's Executive Branch assigning a lead coordinating agency for CCS permitting activities that could work with other agencies with existing permitting authorities to develop clear permit review timelines, establish permit submission sequencing guidelines, and support transparent review processes. California could also establish a multiagency working group to identify overlapping or redundant processes and increase coordination for permit applications and reviews.
- ***Issue policy guidance to clarify CCS eligibility.*** As new clean energy technologies emerge, there are often questions regarding their compatibility with existing policies and regulations. California could incorporate CCS into its integrated resource plan (IRP) process to rigorously assess the potential economic and emissions reduction opportunities afforded by NGCCs with CCS. California could also make CCS an eligible resource under the SB100 goal of 100 percent of retail electricity sales from renewable and zero-carbon resources by 2045. NGCCs with CCS could be allowed to demonstrate that they can meet the zero-carbon resource standard under SB100 (which could be done in a number of ways), aligning California with major studies on reaching carbon neutrality that explicitly value carbon removal options including CCS.[32] For example, combining DAC with CCS at an emitting facility could lead to net-zero emissions. DAC deployed on-site could be sized to capture the equivalent of any remaining emissions not captured by CCS. The CO_2 captured by the DAC facility then could be combined into a single CO_2 stream for transport and storage.
- ***Issue guidance for CO_2 storage.*** In California, there is a lack of legal clarity on geologic pore space ownership, creating a thicket of legal issues for potential project developers interested in CO_2 storage. Uncertainty and management of long-term monitoring and stewardship requirements for CO_2 stored for years or decades are an additional, often-cited barrier to CCS project development in the state. The legislature should provide clarity on pore space ownership and state agencies should revise the current long-term monitoring and stewardship requirements under the CCS Protocol to both increase environmental effectiveness and reduce logistical hurdles for project operators.

- ***Develop state supported CCS demos with industry.*** Demonstration projects could provide valuable insights into the technical and regulatory challenges of a CCS project, reducing uncertainty associated with any new and untested process for project developers and regulators. The state should consider supporting a large, state-sponsored CCS demonstration project that could help overcome three major project barriers: high at-risk costs in the project's early stages; untested permitting processes throughout the value chain; and public acceptance of CCS. The state could prioritize projects that have demonstratable local air quality benefits and local job opportunities in line with its climate and equity goals.

California should pursue key enablers for CCS to contribute towards the state's 2045 carbon neutrality goal.

- ***Incorporate CCS Protocol into Cap-and-Trade Program.*** CCS is currently not an eligible pathway under the Cap-and-Trade program or recognized in the Mandatory Greenhouse Gas Reporting Regulation. As a result, covered entities [electricity generators and industrial sources that emit more than 25,000 metric tons CO_2 annually (tCO_2)] cannot use CCS to reduce their compliance obligations (i.e. their annual emissions "cap"), even if they captured and stored their emissions in compliance with the CCS Protocol. In effect, there is no incentive for these covered entities to deploy CCS now or in years to come even though it could contribute large emission reductions. CARB could adopt the CCS Protocol from the LCFS program into the existing Cap-and-Trade Program to provide additional financial incentive for projects to pursue CCS. This is especially important for NGCCs and cement, which are not eligible for LCFS credits but are covered under Cap-and-Trade. The existing CCS Protocol includes several important safeguards for CCS development, requiring that injection wells use the best available methods, the CO_2 storage zone is adequately studied, and long-term leakage risks are mitigated.[33]
- ***Improve support mechanisms to make CCS projects more attractive.*** CCS projects face significant financing headwinds at project onset due to uncertain permitting timelines, finite tax equity appetite, and competition with more widely deployed infrastructure projects. The state could reduce early stage challenges by providing funding support for front-end engineering design (FEED) and/or feasibility studies. Also, California's Congressional delegation could support an extension of the January 2024 deadline to commence construction under the revised federal Section 45Q tax credit. It will likely take as long as six years to develop and deploy a CCS project with a 30-year financing lifespan; the value of the 45Q tax is currently only available for less than half of a facility's likely operating lifetime of a few decades. Providing long-term certainty for 45Q credits could have a transformational impact on CCS project development. Finally, California could consider modifying the LCFS by setting a long-term price floor or other options to increase certainty, providing project developers with the ability to better anticipate its value. In the last eight years, credit prices have ranged from $25/$tCO_2$ to more than $200/$tCO_2$.[34,35]
- ***Establish public-private partnerships to create LA and Bay Area hubs.*** This study identified clusters of emissions-intensive facilities (or "hubs") located in in the Los Angeles and San Francisco Bay areas that are suitable candidates for CCS retrofit. Such hubs could dramatically reduce pollution from the large source clusters in these areas. Industrial development tends to form around locations with ample energy supplies and transportation systems (e.g. ports, roads, pipelines). Prioritizing CCS capture hubs for projects that demonstrate local air quality benefits and provide jobs in these areas could help ensure the targeted, concentrated—and possibly more economic—development of a CCS industry compared to a proliferation of point-to-point projects. State sponsorship of FEED and/or feasibility studies could reduce the financial burdens associated with initial development of CCS hubs. Together, these proposed hubs could capture nearly 11 percent of the state's 2017 GHG emissions.[36]

- ***Set statewide carbon removal targets.*** Studies show that reaching economywide carbon neutrality by midcentury or earlier is extremely difficult if not unachievable without major contributions from CDR technologies, a complementary suite of technologies to CCS both in infrastructure and expertise.[37] California is ideally suited to become a leader in CDR policy and technology development given its innovation capacity, skilled workforce in relevant sectors, ambition and progress on climate and clean energy policy, and its natural resource endowment. California's ambitious climate targets provide little guidance on the role for CDR despite its critical role in achieving net-negative emissions. Setting a removal target could help provide direction to state agencies to accelerate the development of new CDR projects that will be needed to achieve the state's carbon neutrality goal. A parallel effort could be for California to develop a process, similar to the one conducted by the National Academies of Sciences in 2019 for its *"Negative Emissions Technologies and Reliable Sequestration: A Research Agenda"* report[38] and EFI in its 2019 study, *"Clearing the Air: A Federal RD&D Initiative and Management Plan for Carbon Dioxide Removal Technologies,"*[39] that determines the eligibility of each potential CDR technology and pathway to meet the state's established carbon removal targets. State agencies could be tasked with developing eligibility requirements for CDR pathways to align policies with emission reduction potential.

California should encourage CCS projects that inspire new opportunities to lead global action on climate.

- ***Support innovation at research institutions and laboratories.*** California has one of the most robust innovation infrastructures in the country. The state should use its substantial resources and innovation capacity to support the demonstration and deployment of new clean energy pathways that rely on or are complementary to CCS and could be replicated in other regions of the country and across the globe. Hydrogen, a clean energy carrier with significant innovation breakthrough potential, could be a focus of California's clean research, development, and demonstration (RD&D). A promising option for developing new hydrogen systems is through regional hubs that include production and the supporting infrastructure for hydrogen storage and distribution. California could establish a "Hydrogen Hub Prize" that seeks actionable and scalable roadmap designs of hydrogen hubs from the state's research institutions and laboratories. DAC is another promising clean pathway that needs more RD&D. DAC removes CO_2 directly from the air instead of from concentrated point sources but requires CO_2 disposition options (i.e. storage or utilization) for it to be a complete carbon removal system. California could commission a multi-user DAC research facility that would provide the state's research institutions a test bed for evaluating ways to reduce the technology's energy, water, and land use requirements. California could also support feasibility studies and demonstration projects that combine point source capture with DAC. This "hybrid" concept offers the potential to create process synergies and is an important area of innovation to help an emitting facility achieve net-zero carbon emissions, facilitating compliance with Cap-and-Trade and SB100.

- ***Support options to ensure adequate clean firm power.*** While there is clearly a need for firm generation to ensure reliability, there is also a need for deep decarbonization of the power sector. Studies show that both these objectives can be achieved by supporting policies to ensure the availability of *clean* firm power generation, which has significant value for cost-effective electricity system reliability under deep decarbonization scenarios. As noted, a recently completed study for California concluded that about 30 GW of clean firm generation would significantly lower the cost for achieving a zero emission grid.[40] This and other studies also conclude that CCS for natural gas combined cycle plants (NGCC-CCS) is one of the most cost-effective approaches for providing clean firm power generation. Policies should be supported that: (1) provide a more precise understanding of how much firm power is needed for a grid that is decarbonizing; (2) inform grid reliability planning processes; (3) identify key technologies for providing clean firm power; and (4) identify policy options, including standards for the scaleup and deployment of those technologies that are essential for ensuring reliable, affordable, and clean power. These policies would not replace technology-neutral power sector emission reduction policies, like a clean energy standard. Instead, it would encourage incremental clean firm deployment where it is most likely to be used and useful in a deeply decarbonized power system, can be designed to be wholly compatible with existing power market and climate policy requirements in the state, and does not raise other significant policy concerns. These policies could be replicated in other regions of the country, adjusted to address and meet local system needs and requirements.
- ***Create CO_2 transport and storage operator.*** Building on the recommendation of large-scale demonstration projects, California could develop a new organization focused on coordinating the CO_2 transport, storage, and administrative operations in a specific region or basin, leveraging state resources such as lands and permitting authorities. The new organization could be modeled on other state entities that manage similar products and activities, such as waste management and disposal. It could be either a private or public entity. This organization could be authorized to manage CO_2 transportation under bilateral contracts where participating customers, such as oil refiners or natural gas-fired power generators, could engage through term contracts that set transparent rates (e.g. fixed or tied to commodity prices) and durations.

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Errata

REVISION 1, OCTOBER 25, 2020

- Page S-4: "412,000 jobs in oil and gas" changed to "412,000 traditional energy jobs"
- Page S-12: "biennial integrated resource plan and long-term procurement planning process" changed to "integrated resource plan (IRP)"

REVISION 2, DECEMBER 11, 2020

- Page S-7: "By 2045, one study, estimates that California will need approximately 30 GW of clean firm resource to ensure sufficient supply all year long. That study also found that a 2030 scenario with NGCC-CCS saved $750 million per year in total electricity system costs compared to a system without CCS that relied heavily on renewables and battery storage.21 changed to "This analysis found that a 2030 scenario with NGCC-CCS saved $750 million per year in total electricity system costs compared to a system without CCS that relied heavily on renewables and battery storage. A separate study estimates that by 2045, California will need approximately 30 GW of clean firm resources to ensure sufficient supply all year long.[21]
- S-7: "DAC relies on carbon storage or utilization to after it is captured" changed to "DAC relies on carbon storage or utilization after it is captured"
- S-15: "Create transport and storage operator." changed to "Create CO_2 transport and storage operator."