ENERGY FUTURES
— INITIATIVE —

California Air Resources Board
1001 I Street
Sacramento, CA
95814

September 3, 2021

Re: August 17, 2021 Public Workshop: 2022 Scoping Plan Update – Scenario Concepts Technical Workshop

Dear California Air Resources Board:

The Energy Futures Initiative (EFI) is submitting this letter on the importance of including engineered carbon removal in the modeled scenarios for achieving carbon neutrality in its *2022 Scoping Plan Update*.

During the August 17, 2021 scenario concepts workshop, CARB posed the questions of if carbon capture and sequestration (CCS) should be considered as an abatement option for current fossil fuel combustion technologies (e.g., in industry, electricity generation, or refineries) and/or with industrial processes emissions (e.g., cement). Additionally, the question of how to compensate for residual emissions through the use of negative emissions technologies, such as direct air capture (DAC) was also posed.

Since it was established in 2017, EFI has analyzed many policies, programs and technologies needed for deep decarbonization. Among this suite of technology options, EFI's research has found that engineered carbon removal technologies, including CCS and DAC, are ***essential*** for meeting midcentury carbon neutrality goals and achieving net-negative emissions thereafter. The August 2020 report commissioned by CARB, *Achieving Carbon Neutrality in California*, also shows that California's net-zero emissions goals will require increased research, development, and deployment of engineered carbon removal.

EFI applauds CARB's actions to assess the importance of these technologies during its recent workshops and modeling efforts and would be happy to assist the Board as it continues to develop the *2022 Scoping Plan Update*.

Furthermore, EFI's analysis has also identified numerous co-benefits of widescale deployment of engineered carbon removal in addition to reaching net-zero emissions:

- **Jobs and Economic Development**: EFI analysis has highlighted the importance of engineered carbon removal not only for job creation, but also transitioning conventional energy jobs into clean energy jobs without stranding workers, communities, or assets. This is complementary to CARB's upcoming economic analyses on how the measures assessed in the *2022 Scoping Plan Update* impact jobs, households, and local communities.

- **Optionality, Flexibility, and Innovation**: Maximum optionality and flexibility will be needed to address the needs of different regions of California and of all end use sectors—including the industrial, heavy transportation, and agricultural sectors that are hard to decarbonize. In line with CARB's emphasis on the need to support cost-effective and flexible compliance mechanisms to ensure California meets its greenhouse gas reduction goals, engineered carbon removal solutions should be considered because they are among the very few abatement options for the most difficult to decarbonize sectors. Looking ahead, additional technological breakthroughs will be needed to achieve net-zero, and California can lead the way as it has for decades in fostering innovation through policy.
- **Regional Solutions that Center Social Equity**: Regional and local circumstances must be central to designing climate and social equity solutions. As a relatively new set of technologies, engineered carbon removal and geologic storage must be carefully evaluated in local contexts. CARB's upcoming assessments of the public health, environmental, and socioeconomic benefits from further emissions reductions for the *2022 Scoping Plan Update* will provide vital information for the design of effective policies. Communities must be engaged early and often in conversations about the opportunities as well as potential challenges of these solutions, and CARB's desire to accurately reflect land management priorities and constraints for different regions of California will be important in designing, planning, and implementing appropriate, community-endorsed climate mitigation strategies.
- **Strong and Sustainable Coalitions**: We cannot address climate change at the pace and scale needed to transform our massive energy system without building broad coalitions of support. CARB recognizes the importance of coalitions, exemplified by its multi-state agency effort to facilitate engineered carbon removal solutions across sectors and jurisdictions. EFI has worked with labor, business, other NGOs, financial institutions, foundations, religious leaders, and Federal, State and local officials across the political spectrum to provide analytically based solutions that change how we produce and consume energy at the pace needed for deep decarbonization by mid-century. We applaud CARB's steadfast commitment to facilitating sub-national and national collaboration as we collective work towards a carbon neutral future.

For the past four years, EFI has focused on conducting pragmatic, technically grounded analyses to inform federal, regional, state, and local stakeholders on how to address the climate challenge. Since its founding, EFI has become a leading voice on technology and policy pathways to deep decarbonization.

In addition to the public activities of its principals at events around the world, EFI has published several major studies on achieving deep decarbonization some of which focused on carbon dioxide removal (CDR) and carbon capture, utilization, and storage (CCUS). EFI has conducted two California-specific analyses that found that approximately 15% of the state's 2018 GHG emissions could be abated using CCUS. In our other work to-date, engineered carbon removal and its associated infrastructure underpin a successful path to net-zero by midcentury, while creating job-paying jobs, supporting California's—and the nation's—strong industrial base, and ensuring a resilient power system in the face of a changing climate.

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The following studies are summarized below to provide CARB with key information on the technical potential, social and economic considerations, and innovative policy solutions related to engineered carbon removal solutions:

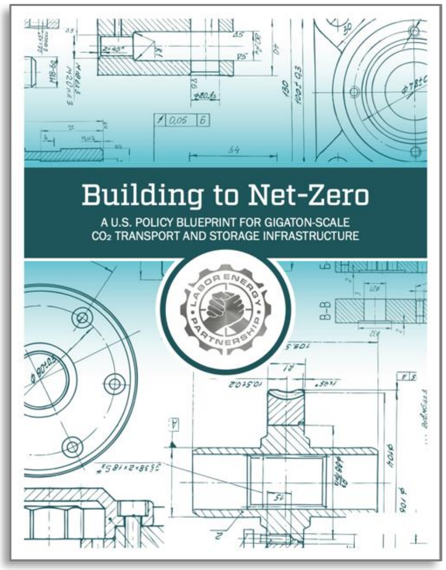
1. Building to Net-Zero: A U.S. Policy Blueprint for Gigaton-scale CO_2 Transport and Storage Infrastructure (June 2021)
2. The Critical Role of CCUS: Pathways to Deployment at Scale (February 2021)
3. An Action Plan for Carbon Capture and Storage in California: Opportunities, Challenges, and Solutions (Oct. 2020)
4. Optionality, Flexibility, and Innovation: Pathways for Deep Decarbonization in California (May 2019)

We hope these resources add to CARB's body of knowledge of the importance of engineered carbon removal for meeting climate imperatives. EFI supports and stands ready to assist CARB in the *2022 Scoping Plan Update* and the state of California in its continued efforts to transition to an equitable clean energy future.

The Energy Futures Initiative Leadership Team,

Ernest J. Moniz	Joseph S. Hezir	Melanie A. Kenderdine	Alex Kizer
Founder & CEO	Managing Principal	Managing Principal	SVP of Research

Building to Net-Zero: A U.S. Policy Blueprint for Gigaton-scale CO_2 Transport and Storage Infrastructure

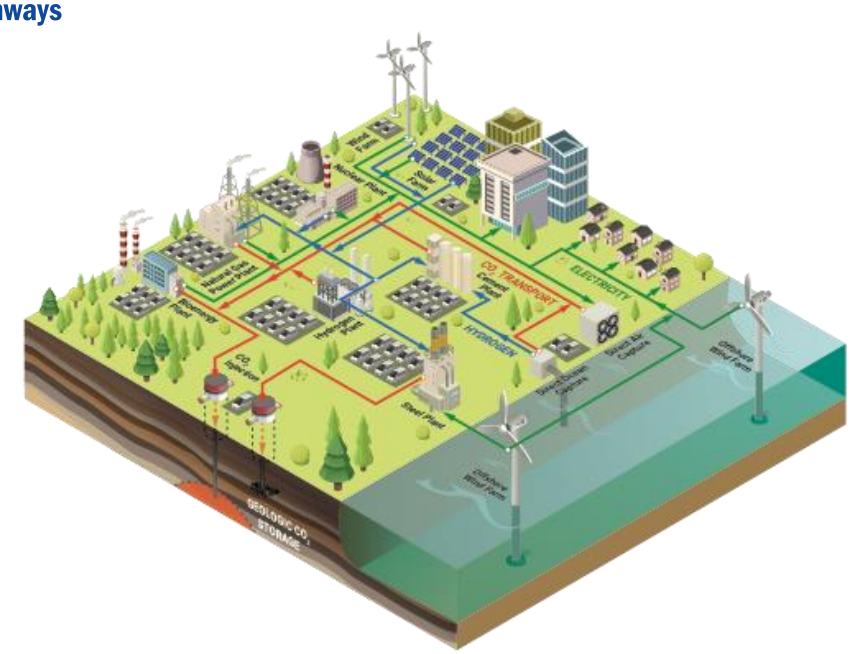


CO_2 management infrastructure can enable a broad range of decarbonization pathways and technologies. Building pipes, pumps, and storage sites can support CO_2 capture, utilization, and storage (CCUS) that can decarbonize the industrial and power sector, as well as carbon dioxide removal (CDR) that can remove legacy emissions and push to zero or net-negative emissions. This report identified the opportunities, challenges, and policy options for developing CO_2 infrastructure capable of moving and storing up to a gigaton of emissions.

CCUS complements other abatement strategies and can accelerate the pace of emission reduction. For example, firm-power generation using CCUS can enable greater penetration of renewable energy; fuel production using CCUS can decarbonize transportation and industrial sectors; and, materials produced using CCUS can create clean, low-carbon supply chains in the United States. As shown in Figure 1, when infrastructure is shared, regional decarbonization solutions can be maximized, creating and preserving jobs across the economy.

Figure 1

Large-Scale CO_2 Transport and Storage Infrastructure Supporting Multiple Sectors and Clean Energy Pathways



CO_2 transport and storage infrastructure could connect multiple CO2 capture and removal site, supporting multiple clean energy pathways across multiple economic sectors. The number of cars at respective sites notionally represents the relative number of jobs that the facility supports

Opportunities for CO_2 Infrastructure Development

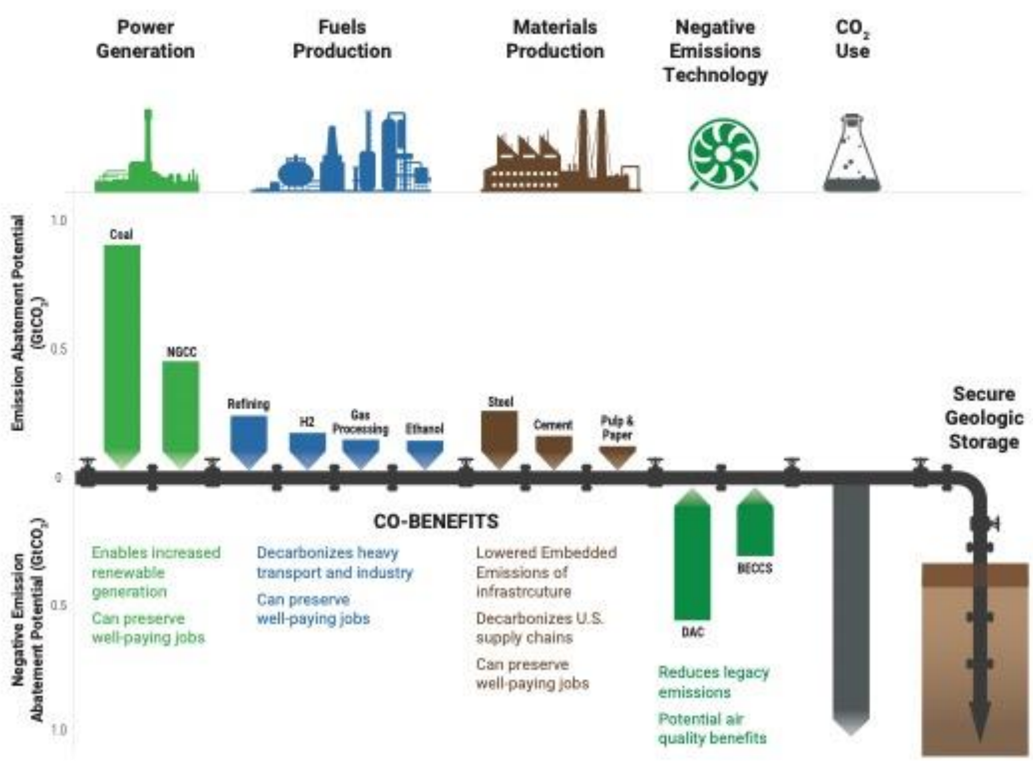
CO_2 capture, removal, transport, storage, and utilization pathways are a critical complement to other emission reduction strategies and an integral component of a net-zero carbon economy. Key opportunities include:

- **Supporting** near-term, economywide emissions reduction and removal of CO_2 from the atmosphere
- **Preserving** jobs in hard-to-decarbonize sectors
- **Creating** new industries and additional good- paying jobs for U.S. workers

Global emissions need to reach net-zero and even net-negative levels this century to limit warming to 1.5 degrees Celsius (°C). All scenarios that meet the Intergovernmental Panel on Climate Change (IPCC) 1.5 °C target require removing 100 to 1,000 $GtCO_2$ by 2100. As shown in Figure 2, CO_2 infrastructure capable of moving and storing one gigaton per year would unlock a broad range of benefits and co-benefits for the United States.

Figure 2

Emissions Abatement and Negative Emissions Opportunities Unlocked by CO_2 Infrastructure

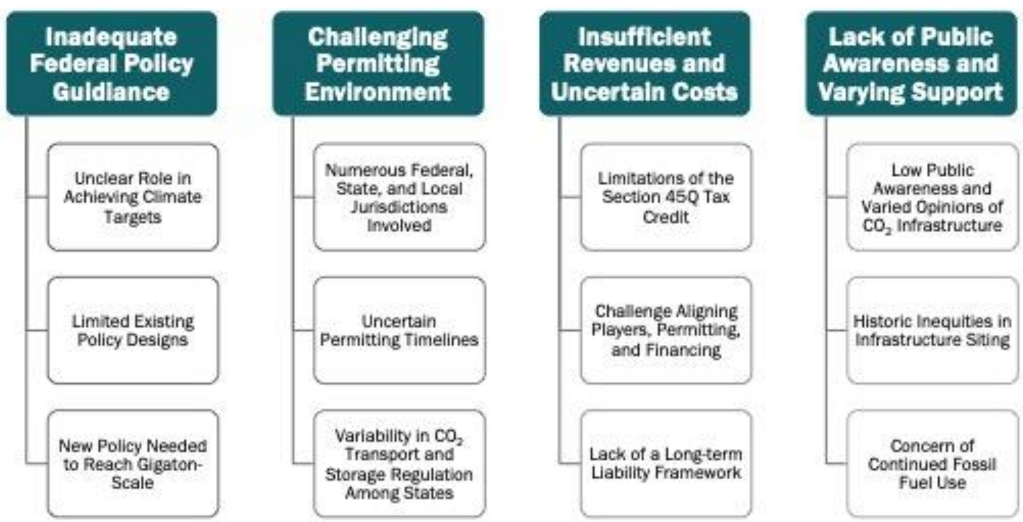


Emissions abatement for power generation, fuels production, and materials production is based on multiplying current U.S. emission levels in these sectors by a reasonable capture rate (60-95 percent, depending on the emissions source). Negative emissions potential for BECCS is based on life cycle emissions (not total CO2 captured at BEECC plants) and the potential for DAC is based on potential deployment by 2030. The CO2 use estimate assumes that the CO2 is not used for EOR, and is based on National Academy estimates in 2019.

Challenges to Gigaton-Scale CO_2 Infrastructure Development

As a relatively new and technically complex set of technologies, CO_2 capture, removal, transport, storage, and utilization pathways face a number of barriers. Figure 3 summarizes the challenges to deploying a gigaton-scale CO_2 system, which can be summarized into four main categories: inadequate federal policy guidance; a challenging permitting environment; insufficient revenues and uncertain costs; and lack of public awareness and varying support.

Figure 3
Key Challenges to Deploying CO2 Infrastructure in the United States



While the Biden Administration released the U.S. Nationally Determined Contribution (NDC) to reduce 50 to 52 percent of emissions by 2030 relative to 2005, it is unclear what the role of CCUS will be to meet U.S. ambitions. CCUS and CDR received $4 billion of funding in the Consolidated Appropriations Act of 2020, including both commercial pilots and demonstration projects. However, the Biden Administration has not set targets for CCUS, discussed the role of CCUS for decarbonizing the power sector, or included carbon removal technologies in the NDC.

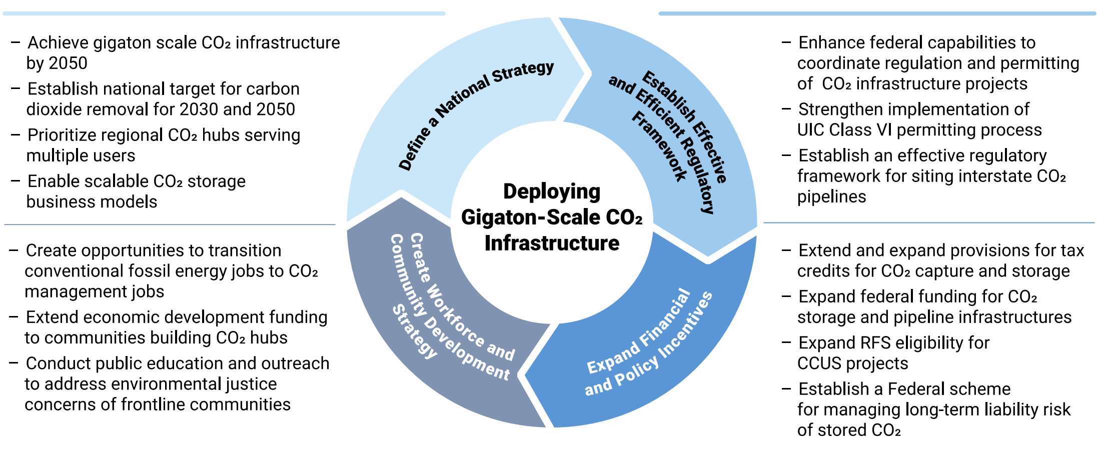
Challenges related to the permitting environment, costs and revenues, and public awareness are discussed in the California context in *An Action Plan for Carbon Capture and Storage in California: Opportunities, Challenges, and Solutions*, summarized below.

Policy Blueprint to Build CO_2 Infrastructure

Recent policy activity placed greater emphasis on and support for carbon capture, utilization, and storage (CCUS) for decarbonizing the industrial and power sectors and contributing to U.S. climate policy goals. More must be done, however, to support the buildout of CO_2 infrastructure on the gigaton scale needed to reach the 2030 NDC target and achieving net-zero emissions by midcentury. Figure 4Figure 4 summarizes the four main categories of recommendations: (1) define a national strategy for gigaton- scale CO2 infrastructure hubs; (2) establish an effective and efficient regulatory framework; (3) expand policy support and strengthen financial incentives; and (4) create a workforce transition and community development strategy.

Figure 4

Policy Blueprint for Gigaton-Scale CO2 Infrastructure Development



Many of the recommendations in this study build on policy proposals advanced by the Biden Administration and proposed legislation by the 117th U.S. Congress. The interest in CCUS is not limited to one party or one legislative chamber; key legislative proposals, such as the SCALE Act, ACCESS 45Q Act, and Clean Energy for America Act, have bipartisan support in both houses of Congress.

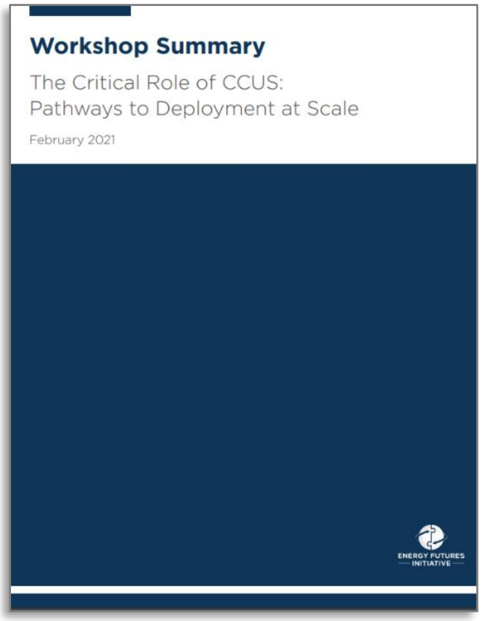
Implications of 2021 Federal Policy for California

In passed legislation and in legislation that is likely to pass, California would have access to a large portfolio of investments that the Department of Energy could make in CCUS, CDR, and hydrogen technologies. California can also benefit from improved financing mechanisms for CO_2 infrastructure, CCUS deployment, and improved permitting processes.

- CCUS Investment: The 2020 Consolidated Appropriations Act authorized $4 billion over five years for CCUS technology, including $1 billion for commercial-scale pilot projects and $2.6 billion for demonstration projects. These projects could be deployed in California given the suitable storage sites
- CDR Investment: Congress appropriated $32.5 million for Direct Air Capture (DAC) research and development for FY21. Further investment is expected in future years.

CDR technologies such as DAC can help California meet ambitious state climate targets.

- **Hydrogen Investment**: The Bipartisan Infrastructure Investment and Jobs Act authorizes $8 billion for four hydrogen hubs. If passed, California could be a prime candidate for one or more of the hubs that can use CCUS to capture emissions from hydrogen production.
- **CO_2 Infrastructure Financing**: The Bipartisan Infrastructure Investment and Jobs Act includes the SCALE Act, which authorizes $5 billion for CO_2 transport and storage infrastructure investment, including through a new loan authority. Californian midstream companies could benefit from the low-interest loans and grants when building CO_2 transport networks.
- **CCUS Deployment Financing**: The 2020 Consolidated Appropriations Act extended the "commence construction" deadline for 45Q tax credits by two years to 2026. Several legislative proposals have called on direct payments for 45Q credits, increasing the value of credits, and extending the construction deadline further. If 45Q is improved and expanded, Californian companies would benefit the most, as these incentives would build on existing incentives through LCFS.
- **Improved Permitting**: The 2020 Consolidated Appropriations Act included the USE IT Act, which clarified that CCUS projects and CO_2 pipelines are eligible for the permitting review process established by the FAST Act. USE IT also directed the Council on Environmental Quality to establish guidance to assist project developers and operators of CCUS facilities and CO_2 pipelines. The initial round of guidance was released in April 20221.


Workshop Summary
The Critical Role of CCUS:
Pathways to Deployment at Scale
February 2021

The Critical Role of CCUS: Pathways to Deployment at Scale

On December 3, 2020, the Energy Futures Initiative (EFI) convened more than 80 representatives from government, industry, labor, academic, and non-profit organizations to discuss the current state of carbon capture, use, and storage (CCUS)[a] globally, as well as the opportunities, challenges, and solutions necessary to see large-scale CCUS deployment in the coming decade.

CCUS is Essential for Rapid Deep Decarbonization

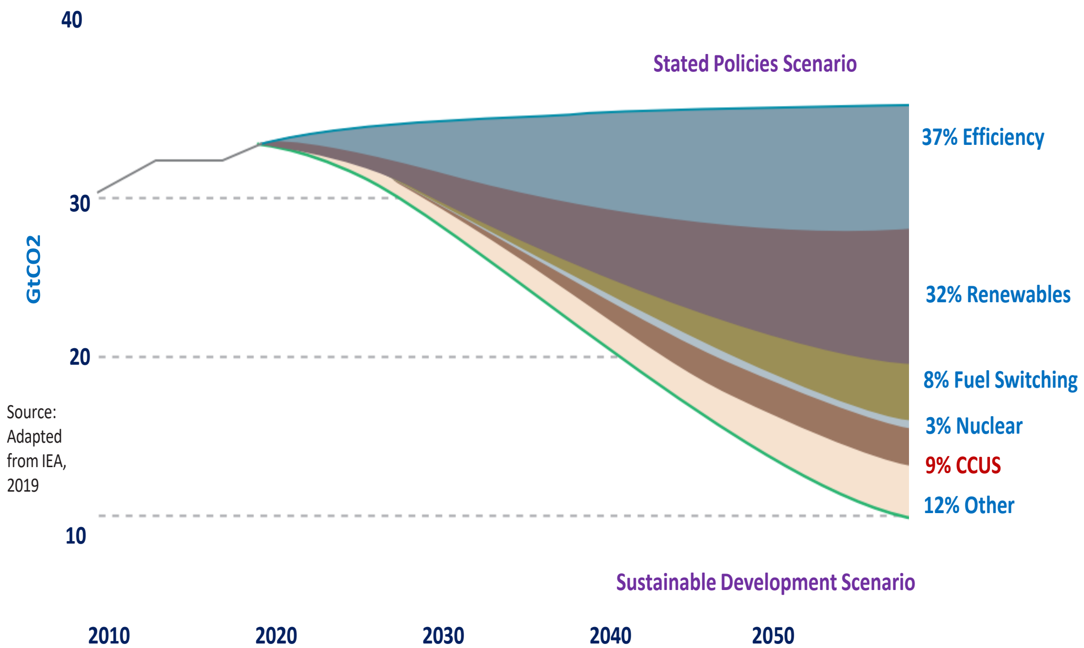
There was general consensus that CCUS is a necessary component of any global strategy to achieve net-zero emissions by midcentury to avoid the most catastrophic impacts of climate change. Carbon capture can be implemented on numerous emissions sources in the electricity and industrial sectors, and it is one of the only decarbonization solutions for a number of sectors, such as cement and steel. According to IEA, "CCUS is in a stronger position to contribute to sustainable economic recovery plans than after the global financial crisis in 2008-09. A decade of experience in developing projects and the recent uptick in activity means that there are a number of advanced 'shovel-ready' projects with potential to double CCUS deployment and create thousands of jobs worldwide by 2025." This is important as the world looks to both rapidly reduce emissions and recover from the economic devastation of the COVID-19 pandemic.

Finally, CCUS paves the way for emerging carbon dioxide removal (CDR) strategies, the widespread deployment of which will likely be essential to limit global temperature increases to the 1.5-degree to 2-degree Celsius scenarios projected by international bodies like the Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency (IEA). In fact, in its September 2020, flagship report, CCUS in Clean Energy Transitions, the IEA concluded that "reaching net zero will be virtually impossible without CCUS" (Figure 5). This conclusion and the growing recognition by scientists, policy makers, and governments that a net-zero target is necessary for holding temperature increases to 1.5 degrees by mid-century, provided the motivation for this workshop.

[a] This includes discrete discussions of carbon capture and storage (CCS) and carbon capture and utilization (CCU).

Figure 5

Incremental Value of CCS to Meeting IEA's Sustainable Development Scenario Relative to Its State Policies Scenario



This figure shows the emissions reductions by technology category in the IEA's Sustainable Development Scenario relative to its Stated Policies Scenario; this includes a nine percent share of CCUS. *Source: International Energy Agency, 2019.*

Challenges for Rapid Deployment of CCUS

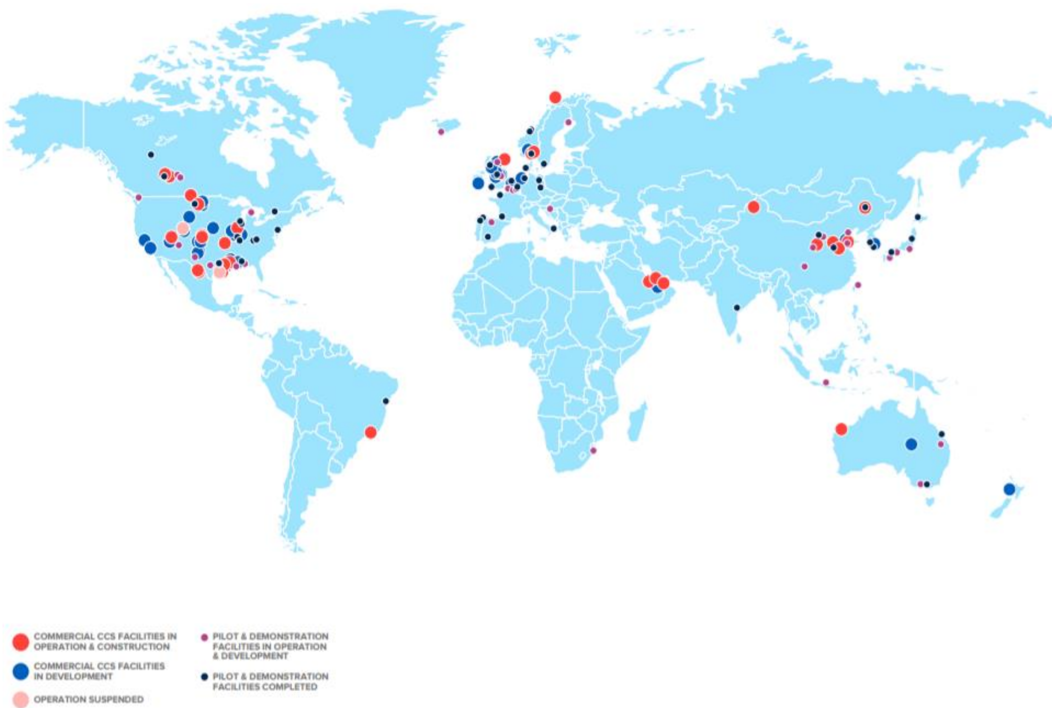
Presently, there are policy, regulatory, investment, and public acceptance challenges in the U.S. and in other countries around the world. IEA describes options to address these challenges, including the needs of individual countries as follows: "There is no one-size-fits-all policy template: the appropriate choice or mix of instruments for each country depends on local market conditions and institutional factors. On their own, technology-neutral measures such as carbon pricing are generally not sufficient. Measures targeted at specific CCUS applications, including capital grants and operational support, can help build a business case for investment and drive widespread deployment in the near term."

Supportive, consistent, and durable policies and regulations at national, regional, and state levels will be necessary to ensure that the environment is protected, and the CO_2 is permanently and securely stored. At the same time, project developers must be able and willing to navigate the permitting or other policy mechanisms that make a project financially viable. The development of strong and predictable policy and regulatory environments for CCUS, especially for geologic storage, will also be critical for CDR pathways that require storage, such as direct air capture (DAC), and bioenergy with carbon capture and storage (BECCS).

Even with these obstacles and considerations, CCUS has been deployed around the world. Figure 6 details the location of existing projects. An essential component of the EFI workshop was highlighting some of these key projects and hearing the lessons learned from specific projects across the range of project types.

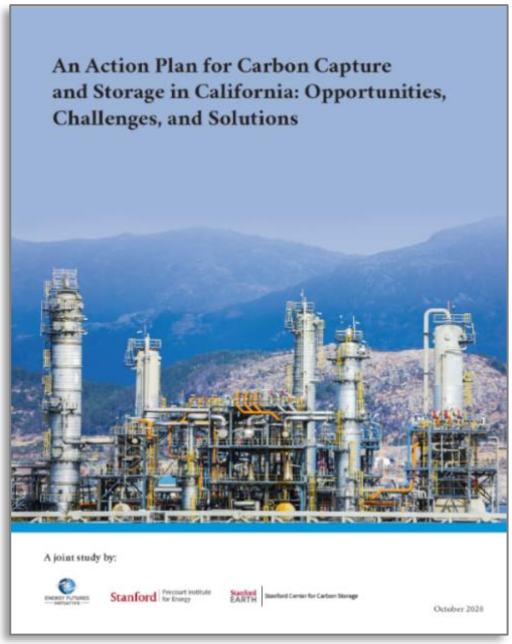
Figure 6

Global CCS Facilities at Various Stages of Development



This figure shows the current state of CCUS projects around the world, showing the increasing interest in the industry as well as the potential for regional hub systems in America, Europe, Arabia, and East Asia. Source: Global CCS Institute, Global Status of CCS, 2020

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



This study 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. CCS, like all other emission reduction technologies, is not a "silver bullet" technology for decarbonization. Carbon capture paired with permanent geologic storage 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.

The report built on the finding from EFI's May 2019 report, Optionality, Flexibility and Innovation*: Pathways to Deep Decarbonization for California (detailed below)*, that identified **CCS as one of most significant pathways to reaching the state's 2030 GHG target.**

Technoeconomic analysis done for this study identified **76 existing electricity generation and industrial facilities in California as candidates for CCS, representing close to 15% of the state's current GHG emissions.** To put this in perspective, in 2017, California's power sector emitted 16% of the total. The analysis also analyzed geologic storage potential for the state of California by developing an exclusion zone to avoid consideration of areas with sensitive habitats, population zones, and a history of geologic vaulting, among other criteria.

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

As of September 2020, there are five announced CCS projects in varying stages of planning and development in California. 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.
A robust regulatory environment can advance CCS deployment by providing certainty and environmental and safety assurances to CCS developers, investors, and local and regional communities. In contrast, the absence of a sound regulatory environment or one that is unclear and/or unpredictable can act as a barrier to CCS development.

Opportunities for CCS in California

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 has one of the largest geologic storage potentials in the United States, with over 70 gigatons (Gt) of storage potential, the majority of which is located in the Central Valley.
- There are 76 existing energy and industrial facilities [51 industrial and 25 natural gas combined cycle (NGCC) plants] identified by this analysis to be candidates for CCS retrofit in California. These facilities emit 59 Mt CO_2e/yr (Table 1).

Table 1
Sources of Emissions, Potential Capturable Emissions, Costs, and Incentive Eligibility

Metric	NGCC	Hydrogen	CHP	Refining	Cement	Ethanol
Number of Facilities	25	16	15	9	8	3
Total Emissions, 2018 (MtCO_2e)	21.6	11.2	10.1	6.3	7.8	.43
Assigned Capture Rate	90%	90%	90%	90%	90%	100%
Total Capturable Avoided Emissions (MtCO_2)	27.5	10.1	9.1	5.2	7.0	.43
Weighted Average Capturable Emissions (tCO_2 per facility per year)	1,100,000	630,000	600,000	575,000	880,000	142,000
Estimated Capture Cost Range ($/t$CO_2$)	$62 -$96	$58-$101	$60-$131	$58 -$73	$48 - $75	$20 - $23
LCFS Eligibility	No*	Yes**	Yes***	Yes**	No	Yes

* Elk Hills Power is considered 40% LCFS eligible as some of the electricity will be used for oil field operations
**Hydrogen and Refining were considered 80% LCFS eligible as some refined product is exported out of state.
*** CHPs associated with refining operations were considered 60% LCFS eligible due to rationale in ** yet reduced another 20% because some power generated by CHPs is sold to the grid. CHPs associated with upstream oil and gas production activities were considered to be 50% LCFS eligible.

- Roughly 50 MtCO_2e/yr of capturable emissions require development of up to 1150 miles of new pipeline connecting emissions sources with suitable geologic storage. Although pipelines have relatively low capital and installation costs, permitting and building a new CO_2 pipeline in California is expected to be a formidable task.
- There are potential CCS hubs in the Los Angeles and San Francisco Bay areas, which could result in emissions reductions of 25.2 MtCO_2/yr and 14 MtCO_2/yr, respectively (Figure 7). Regional CCS hubs offer 'economy of effort," where FEED, permitting and construction could be economized due to co-location of emission sources. Project returns may also be enhanced with centralized storage facilities managing flows from multiple sources.

Figure 7
CCS Project Development Opportunities

Map illustrates potential project development opportunities which together abate 59 Mt CO_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.

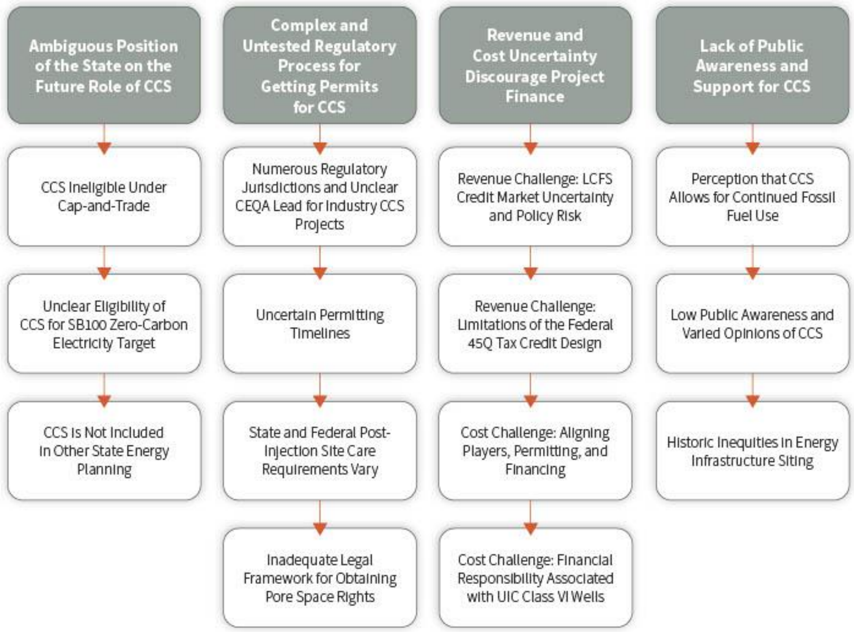
- While the primary objective of CCS is to reduce CO_2 emissions and mitigate climate change, post-combustion capture can also result in the reduction of criteria air pollutant emissions from certain facilities.

Challenges for CCS Project Development 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 (Error! Reference source not found.).

Figure 8

Challenges to CCS Project Development

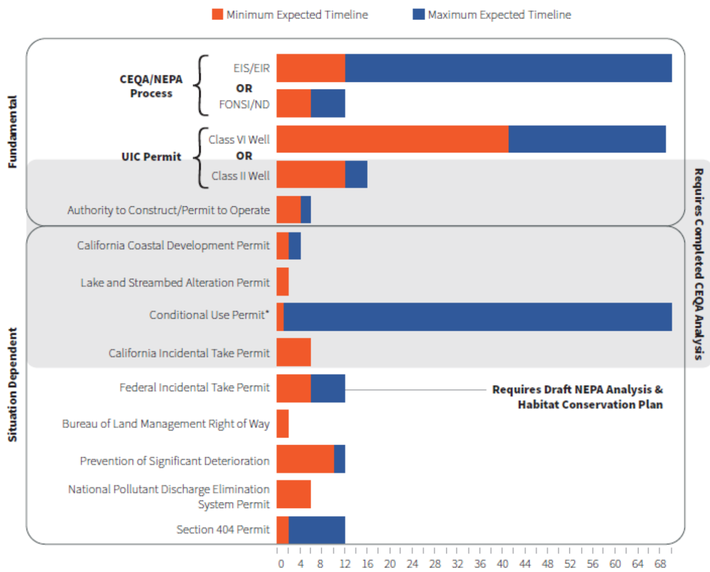


This analysis identified key challenges for CCS project development in California through interviews with project developers, financiers, and industry stakeholders, as well as archival research and analysis of California's policy landscape.
Source: Energy Futures Initiative and Stanford University, 2020.

- A stable and consistent policy environment is critical for developing and deploying greenhouse gas mitigation technologies at scale. CCS has received some state policy incentives—namely eligibility under the LCFS—but it remains ineligible for some of the state's largest decarbonization policies and strategies.
- Every CCS project is unique from a planning and permitting perspective. The location and project type will impact what permits are necessary and which local, state, regional, and/or federal agencies would be involved.
- CCS projects in California require at least three fundamental permits from different regulatory processes: Authority to Construct and Permit to Operate; either a Class VI or Class II well permit; and either a CEQA or a joint CEQA/NEPA review. The notional permitting timelines depicted in Figure 9 show two key permits that will impact the total permitting timeframe: the Class VI well application, and the CEQA process.

Figure 9

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.*

This figure illustrates timelines of permitting process 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. Source: Energy Futures Initiative and Stanford University, 2020.

- Public acceptance can make or break a CCS project, and opinions on CCS are wide ranging and highly variable. This is due in part to the fact that these are relatively new infrastructures and technologies with which the public is unfamiliar. Analysis suggests that individuals are influenced by relationships with their communities; better community relationships translate into greater individual support for CCS.

An Action Plan for CCS in California & Policy Recommendations

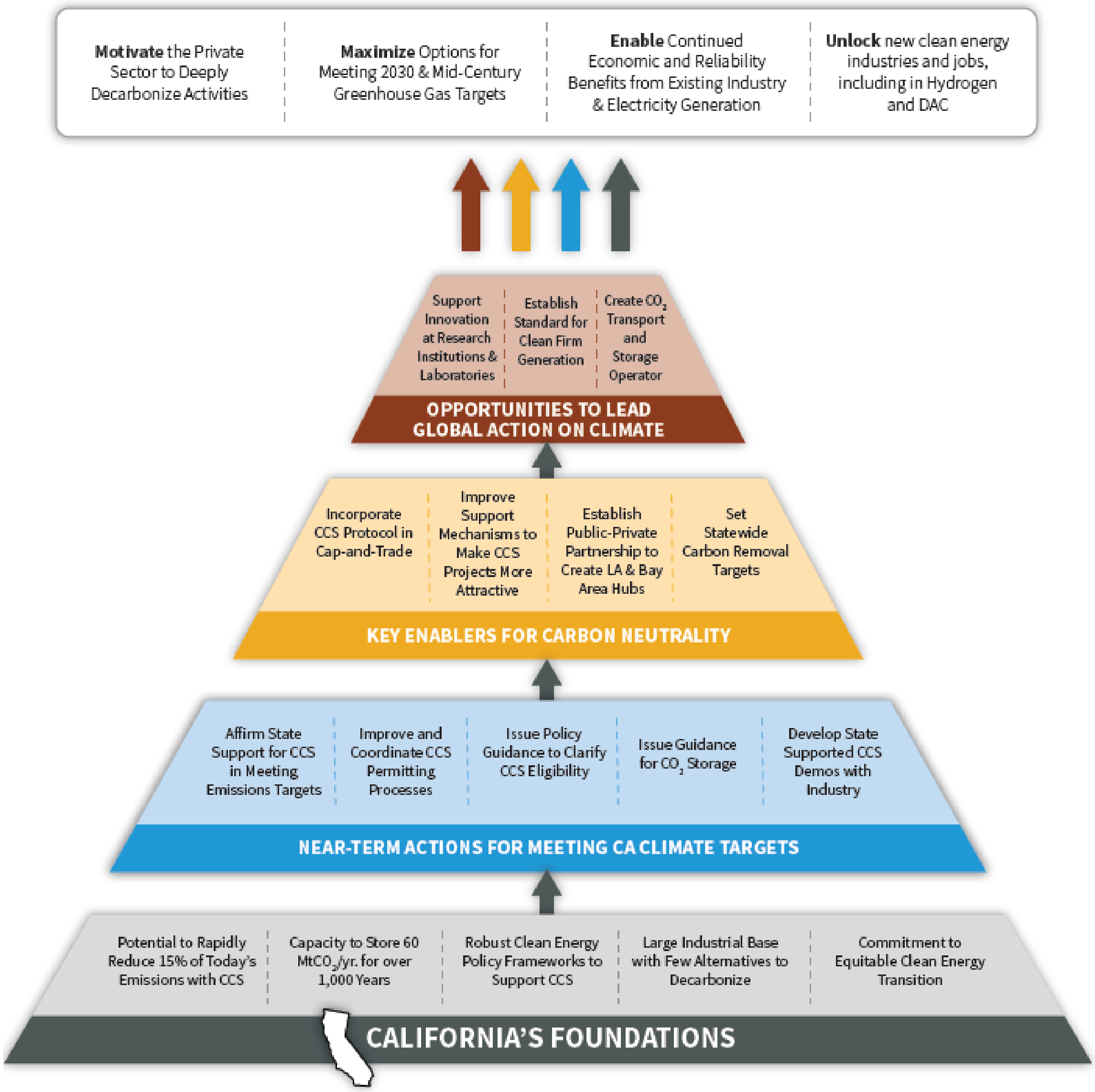
A combination of policy actions supported by broad coalitions can maximize the value of CCS for meeting the state's economywide decarbonization goals, motivating the private sector to decarbonize, enabling economic and reliability benefits from existing industries and power generation, and unlocking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

Figure 10 details the following goals: 1) Maximizing options for meeting 2030 and 2045 greenhouse 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-billiondollar, clean energy industries—such as hydrogen, CO_2 utilization, DAC, and fuels from biomass waste—creating new jobs in the process.

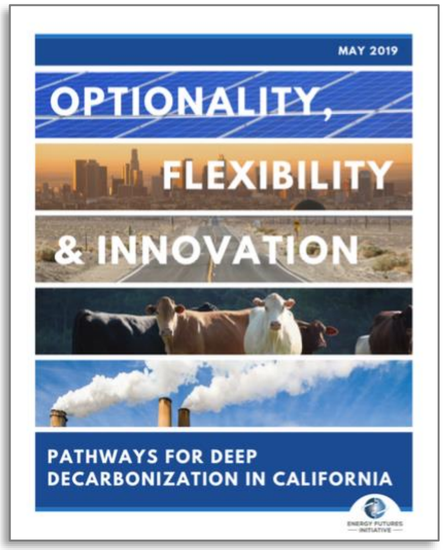
Figure 10

A Policy Action Plan for CCS in California to Meet the High-Level Goals



The analysis in this report helped form the high-level goals for CCS in California, described at the top of the figure. California can build on its strong foundation for CCS to develop and implement the specific recommendations. Each row of the figure above California's Foundations is organized by key drivers that increase in potential impact on CCS project development from the bottom to the top. Source: Energy Futures Initiative and Stanford University, 2020.

Optionality Flexibility and Innovation: Pathways to Deep Decarbonization in California



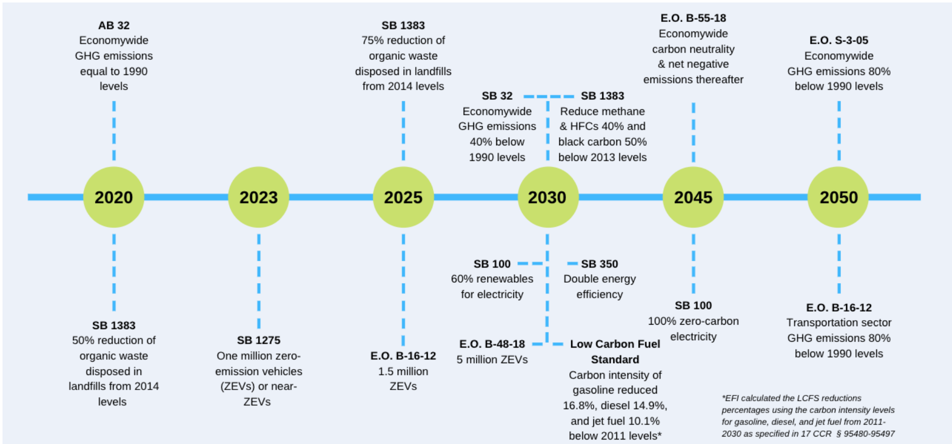
California is a global leader in climate policy. It has adopted aggressive goals to reach a low-carbon future at a scale and pace needed to meet the underlying Paris commitment of keeping temperature increases to two degrees Celsius, or even significantly lower, by the end of the century. If California meets its aggressive goals, it will enhance its leadership status, setting an example for the world where, unfortunately, carbon dioxide emissions continue to rise. As the world's fifth largest economy, what happens in California is critical for shaping the global response to climate change, reinforcing the importance of California's leadership.

This study analyzes the options—described as "pathways"—for meeting California's near- and long-term carbon emissions reduction goals. This analysis is designed to work within the parameters of existing state policy; it does not offer explicit policy recommendations.

California's decarbonization goals include both economywide and sector-specific policy targets (Figure 11): Executive Order S-3-05 (2005) calls for an economywide emissions reduction of 80% by 2050 (from 1990 levels); Executive Order B-55-18 establishes a statewide goal of carbon neutrality by 2045; SB 100 (2018) requires 60% renewable electricity generation (excluding large hydro) by 2030, and net-zero-emissions electricity by 2045. Some policies are more prescriptive (e.g., five million zero emissions vehicles by 2030), while others are less so (e.g., 40% reduction of emissions economywide by 2030).

Figure 11

California's GHG Emissions Reductions Policy Timeline



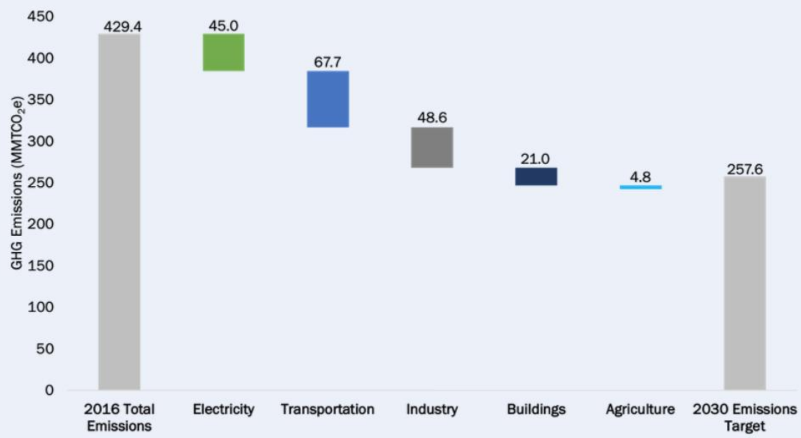
To meet its aggressive GHG emissions reduction goals, California has a number of policies aimed at reducing emissions from various sectors and end uses. Note that bill numbers were used as a shorthand. Source: EFI, 2019

To develop decarbonization pathways and technology options for California, this study focuses on two targets, identifying separate but overlapping tracks: aggressive decarbonization by 2030 and deep decarbonization by midcentury, both from a 2016 baseline. Each target presents its own unique challenges and opportunities. To support these different tracks, the analysis emphasizes the value of technology optionality and flexibility. Over the longer term, managing an economy that has the scale and sector diversity of California's, and is deeply decarbonized, presents dynamic challenges that have not been addressed previously. For both the near and long term, engaging a range of stakeholders is key; energy incumbents and legacy infrastructures may slow the deployment of existing clean technologies in the near term.

The top-level outcome of the analysis: ***California can indeed meet its 2030 and midcentury targets***. Figure 12 shows meeting the 2030 target will require success across economic sectors with multiple technologies contributing in each.

Figure 12

Identified Emissions Reduction Potential for Meeting the 2030 Targets by Sector



California can meet its 2030 target of a 40 percent emissions reduction with commercially available technology pathways. Emissions reduction strategies will have to contend with policy interactions, however, as well as the projected emissions growth in certain sectors. Source: EFI, 2019.

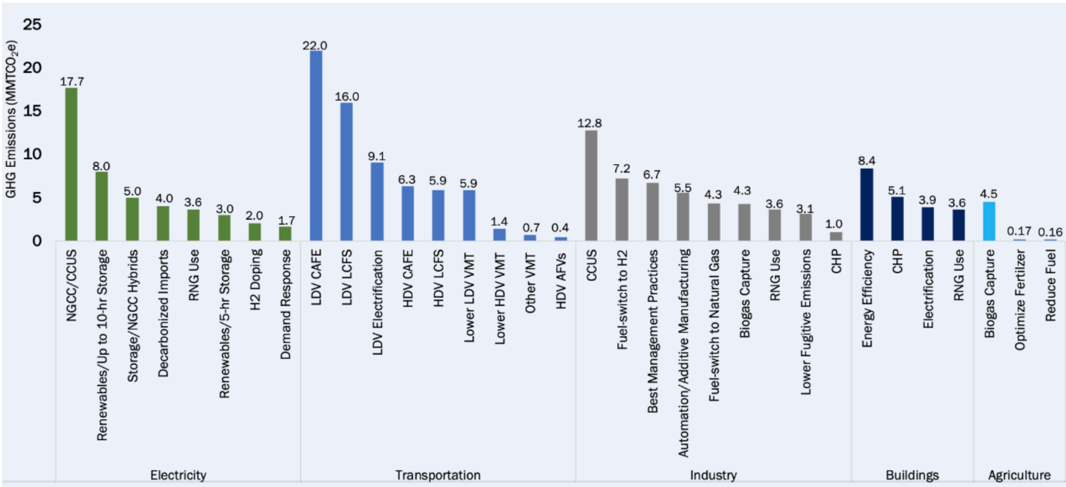
Achieving deep decarbonization in the midcentury timeframe will depend on innovation, including in clean energy technologies that cut across sectors. Meeting both goals and managing the costs will require a strong focus on, and commitment to, technology optionality, flexibility, and innovation. This focus is essential for several critical reasons:

- The energy system must provide essential services (light, heat, mobility, electricity, etc.) reliably at all times;
- The current cost of many important low- and zero-carbon technologies is too high;
- Energy delivery infrastructure must be available, reliable and secure as the system transforms;
- Affordable negative emissions technologies will ultimately be important at large-scale for deep decarbonization and acceptable stabilization of the earth's temperature; and
- Success will require aligning the interests and commitment of a range of key stakeholders.

Looking to 2030, this analysis provides a comprehensive analysis of 33 clean energy policy and technology pathways across California's economic sectors and assesses the emissions reduction potential of each (Figure 13). The portfolio prioritizes technologies with strong technical performance and economics; pathways that augment existing energy infrastructure are emphasized as they offer significant cost and market readiness benefits.

Figure 13

Identified Emissions Reduction Potential for Meeting the 2030 Targets by Pathway



The estimated emissions reduction potential for each pathway is shown by sector. They are based on an attempt to meet California's target to reduce emissions economy wide by 40 percent. This approach attempts to meet the target with an equal share from each economic sector. Source: EFI, 2019.

The growing impacts of climate change on energy systems and new and changing supply chains for sustainable energy technologies must be accommodated in policies and planning. Certain clean energy pathways are more susceptible to disruption, such as hydroelectric generation or power lines exposed to wildfires. Materials and metals needed for clean energy technologies may see price spikes or supply disruptions in the future.

These factors imply that detailed, bottom-up analysis of specific pathways, while instructive for meeting 2030 goals, have little value for informing the technologies needed to operate low- to zero-carbon energy systems by midcentury. The near-term focus should be on working as hard as possible to develop as many viable options as possible, making it clear that innovation must be at the heart of a decarbonization strategy.

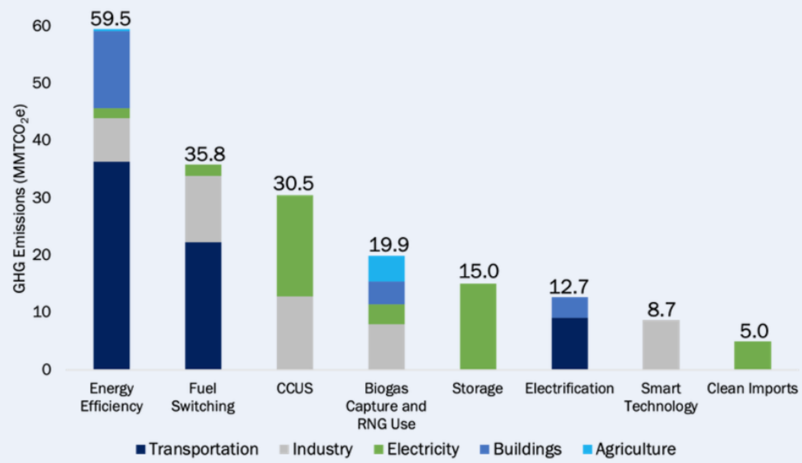
This report presents a "success model" for the longer term, strictly to illustrate both one of the many strategies that could meet long-term goals as well as to demonstrate the overall difficulty of achieving midcentury goals without having a range of options for doing so. It identifies an analysis-based innovation portfolio for California, focused on technologies with long-term breakthrough potential. Technologies were screened based on California's existing policies and programs, energy system and market needs, and other distinctive regional qualities that position California to be a technological first mover and global leader. Eleven breakthrough technologies were identified as major potential contributors to California's deep decarbonization over the long-term, including hydrogen produced by electrolysis, smart systems, floating offshore wind, seasonal energy storage, and clean cement, among others. Research and development on these technologies with breakthrough potential must pick up the pace today and be sustained to support their development.

Major Findings for Aggressive Decarbonization by 2030

- Meeting California's carbon reduction goals by 2030 will require a range of clean energy pathways across all economic sectors—Electricity, Transportation, Industry, Buildings and Agriculture (Figure 14). This is due to the uncertainty of each pathway and the fact that there are no "silver bullet" solutions. There are sufficient commercially available pathways to meet 2030 targets, though some technologies are less expensive and more advanced than others. To meet the 2030 target, however, it is expected that there will be incremental improvements and cost reductions in key technologies, for example, CCUS at industrial facilities and natural gas power plants.

Figure 14

Identified Emissions Reduction Potential for Meeting the 2030 Targets by Cross-Cutting Technologies



Some decarbonization strategies are applicable to multiple sectors of the economy. Of these, energy efficiency/demand reduction is most significant, representing the largest emissions reduction potential and cutting across all five sectors. Source: EFI, 2019.

- California's ambitious policy to double economywide energy efficiency is an important step for meeting 2030 decarbonization targets. Energy efficiency, defined broadly, is likely to be the most cost-effective approach to decarbonization in the energy end-use sectors in California. This includes technologies and processes that increase fuel efficiency of vehicles; demand-response mechanisms in the Electricity, Transportation, and Buildings sectors; highly efficient end-use technologies in all sectors, especially Buildings and Industry; and measures that help reduce energy consumption in sectors that have high non-combustion emissions, such as Industry and Agriculture.
- Transportation is the single largest emitting sector in California and requires transformational change to achieve aggressive decarbonization by 2030. Existing policies will have a major impact on the sector's emissions reduction by 2030. Transportation subsectors that are difficult to decarbonize—heavy-duty vehicles, aviation, marine, and rail—options for achieving deep decarbonization over the long term have to extend beyond energy/fuel-based technologies, including new

infrastructure systems, platform technologies, behavioral incentives, urban design, and advancements in materials science.

- Clean fuels (e.g., renewable natural gas [RNG], hydrogen, biofuels) are critical clean energy pathways due to the enormous value of fuels in providing flexibility to energy systems. Fuels that are durable, storable, and easily transportable play a fundamental role in ensuring that all sectors can operate at the scale, timing, frequency, and levels of reliability that are required to meet social, economic, and stakeholder needs.
- California can meet its 60% renewable energy target by 2030 with continued expansion of wind and solar resources; some geothermal and increased imports of clean electricity (mostly hydro) will play a role as well. Natural gas generation will continue to play a key role in providing California's grid with operational flexibility and enabling the growth and integration of intermittent renewables.

Major Findings for Deep Decarbonization by Midcentury

Meeting California's deep decarbonization goals by midcentury will be extremely difficult (if not impossible) without energy innovation. This is due to many challenges inherent to deep decarbonization planning, including:

- **Predicting the mix of clean energy technologies needed by 2050.** While many studies explore technology pathways over the long term, they should not be used to prescribe the optimal energy mix by midcentury.
- **Rising marginal costs of abatement.** It is highly likely that costs will increase over time as the lowest cost opportunities to reduce emissions are widely deployed.
- **Performance issues of deeply decarbonized energy systems.** Managing a large, carbon-free electric grid offers challenges in terms of operation, design, size, and the growing, climate change-related uncertainty concerns about wind and hydro availability, for example. Also, scalable clean technologies are not readily available for meeting deep decarbonization goals in several key applications.
- **Cost-effective and efficient negative emissions technologies are needed by 2045.** Technologies that could help achieve net neutrality are in relatively early stages of development and include carbon dioxide capture from dilute sources; massive utilization of captured carbon dioxide in commodity products; and both geological and biological sequestration at very large scale.

There are technology priorities with long-term innovation breakthrough potential that California should develop; these include hydrogen production with electrolysis, advanced nuclear, green cement, and seasonal storage, among others. These technology priorities were screened based on California's policies and programs, energy system and market needs, and other distinctive

Technology Priorities with Long-term Breakthrough Potential

Technologies were identified as having longterm breakthrough potential for California based on EFI-developed screening criteria. Source: EFI, 2019.

regional qualities that position California to be a technological first mover: a strong resource base, relevant workforce expertise, and robust scientific and technological capacity. A broader list of candidate technologies was also developed and organized by energy supply (electricity and fuels), energy application (Industry, Transportation, and Buildings), and cross-cutting technology areas (e.g., Large Scale Carbon Management).

A Repeatable Framework for Decarbonization

This report is meant to advise California's near- and long-term decarbonization strategy. It offers insights on decarbonization pathways, timescales, technology utilization, energy system operational needs, costs, and energy innovation. It provides a comprehensive review of on-the-ground issues that may aid or slow the state's progress toward deep decarbonization. In addition to benefitting California, there are high-level findings that may also provide a framework for decarbonization strategies that can, and should, be repeated in other economies around the world, including:

- Energy system "boundary conditions," including considerable system inertia that works against rapid change, complex supply chains, long-duration of technology development, and commodity business models must be taken into consideration when developing decarbonization strategies.
- There is no "silver bullet" technology for deep decarbonization. Technology optionality and flexibility are critical to any decarbonization strategy, especially for the difficult-to-decarbonize sectors.
- Existing carbon infrastructure and expertise must be aligned with deep decarbonization goals to prevent the creation of strong and dilatory political and business opposition to decarbonization pathways when acceleration is called for.
- Decarbonization pathways should address multiple timescales, emphasizing commercially available technologies in the near-term and developing (and/or supporting the development of) new technologies with long-term innovation potential.
- Decarbonization pathways should support local and regional energy capacity that includes the existing workforce, the structure of economic sectors, clean technology firms, natural and scientific resources, and many other factors that shape the opportunities and challenges on the ground.