Workshop Summary

The Critical Role of CCUS: Pathways to Deployment at Scale

February 2021

ENERGY FUTURES INITIATIVE

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About Energy Futures Initiative

The Energy Futures Initiative advances technically-grounded solutions to climate change through evidence-based analysis, thought leadership, and coalition-building. Under the leadership of Ernest J. Moniz, the 13th U.S. Secretary of Energy, EFI conducts rigorous research to accelerate the transition to a low-carbon economy through innovation in technology, policy, and business models. EFI maintains editorial independence from its public and private sponsors.

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Introduction

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.

This virtual workshop, held under Chatham House rule, featured opening remarks by international experts in energy, decarbonization, and labor. Following the keynote discussion, a range of experts provided insights into a variety of technologies, policies, and business model approaches to enable CCUS in the four main sessions. The expert presentations and panel discussions focused on the role of CCUS in clean energy transitions; experiences with CCUS—the critical niche it fills, the opportunities, challenges, and lessons learned from existing and planned projects; key technologies enabled by CCUS; and a roadmap for deploying CCUS in the United States.

The workshop concluded with remarks that again illuminated the importance of an equitable transition to net-zero emissions economy-wide by highlighting the importance of power generation or industry to certain communities, economies, and jobs. The insights from this workshop are summarized in this document.

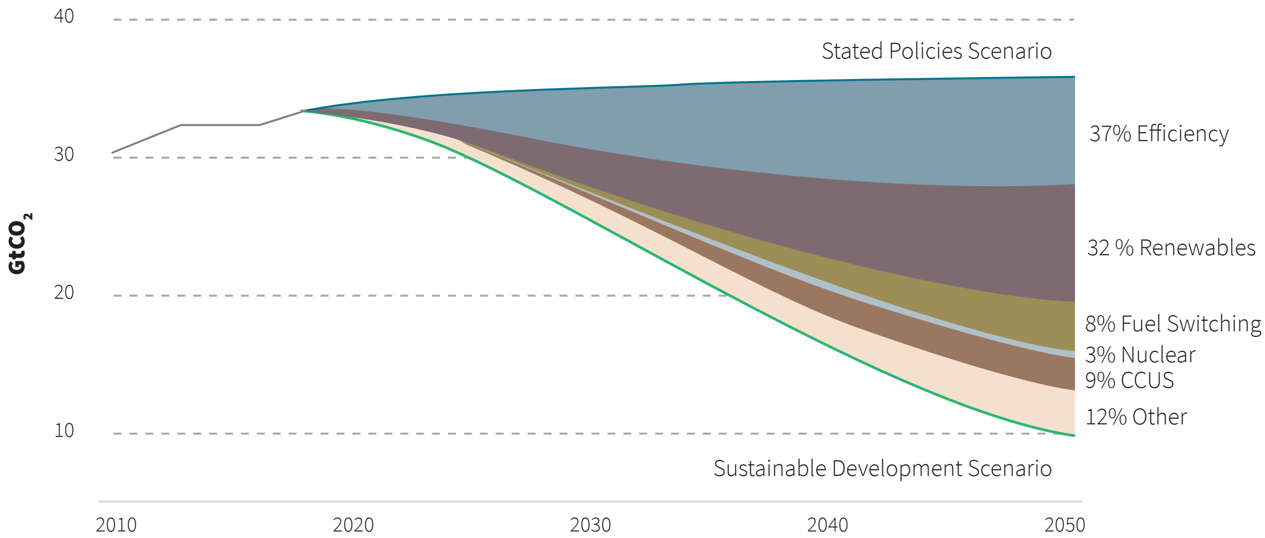
CCUS is Essential for Rapid Deep Decarbonization. There was general consensus that CCUS is a necessary component of any global strategy to achieve net-zero emissions by midcentury to avoid the most catastrophic impacts of climate change. Carbon capture can be implemented on numerous emissions sources 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 the International Energy Agency (IEA), CCUS is currently "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."[b] This is

a. This includes discrete discussions of carbon capture and storage (CCS) and carbon capture and utilization (CCU).
b. IEA (2020), *CCUS in Clean Energy Transitions*, IEA, Paris https://www.iea.org/reports/ccus-in-clean-energy-transitions.

Figure 1

Incremental Value of CCS to Meeting IEA's Sustainable Development Scenario Relevant to Its Stated 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.

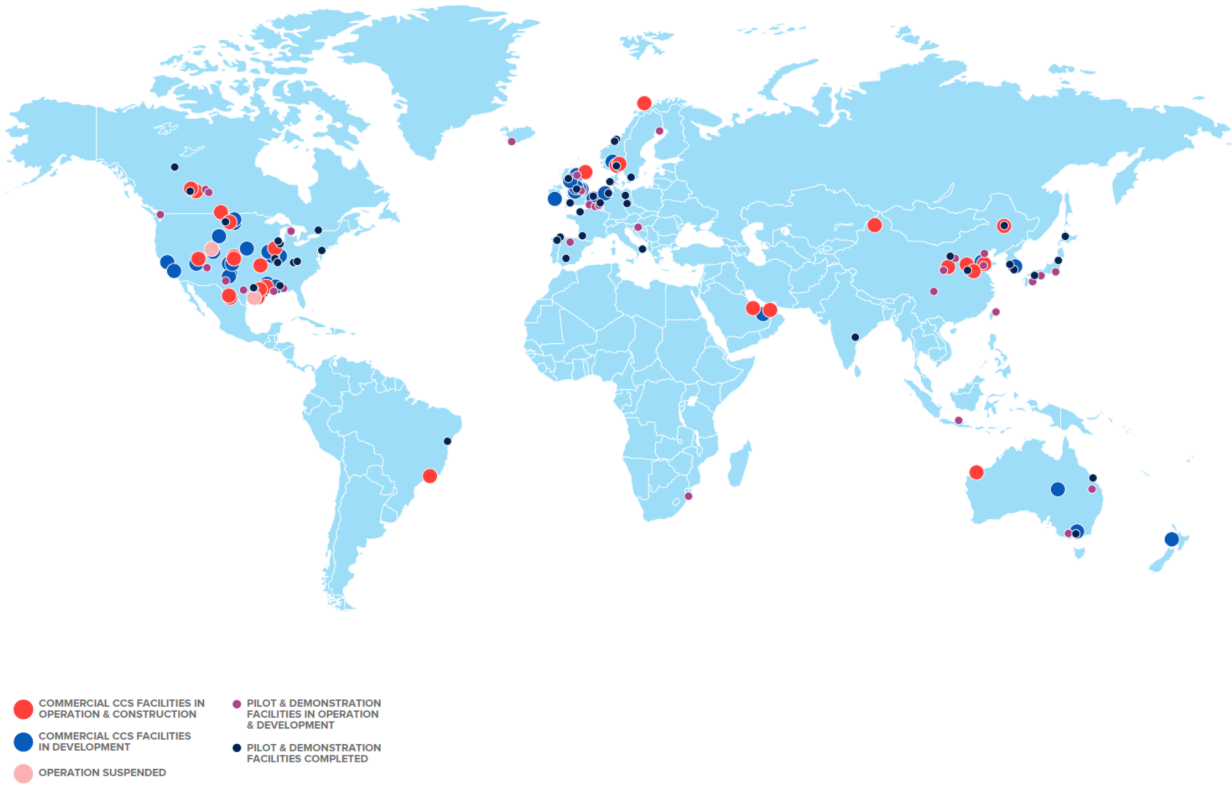
important as the world looks to both rapidly reduce emissions and recover from the economic devastation of the COVID-19 pandemic.

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 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" (see Figure 1). This conclusion and the growing recognition by scientists, policymakers, and governments that a net-zero emissions target is necessary for holding temperature increases to 1.5 degrees by mid-century, provided the motivation for this workshop.

c. IEA (2020), *CCUS in Clean Energy Transitions,* IEA, Paris https://www.iea.org/reports/ccus-in-clean-energy-transitions.

Figure 2

Global CCS Facilities at Various 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

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."[c]

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 2 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.

Framing the Issues

The workshop began with an acknowledgement that the world is currently facing three critical challenges: the COVID-19 pandemic, the COVID-related economic recession, and climate change. These challenges could share common solutions and needs.

Rebuilding Global Economies, Post-COVID. As the world navigates its way out of the pandemic, it could, in the words of President Biden, "build back better," by creating jobs and addressing the climate challenge at the same time. Doing so could also address equitable solutions to the climate crisis, build diverse coalitions needed for rapid action, establish strong partnerships as the world rebuilds in the post-pandemic era, and encourage investments in innovation.

CCUS offers an example of a climate mitigation solution that addresses all of these post-COVID concerns. It has the support of a wide range of stakeholders, and it can create jobs and aid in the clean energy transition. It offers sizeable economic benefits and dramatic emissions reductions in both the power sector and in vital industrial sectors that have few alternatives to decarbonize.

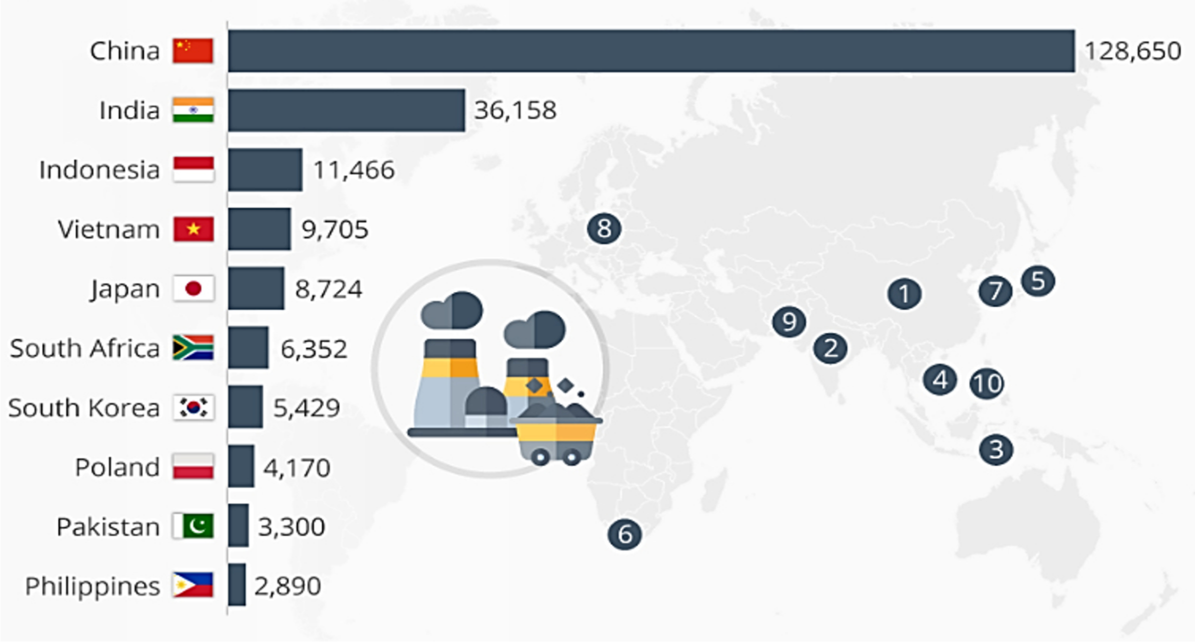
Meeting Net-Zero Targets Across the Globe. The increased focus of national governments on net-zero targets in the European Union, UK, Japan, Korea, Canada, and New Zealand, among others, underscores the critical importance of keeping global temperature increases to 1.5 degrees. Meeting a net-zero target, however, requires support for key policy and technology investments. Speakers expressed optimism that the U.S. Would join these countries by setting a net-zero emissions target and taking action to meet this goal.

As more countries set net-zero targets and strategize how to achieve these goals, two main considerations were raised. First, the world should build new facilities, buildings, industrial sites, and power plants to be as low emitting as possible. Second, legacy infrastructure must be considered and accommodated to avoid stranding investments, other capital-intensive assets, as well as the workers that support operation and maintenance.

This is a global issue but is especially relevant in parts of Asia, where there are many power plants—largely coal-fired—that are less than ten years old. These young plants prove to be problematic in the transition to a net-zero world. These facilities are critical for electrification and economic development; CCUS provides an option for ensuring their ongoing contributions to local economies while dramatically reducing emissions. Figure 3 shows megawatts of coal plants under construction around the world in 2018.

Figure 3

Megawatts of Coal Plants Under Construction in 2018



China had a significant amount of coal-fired power plants under construction in 2018, despite the imperatives to transition to cleaner energy sources. CCUS offers an opportunity for countries with significantly younger coal fleets to continue to utilize those assets, while achieving emissions reductions needed to curb climate change. Source: Global Energy Monitor, Greenpeace India, and the Sierra Club, 2018.[d,e]

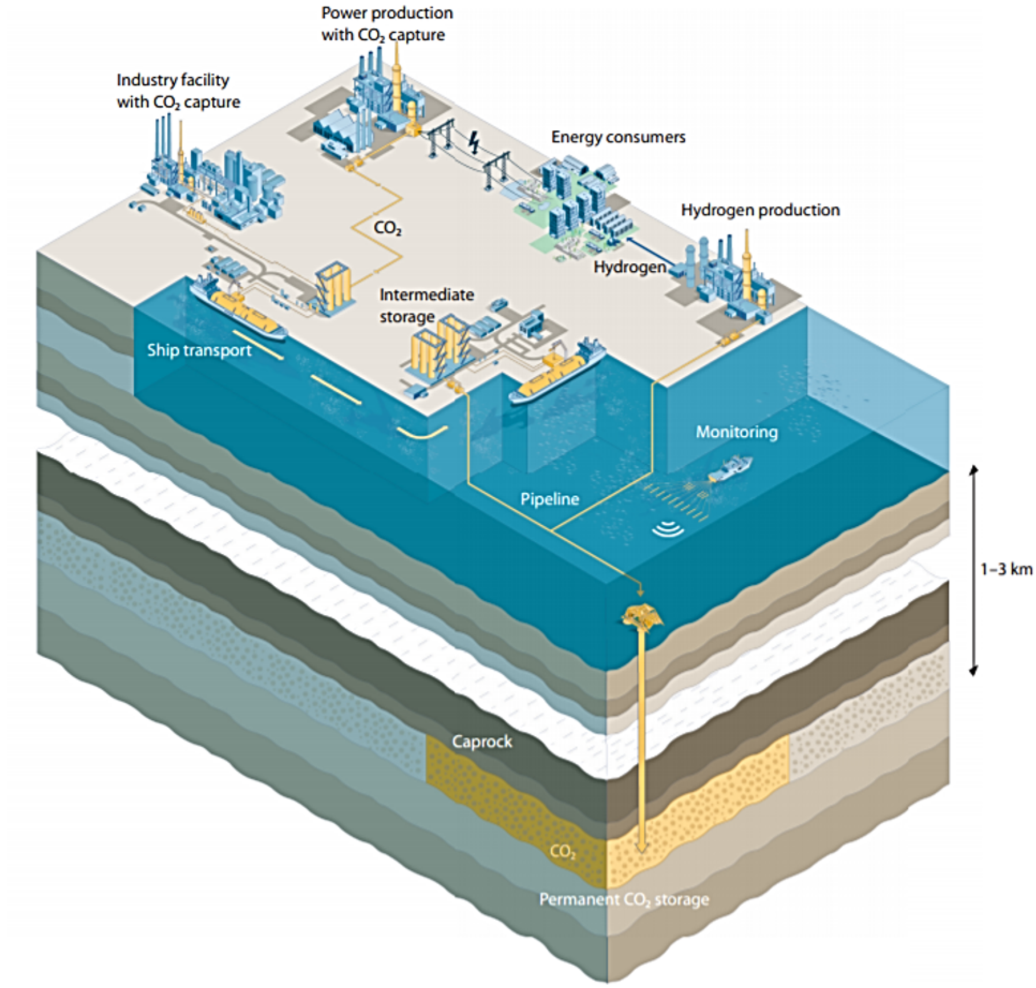
Addressing Different National, Regional, Local Needs. The varying regional needs for CCUS were highlighted as a key framing issue. In the U.S., many states and cities have decarbonization goals, and there will be different paths to decarbonization for various regions; CCUS could play a critical role. For example, EFI's October 2020 report, An Action Plan for Carbon Capture and Storage in California: Opportunities, Challenges, and Solutions (discussed in Session Four), estimated that California could meet 15% of its 2030 economy-wide emissions reduction target with CCUS in the power and the industrial sectors. In contrast, EFI's November 2020 study, Net-Zero New England: Ensuring Electric Reliability in a Low-Carbon Future concluded that CCUS is not a viable option because of the lack of geologic storage potential and historic challenges with infrastructure siting in the region. Under the Biden-Harris

d. Global Energy Monitor, Greenpeace Environmental Trust, & Sierra Club (2019), Boom and Bust 2019: Tracking the Global Coal Plant Pipeline, Global Energy Monitor, Greenpeace Environmental Trust, & Sierra Club, https://www.greenpeace.org.au/wp/wp-content/uploads/2019/03/BoomAndBust_2019_r6.pdf.

e. McCarthy, Niall (2019), Where The Most Coal Power Plants Are Under Construction, Statista, https://www.statista.com/chart/17517/megawatts-of-coal-power-capacity-under-construction/.

Figure 4

Longship Initiative: Illustration of Carbon Capture from Industrial Facilities/Power Production, Transport by Pipeline/Ship, Geologic CO_2 Storage



A CCUS value chain that encompasses multiple emissions sources and carbon transport options, ultimately securing emissions in deep geological storage. Source: Norweigan Ministry of Petroleum and Energy, Longship Carbon Capture and Storage, 2019-2020.

Administration, it is possible that national CCUS deployment could be a key climate mitigation opportunity; however, it is critical to closely assess the regional variations in the applicability of and use cases for CCUS.

Overview of Several Successful CCUS Projects. The session concluded with a brief overview of CCUS efforts in Norway (e.g., the recently launched Longship initiative, see Figure 4), the UK, Japan, the Middle East, and Canada as successful examples of public-private partnerships supporting CCUS. These initial efforts are important first movers for technologies where there will be massive needs in the near- and long-term.

The speakers noted that the U.S. has historically been the global leader in innovation and clean energy technology and expressed an expectation that this leadership role would resume with the new administration. As the Biden-Harris Administration works to restore U.S. leadership in clean energy technology development and deployment, a central focus on jobs and other local issues (e.g., siting, public participation, and justice) will be key to success for developing CCUS projects at the speed and frequency needed to meet near-term and midcentury climate goals.

Session One

The Role of CCUS in Clean Energy Transitions

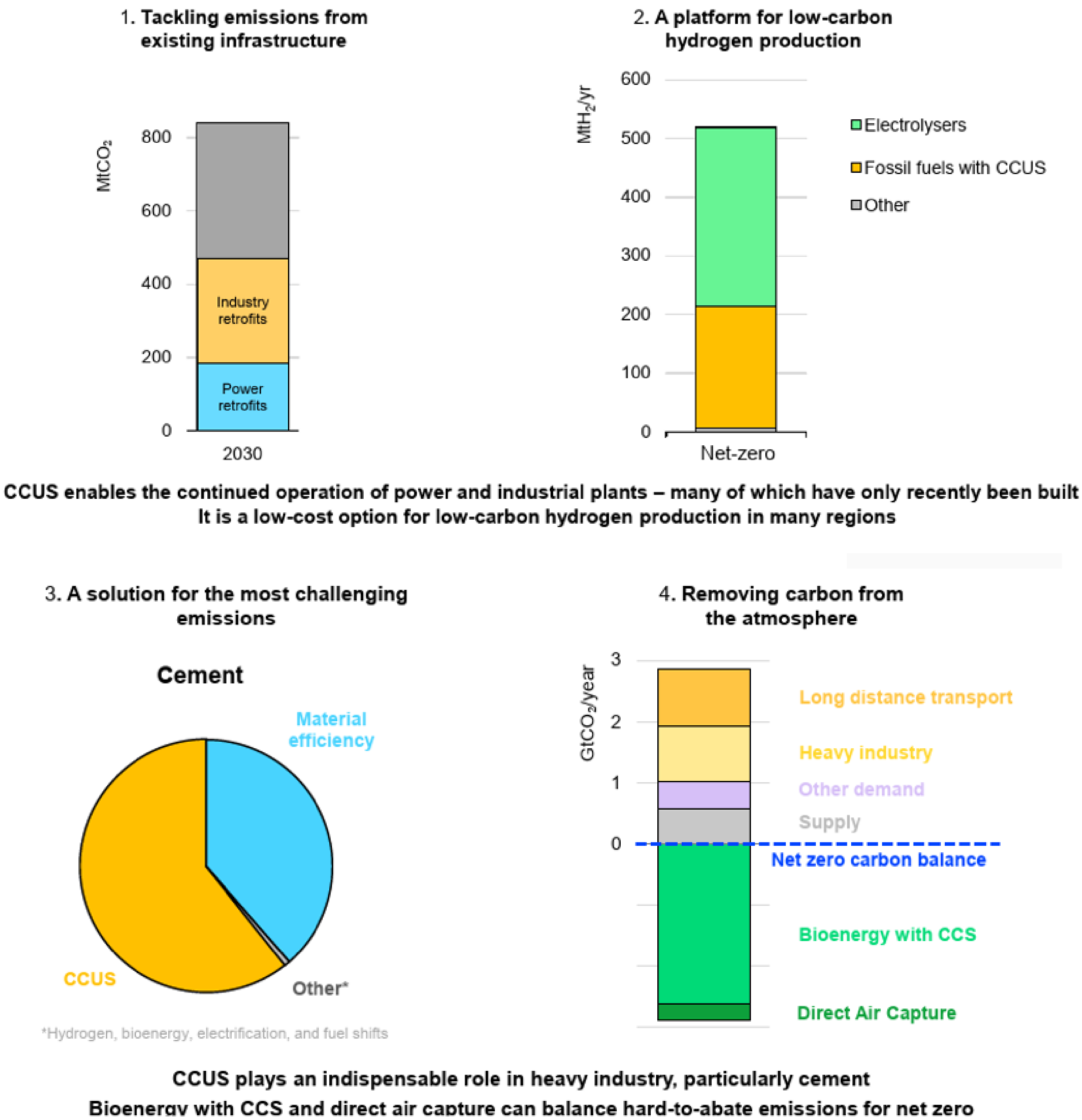
The first session of the workshop was a presentation on the IEA's September 2020 flagship report, The Role of CCUS in Clean Energy Transitions. The report is part of the IEA's Energy Technology Perspectives series, which took a technology-neutral approach to illuminate the opportunities and challenges for meeting international energy and climate goals. The study found that currently, the world's 20 existing largescale CCUS projects, while important, are seriously insufficient for meeting a two-degree target by 2050. New net-zero targets, a broader experience base, and stronger investment incentives are, however, building momentum for CCUS.

Strategic Roles for CCUS. As noted earlier, the IEA study concluded that "reaching net zero will be virtually impossible without CCUS." It identified four strategic roles for CCUS (summarized in Figure 5):

1. **Dramatically reducing emissions from existing infrastructure.** CCUS can be retrofitted to existing power and industrial plants that could otherwise emit 600 billion tons of CO_2 over the next five decades – about 17 years' worth of current annual emissions.
2. **Providing a platform for low-carbon hydrogen production.** Heavy industries account for almost 20% of global CO_2 emissions today. CCUS is the only demonstrated technology solution for deep emissions reductions from cement production. It is also the most cost-effective approach in many regions to curb emissions in iron, steel, and chemicals manufacturing. Captured CO_2 is a critical part of the supply chain for synthetic fuels from CO_2 and hydrogen – one of a limited number of low-carbon options for long-distance transport, particularly aviation.
3. **Providing a solution for the most challenging emissions.** CCUS can support a rapid scaling up of low-carbon hydrogen production to meet current and future demand from new applications in transport, industry, and buildings.
4. **Removing carbon from the atmosphere.** For emissions that cannot be avoided or reduced directly, CCUS underpins an important technological approach for removing carbon and delivering a net-zero energy system.

Figure 5

Four Strategic Roles for CCUS



The IEA identified four strategic roles for CCUS in its 2020 flagship report: tackling emissions from existing infrastructure, providing a platform for low-carbon hydrogen production; providing a solution for the most challenging emissions; and removing carbon from the atmosphere. Source: IEA, 2020.

Growing Interest in CCUS. The recognition of the need for and importance of CCUS is reflected in the growing number of planned projects around the world. In the last three years alone, more than 30 commercial projects have been announced. Deployment in some crucial sectors, including steel and cement, however, is lagging even though CCUS is one of the few emissions reductions opportunities. CCUS, on the other hand, is relatively over-represented in other subsectors, including natural gas processing and fertilizer production. At the same time, the project portfolio for CCUS is growing in diversity to include power generation, cement, and hydrogen.

The IEA study concluded that the success of CCUS will depend on the deployment of infrastructure to connect emissions sources with suitable geologic storage. A rapidly emerging trend for CCUS is the development of hubs and cluster models that utilize shared CO_2 transportation and storage infrastructure to reduce costs and optimize infrastructure use.

The session concluded with an overview of the critical need for government and industry action in this decade to accelerate the progress of CCUS. The IEA identified the following four high priority areas for government and industry:

1. Create the conditions for investment by placing a value on reducing emissions and providing direct support for new or developing CCUS projects.

2. Coordinate and underwrite the development of industrial hubs with shared CO_2 infrastructure.

3. Identify and encourage the development of CO_2 storage in key regions.

4. Boost innovation to reduce costs and ensure that critical emerging technologies become commercial, including in sectors where emissions are hard to abate.

Session Two

Experiences with CCUS: The Need, Opportunities, Challenges, and Lessons Learned

This session began with a brief presentation on the Global CCS Institute's annual Global Status of CCUS 2020 report. It concluded that despite the challenges of COVID-19, the pipeline of projects that are operational and those under development grew for the third year in a row. The report provides detailed information on and analyses of the global CCS facility pipeline, international policy perspectives, CO_2 storage, and the CCS legal and regulatory environment. Additional points highlighted in the presentation:

- There are 26 CCS facilities in operation, three under construction, 34 under development, and two that have suspended operations. There were 17 new facilities added to the pipeline in 2020 alone.

- The number of countries, cities, and companies that have committed to net-zero emissions targets increased in 2020 despite the adversities of the COVID-19 pandemic, accelerating CCS development.

- Policy and funding support for CCS continued its momentum.

- There are three factors that help make the business case for CCS around the world:

    - An enhanced tax credit in the United States
    - Hubs and clusters
    - Hydrogen as the fuel of the future

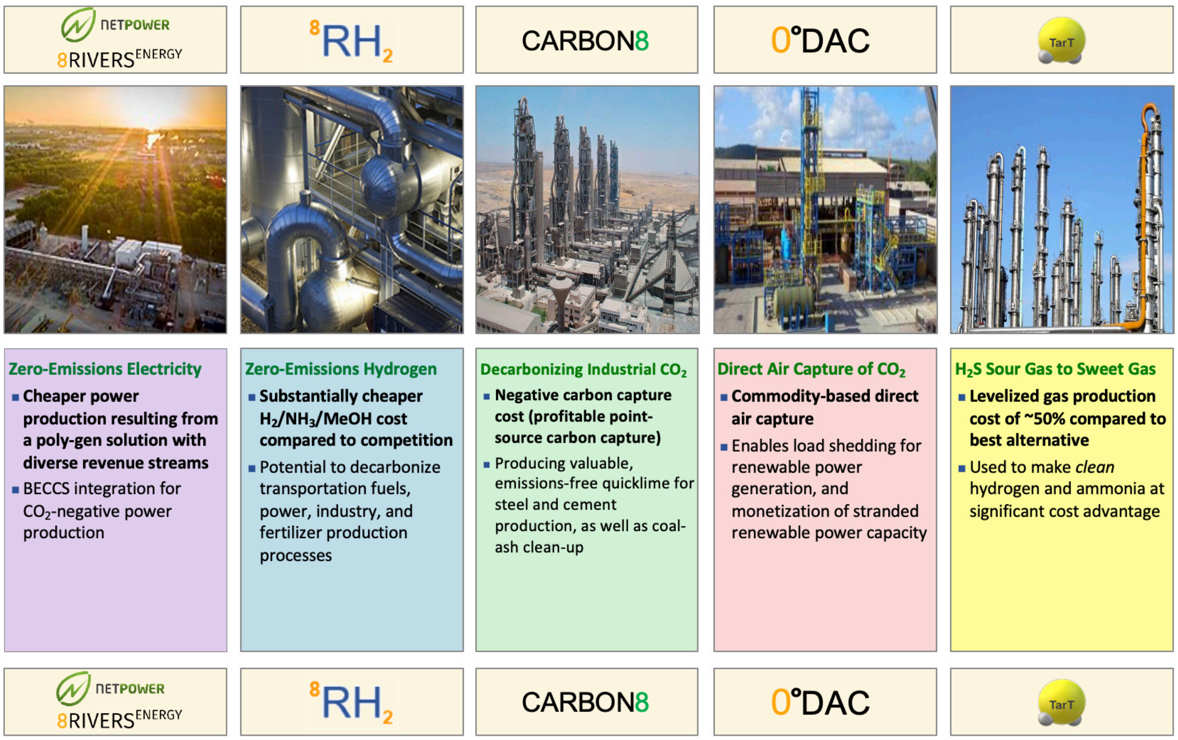
- Despite the progress on CCS in 2020, to achieve net-zero emissions by midcentury, CCS capacity must increase more than a hundredfold by 2050.

A Range of Uses for CCUS. Following the study overview, the panel discussion elicited insights from CCUS experts in industry who are working on CCUS projects around the globe. Each representative described their company's CCUS project(s), lessons learned from previous projects, and insights about the future of CCUS. Below is a summary of some of the key insights gleaned from this discussion:

- Bioenergy with CCS (BECCS) is a negative emissions technology that can play a major role in reducing emissions, as it is relatively simple, does not require the development of entirely new

Figure 6

8 Rivers: BECCS, Industrial Carbon Capture, Direct Air Capture



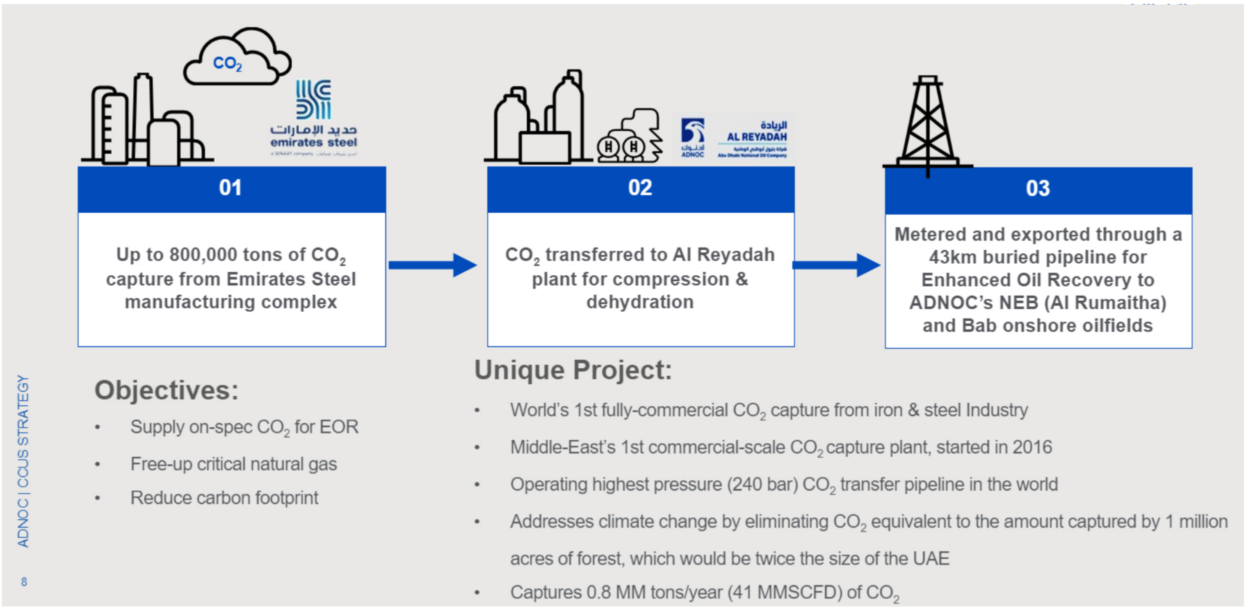
Technical processes developed by 8Rivers Energy facilitate capture, utilization, and storage of carbon dioxide, and can be adapted for use with bioenergy to ultimately achieve negative emissions. Source: 8 Rivers, 2020.

technologies, and is low cost (see Figure 6 for BECCS and zero carbon electricity). Furthermore, BECCS can be paired with renewables to create zero or negative carbon transportation fuels that can easily be integrated into existing transportation infrastructure. Finally, BECCS is a very suitable technology to deploy regionally due to the need for networks for gathering feedstocks that make clustering suitable.

- CCUS in steel manufacturing presents a significant opportunity since, according to Our World in Data, in 2016, steel and iron production contributed 7.2% of global greenhouse gas emissions and has very few other options to reduce emissions. There are currently two projects underway in the United Arab Emirates conducted by the Abu Dhabi National Oil Company (ADNOC) that will reduce an estimated 2.4 $MtCO_2$/year (Figure 7).

Figure 7

CCUS for Steel: Al Reyadah Project Description



This figure shows the processes for a low-carbon steelmaking operation utilizing carbon capture and sequestration.
Source: ADNOC, 2020.

- There is an important role for government support of CCUS absent internalization of the external costs of climate change. Public-private partnership for hubs and clusters is emerging as the ideal business model for risk sharing and investment in CCUS projects. The Longship project in Norway, for example, received nearly two-thirds of its funding from the government to cover investments and 10 years of operations; industry will be responsible for funding the balance of costs and must build and operate its own facilities.

- The knowledge and experience of oil and gas corporations can be leveraged to deploy CCUS because it involves many of the same skillsets for planning, developing, deploying, operating, monitoring, and testing CO_2 injection wells. The oil and gas industry also has significant experience with pipelines, another skillset that could support the buildout and maintenance of CCUS infrastructure.

- Financial incentives from governments are currently the key driver of CCUS but the industry needs long-term commitments and more durable policies to ensure widescale deployment.

The session concluded with a “lightning round” of questions in which panelists provided advice to the Biden-Harris Administration about lessons learned about CCUS deployment. Responses included: extending the 45Q tax credit construction deadline; clarifying regulation; developing a long-term CCUS policy that acknowledges the geographic and industrial variations of the U.S. (i.e. not a one-size-fits all CCUS policy); leveraging partnerships with industry to harness expertise and accelerate development; and incorporating CCUS development within a broader pandemic recovery effort.

Session Three

Key Technologies Enabled by CCUS

The third session of the workshop featured executives from three companies leading in cutting-edge emissions reduction technologies. The discussion focused largely on CCUS in cement and power generation, as well as DAC (see Figure 8).

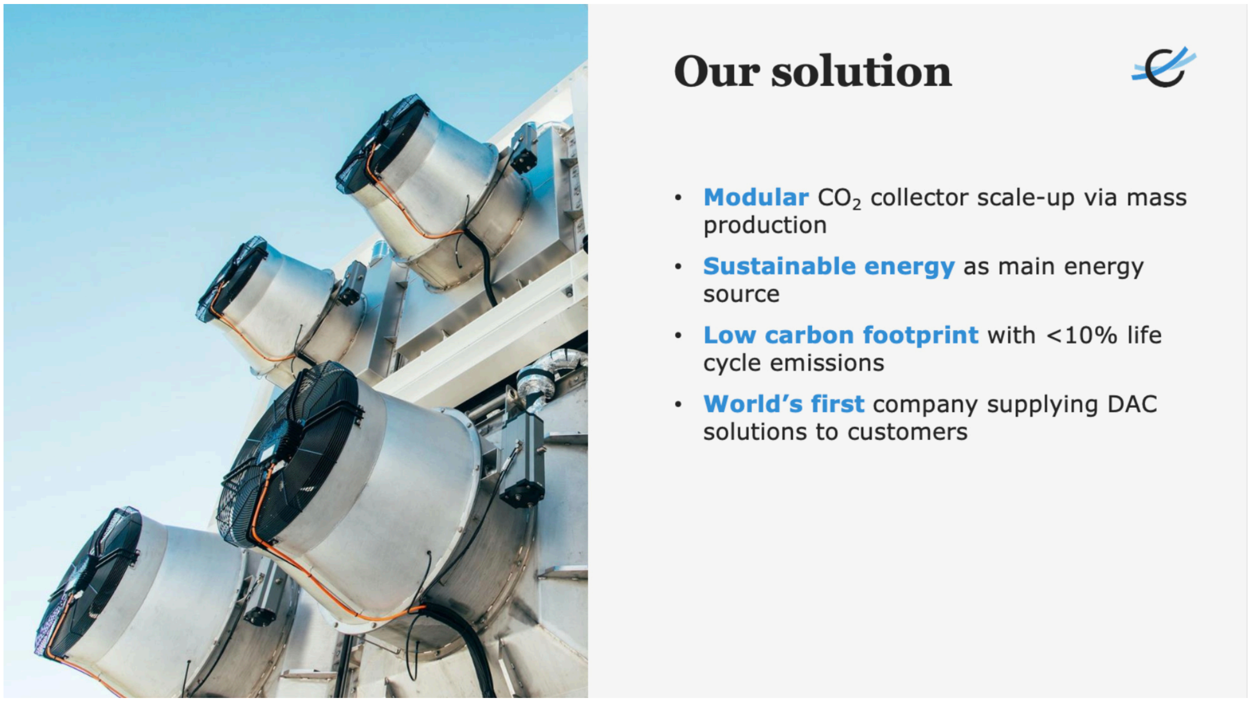
Though these companies' technologies are entirely different in their application and use, a commonality is that all of them leverage modular designs that enable these technologies to be utilized for several applications and scaled up.

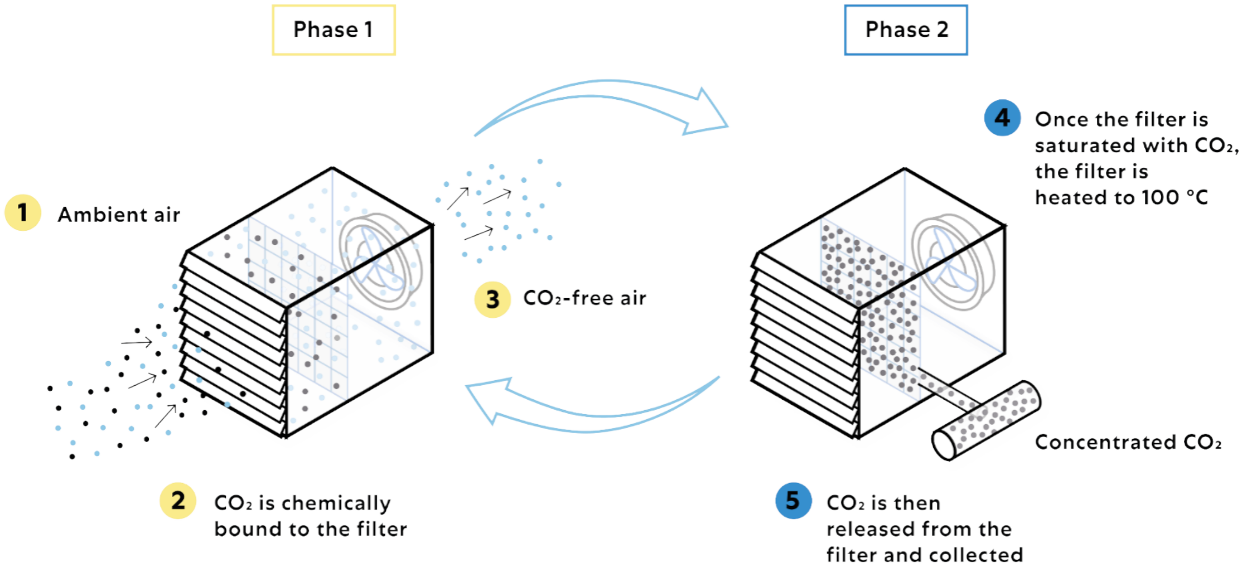
Key insights offered during the moderated Q&A included:

- There is optimism that more supporting policies for DAC in the U.S. will drive its deployment. Already, DAC facilities anywhere in the world are eligible for credits under the CCS Protocol of California's Low Carbon Fuel Standard (LCFS), which currently trade for around $200/ton of CO_2 captured and stored.
- Oil and gas, power, and chemicals are siloed, so breaking down the barriers between sectors would be a major opportunity to deploy cutting-edge CCUS applications in efficient ways.
- Low-carbon cement policies are being led by the state and local levels (e.g., procurement standards, low-carbon cement requirements, tax incentives) and these models can serve as a basis for other jurisdictions.
- Policy support is necessary to bridge the financial gap for various CDR technologies; voluntary markets, philanthropies, and corporations wishing to offset their carbon footprint, will be insufficient in the long term.

Figure 8

Climeworks: Direct Air Capture Technology





This figure shows Switzerland-based Climeworks' direct air capture technology. Source: Climeworks, 2020.

Session Four

Roadmap for Deploying CCUS in the United States

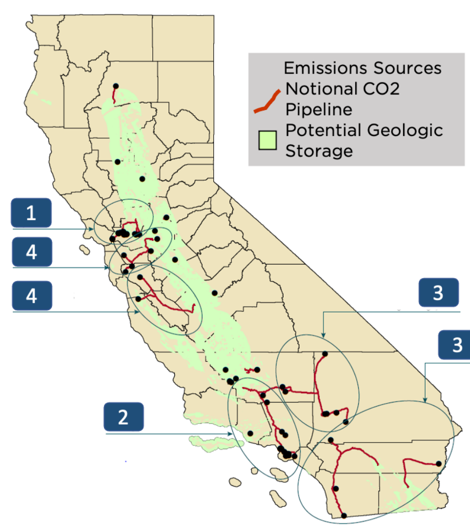
The final session began with a presentation of the October 2020 EFI and Stanford University Study, An Action Plan for Carbon Capture and Storage in California: Opportunities, Challenges, and Solutions. This study included a technoeconomic analysis to identify the CCUS opportunity in California: 76 emissions sources with capturable emissions totaling 60 $MtCO_2$/year and saline formations with CO_2 storage capacity of 100 to 500 gigatons, which is enough to store 60 $MtCO_2$ per year for more than 1,000 years (Figure 9).

Additional opportunities in terms of jobs and air quality benefits were also identified. This study clearly articulated the social equity benefits associated with the relationship between carbon capture from California's industrial facilities and the associated reduction in criteria pollutant emissions for residents living near these capture sites (Figure 10).

California offers strong financial support for CCUS through the LCFS CCS Protocol. This, combined with the federal 45Q tax credit, creates opportunities in

Figure 9

Carbon Capture Sources, Notional Infrastructure, Potential Storage Sites in California



Co-located capture and storage	• 3 ethanol plants, 6 NGCC, 6 CHPs and 1 cement plant
1. Northern California Gathering System and Storage Hub	• 8 hydrogen 4 refineries, 5 CHPs, and 3 NGCC
2. Southern California Gathering System and Storage Hub	• 8 hydrogen, 5 refineries, 4 CHPs, 1 cement, and 5 NGCC
3. Desert and Salton Sea Gathering Systems	• 5 cement, 1 CHP, 6 NGCC
4. Central California and S. Bay Gathering System	• 1 cement, 5 NGCC

The analysis in An Action Plan for Carbon Capture and Storage in California identified four potential CCS "hubs" as well as 16 co-located emissions sources and CO_2 sinks. Source: Energy Futures Initiative and Stanford University, 2020.

Figure 10

Social Equity and Community Benefits from Industrial Carbon Capture in California

Local Air Quality Improvements

- Some industrial facilities with high CO_2 emissions also emit high levels of criteria air pollutants such as sulfur dioxide (SO_2), nitrous dioxide (NO_2), and particulates
- **Post-combustion carbon capture requires reduction of these other pollutants creating local air quality benefits**

Local Economic Activity

- CCS projects can **stimulate local economic activity**, including new construction, operations, and maintenance jobs
- **Multiplier effects across the supply chain can drive additional economic benefits**

Job Creation and Preservation

- The economic benefits associated with **job training** could provide new employment opportunities in the low carbon economy
- CCS activities support **employment** for skill sets which may otherwise become obsolete in a clean energy transition

CCS can provide local air quality improvements on certain facilities, local economic benefits, and job creation and preservation. Source: Energy Futures Initiative and Stanford University, 2020.

the state for CCUS. There are, however, several barriers to its widescale deployment. These challenges fall into four general categories.

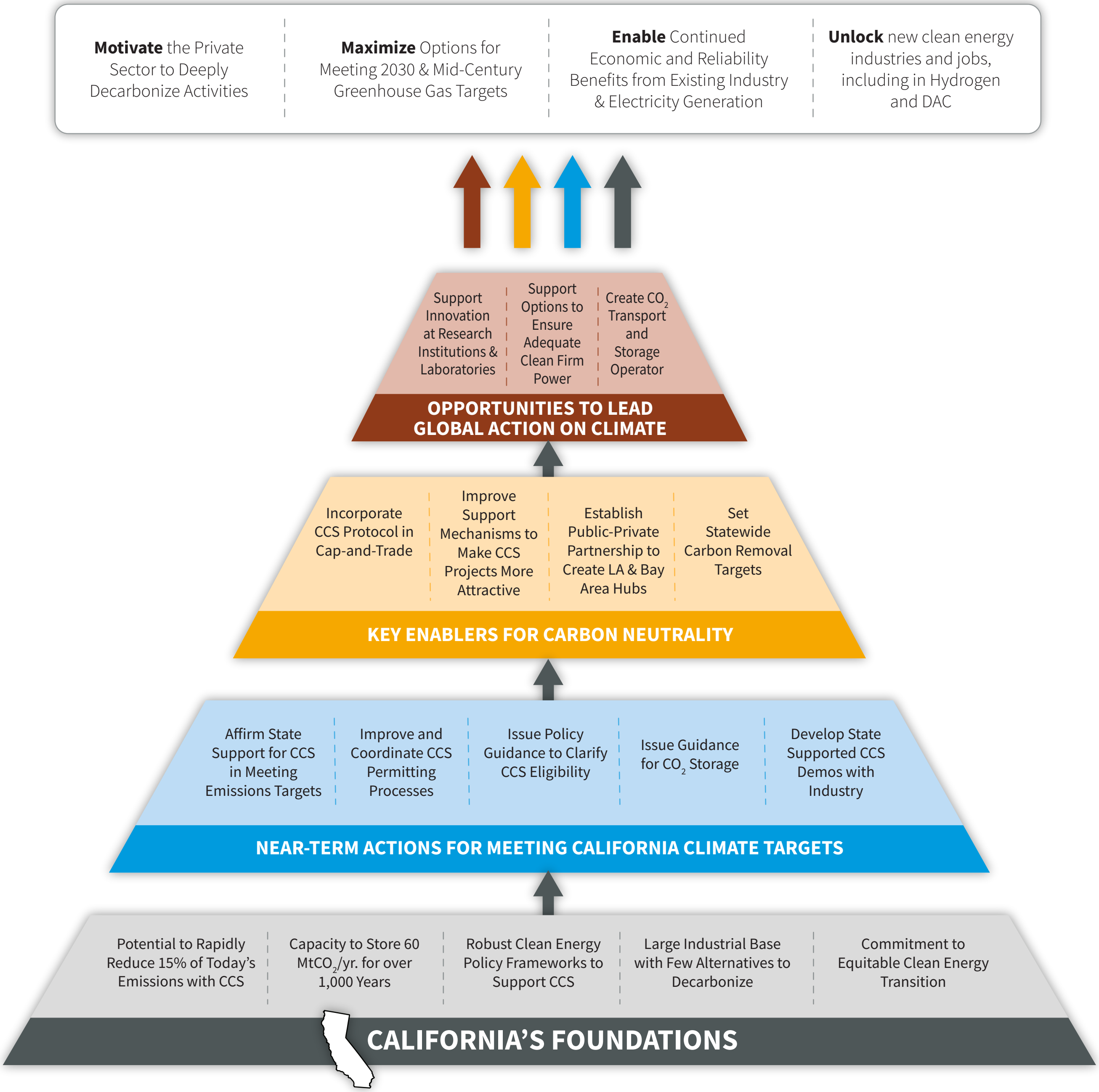
- Ambiguous position of the state on the future role of CCS
- Complex and untested regulatory process for getting permits for CCS
- Revenue and cost uncertainty discourage project finance
- The lack of public awareness and support for CCS

To address these challenges and take advantage of the CCS opportunity in California, the state needs to create new policies, adjust current policies, and develop demos, among other recommendations, which are detailed in the study (Figure 11). The recommendations were aimed at achieving the following goals:

- Motivate the private sector to deeply decarbonize activities
- Maximize options for meeting 2030 and midcentury greenhouse gas targets
- Enable continued economic and reliability benefits from existing industry and electricity generation
- Unlock new clean energy industries and jobs, including in hydrogen and DAC

Figure 11

High Level Goals, Strong Foundations, and Actions to Support CCS in California



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.

Following the study briefing, the final panel, comprised of experts in policy, advocacy, and research and development, discussed options for supporting a U.S. CCUS roadmap. This panel provided unique perspectives on various elements of the CCUS landscape in the U.S. summarized as follows:

- The midcontinent region has seen significant interest in CCUS and activities for deployment as well as earlier stage analysis. There is a 16-state carbon capture work group, which includes more than 400 stakeholders, and several on-going efforts to deploy CCUS, preserve jobs and industries, and explore additional opportunities to support CCUS.

- There are opportunities for CCUS in the power sector to help states and utilities achieve net-zero carbon goals, complementary to widescale deployment of renewables and other carbon-free generation sources. It is imperative to consider the impacts on local communities, engage local stakeholders in discussions about CCUS early and often, and ensure that decisions are made with equity and environmental justice at the forefront.

- DOE's National Laboratories are a locus for innovation and development of various CCUS technologies. There are currently 101 projects underway at the National Energy Technology Laboratory (NETL).

The panelists identified the following challenges to CCUS in the U.S.:

- Lack of a nationwide carbon price limits the deployment of CCUS projects to those qualifying for existing incentives, namely LCFS and 45Q; however, these credits alone are not enough to get the biggest emitters to pursue CCUS projects.

- CCUS needs a broader portfolio approach, utilizing the incentives, standards, and other tools applied for wind, solar, and energy efficiency to see CCUS deployment at scale.

- Public acceptance of CCUS and skepticism towards fossil fuel companies is a major challenge, and these companies, many of which have decarbonization targets and commitments, should follow through with these commitments by investing in decarbonization solutions, pushing for policies and regulations to address climate change, and immediately reducing their own carbon footprints.

- There is considerable unlocked technical potential to develop CCUS in the U.S. where technology-neutral national climate policies are likely to maximize its value. These policies should also address current challenges with the economy and with social inequality.

- The relatively limited experience in saline reservoir CO_2 storage as compared to that for enhanced oil recovery (EOR) is a major challenge because the future of CCUS is saline storage, yet the vast majority of CCUS projects currently inject the CO_2 for EOR. The EPA UIC Class II well permitting process (for EOR) is much more straightforward, tested, and understood, while only two Class VI permits (for geologic storage) have been issued in the U.S.

Other major U.S. challenges identified in EFI analysis have limited CCUS deployment. These include the lack of large-scale examples and hub models. The U.S., for example, has only one power sector capture project (Petra Nova), which was halted during the COVID-19 crisis for economic reasons. There are also issues with aligning players, permitting, and financing for CCUS that currently contribute to a difficult business environment. Finally, the untested and uncertain permitting requirements for CCUS, including varied and conflicting state and local regulations, and regional variations in emissions sources and sinks, require regional planning and solutions to optimize infrastructure.

Next, speakers highlighted some of the changes that will be necessary for widescale CCUS deployment and the steps that the Biden-Harris Administration can take to support this outcome. Recommendations include:

- Developing a comprehensive and sustained policy that supports jobs and workforce training, such as apprenticeship programs, provides incentives for CCUS, and focuses on difficult to decarbonize sectors with few other options. Such a net-zero infrastructure agenda could reconcile the divisions between environmental justice and climate advocates and those advocating for carbon capture.

- Pursuing a much broader RD&D agenda, including more projects demonstrating storage of CO_2 in saline reservoirs as well as analysis of the local air quality benefits from carbon capture on various sources of emissions.

- Establishing policies that provide long-term certainty on the need for permanent solutions to reducing emissions (e.g., a carbon price, border adjustments, etc.) so companies can be confident that investments will not be stranded.

- Working across the federal government on a cohesive and comprehensive climate plan, articulated and implemented across the administration, including tax and investment policies that are consistent, sustained, and focused on achieving overarching goals.

- Collaborating through public-private partnerships involving state and federal government and industry to develop shared CO_2 transportation and storage infrastructure, and creating a supportive environment for CCUS through policy- and investment-supported hubs and clusters.

- Supporting new business models for geologic storage (e.g., utilities) as well as markets for carbon capture and removal.

In a final "lightening round" of questions, the participants highlighted who they think is missing from the growing coalition around CCUS. This included:

- Environmental justice organizations

- Environmental advocacy organizations that see no role for fossil fuels in the energy transition

- Many industrial players who have not yet put "skin in the game"

- In the U.S., the steel industry has not yet been included; however, there is a huge opportunity for carbon capture from steel production that could provide dramatic emissions reductions, jobs, and other local benefits.

Overall, this session illuminated actionable recommendations that will be needed from stakeholders in advocacy, policymakers, and industry representatives.

Conclusion

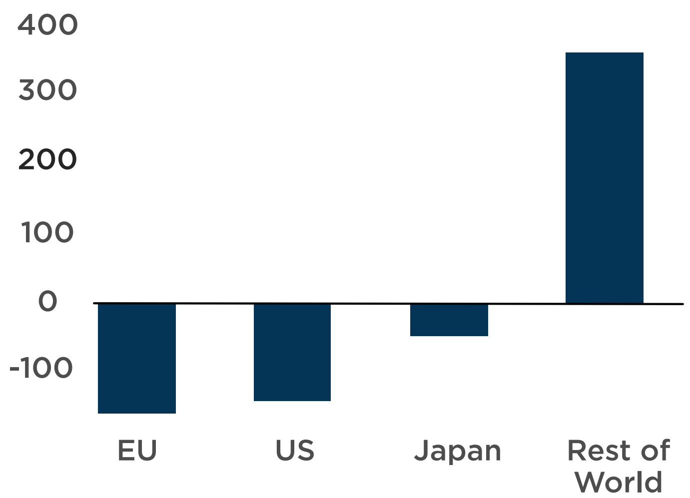
The workshop concluded with remarks from the workshop co-chair who placed CCUS in context of the importance of developing a scientifically driven strategy for dramatically reducing carbon emissions from all sectors of the economy, recognizing national, regional, and global differences, including the different drivers that are affecting progress on meeting climate goals. Figure 12 shows changes in global CO_2 emissions by country/region, demonstrating the uneven reductions around the world.

Such a strategy would engage a broad coalition from the political left and right, and from many stakeholders and advocates of environmental justice, climate justice, environmental organizations, and labor unions. To summarize these needs, the following six key points were offered:

- We cannot accelerate climate solutions without building and sustaining coalitions
- We must recognize regional needs and opportunities and address them. Social equity and justice must be at the forefront of regional solutions

Figure 12

Change in Energy Related CO_2 Emissions by Region, 2018-2019



Energy-related CO_2 emissions by country and region demonstrate the uneven reductions around the world. Source: International Energy Agency, accessed March 2020.

- Focusing on jobs, especially in the face of the COVID-19 pandemic and the associated recession, is critical
- Comprehensive energy and climate policy must maximize optionality and flexibility—there is no "silver bullet" to combating climate change
- Clean energy solutions must emphasize secure supply chains and include embedded emissions in policy solutions
- The world needs innovation to meet net-zero emissions targets by midcentury

The workshop underscored the value of CCUS as a critical component of any climate action plan. CCUS provides optionality as the world transitions to lower carbon and enables an equitable transition by creating new jobs and preserving existing jobs that may otherwise become stranded.

Finally, because CCUS is a proven technology that can be deployed immediately (barring financial and regulatory barriers), it can provide substantial near-term emissions reductions across several important economic sectors with few other options to decarbonize. As the U.S. and the world look ahead, there are many steps that can and must be taken to deeply decarbonize the U.S. and global economies.

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