Surveying the BECCS Landscape

ENERGY FUTURES INITIATIVE

Part of the EFI Report Series
Bioenergy with Carbon Capture and Storage: Sowing the Seeds of a Negative-Carbon Future

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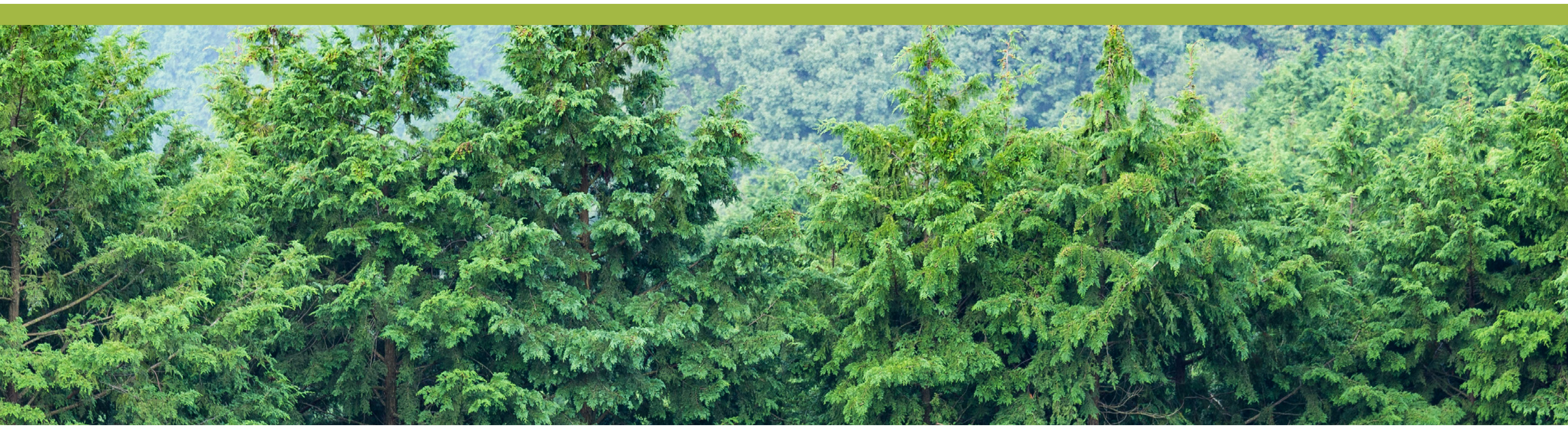
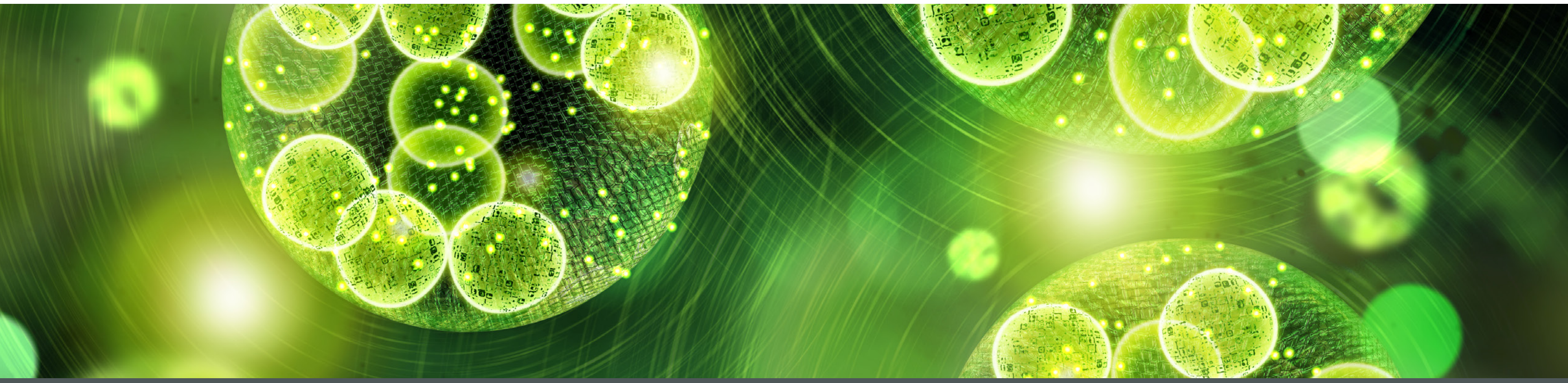
EXECUTIVE SUMMARY





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ABOUT THE 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. EFI's reports are available for download at www.energyfuturesinitiative.org.

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ABOUT THIS STUDY

This report is a systematic review of the literature to understand the key opportunities and challenges associated with bioenergy with carbon capture and storage (BECCS), a broad set of systems that integrate the use of energy derived from biomass with the capture and long-term storage of carbon. BECCS has received much attention due to its potential to remove greenhouse gas emissions from the atmosphere; however, there are uncertainties regarding BECCS pathways that may have adverse economic, social, and environmental impacts. While BECCS can potentially decarbonize numerous sectors, including agriculture, forestry, electricity, waste, and industry, BECCS deployment in practice has been limited, and the actual emissions reduction potential of a given project depends on the project's exact configuration, given the varying technical potential of BECCS projects in different geographic regions. Additionally, both the opportunities and challenges for rural and environmental justice communities are underexplored.

The Energy Futures Initiative (EFI) conducted this review as the first phase of a study on the potential contributions of BECCS in achieving the U.S. goal of net-zero greenhouse gas emissions by midcentury. Building on the previous work on carbon dioxide removal and carbon capture, utilization, and storage, EFI has examined the role of BECCS as a domestic decarbonization option, as well as in the context of advancing other national policy objectives such as sustainable agricultural and forestry practices and rural economic development. This report defines BECCS and its component parts; discusses the current state of BECCS and associated industries in the United States; and identifies the opportunities and challenges for BECCS. The findings of this literature review will inform the second phase of the study, which involves a deeper dive analysis into the specific issues through commissioned white papers and an expert workshop. EFI will use the insights gleaned from the literature review, white papers, and workshop discussions to develop a comprehensive national strategy and policy roadmap for BECCS.

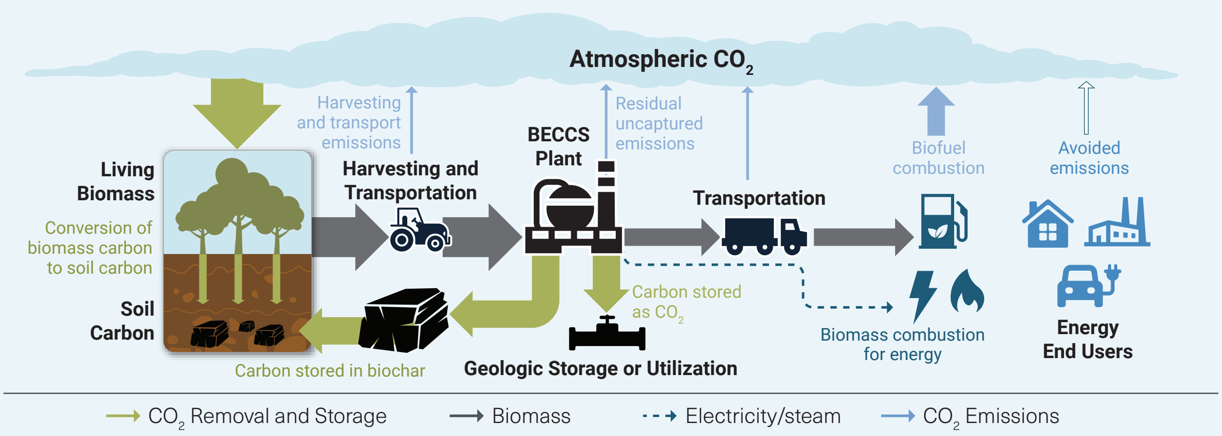
Given the complexity and breadth of the potential suite of BECCS applications, EFI reviewed a wide array of sources including peer-reviewed studies, non-peer reviewed reports, news articles, web content, and legislative and executive documents. The search, screening, and review process was iterative as EFI gathered new knowledge throughout the research process. In total, over 300 sources were reviewed and included in this report.

Executive Summary

Bioenergy with carbon capture and storage (BECCS) refers to a set of distinct systems that share common features: a biomass feedstock, biomass-to-energy conversion and creation of a useful energy product, carbon capture, and carbon storage or utilization. Despite this clear definition, however, there is little consensus on (1) precisely which set of biomass feedstocks, conversion techniques, and carbon capture approaches should categorically be labeled as BECCS and (2) whether a project must be carbon-neutral or -negative to qualify as a BECCS project, complicating the analysis and policy environment.

BECCS has garnered attention in large part because of its potential to produce net-negative greenhouse gas (GHG) emissions, serving as a form of carbon dioxide removal (CDR). Bioenergy can produce modest emissions because the carbon that is released during combustion was previously removed from the atmosphere by photosynthesis during the growth of the plants and could be sequestered again through plant regrowth.[1] The BECCS process captures and stores some of the carbon that would otherwise be released, which can, but does not necessarily, result in net-negative GHG emissions over the process's life cycle (Figure 1).

Figure 1: Carbon Flows from BECCS[2,3]



BECCS is a set of systems that use biomass to produce energy and capture and store the embedded carbon, which can result in a net removal of greenhouse gases from the atmosphere. Plants (e.g., trees, crops) naturally absorb atmospheric carbon dioxide (CO_2) through photosynthesis and convert it into biomass carbon. BECCS involves harvesting these biomass "feedstocks" and converting them into useful energy (e.g., electricity, biofuels), while also capturing some of the carbon that would otherwise be released back to the atmosphere as GHGs. This carbon is then either used or permanently stored, either underground or in soils. Note: the width of the arrows signifies the approximate proportional share of carbon released or absorbed. Source: Adapted from Global CCS Institute, 2019 and Tanzer and Ramirez, 2019. Icons from The Noun Project.

BECCS technologies can displace emissions from fossil fuel production and consumption, and can be deployed in tandem with other decarbonization solutions, such as forestry CDR, agricultural CDR, methane mitigation, waste reduction, CCUS, bioenergy, clean fuels, clean power, and hydrogen. In addition to its climate benefits, BECCS projects have the potential to provide other environmental, economic, and jobs benefits.

While BECCS technologies build upon a well-established foundation of fully commercialized bioenergy and carbon capture, utilization, and storage technologies, a legacy of many non-technology barriers to deployment means that BECCS projects are at an earlier stage of demonstration and deployment. The handful of BECCS projects deployed globally are mostly pilot- or demonstration-scale, capturing less than 400 kilotons (kt)[a] of carbon dioxide (CO_2) a year for enhanced oil recovery (EOR) or other utilization (Table 1).[4] Most of these projects capture CO_2 from ethanol production, biomass power plants, or waste incineration. The Illinois Industrial Carbon Capture and Storage (CCS) project at Archer Daniels Midland's (ADM) Decatur, Illinois ethanol production facility—one of five projects in the United States—is the only large-scale (about 1 megaton [Mt]) BECCS facility in operation worldwide, and the only one with dedicated CO_2 storage. The project has yet to achieve its full capacity, however, and the Decatur plant still emits more CO_2 from fossil fuel combustion than it removes through BECCS.[5,6]

Policy has shaped incumbent industries that could form a foundation for BECCS. Various mandates and tax incentives have created a robust biofuels market in the U.S. transportation sector; electricity-sector regulations in Europe have incentivized the growth of U.S. wood pellet exports to supply biopower generation; and new policies such as the 45Q Carbon Oxide Sequestration tax credit and California's Low Carbon Fuel Standard (LCFS) have engendered investment in carbon transport, utilization, and sequestration systems in United States.[7,8,9] The creation of a full-scale BECCS industry, both in the United States and globally, will be contingent on new, dedicated policy.

a This report uses SI units and prefixes throughout; "tons" (t) refers to metric tons unless otherwise specified. In a few instances figures will use non-SI units, which are noted. Biomass is measured in dry metric tons (also referred to as "bone dry"), a metric ton of biomass at 0 percent moisture. In some cases, other sources use energy-equivalent dry tons to directly compare feedstocks with different heat contents and conversion efficiencies.

Table 1: Operational BECCS Projects Globally[10]

Name	Sponsors	Sector	Country	Year	Feedstock	Carbon Captured ($MtCO_2$/yr)	Carbon Disposition
Arkalon CO_2 Compression Facility	Conestoga Energy Partners	Ethanol Production	United States	2009	Corn, sorghum	0.29-0.31	EOR
OCAP[11]	Linde	Ethanol Production and Oil Refinery	Netherlands	2011	Corn	0.4*	Utilization
Bonanza Bioenergy CCUS EOR	Conestoga Energy Partners	Ethanol Production	United States	2012	Corn, sorghum	0.10-0.16	EOR
Husky Energy Lashburn and Tangleflags CO_2 Injection Project[12]	Cenovus Energy,[13] Lashburn and Tangleflags	Ethanol Production	Canada	2012	Corn, non-food quality grain	0.09	EOR
Twence CO_2/Sodium Bicarbonate Plant[14]	Twence	Waste-to-Energy	Netherlands	2014	Residual waste	0.003	Utilization
Calgren Renewable Fuels CO_2 Recovery Plant	Calgren Renewable Fuels, AirLiquide	Ethanol Production	United States	2015	Corn, sorghum, agricultural waste	0.15	Utilization (Liquefied for use in food, beverage, manufacturing)
Lantmännen Agroetanol Purification Facility[15]	Lantmännen	Ethanol Production	Sweden	2015	Wheat, starch-rich residues	0.15-0.2	Utilization
Alco Bio Fuel Bio-Refinery CO_2 Recovery Plant[16]	Alco Bio Fuel	Ethanol Production	Belgium	2016	Corn	0.1	Utilization
Cargill Wheat Processing CO_2 Purification Plant	Cargill	Ethanol Production	United Kingdom	2016	Wheat	0.1	Utilization
Saga City Waste Incineration Plant	Saga City	Waste-to-energy	Japan	2016	Municipal waste	0.003	Utilization

(continued)

Name	Sponsors	Sector	Country	Year	Feedstock	Carbon Captured ($MtCO_2$/yr)	Carbon Disposition
Illinois Industrial Carbon Capture & Storage	ADM	Ethanol Production	United States	2017	Corn	0.52-1.0	Geologic storage
AVR CO_2 Capture Plant[17]	AVR	Waste-to-energy	Netherlands	2019	Residual waste	0.06	Utilization
Drax BECCS Plant[18]	Drax	Power Generation (coal and biomass)	United Kingdom	2019	Compressed wood pellets	0.00003**	Not specified
Stockholm Exergi AB[19]	Stockholm Exergi	Combined Heat and Power	Sweden	2019	Biomass, residual waste	0.8 (anticipated)***	Not specified
Charm Industrial[20]	Charm Industrial	Bio-oil Production	United States	2020	Waste biomass	0.001 (total)	Not specified
Mikawa Post Combustion Capture Demonstration Plant[21]	Sigma Power Ariake Co. Ltd.	Power Generation (coal and biomass)	Japan	2020	Palm kernel shell	0.18	Not specified

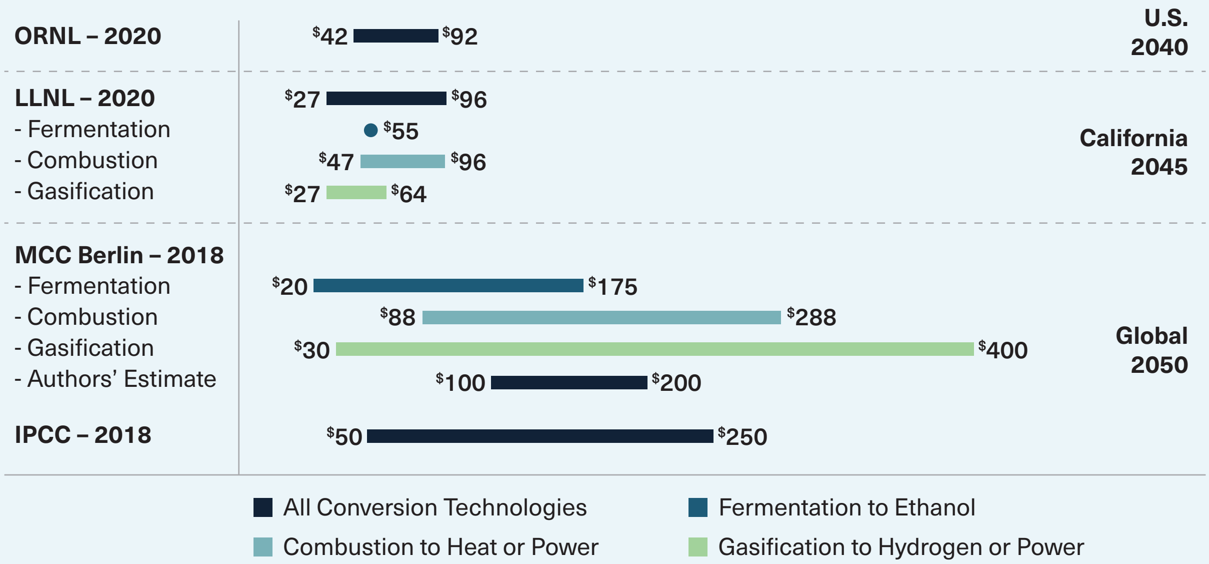
** The OCAP plant receives its CO_2 from a fuel refining facility (hydrogen production) and from an ethanol production plant. Only part of the total CO_2 (400 kt/yr) qualifies as bioenergy with carbon capture and utilization.*

*** The project is currently releasing CO_2 after its capture, but the long-term plan is to focus on offshore storage as part of the Zero Carbon Humber project.*

**** The Stockholm Exergi AB project is currently in its pilot phase and plans to capture its first kilogram of CO_2 by 2025. Once the plant achieves normal operations, it is expected to capture 0.8 $MtCO_2$/yr.*

Current estimates for BECCS carbon removal costs range widely from $20 per metric ton of CO_2 (tCO_2) to $400/$tCO_2$; estimates vary for different feedstocks, conversion and capture technologies, and system configurations (Figure 2).[22] Projects with access to abundant, cheap biomass, feedstock production co-located with energy conversion, and proximity to geologic storage can achieve lower cost and may be economic today. However, innovation in technologies, policies, and business models—both to bring down the cost of BECCS projects and to facilitate explicit valuation of their climate (i.e., CDR) benefits—will be required to make widespread deployment commercially viable.

Figure 2: BECCS Pathway CO_2 Abatement Cost Estimates ($/$tCO_2$)[23,24,25,26]



Cost estimates for BECCS projects range from \$20/tCO_2 to \$400/tCO_2 removed. These estimates vary widely across literature and differ by geographic scope, time, and technology. Costs for most BECCS projects in the United States are expected to be less than \$100/tCO_2 by 2040. Source: Data from Langholtz et al., 2020 (ORNL), Baker et al., 2020 (LLNL), Fuss et al., 2018 (Mercator Research Institute on Global Commons and Climate Change, Berlin [MCC Berlin]), and IPCC, 2018.

THE IMPORTANCE OF BECCS AND CDR TO DEEP DECARBONIZATION

In the 2018 *Special Report on Global Warming of 1.5°C (SR1.5)*, the Intergovernmental Panel on Climate Change (IPCC) found robust differences between the impacts to natural and human systems from global warming of 1.5 degrees Celsius over pre-industrial global temperatures and the impacts from warming of 2 degrees Celsius (and higher).[27] Limiting global temperature increase to a 1.5-degree target requires global CO_2 emissions to reach net-zero by 2050 and be net-negative thereafter.[28] BECCS as a form of CDR is projected to be important to achieving these targets.

Without CDR—i.e., removal of carbon from the atmosphere and oceans and subsequent storage—net-negative emissions are impossible to reach.[29] CDR can also help achieve interim targets more quickly and affordably by compensating for difficult-to-decarbonize sectors with few mitigation options (e.g., heavy industry, aviation, and agriculture). CDR serves as an important complement to mitigation strategies, not a substitute. Substantial reductions in emissions from fossil fuel use and other sources will still be necessary.

CDR includes natural pathways, such as afforestation and agricultural soil management, and technological[b] pathways, such as BECCS and direct air capture (DAC).[30] BECCS is a major part of the CDR equation in IPCC's *SR1.5* scenarios: all scenarios that limit warming to 1.5 degrees use some form of negative emissions, including up to 8 gigatons (Gt) of annual emissions removals via BECCS by 2050.[31] Even more BECCS deployment is required in scenarios with higher overshoot.[c] For context, the total amount of mitigation or removal required to reach net-zero at the time of IPCC's analysis was 42 Gt; 8 Gt is approximately the gross CO_2 emissions from fossil fuels and cement in 2019 of the United States and the European Union (EU) combined.[32]

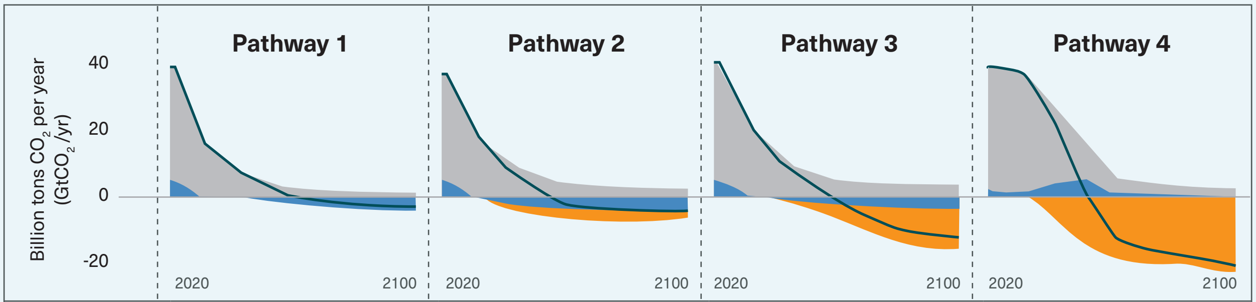
BECCS is favored in IPCC scenarios in part because it is the technological CDR solution most often included in integrated assessment models (IAMs). IPCC expects BECCS to occupy a less prominent role in future modeling as other CDR pathways become better understood and incorporated into IAMs.[33] The illustrative IPCC scenarios (Figure 3) have different constraints on the amount of BECCS allowed, with lower-BECCS scenarios requiring a faster shift away from fossil fuels and a steeper decline in total energy demand. Subsequent modeling from other sources, such as the International Energy Agency (IEA), has also indicated a need for gigaton-scale BECCS.[34] Other research has shown how BECCS can help meet global climate targets at lower cost.[35] However, as other CDR pathways become better understood and incorporated into IAMs, IPCC expects BECCS to occupy a less prominent role in future modeling.[36]

BECCS is also crucial to net-zero scenarios because it occupies a unique middle ground in the CDR landscape. BECCS pathways could potentially provide greater and more permanent carbon removal on a global scale than natural solutions, which are limited by land availability and which store carbon on a shorter timescale. Other technological methods, such as DAC, share BECCS's ability to scale, but currently are more costly (and could continue to be in the future).[37] This combination of qualities gives BECCS distinct value, but achieving necessary CDR levels to reach net-zero will likely require using BECCS as part of a portfolio of CDR options.

b BECCS is sometimes referred to as a "technologically enhanced natural CDR" (i.e., a hybrid of natural and technological CDR), but is grouped here with technological pathways, following the IPCC.

c I.e., scenarios in which global temperature increase exceeds 1.5 degrees before returning to that level.

Figure 3: The Role of BECCS in Limiting Global Warming to 1.5°C[38]



	Pathway 1	Pathway 2	Pathway 3	Pathway 4
Scenario description	Innovation leads to lower energy demand	Sustainable development at a global scale	Emissions reductions due to innovation in production	GHG-intensive lifestyles continue, leading to high energy demand
2050 energy demand vs. 2010	32% less	2% more	21% more	44% more
Fossil fuel consumption	Decreases rapidly and drastically and nears zero by 2100	Decreases regularly	Decreases gradually	Stays stable then decreases
CDR used	Afforestation only, no CCS (or BECCS)	Afforestation and limited BECCS	Afforestation and moderate BECCS	Less afforestation and widespread BECCS

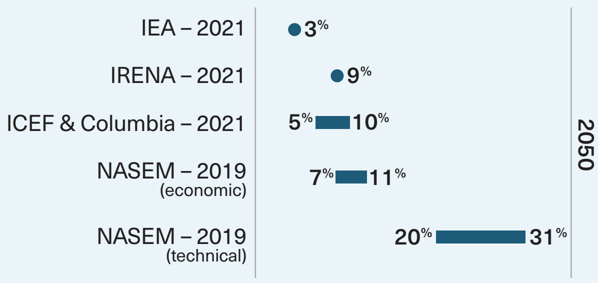
Fossil fuels   AFOLU   BECCS   Net emissions

IPCC modeling includes BECCS in three of four modeled pathways, with BECCS introduced by 2030 in all three scenarios. With immediate emissions reductions in the near-term, fewer GHG removals from BECCS are required by midcentury (as shown in Pathway 2). When mitigation is delayed (as shown in Pathway 4), substantial GHG removal is required to meet net-zero emissions by 2100. ***Note****: AFOLU = agriculture, forestry, and other land use. Afforestation is included in this category along with other emissions sources and sinks. Source: IPCC, 2018.*

A key question is whether BECCS has a technical potential commensurate with the need for CDR projected by IPCC and others. Global projections for the potential abatement from BECCS range from 1.3 $GtCO_2$/yr to 15 $GtCO_2$/yr (or 3 percent to 31 percent of 2018 net GHG emissions[d]) in 2050 (Figure 4). The main constraints on technical potential are feedstock availability and CO_2 storage or use options; varied estimates of potential rely on differing assumptions about these variables.

d GHG emissions data includes land-use change emissions.

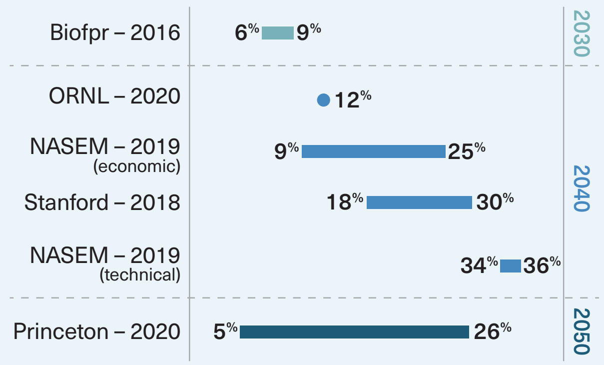
Figure 4: BECCS Global Carbon Removal Potential Estimates (Percent of Net 2018 GHG Emissions)[39,40,41,42,43]



Global projections for BECCS potential abatement range from 1.3 $GtCO_2$/yr to 15 $GtCO_2$/yr in 2050, the equivalent of 3 percent to 31 percent of 2018 global net GHG emissions of 48.9 $GtCO_2$ (which includes both emissions and removals from land-use change and forestry). The estimates vary widely based on different assumptions of feedstock availability, costs, financial incentives, and favorable policies made by each study. Source: Data from IEA, 2021, IRENA, 2021, Sandalow et al., 2021 (ICEF & Columbia), and NASEM, 2019.

The Biden administration's recent commitment to reducing economywide GHG emissions by at least 50 percent by 2030—along with the longer-term goal of net-zero GHG emissions by 2050—highlights the importance of rapid deployment of CDR technologies in the United States. Various studies have estimated the emissions-reduction potential of BECCS in the United States to be between 0.3 $GtCO_2$/yr and 2.2 $GtCO_2$/yr across various timeframes—possibly enough to bring U.S. emissions one-third of the way to net-zero (Figure 5).[e]

Figure 5: BECCS U.S. Carbon Removal Potential Estimates (Percent of Net 2018 GHG Emissions)[44,45,46,47,48,49]



Five studies show that the United States can reduce emissions via BECCS technologies by 0.3 $GtCO_2$/yr to 2.2 $GtCO_2$/yr, the equivalent of 5 percent to 36 percent of 2018 net GHG emissions of 5.9 $GtCO_2$ (which includes both emissions and removals from land use, land-use change, and forestry). The estimates vary depending on timeframe and assumptions regarding feedstock availability, costs, incentives, and policies. Source: Data from Rogers et al., 2016 (Biofpr), Langholtz et al., 2020 (ORNL), NASEM, 2019, Baik et al., 2018 (Stanford), and Larson et al., 2020 (Princeton).

The United States may also play a role in BECCS deployment by exporting biomass. The country is already a net exporter of ethanol (top destinations are Canada, Brazil, and India) and the largest supplier of wood pellets to the EU's burgeoning biomass industry.[50,51] Three-quarters of all pellets produced in the United States in 2020 were exported.[52] Europe may need to rely on either continued biomass trade (both intraregional and external) or non-BECCS options to meet its CDR needs. One estimate puts Europe's emissions abatement potential from BECCS at just 0.2 Gt, or 5 percent of current emissions—half of the 10 percent the European Commission says will need to be addressed through CDR.[53] The United States'

e For reference, 2.2 Gt is equivalent to the total emissions from the transportation and residential buildings sections in 2019, or the energy-related CO_2 emissions of the seven highest-emitting states combined (TX, CA, OH, PA, LA, IL, FL).

role in future BECCS trade will be highly dependent on both its own policy as well as the policy of potential trading partners, such as Europe; different studies have projected that the United States could become either an exporter or an importer of biomass for use in BECCS projects.[54,55]

LITERATURE REVIEW KEY FINDINGS

Several themes emerged from this systematic review of the literature, cutting across technologies, policies, industries, infrastructure, and biomass feedstocks related to BECCS. The key findings below provide insights for further research to better understand the opportunities and challenges for BECCS deployment in the United States.

BECCS encompasses a wide range of technologies; many potential pathways are underexplored and require additional analysis. BECCS is a set of systems encompassing biomass feedstocks, conversion processes, end uses, and carbon capture approaches. The focus in the literature is largely on adding carbon capture to wood-based power and ethanol production, but there are many other applications with potential climate, environmental, and socioeconomic benefits. BECCS systems that produce other energy products—such as renewable natural gas (RNG) and hydrogen—or harness other forms of carbon storage—such as biochar—represent underexplored and underdeveloped decarbonization pathways. Increased interest in CDR by the research community has emphasized the importance of the carbon removal value of BECCS projects rather than solely their energy output. This, in part, has led to the development of the term biomass carbon removal and storage (BiCRS), which covers both energy and non-energy pathways for sequestering biogenic carbon.

IAMs include significant CDR from BECCS, but the achievable scale of deployment is highly uncertain. CDR is needed to reach net-zero goals, and BECCS has the potential to play a significant role in meeting those needs as one among other CDR pathways. BECCS deployment features prominently in modeling of global deep decarbonization pathways, but its presence in the modeling is best understood as a placeholder for a broad suite of CDR options. BECCS has an important niche among CDR options because of (1) greater permanence and more scaling potential than natural solutions and (2) lower cost and higher technological readiness than other technological solutions. Modeling studies project the need for massive global BECCS deployment, up to 8 $GtCO_2$/yr by 2050. However, the real-world deployment potential for BECCS may be constrained far below these estimates by limited by feedstock availability, access to CO_2 infrastructure and disposition options, and socioeconomic or environmental limitations.[56,57] Global projections for the emissions abatement potential of BECCS in 2050 range from 1.3 $GtCO_2$/yr to 15 $GtCO_2$/yr, or 3 percent to 31 percent of 2018 net GHG emissions.[58,59,60,61,62] BECCS can also help the United States move towards its climate goals, but the potential size of its contribution is unclear; various studies estimate that BECCS can reduce U.S. emissions in 2050 by 0.3 $GtCO_2$/yr to 2.2 $GtCO_2$/yr, the equivalent of 5 percent to 36 percent of 2018 GHG emissions.[63,64,65,66,67,68]

Emission reductions and environmental impacts of BECCS projects are project-specific, and not all BECCS projects are carbon-negative. The amount of carbon removed from the atmosphere over the life cycle of a BECCS project is highly circumstantial, depending on factors such as geography, land-use change, feedstock characteristics, energy conversion technology, and carbon capture approach. These circumstances can result in any given project having net-positive or net-negative GHG emissions. Additionally, the literature found both potential environmental benefits and drawbacks associated with BECCS projects related to its effects on land, water, air quality, energy consumption, biodiversity, and forest resilience. The precise impacts depend on the project circumstances, such as the environmental and social conditions of the location and the timeframe of the project.

Current GHG accounting rules are limited in fully capturing the systemwide changes in emissions and removals from BECCS. Establishing more robust GHG accounting rules would reduce risks and uncertainty for project developers seeking to secure carbon credits or incentives for BECCS projects and could promote investment in BECCS technologies. Developing such rules and identifying the full emissions impact of any process or product, however, is enormously complicated and requires making difficult decisions on scope and methodology. The nature of BECCS as a set of pathways encompassing multiple sectors makes these calculations even more complex.

The scientific and policy communities regularly highlight several specific issues related to GHG accounting for BECCS. First, GHG accounting rules are inconsistent as to whether and how specific sources of emissions are included when estimating the overall emissions impact of BECCS pathways. Second, a typical GHG accounting simplification—counting all bioenergy-related emissions in the land-use sector and assuming zero emissions at point of combustion—shifts the most important emissions measurement burden from the energy sector to the land-use sector where measurement, recording, and verification is far more complex and requires numerous contestable assumptions. The focus on land-use emissions is further complicated by the difficulty of determining the counterfactual use of that land. Third, system boundaries are typically drawn narrowly on the feedstock supply chain and disposition, though some authors recommend including induced effects in the broader economy. Lastly, whether the temporal distribution of emissions and removals is an important consideration when accounting for BECCS emissions remains in dispute.

The current U.S. BECCS industry is limited, but has potential for significant growth. While there are only five BECCS projects in operation in the United States today, the country has several characteristics that make it suitable for BECCS deployment including well-established relevant industries (e.g., biofuels, biopower, forestry, agriculture, wood pellet production, and pulp and paper), significant natural resources (e.g., biomass and geologic storage), and growing policy support (e.g., the newly extended 45Q tax credit and the Energy Act of 2020). The BECCS industry is still in its early stages of development and deployment because of costs; the lack of research, development, and demonstration (RD&D) funding; and the variability of its geographical application (i.e., regional variations in biomass availability, supply chains, regional demand for energy output, and CO_2 storage potential).

Abatement cost estimates range from \$20/tCO_2 to \$400/tCO_2, which vary depending on feedstocks, conversion and capture technologies, and system configurations. Globally, 16 pilot or demonstration-scale BECCS projects exist today; all but one of which capture less than 400 kt of CO_2 per year.

Expanded biomass supply chains and CO_2 infrastructure are needed to support a national BECCS industry; coordinating this infrastructure with other decarbonization pathways offers economies of scope and scale. A key challenge to growing a BECCS industry in the United States is that biomass supply, feedstock pre-processing facilities, bioenergy conversion facilities, and CO_2 storage locations are rarely co-located, requiring distinct infrastructure to transport specific feedstocks, energy products, and/or CO_2; co-location of BECCS projects with other decarbonization pathways could leverage shared CO_2 infrastructure and make those projects more economical. Part of the appeal of BECCS pathways is that they sit at the intersection of many different decarbonization solutions, such as forestry CDR, agricultural CDR, methane mitigation, waste reduction, CCUS, bioenergy, clean fuels, clean power, and hydrogen hubs. Because there are tradeoffs between developing economies of scale and creating local or regional BECCS supply chains, BECCS projects must be developed with careful consideration of local circumstances.

BECCS pathways present rural economic development opportunities. Today, more than a million people are employed in bioeconomy industries like forestry, pulp and paper, and bioenergy.[69] Increased demand for biomass feedstocks can stimulate rural economies and the entire supply chain for BECCS could create economic opportunities for communities living near forests or other feedstocks. BECCS projects could create a market for biomass that helps offset declining demand from traditional forest products industries. By creating an additional demand for wood for bioenergy pellets, BECCS could provide a boost to regions that have suffered economic losses and provide an opportunity to repurpose existing human capital in sectors like pulp and paper.

BECCS pathways face opposition; there is need for approaches to BECCS that address environmental justice (EJ) concerns. CCUS and CDR are often seen as “false solutions” to addressing climate change that could diminish society’s urgency for more benign opportunities for direct emissions reductions.[70,71,72,73,74] There are environmental concerns about the impact of BECCS projects on air, water, and noise pollution, as well as safety concerns about geologic storage. Previous studies have tended to focus on international EJ concerns, rather than on U.S.-specific issues. Multiple EJ issues need to be addressed, such as environmental impacts; disproportionate siting in vulnerable communities; and categorical opposition to technologies like bioenergy and CCUS.

Federal programs have focused on bioenergy and CCUS distinctly; there is opportunity in existing programs and policies to address BECCS directly. BECCS is beginning to appear more often in legislation, public policies, and federal programs, but these efforts are not commensurate with a scale-up to a gigaton-scale industry. Growing the BECCS industry enough to have a meaningful impact on U.S. emissions will require support and expertise from multiple agencies, making federal interagency collaboration paramount. There is both opportunity and precedent for such collaboration. For example, the Biomass Research and Development Initiative (BRDI) could be revitalized as part of federal BECCS efforts going forward. New interagency collaborations could be undertaken as well. There is also a need for bioenergy policy and CCUS policy to work in tandem, rather than in their current silos.

KEY ISSUES AND AREAS FOR FUTURE STUDY

The key findings from this literature review show that several economic, environmental, and social issues need to be addressed in order to deploy BECCS in the United States at the scale called for in most climate studies. After discussion with the study advisory board, EFI commissioned four papers to examine the following key issues in greater detail during the second phase of this study:

- The opportunities for BECCS to contribute to sustainable and resilient forests in the Western United States;[f]
- An evaluation of the socioeconomic and environmental justice impacts of the BECCS industry;
- GHG accounting issues and means of ensuring BECCS contributes to net-zero or net-negative emissions; and
- Sustainable sourcing of U.S. biomass feedstocks for BECCS projects.

These commissioned papers will inform an expert workshop that will culminate in a comprehensive final report exploring the opportunities, challenges, and policies needed to support the thoughtful deployment of BECCS in the United States—a deployment that will work to achieve national goals for climate, resiliency, sustainable agriculture, energy security, and rural economic development.

NAVIGATING THIS REPORT

This report is divided into three sections as follows:

- **What is BECCS?**: a review of BECCS pathways, looking at the range of feedstocks, biomass-to-energy conversion options, bioenergy products and uses, and the options for CCUS as well as the potential benefits of BECCS through integration with other decarbonization options and technoeconomic comparison of a variety of BECCS pathways;
- **The U.S. BECCS industry landscape**: provides a comprehensive review of the industry landscape for the deployment of BECCS in the United States including existing industries relevant to future BECCS deployment, BECCS feedstock and decarbonization potential, existing BECCS projects, and federal policies and programs to support BECCS; and
- **Key issues identified in the literature**: discusses major issues identified from a systematic review of the literature. This includes GHG accounting methods for BECCS, supply chain challenges, RD&D gaps, environmental impacts and resource requirements, and socioeconomic and EJ considerations.

f The West is a region of particular interest both because of its high percentage of public forest ownership (compared to other regions, such as the Southeast) and its ongoing struggle with forest fires.

References

1 IEA Bioenergy, "Carbon neutrality," accessed October 7, 2021, https://www.ieabioenergy.com/iea-publications/faq/woodybiomass/carbon-neutrality/.

2 Christopher Consoli, *Perspective Bioenergy and Carbon Capture and Storage*, Global CCS Institute, 2019, https://www.globalccsinstitute.com/wp-content/uploads/2020/04/BIOENERGY-AND-CARBON-CAPTURE-AND-STORAGE_Perspective_New-Template.pdf, p. 3.

3 Samantha Eleanor Tanzer and Andrea Ramírez, "When are negative emissions negative emissions?" *Energy & Environmental Science* 12, no. 4 (2019): 1210-1218, https://doi.org/10.1039/C8EE03338B.

4 International Energy Agency (IEA), *Special Report on Carbon Capture Utilisation and Storage: CCUS in clean energy transitions*, 2020, https://iea.blob.core.windows.net/assets/181b48b4-323f-454d-96fb-0bb1889d96a9/CCUS_in_clean_energy_transitions.pdf.

5 Johnathan Hettinger, "Despite hundreds of millions in tax dollars, ADM's carbon capture program still hasn't met promised goals," *Midwest Center for Investigative Reporting*, November 19, 2020, https://investigatemidwest.org/2020/11/19/despite-hundreds-of-millions-in-tax-dollars-adms-carbon-capture-program-still-hasnt-met-promised-goals/.

6 U.S. Environmental Protection Agency (EPA), "Archer Daniels Midland Co.: Data Year 2020," Facility Level Information on GreenHouse gases Tool (FLIGHT), accessed October 8, 2021, https://ghgdata.epa.gov/ghgp/service/facilityDetail/2020?id=1005661&ds=E&et=&popup=true.

7 National Academies of Sciences, Engineering, and Medicine (NASEM), "Renewable Fuel Standard: Potential Economic and Environmental Effects of U.S. Biofuel Policy," *The National Academies Press,* 2011, https://www.nap.edu/read/13105/chapter/3, p. 17-23.

8 Energy Futures Initiative (EFI), *Clearing the Air: A Federal RD&D Initiative and Management Plan for Carbon Dioxide Removal Technologies*, September 2019, https://www.dropbox.com/s/x0880okedchb18p/EFI%20Clearing%20the%20Air%20Full%20Report.pdf?dl=0, p. 54.

9 Energy Futures Initiative (EFI) and Stanford University, *An Action Plan for Carbon Capture and Storage in California: Opportunities, Challenges, and Solutions*, October 2020, https://static1.squarespace.com/static/58ec123cb3db2bd94e057628/t/5fda383062e28f00961c98db/1608136765723/EFI-Stanford-CA-CCS-FULL-rev2-12.11.20.pdf, p. S-6.

10 International Energy Agency, Special Report on Carbon Capture Utilisation and Storage: CCUS in clean energy transitions, 2020, https://iea.blob.core.windows.net/assets/181b48b4-323f-454d-96fb-0bb1889d96a9/CCUS_in_clean_energy_transitions.pdf

11 Linde Group, Pure CO_2 for Greenhouses (Schiedam, NL: OCAP CO_2 B.V., 2018), n.p., https://www.ocap.nl/nl/images/OCAP_Factsheet_English_tcm978-561158.pdf.

12 Advanced Biofuels USA, "Husky Energy Unveils Carbon Capture and Enhanced Oil Recovery Initiative," May 29, 2012, https://advancedbiofuelsusa.info/husky-energy-unveils-carbon-capture-and-enhanced-oil-recovery-initiative/.

13 Cenovus, "Cenovus closes transaction to combine with Husky," January 4, 2021, https://www.cenovus.com/news/news-releases/2021/01-04-2020-Cenovus-closes-transaction-to-combine-with-Husky.html.

14 Twence, "CO2 Capture," accessed September 10, 2021, https://www.twence.nl/en/innovation/reuse.html.

15 IEA Bioenergy, "Lantmännen Agroetanol, Sweden – Stringent CO2 reduction criteria lead to business success," Bioenergy Success Stories, February 2018, https://www.ieabioenergy.com/wp-content/uploads/2018/02/7-Lantma%CC%88nnenAgroetanol_SE_Final.pdf, p. 1.

16 "GHG (Green House Gas) Emission Savings," Alco Bio Fuel, accessed September 24, 2021, https://www.alcobiofuel.com/ghg-savings/.

17 AVR, "CO_2 – capture plant," accessed September 10, 2021, https://www.avr.nl/en/optimal-process/co2-capture-plant/.

18 IEA, "CCUS around the world – Drax BECCS," accessed September 10, 2021, https://www.iea.org/reports/ccus-around-the-world/drax-beccs.

19 Stockholm Exergi, "A full-scale facility is the goal," accessed September 10, 2021, https://www.stockholmexergi.se/minusutslapp/beccs/fullskalig-anlaggning/.

20 Katie Holligan, "Charm Completes Removal of 1,000 Tons CO_2e for Shopify Ahead of Schedule," blog post, Charm Industrial, September 1, 2021, https://charmindustrial.com/blog/charm-completes-removal-of-1000-tons-co2e-for-shopify.

21 Toshiba, "Efforts for CO_2 emission reduction – CO_2 capture technology," Toshiba Energy Systems & Solutions Corporation, accessed September 10, 2021, https://www.toshiba-energy.com/en/thermal/product/zero-emissions.htm.

22 Sabine Fuss et al., "Negative emissions—Part 2: Costs, potentials and side effects," *Environmental Research Letters*, May 2018, https://iopscience.iop.org/article/10.1088/1748-9326/aabf9f/pdf.

23 Matthew Langholtz et al., "The Economic Accessibility of CO2 Sequestration through BECCS in the US," *Land*, August 2020, https://www.mdpi.com/2073-445X/9/9/299, p. 299.

24 Sarah Baker et al., *Getting to Neutral: Options for Negative Carbon Emissions in California*, January 2020, Lawrence Livermore National Laboratory, LLNL-TR-796100, https://www-gs.llnl.gov/content/assets/docs/energy/Getting_to_Neutral.pdf, p. 134.

25 Sabine Fuss et al., "Negative emissions—Part 2: Costs, potentials and side effects," *Environmental Research Letters*, May 2018, https://iopscience.iop.org/article/10.1088/1748-9326/aabf9f/pdf.

26 Heleen de Coninck et al., *Strengthening and Implementing the Global Response*, in: Global Warming of 1.5°C: Summary for Policymakers, The Intergovernmental Panel on Climate Change (IPCC), 2018, https://pure.rug.nl/ws/portalfiles/portal/168495473/SR15_Chapter4_Low_Res.pdf, p. 344.

27 Intergovernmental Panel on Climate Change (IPCC), *Summary for Policymakers*, in: Global Warming of 1.5°C, 2018, https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_SPM_version_report_LR.pdf, p. 7-11.

28 Intergovernmental Panel on Climate Change (IPCC), *Summary for Policymakers*, in: Global Warming of 1.5°C, 2018, https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_SPM_version_report_LR.pdf, p. 12-14.

29 Intergovernmental Panel on Climate Change (IPCC), *Summary for Policymakers*, in: Global Warming of 1.5°C, 2018, https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_SPM_version_report_LR.pdf, p. 17.

30 Energy Futures Initiative (EFI), *Clearing the Air: A Federal RD&D Initiative and Management Plan for Carbon Dioxide Removal Technologies*, September 2019, https://www.dropbox.com/s/x0880okedchb18p/EFI%20Clearing%20the%20Air%20Full%20Report.pdf?dl=0, p. S4-S5.

31 Intergovernmental Panel on Climate Change (IPCC), *Summary for Policymakers*, in Global Warming of 1.5°C, 2018, https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_SPM_version_report_LR.pdf, p. 17.

32 Estimates are 2019 "Fossil Fuels/Territorial" emissions for the U.S. and EU 27 estimate is from Friedlingstein et al., "Country emissions," *Global Carbon Atlas*, 2020, http://www.globalcarbonatlas.org/en/CO2-emissions

33 Joeri Rogelj et al., *Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development*, in: Global Warming of 1.5°C, https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_Chapter2_Low_Res.pdf, p. 122.

34 International Energy Agency (IEA), *Net Zero by 2050: A Roadmap for the Global Energy Sector*, 2nd rev., 2021, https://iea.blob.core.windows.net/assets/405543d2-054d-4cbd-9b89-d174831643a4/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf, p. 78.

35 Mathilde Fajardy et al., "The economics of bioenergy with carbon capture and storage (BECCS) deployment in a 1.5°C or 2°C world," *Global Environmental Change* 68 (2021): 102262, https://doi.org/10.1016/j.gloenvcha.2021.102262, p. 10.

36 Joeri Rogelj et al., *Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development*, in: Global Warming of 1.5°C, https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_Chapter2_Low_Res.pdf, p. 122.

37 Energy Futures Initiative (EFI), *Clearing the Air: A Federal RD&D Initiative and Management Plan for Carbon Dioxide Removal Technologies*, September 2019, https://www.dropbox.com/s/2y36ngfrcbpv37f/EFI%20Clearing%20the%20Air%20Full%20Report.pdf?dl=0, p. 12-13.

38 Intergovernmental Panel on Climate Change (IPCC), *Summary for Policymakers*, in: Global Warming of 1.5°C, 2018, https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_SPM_version_report_LR.pdf, p. 14.

39 Climate Watch, "Historical GHG Emissions," accessed June 30, 2021, https://www.climatewatchdata.org/ghg-emissions?chartType=area&end_year=2018&start_year=1990.

40 Data for Net Zero Emissions scenario shows 1.3 $GtCO_2$ /yr removed via BECCS, from International Energy Agency (IEA), *Net Zero by 2050: A Roadmap for the Global Energy Sector*, 2021, https://www.iea.org/reports/net-zero-by-2050, p. 78.

41 Data for 1.5°C Scenario shows 4 $GtCO_2$/yr removed via BECCS in power, cogeneration, and industry, from International Renewable Energy Agency (IRENA), *World Energy Transitions Outlook: 1.5°C Pathway*, 2021, www.irena.org/publications, p. 263 Table A.1.

42 Data shows a potential of 2.5 to 5 $GtCO_2$/yr, based on an assumption of 0.45 to 0.91 tCO2 captured by each "oven dry" ton of biomass and a global supply of 5.5 Gt of such biomass, from David Sandalow et al., *Biomass carbon removal and storage (BiCRS) roadmap,* Innovation for Cool Earth Forum (ICEF), 2021, https://www.icef.go.jp/pdf/summary/roadmap/icef2020_roadmap.pdf, p. 16-17.

43 Data shows two ranges: the economic range of 3.5 to 5.2 $GtCO_2$/yr is a safe removal rate based on current technological understanding, no additional land usage, and a carbon price under \$100/tCO_2 and the potential range of 10 to 15 $GtCO_2$/yr is based on an IPCC estimate and assumes 380-700 Mha of additional land area will be dedicated for BECCS, from National Academies of Sciences, Engineering, and Medicine (NASEM), "Negative Emissions Technologies and Reliable Sequestration: A Research Agenda," *The National Academies Press*, 2019, https://doi.org/10.17226/25259, p. 7 and 116.

44 U.S. Environmental Protection Agency (EPA), "Data Highlights: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2018," https://www.epa.gov/sites/default/files/2020-04/documents/us-ghg-inventory-1990-2018-data-highlights.pdf, p.1.

45 Data shows a range of 360 to 528 $MtCO_2$ /yr based on the biomass availability in DOE's Billion Ton study, from Jonathan N. Rogers et al., "An assessment of the potential products and economic and environmental impacts resulting from a billion ton bioeconomy," *Biofuels, Bioproducts and Biorefining* 11, no. 1 (2017), https://doi.org/10.1002/bbb.1728, p. 122, Figure 14.

46 Data shows a biomass supply of 740 Mt/yr and a saline formation sequestration potential of 737 $GtCO_2$/yr, from Matthew Langholtz et al., "The Economic Accessibility of CO2 Sequestration through BECCS in the US," *Land*, August 2020, https://www.mdpi.com/2073-445X/9/9/299.

47 Data shows two ranges: the economic range of 3.5 to 5.2 $GtCO_2$/yr is a safe removal rate based on current technological understanding, no additional land usage, and a carbon price under $100/$tCO_2$ and the potential range of 10 to 15 GtCO2/yr is based on an IPCC estimate and assumes 380-700 Mha of additional land area will be dedicated for BECCS, from National Academies of Sciences, Engineering, and Medicine (NASEM), "Negative Emissions Technologies and Reliable Sequestration: A Research Agenda," *The National Academies Press*, 2019, https://doi.org/10.17226/25259, p. 7 and 116.

48 Data shows an economic biomass supply of 610 to 1040 Mt/yr and consequently a CO_2 removal potential of 1040 to 1780 $MtCO_2$/yr., from Ejeong Baik et al., "Geospatial analysis of near-term potential for carbon-negative bioenergy in the United States," *Proceedings of the National Academy of Sciences* 115, no. 13 (2018): 3290-3295, https://doi.org/10.1073/pnas.1720338115.

49 Data shows a range of 318 to 1506 $MtCO_2$/yr from "Annual - BECCS-electricity" + "Annual - BECCS-H2" + "Annual - BECCS-pyrolysis" in dataset for Eric Larson et al., *Net-Zero America: Potential Pathways, Infrastructure, and Impacts, Interim report*, Princeton University, December 15, 2020, https://netzeroamerica.princeton.edu/img/Princeton_NZA_Interim_Report_15_Dec_2020_FINAL.pdf, p. 232.

50 Renewable Fuels Association (RFA), "Ethanol Trade & Exports," accessed November 17, 2021, https://ethanolrfa.org/policy/trade-and-exports.

51 Francisco Aguilar et al., "Expansion of US wood pellet industry points to positive trends but the need for continued monitoring," *Scientific Reports* 10, 18607 (2020). https://doi.org/10.1038/s41598-020-75403-z.

52 U.S. Energy Information Administration (EIA), "Monthly Densified Biomass Fuel Report, December 2020," March 17, 2020, https://www.eia.gov/biofuels/biomass/?year=2020&month=12#table_data.

53 Lorenzo Rosa et al., "Assessment of carbon dioxide removal potential via BECCS in a carbon-neutral Europe," *Energy & Environmental Science*, no. 14 (2021): 3086-3097, https://doi.org/10.1039/D1EE00642H.

54 Alice Favero and Emanuele Massetti, "Trade of woody biomass for electricity generation under climate mitigation policy," *Resource and energy economics* 36, no. 1 (2014): 166-190, https://www.econstor.eu/bitstream/10419/72945/1/736398163.pdf .

55 Adam Daigneault and Alice Favero, "Global forest management, carbon sequestration and bioenergy supply under alternative shared socioeconomic pathways," *Land Use Policy* 103, no. 105302 (2021), https://doi.org/10.1016/j.landusepol.2021.105302.

56 Intergovernmental Panel on Climate Change (IPCC), *Summary for Policymakers*, in: Global Warming of 1.5°C, 2018, https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_SPM_version_report_LR.pdf, p. 17.

57 Joeri Rogelj et al., *Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development*, in: Global Warming of 1.5°C, https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_Chapter2_Low_Res.pdf, p. 121-125.

58 Climate Watch, "Historical GHG Emissions," accessed June 30, 2021, https://www.climatewatchdata.org/ghg-emissions?chartType=area&end_year=2018&start_year=1990.

59 International Energy Agency (IEA), *Net Zero by 2050: A Roadmap for the Global Energy Sector*, 2021, https://www.iea.org/reports/net-zero-by-2050, p. 78.

60 International Renewable Energy Agency (IRENA), *World Energy Transitions Outlook: 1.5°C Pathway*, 2021, www.irena.org/publications, p. 263 Table A.1.

61 David Sandalow et al., *Biomass carbon removal and storage (BiCRS) roadmap*, Innovation for Cool Earth Forum (ICEF), 2021, https://www.icef.go.jp/pdf/summary/roadmap/icef2020_roadmap.pdf, p. 16-17.

62 National Academies of Sciences, Engineering, and Medicine (NASEM), "Negative Emissions Technologies and Reliable Sequestration: A Research Agenda," *The National Academies Press*, 2019, https://doi.org/10.17226/25259, p. 7 and 116.

63 U.S. Environmental Protection Agency (EPA), "Data Highlights: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2018," https://www.epa.gov/sites/default/files/2020-04/documents/us-ghg-inventory-1990-2018-data-highlights.pdf, p.1.

64 Jonathan N. Rogers et al., "An assessment of the potential products and economic and environmental impacts resulting from a billion ton bioeconomy," *Biofuels, Bioproducts and Biorefining* 11, no. 1 (2017), https://doi.org/10.1002/bbb.1728, p. 122, Figure 14.

65 Matthew Langholtz et al., “The Economic Accessibility of CO2 Sequestration through BECCS in the US,” *Land*, August 2020, https://www.mdpi.com/2073-445X/9/9/299.

66 National Academies of Sciences, Engineering, and Medicine (NASEM), “Negative Emissions Technologies and Reliable Sequestration: A Research Agenda,” *The National Academies Press*, 2019, https://doi.org/10.17226/25259, p. 7 and 116.

67 Ejeong Baik et al., “Geospatial analysis of near-term potential for carbon-negative bioenergy in the United States,” *Proceedings of the National Academy of Sciences* 115, no. 13 (2018): 3290-3295, https://doi.org/10.1073/pnas.1720338115.

68 Eric Larson et al., *Net-Zero America: Potential Pathways, Infrastructure, and Impacts, Interim report*, Princeton University, December 15, 2020, https://netzeroamerica.princeton.edu/img/Princeton_NZA_Interim_Report_15_Dec_2020_FINAL.pdf.

69 Data for NAICS codes 1133 Logging, 321 Wood Products, and 322 Paper Manufacturing in “One-Screen Data Search: All Employees, Thousands, Seasonally Adjusted,” U.S. Bureau of Labor Statistics (BLS), accessed July 19, 2021, https://data.bls.gov/PDQWeb/ce.

70 Adam Mahoney, “This new bill wants to bring the Green New Deal to a city near you,” *Grist*, April 20, 2021, https://grist.org/politics/green-new-deal-aoc-cori-bush-cities-infrastructure/.

71 Maddie Stone, “The climate solution Democrats aren’t talking about,” *Grist*, September 12, 2019, https://grist.org/article/the-climate-solution-democrats-arent-talking-about/.

72 Friends of Bernie Sanders, “The Green New Deal,” *BernieSanders.com,* accessed August 5, 2021, https://berniesanders.com/issues/green-new-deal/.

73 Center for Biological Diversity, “650 Groups Tell Congress: Leave Dirty Power Out of Clean Electricity Standard,” May 12, 2021, https://biologicaldiversity.org/w/news/press-releases/650-groups-tell-congress-leave-dirty-power-out-of-clean-electricity-standard-2021-05-12/.

74 White House Environmental Justice Advisory Council (WHEJAC), *Justice40 Climate and Economic Justice Screening Tool & Executive Order 12898 Revisions*, May 2021, https://www.epa.gov/sites/default/files/2021-05/documents/whiteh2.pdf, p. 57-59.