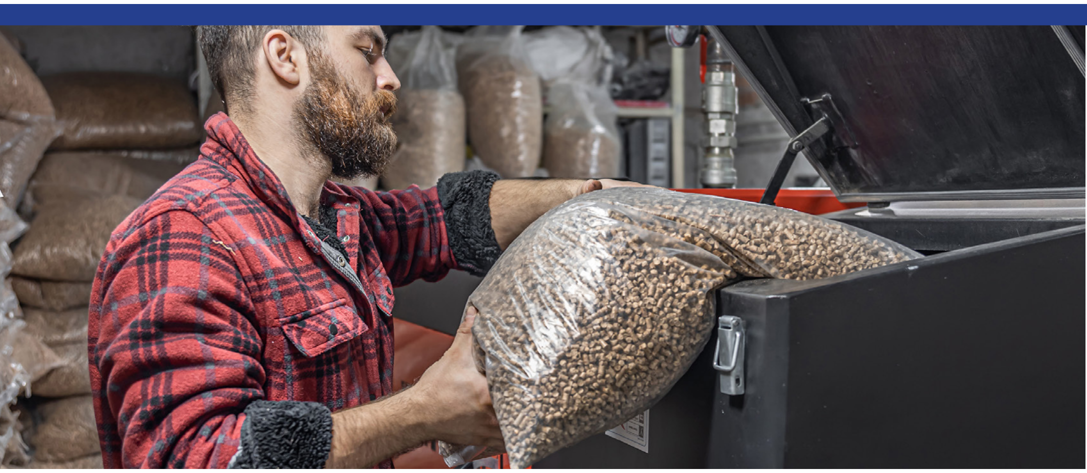
EFI FOUNDATION

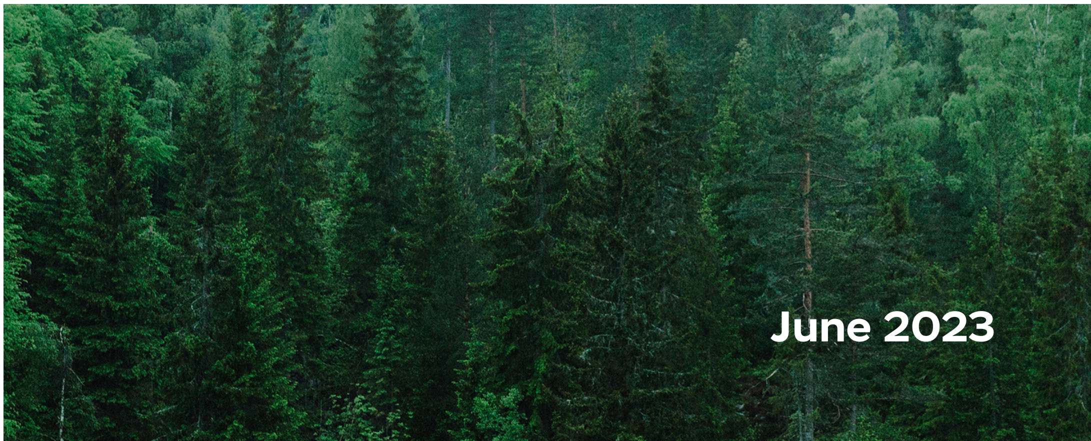
Taking Root

A Policy Blueprint for Responsible BECCS Development in the United States

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





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About This Study

The EFI Foundation embarked on a multi-year study titled "Bioenergy with Carbon Capture and Storage: Sowing the Seeds of a Negative-Carbon Future." This project addressed several important questions:

- What is the state of bioenergy with carbon capture and storage (BECCS) today?
- How realistic are BECCS development projections?
- What would be a plausible goal for BECCS deployment in the United States?
- What are the principal challenges and uncertainties that need to be addressed?
- What additional policy measures are needed?

Phase I of this project focused on a comprehensive literature review, and findings were published in *Surveying the BECCS Landscape*. In that report, EFI identified gaps in research and policy literature. Phase II examined selected issues through three commissioned expert white papers[a] and two workshops that convened researchers, policymakers, and other stakeholders.

This report synthesizes policy findings and recommendations into eight major elements that encompass both the opportunities and challenges for BECCS deployment in the United States. Additional supporting papers will be published separately.

The EFI Foundation 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 Foundation maintains editorial independence from its public and private sponsors.

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[a] In the text of the report, these white papers are abbreviated as *Accounting Considerations, Sustainable Biomass Sourcing,* and *Forest Health Treatments.*

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Executive Summary

Bioenergy with carbon capture and storage (BECCS) is a suite of technological processes that, when combined, offers a three-fold value proposition: sustainable biomass management, clean energy production, and carbon dioxide removal (CDR) from the atmosphere. The wide-ranging scope of BECCS intersects with federal policies for sustainable agriculture and forestry, clean energy policy, and climate policy. This summary report, *Taking Root: A Policy Blueprint for Responsible BECCS Development in the United States,* details a holistic policy blueprint to accelerate responsible BECCS deployment in the U.S.

Bioenergy in the United States is currently the largest single source of renewable energy and a major component of domestic energy production through ethanol used in transportation. Combining bioenergy with carbon capture, however, is in the early stages of deployment. Various analyses identify a large role for BECCS to provide net-negative carbon dioxide (CO_2) emissions as part of a portfolio of measures to achieve net-zero greenhouse gas (GHG) emissions by midcentury. BECCS deployment in parallel with GHG mitigation measures can help achieve climate goals more quickly as well as counterbalance residual emissions from difficult-to-decarbonize sectors of the economy. The climate change effects of BECCS involve complex interactions among land, energy, and industrial systems and require careful assessment to inform policymaking.

Recent federal legislation, including the Energy Act of 2020, the Bipartisan Infrastructure Law (BIL), the CHIPS and Science Act, and the Inflation Reduction Act (IRA), provide new incentives for climate and clean energy that could accelerate BECCS deployment. The 2018 Farm Bill also supports programs for sustainable agriculture. These measures provide valuable incentives, but they address the full scope of BECCS deployment in a piecemeal or indirect manner.

Over the past two years, the EFI Foundation has been engaged in a series of analyses of the potential for accelerated BECCS deployment, including technical, environmental, and economic feasibility, as well as opportunities to enhance federal agricultural, energy, and environmental policies to realize that potential. The principal findings emerging from this work are that:

- Accelerated BECCS deployment in the United States can greatly contribute achieving net-zero GHG emissions by midcentury and net-negative emissions beyond.
- BECCS can play an important role in increasing domestic supply of clean and sustainable energy.

- A considerable level of biomass feedstocks exists in the United States from non-food crops, wastes, and forest residues to support expanded BECCS deployment in a manner compatible with food production and sustainable forestry.
- There are opportunities to integrate BECCS deployment with wildfire management programs in ways that provide mutual benefits.
- The climate change mitigation potential of BECCS is highly dependent on context. Assessments of BECCS's net-negative GHG emissions potential can vary based on the choice of baselines (system changes in the absence of BECCS), system boundaries, and timescales.

To realize this potential, the report recommends a holistic policy framework of eight major elements organized into three broad themes: policies to expand and accelerate BECCS deployment; leveraging the social, economic, and environmental co-benefits of BECCS; and rules of the road to promote responsible development (Figure ES1). Specific measures include:

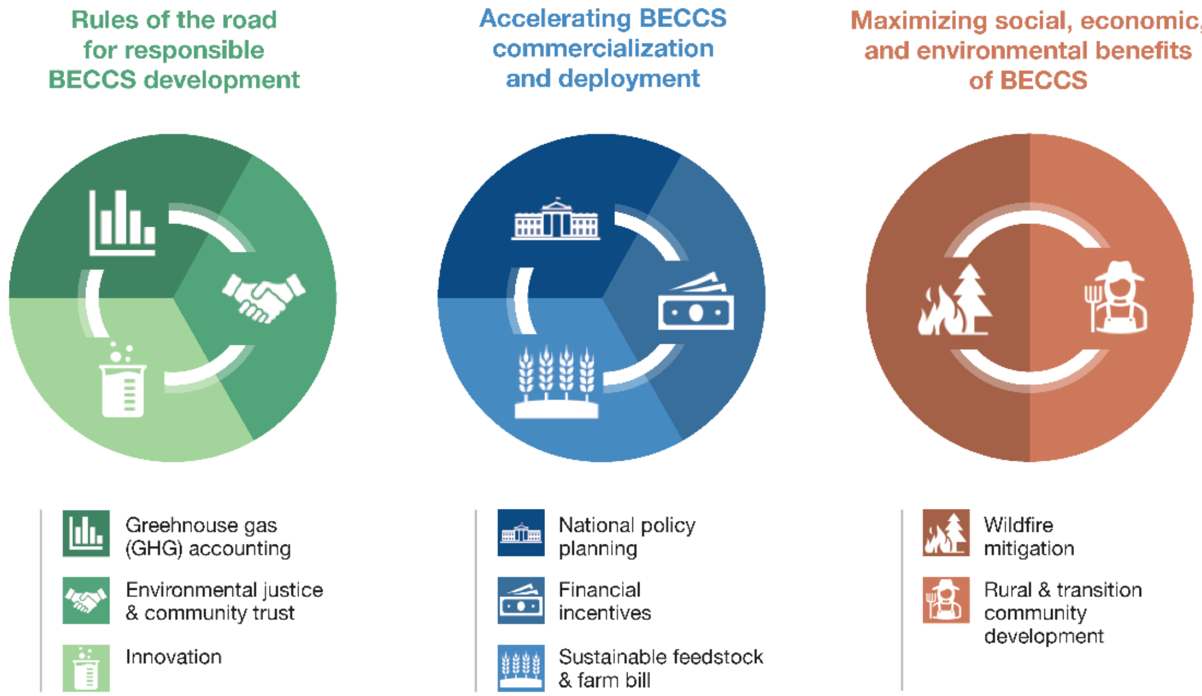
- Setting national policy goals for BECCS, including a national goal for the contribution from BECCS to CDR of at least 500 million metric tons[b] of CO_2 per year as well as a goal for clean energy production of at least 1 billion barrels of oil-equivalent (BOE) from clean power and clean liquid and gaseous fuels.
- Ensuring that federal financial incentives for demonstration and deployment are sufficient to encourage BECCS projects across a variety of feedstocks and energy types, and that tax credits, fuel standards, and CDR purchasing incorporate BECCS and value its unique combination of benefits.
- Incorporating measures into the upcoming 2023 Farm Bill to reauthorize current sustainable agriculture and forestry programs, increase funding, and clarify and expand program authorities to include sustainable biomass production pathways to support BECCS.
- Incorporating authorization and funding for BECCS feedstock supply as a wildfire management practice in federal forests and removing the restriction to allow biofuels produced from such feedstocks to qualify under the U.S. Environmental Protection Agency's (EPA) Renewable Fuels Standard (RFS).
- Establishing science-based, transparent guidelines for estimating the net GHG emissions contribution from BECCS for purposes of qualification for incorporation into climate policy plans and qualification of BECCS projects for federal incentives.

[b] Unless otherwise specified, references to "tons" in this report refer to metric tons.

- Ensuring that new BECCS projects are deployed in a responsible manner, with effective community engagement, collateral economic development and job creation, and effective environmental protection. Proactive engagement with frontline communities should address environmental justice concerns and adopt community benefits plans.
- Harnessing BECCS as a pathway for rural communities, energy communities, and other areas experiencing economic dislocation to contribute to and benefit from the clean energy transition.
- Expanding federal research, development, and demonstration (RD&D) programs to spur innovation across the entire BECCS value chain and strengthening collaboration among the U.S. Department of Energy (DOE), U.S. Department of Agriculture (USDA), and EPA on BECCS in program planning and execution.

Figure ES1

Policy recommendation themes and elements to accelerate BECCS deployment



Source: EFI Foundation, 2023.

Part I: The BECCS Value Proposition

What is BECCS?

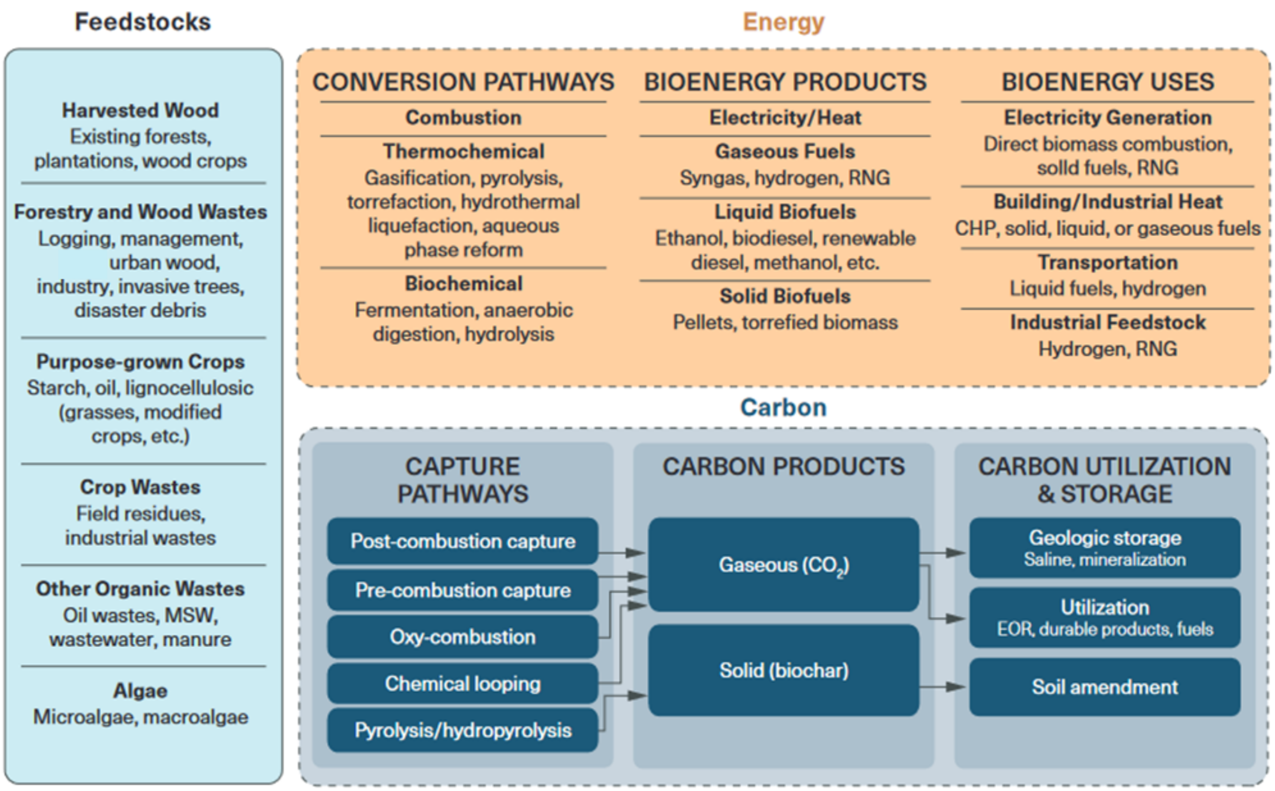
Bioenergy with carbon capture and storage (BECCS) is a family of technologies that combine existing bioenergy technologies—which produce electricity, heat, and fuels from plants and other biomass that can be regenerated—with carbon capture, utilization, and storage (CCUS). This combination fuses plants' natural ability to absorb carbon dioxide (CO_2) with CCUS solutions that prevent that carbon from returning to the environment. The result can provide both a source of clean energy and a way to remove CO_2 already in the atmosphere, potentially resulting in net-negative CO_2 emissions.

BECCS is more complex than other forms of energy. The supply of biomass feedstocks cuts across land and other resource uses (agriculture, forestry, and livestock management), with multiple conversion processes and multiple energy products (e.g., solid, liquid, and gaseous fuels).[1] As is summarized in Figure 1, BECCS uses a wide variety of biomass feedstocks, including wood, agricultural crops, and wastes from municipal, industrial, and agricultural sources. A Congressional Research Service report found 14 definitions of "biomass" or some variation, such as "renewable biomass," in federal statutes.[2] This biomass can be converted to electricity, heat, or fuels through different conversion processes. Carbon captured in either combustion or conversion to fuels can be stored underground or used in other forms.

BECCS has the potential to provide direct and indirect benefits to the climate, energy systems, local environments, and the U.S. economy. BECCS provides several sources of emissions benefits, including providing low- or negative-carbon energy that can potentially displace higher-emissions sources, especially in hard-to-decarbonize end uses. BECCS can also potentially serve as a method of atmospheric carbon dioxide removal (CDR), compensating for remaining emissions from other sources and remediating the residual CO_2 from past emissions. BECCS feedstock production can reinforce sustainable land management practices, reduce wildfire risk, and enable productive use of nonfood producing and marginal lands. Finally, responsible BECCS deployment can provide new jobs and associated economic development in rural areas and communities undergoing economic disruption.

The BECCS value chain extends across many disciplines and fields of economic activity: agriculture; forestry; energy production, distribution, and use; environmental protection; and carbon management. While there are many individual policies and programs that directly or indirectly affect the BECCS value chain, there currently is a lack of a holistic policy framework to guide BECCS development.

Figure 1
Components of BECCS



Abbreviations: RNG = renewable natural gas; MSW = municipal solid waste; CHP = combined heat and power; EOR = enhanced oil recovery. Source: Adapted from William Stafford et al., "WIDER Working Paper 2017/87 - Biofuels Technology: A Look Forward," April 2017, https://www.wider.unu.edu/sites/default/files/wp2017-87.pdf.

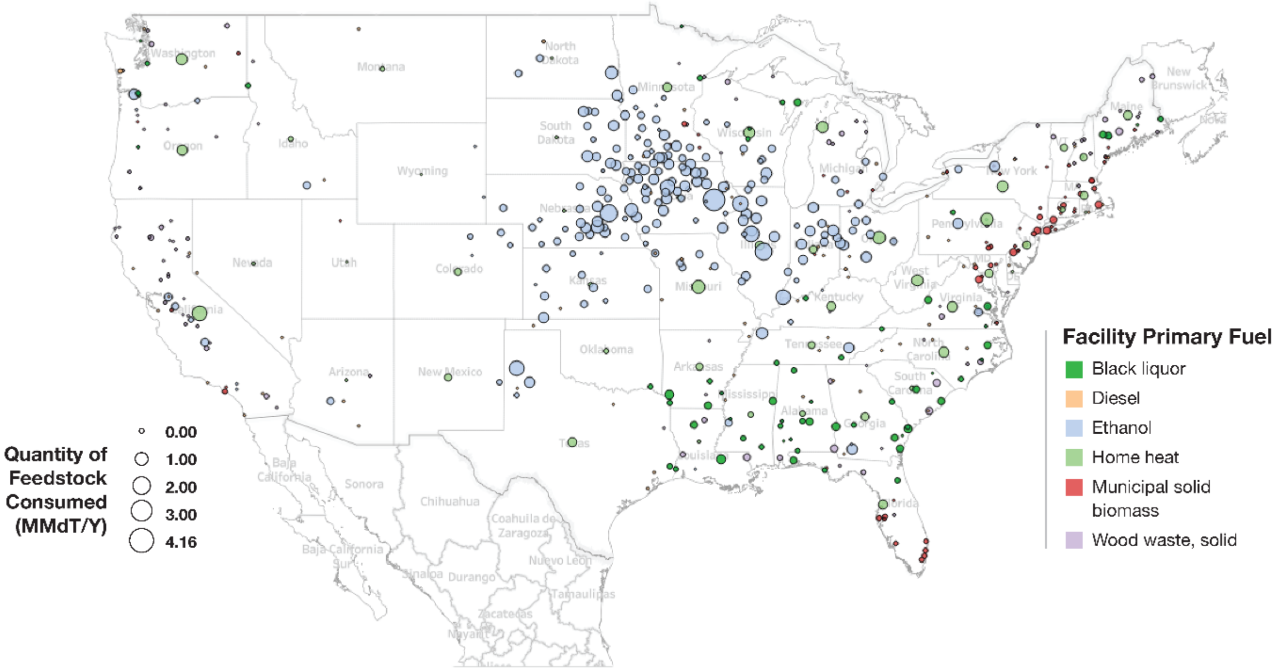
Potential Contributions of BECCS to Clean Energy and Carbon Removal

Bioenergy (without carbon capture), primarily in the forms of ethanol and wood materials, is currently the largest single source of renewable energy in the United States and is a major component of domestic energy production. The International Energy Agency estimates that bioenergy accounts for about 10% of total global energy supply, including traditional uses for heating and cooking.[3] The U.S. is a world leader in bioenergy, the leading producer and exporter of ethanol (45% of production in 2018), and the leading exporter of wood pellets (26% of production in 2021, much of which is consumed in Europe for electricity production).[4,5,6,7] Bioenergy is the *only* renewable energy source used across all energy-consuming sectors.[8] Wood and wood waste biomass plants generate 53 terawatt-hours (TWh) per year of baseload electricity, making up 1% of total generation.[9] Biorefineries produce 15 billion gallons of ethanol for transportation fuel (primarily from corn), comprising 5% of the total finished production of all forms of liquid fuels in the U.S.[10,11] Biorefineries also produce a residue by-product that is used for animal feed. Various biomass feedstock materials are used for residential heating, industrial use, on-farm energy, and non-energy use (e.g., products, chemicals).[12]

A 2014 DOE survey, illustrated in Figure 2, identified more than 500 bioenergy facilities across the United States.[13] The map shows the regional clusters of bioenergy deployment. Ethanol facilities, which have the highest output and are most numerous, are centered in the Midwest Corn Belt. In the Southeast, Northeast, and Upper Midwest, robust working forests supply bioenergy production. Waste-to-energy projects also are concentrated in urban areas of the Northeast and Florida. Since DOE's last survey, new types of bioenergy production have become more widespread, and new regional clusters have emerged. For example, renewable natural gas production has grown in and around California, boosted by incumbent agricultural and energy industries and by clean fuel policies.[14]

Figure 2

Major categories of bioenergy facilities by input, 2014



This map shows 515 facilities in major bioenergy categories, excluding biochemical facilities (which may also produce energy) and less common sources of bioenergy. "Home heat" data represents the quantity of bioenergy consumed for residential heating in each state (e.g., in wood stoves), but is not geographically specific. Source: U.S. Department of Energy, "2016 Billion-Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy" (Oak Ridge National Laboratory, 2016), https://www.energy.gov/sites/default/files/2016/12/f34/2016_billion_ton_report_12.2.16_0.pdf.

Corn ethanol use in motor vehicles is an established biofuel production pathway, driven by long-standing, proactive policy. The growth of ethanol produced from feed corn and corn residue has been driven by an effective combination of fuel standards, tax credits, and farm subsidies. These policies were premised on environmental policies for criteria pollutant reduction (specifically carbon monoxide) and energy policies to promote domestic energy supplies.[15]

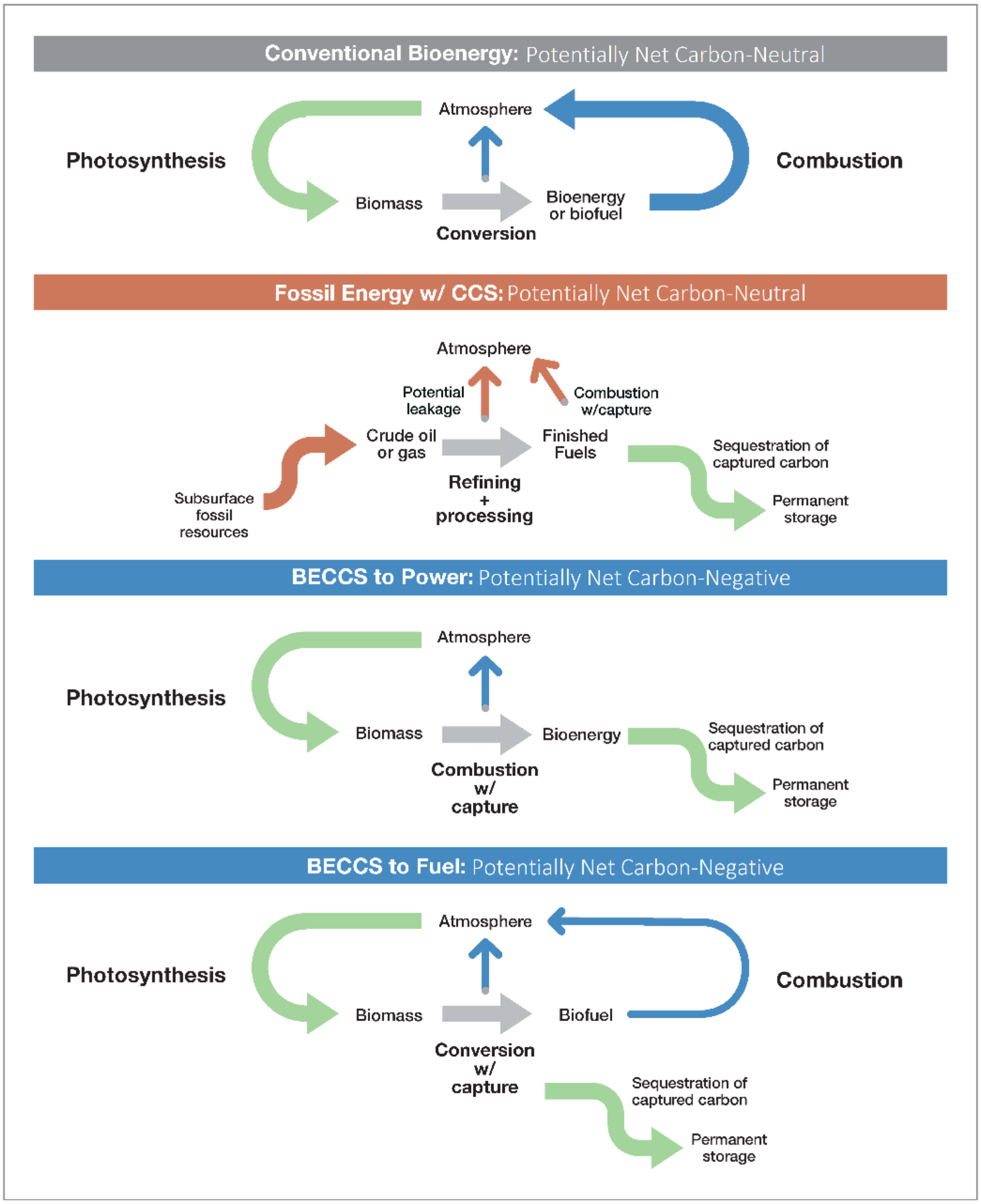
Other biomass pathways are not as well-developed and could become new and impactful energy and climate solutions. New sources of biomass, types of bioenergy (e.g., sustainable aviation fuels, hydrogen), or production processes that integrate carbon capture (e.g., pyrolysis) have the potential to further expand the role of bioenergy in the United States. For example, modeling from Princeton University estimates that BECCS could supply between 5.3 exajoules and 9.6 exajoules (0.9 billion to 1.6 billion BOE) of U.S. energy (fuels and power) per year by 2050, the equivalent of 7% to 12% of current final energy consumption.[16] These next-generation solutions, however, face obstacles of cost, logistics, technological readiness, and sustainability. Additional policies and incentives will be required to attract the investments needed for large-scale deployment.

Bioenergy without carbon capture can potentially be carbon-neutral with respect to its impact on climate, assuming that the right conditions are met, especially around the growth and harvesting of biomass.[17] Combining bioenergy with CCUS similarly offers the potential for net-negative emissions (i.e., carbon removal) if the captured carbon exceeds emissions released elsewhere in the process.[18] This means that if done carefully and efficiently, BECCS can make an important contribution to achieving net-zero[c] climate policy goals. Figure 3 compares the carbon flows of bioenergy (without carbon capture), biopower with carbon capture, and liquid biofuels with carbon capture. In traditional bioenergy, carbon is absorbed through photosynthesis and then returned to the atmosphere through combustion or conversion to fuels. In BECCS, some of the carbon from conversion and combustion are also absorbed and stored permanently. Figure 3 also contrasts BECCS with fossil energy with carbon capture, which, like standard bioenergy, can achieve carbon neutrality but does not provide net-negative CO_2 emissions.

[c] Net zero means the amount of emissions removed (e.g., through CDR) is greater than or equal to any remaining emissions.

Figure 3

Idealized carbon flows for BECCS and conventional bioenergy

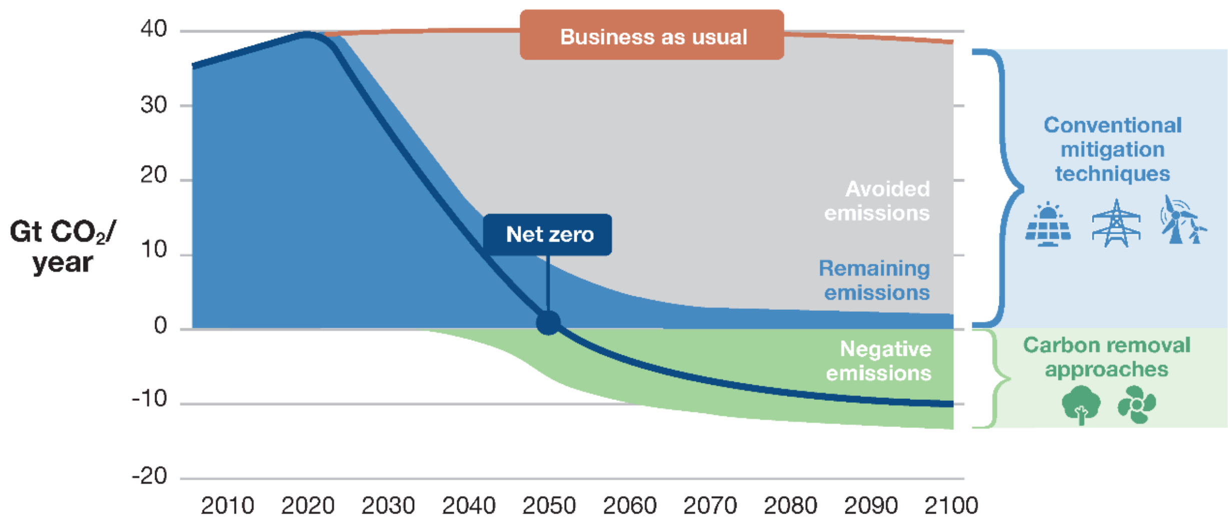


These diagrams represent simplified and idealized versions of carbon flows in various processes. While carbon neutrality or negativity is assumed for an idealized process, this is only true in situations where all emissions are captured and the processes are efficient enough that any non-captured emissions are equal to or less than the captured emissions. The arrow size represents the relative magnitude of carbon in each step, and in all four diagrams the smaller arrows represent the volume of carbon that enters the atmosphere. Source: Adapted from National Academies of Sciences, Engineering, and Medicine, Negative Emissions Technologies and Reliable Sequestration: A Research Agenda (Washington, D.C.: National Academies Press, 2019), https://doi.org/10.17226/25259.

The importance of adding carbon capture to bioenergy processes becomes clear in understanding the necessity of CDR. Meeting science-based climate change goals requires major reductions in current GHG emissions from every sector of the global economy, as well as removal of legacy CO_2 from the atmosphere and oceans. The UN International Panel on Climate Change (IPCC) estimates that in the median scenario approximately 6 billion tons (gigatons or Gt) of legacy CO_2 will need to be removed from the atmosphere on an annual basis by 2050 to limit the rise in temperature to 2 degrees Celsius and avoid the worst effects of climate change.[19] The IPCC estimates that global CO_2 emissions will need to reach net zero by around midcentury to achieve these temperature targets; by the end of the century, net-negative GHG emissions will be required, with a contribution from CDR in the range of 16 Gt to 20 Gt per year (Figure 4).[20]

Figure 4

The need for large-scale carbon removal to meet climate goals



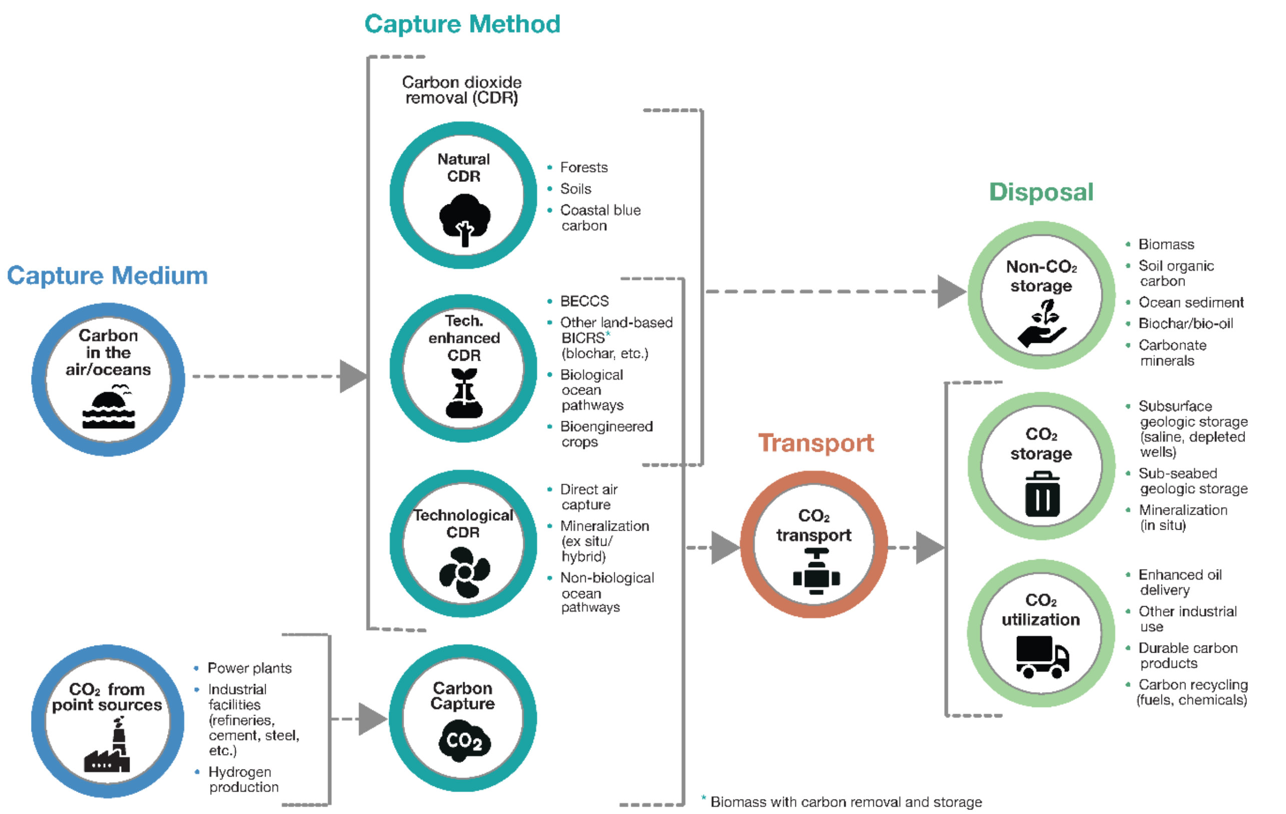
"Business as usual" represents an estimate for emissions if climate action is not taken. "Avoided emissions" represents the amount reduced by "conventional mitigation" (e.g., renewables, electrification, energy efficiency) compared to business as usual. "Remaining emissions" includes sectors that are difficult to abate through conventional means, such as aviation. While CO_2 is the primary focus of emissions reduction efforts, other greenhouse gases (e.g., methane) also require mitigation and/or removals. Source: Adapted from Intergovernmental Panel on Climate Change (IPCC), "Sixth Assessment Report, Working Group III: Mitigation of Climate Change," 2022, https://www.ipcc.ch/report/ar6/wg3/; Ellie Johnston, "Achieving a Balance of Sources and Sinks," World Resources Institute, March 20, 2018, https://www.wri.org/climate/expert-perspective/achieving-balance-sources-and-sinks.

In line with this global goal, achieving net-zero emissions in the United States by 2050 could require CDR on the scale of 1 Gt to 2 Gt per year.[21] CDR measures complement conventional mitigation measures to compensate for residual emissions from hard-to-abate sectors such as heavy industry, aviation, and shipping. The combination of CDR and mitigation also will speed the pace of decarbonization. Beyond midcentury, CDR is the only measure that can achieve global net-negative emissions to reduce atmospheric GHG concentrations.[22]

Reaching large-scale levels of CDR will require contributions from multiple pathways in parallel, encompassing natural, technological, and hybrid approaches—such as BECCS.[23] These approaches are illustrated in Figure 5. BECCS represents an attractive CDR approach because it has a high potential to scale, stores carbon permanently or on long timescales, builds on known technologies, and has lower costs and cost uncertainty relative to other CDR options.[24] Crucially, BECCS can produce both clean energy and net removal of carbon from the environment through permanent storage of the captured carbon. Other CDR methods are net energy consumers.

Figure 5

Carbon management pathways

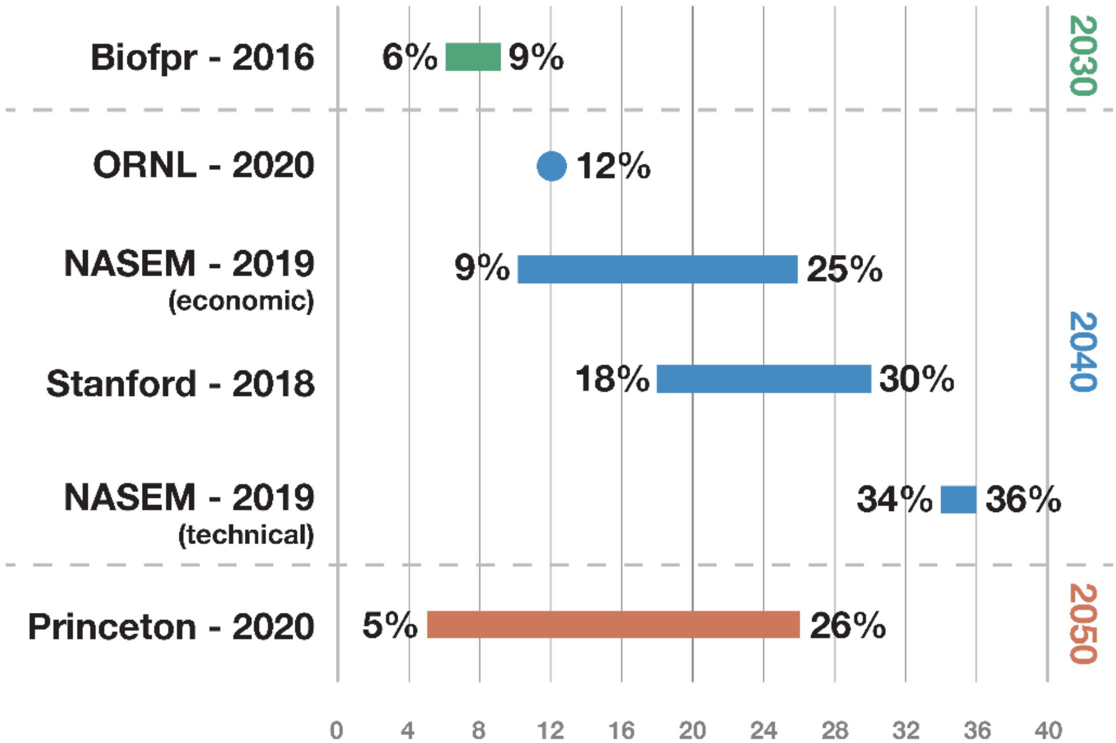


Carbon management encompasses a broad suite of pathways. BECCS occupies an important niche between technological and natural CDR. BECCS also sits at the intersection of point-source carbon capture and CDR. Different BECCS pathways take advantage of different carbon disposal mechanisms, encompassing all three listed in the figure. Source: Reproduced from Energy Futures Initiative, "CO2-Secure: A National Program to Deploy Carbon Removal at Gigaton Scale," December 7, 2022, https://energyfuturesinitiative.org/reports/co2-secure-a-national-program-to-deploy-carbon-removal-at-gigaton-scale/.

Various modeling analyses of both global and U.S. net-zero pathways generally assume very large contributions from BECCS and from forestation pathways (reforestation and afforestation) in their estimates of net emissions reductions.[25,26] Figure 6 summarizes estimates from the scientific literature for U.S. BECCS showing a potential range from 0.3 Gt to 2.2 Gt per year of CDR, equivalent to 5% to 36% of current domestic GHG emissions.[27] The estimates vary depending on timeframe and assumptions regarding feedstock availability, costs, incentives, and policies.

Figure 6

BECCS U.S. carbon removal potential estimates (% of 2018 net GHG emissions)



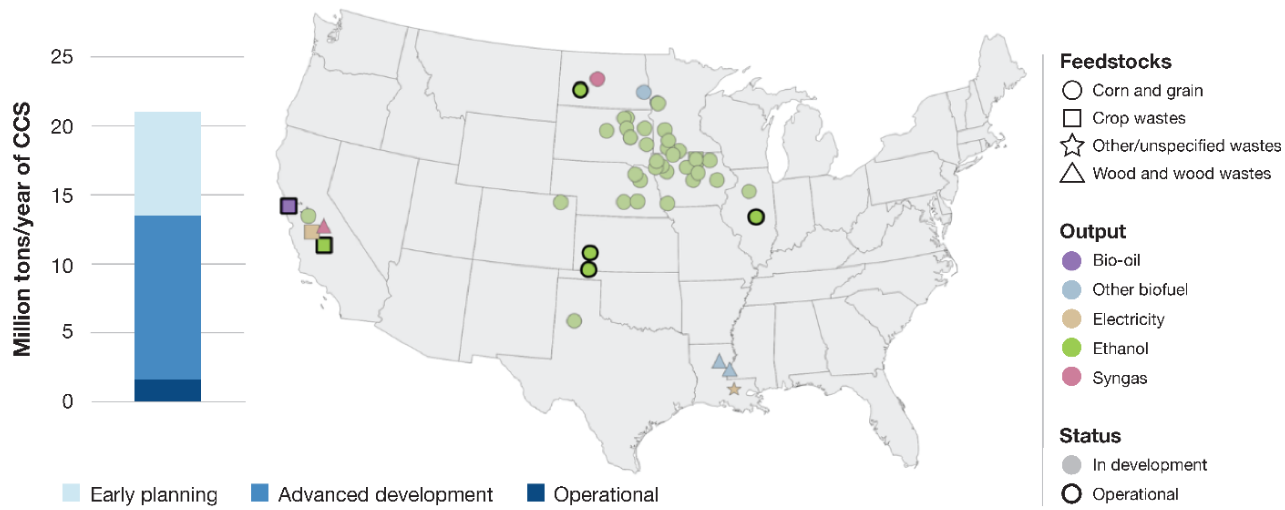
The five study results in the figure show that large-scale BECCS deployment can achieve net emissions reductions of 0.3 $GtCO_2$/yr to 2.2 $GtCO_2$/yr, the equivalent of 5% to 36% of 2018 net GHG emissions of 5.9 Gt CO_2. Source: Data from Jonathan N. Rogers et al., "An Assessment of the Potential Products and Economic and Environmental Impacts Resulting from a Billion Ton Bioeconomy," Biofuels, Bioproducts and Biorefining 11, no. 1 (2017): 110–28, https://doi.org/10.1002/bbb.1728; Matthew Langholtz et al., "The Economic Accessibility of CO_2 Sequestration through Bioenergy with Carbon Capture and Storage (BECCS) in the US," Land 9, no. 9 (September 2020): 299, https://doi.org/10.3390/land9090299; National Academies of Sciences, Engineering, and Medicine, Negative Emissions Technologies and Reliable Sequestration: A Research Agenda (Washington, D.C.: National Academies Press, 2019), https://doi.org/10.17226/25259; 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 (March 27, 2018): 3290–95, https://doi.org/10.1073/pnas.1720338115; Eric Larson et al., "Net-Zero America: Potential Pathways, Infrastructure, and Impacts" (Princeton University, October 29, 2021), https://netzeroamerica.princeton.edu/the-report.

BECCS deployment is in its infancy, with just six operational plants in the U.S. and 17 operational plants globally as of the end of 2022.[28] These plants are mostly small-scale demonstration projects that collectively capture only about 2 million tons of CO_2 per year.[29] As shown in Figure 7 below, an additional 44 projects are in development in the United

States. The majority of these bioenergy projects are planned retrofits to existing corn ethanol production facilities geographically concentrated in the Midwest. Many of these projects are being developed in conjunction with the proposed Summit Carbon pipeline project in the Midwest (with 34 participating plants as of May 2023).[30] In addition, there are at least 11 proposed new, fully integrated BECCS facilities that will produce biopower and a variety of biofuels.[31] The new projects under development represent an important step in realizing the potential for increasing project diversity in feedstocks, output, and geography. Of the 50 total—44 planned and six operational—BECCS facilities nationwide, the 42 projects that report their intended size could capture a total of more than 21 Mt CO_2 per year in the coming years.

Figure 7

Planned and operational BECCS facilities in the United States



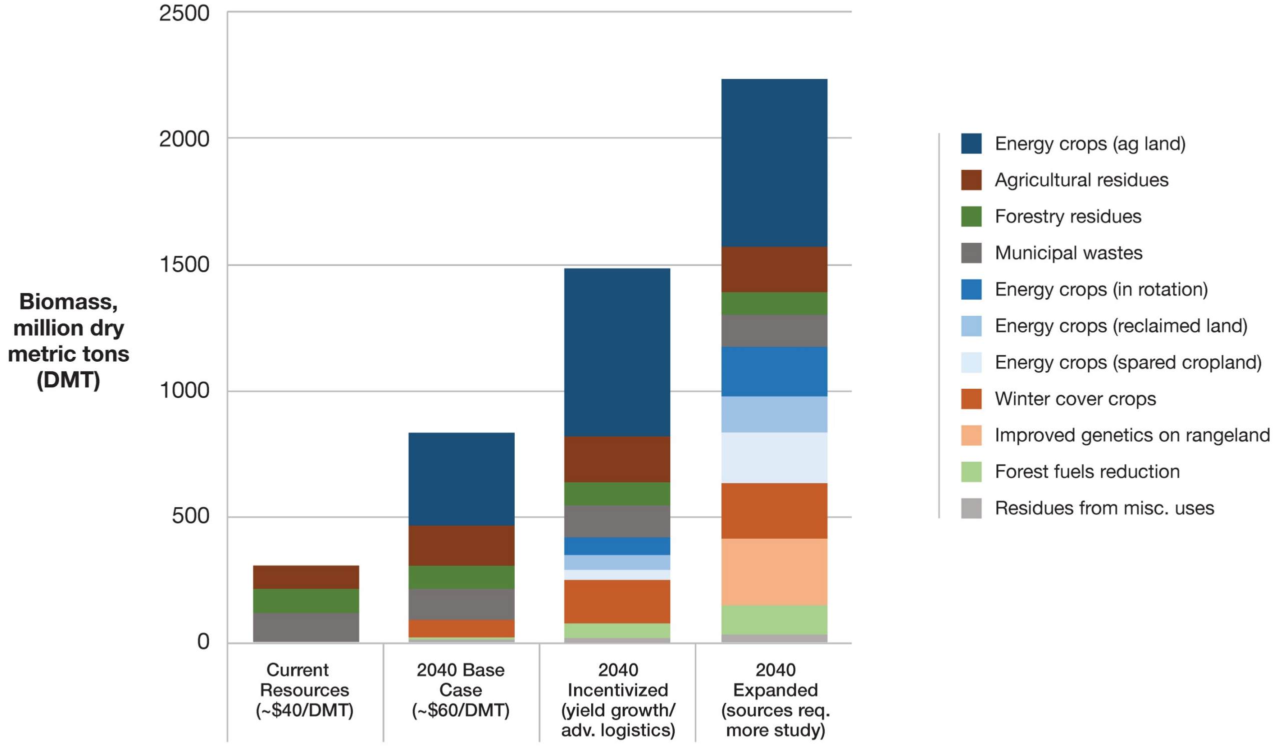
This map identifies BECCS facilities across the United States, designated by their status, primary feedstocks, and output. The characteristics and intended capture totals of each BECCS facility were determined through internal analysis of public announcements for BECCS projects through May 2023. Source: Global CCS Institute, "Facilities Database," CO2RE, accessed June 1, 2023, https://co2re.co/FacilityData.

BECCS could be deployed at large scale in the U.S. without adverse impacts on food production or utilizing primary forests. The current bioenergy industry has a relatively small land footprint. When accounting for the uses of corn ethanol by-products, ethanol production from feed corn comprises about 13.9 million acres of land, or about 1.5% of total U.S. farmland.[32,33] Wood pellet production is largely from low value residues (e.g., bark and sawdust) and by-products (e.g., stemwood unsuitable for saw timber) from forest lands being managed for higher value wood products. Pellet production occurs mainly in the Southeast, where it is a small share of total annual harvesting. In the near term, BECCS can serve to reduce emissions from existing bioenergy production; in both the near and long term, BECCS can take advantage of new, sustainably produced biomass resources to responsibly scale up the industry and potentially achieve additional co-benefits.

Expanded deployment of BECCS can target a much larger untapped resource base. A 2016 DOE study estimated that about 360 million dry metric tons of biomass are used in current bioenergy production, and that the quantity of feedstocks produced could be about doubled using readily available from currently unused agricultural and forestry residues, as well as municipal wastes.[34] Building upon these estimates, the *Sourcing Biomass Feedstocks* white paper found that, with proper incentives, an estimated 0.8 billion tons to 2.2 billion tons of biomass could be produced sustainably by 2040 in total.[35] These numbers include constraints around sustainability, including that agricultural production meets projected demand for food, animal feed, ethanol, fiber, and exports.[36]

Figure 8

U.S. biomass supply potentials sustainable feedstocks



The figure above shows potential available biomass under different scenarios, expanding on the data from DOE's 2016 Billion-Ton Report (BT16). The first was based on current conditions, and the next three are different scenarios in 2040: the Base Case, reflecting "a conservative estimate of well-documented resources;" the Incentivized scenario, representing greater production though investments in production and logistics; and the Expanded scenario, which includes sustainable sources with more uncertain production potential. Agricultural residues, forestry residues, municipal wastes, and energy crops on agricultural land were estimated by DOE in BT16; other resources were examined for this study. All estimates include constraints around sustainability criteria, including meeting projected demand for food, feed, ethanol, fiber, and exports. Colors represent the different categories of feedstocks as defined in BT16: green for forest resources, gray for waste resources, orange for agricultural resources, and blue for energy crops (see Figure 9 for more detail). Source: John Field et al., "Sustainably Sourcing Biomass Feedstocks for BECCS in the United States" (Oak Ridge National Laboratory, 2023).

As shown in Figure 8, much of this resource base consists of energy crops (e.g., switchgrass, miscanthus, and short-rotation woody crops like poplar) that can be grown on land that is unsuitable or currently unused for food production, such as former mining lands. Utilization of forest residues,[d] as well as municipal solid wastes, constitutes the remainder. If all feedstocks included in DOE's estimates for 2040 were used for BECCS, then potentially 600 Mt to 1,800 Mt of CO_2 could be sequestered.[37] The potential could be even higher if the other feedstocks examined in the white paper were included. Regrowth of the harvested biomass, as well as avoidance of emissions from decaying residues, could provide additional climate benefits.

In addition to supplying BECCS applications, the feedstocks identified in this analysis provide a variety of environmental and climate benefits. The growth of energy crops in rotation on spared cropland (i.e., land no longer used for food production because of increased overall productivity of cropland) or reclaimed land can reverse soil degradation and expand future food production. Improved management of livestock rangeland could create more land viable for bioenergy feedstocks, such as those better adapted to arid and semi-arid environments.[38] Fuel reduction treatments make timberlands more defensible from wildfires and can enable forest diversity.[39]

The geographic distribution of various sources of biomass feedstock for BECCS conversion is shown in Figure 9.[40] The broad range of geographic distribution of these feedstocks, including wastes, timberland resources, agricultural residues, and energy crops, present economic opportunities for biomass landowners and BECCS project developers across the country. Municipal waste resources are concentrated in urban areas and could serve as a feedstock for clean firm power applications,[e] while agricultural and forest residues in more rural areas could revitalize these communities to supply biofuels or novel bioenergy pathways.

The principal challenge to expanding BECCS deployment from these biomass resources is economic and logistical (including ensuring sustainable production and land management), not technological.[41] Biomass materials have much lower energy density and much greater spatial dispersion than conventional fossil fuels, increasing the cost of collection and transportation. There is currently a lack of incentives and infrastructure necessary for this biomass to be collected and used for energy.[42]

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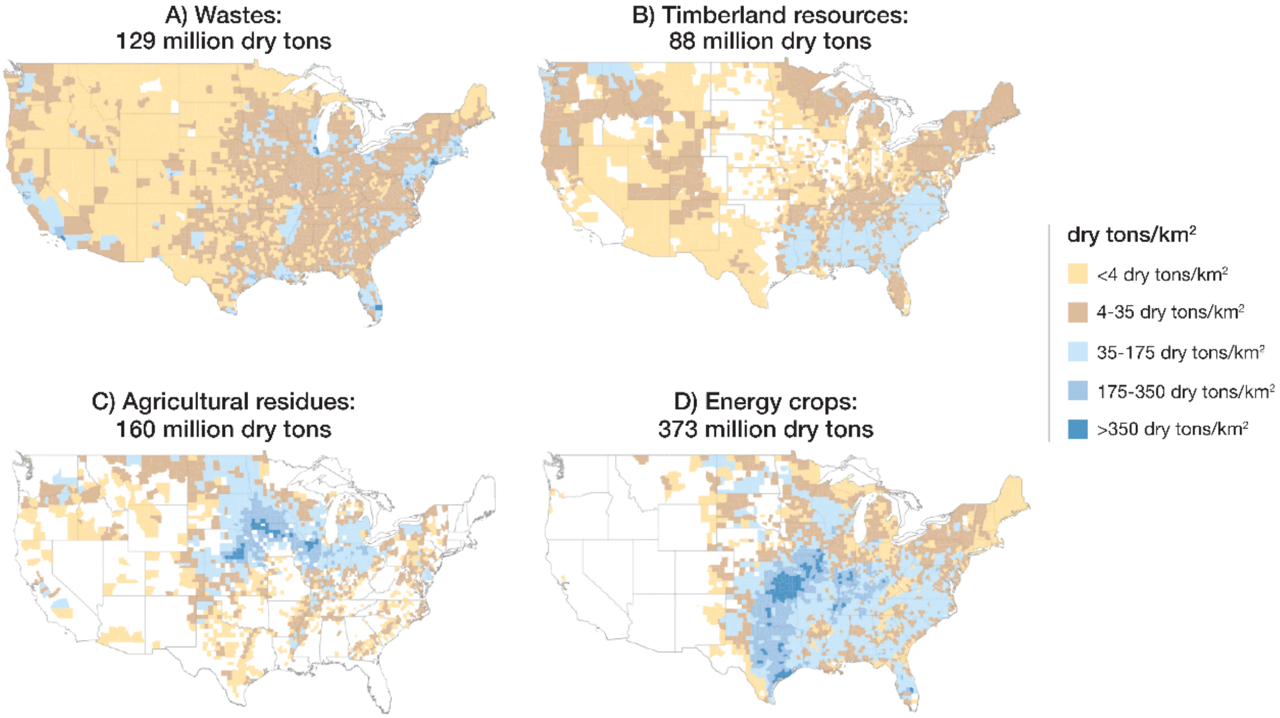
[d] The term "forest residues" is used broadly in this report to encompass residues from dead and decomposing woody materials on the ground, residues from forestry operations (tops, branches, and thinnings), and residues from wood processing operations (sawdust, bark, and black liquor).

[e] Clean firm power generation is available 24/7 and dispatchable to adjust to varying electricity demand. Clean firm power provides systems-level benefits to the electricity grid by balancing clean intermittent sources of power generation, such as solar and wind, to maintain grid stability and by complementing other balancing resources such as storage and hydropower.

Figure 9

Geographic distribution of potential biomass resources



Maps identifying the potential concentration of various biomass feedstocks across the continental United States. Wastes are organic fractions of municipal solid wastes, oils and greases, mill processing wastes, and animal manure. Timberland resources refers largely to the existing forest products industry. Agricultural residues refer to feedstocks such as corn stover or cereal straw that are currently available as a crop production byproduct. Energy crops include switchgrass, miscanthus, and short-rotation woody crops as potential feedstock sources. Source: John Field et al., "Sustainably Sourcing Biomass Feedstocks for BECCS in the United States" (Oak Ridge National Laboratory, 2023).

The Current Policy Landscape for BECCS

Four laws have dramatically changed the landscape for the U.S. clean energy transition: the December 2020 "omnibus" (including the Energy Act of 2020), the Bipartisan Infrastructure Law (BIL), Inflation Reduction Act (IRA), and the CHIPS and Science Act.[43,44,45,46] The principal thrust of the spending provisions in these new laws is focused on specific clean energy solutions such as battery electric vehicles, hydrogen hub development, and direct air carbon capture. The general intent of the new tax provisions is to establish incentives for clean power generation and clean fuels production. BECCS is specifically identified in only a few program areas, mainly in the research and development (R&D) authorizations of appropriations for R&D programs.[47] BECCS can benefit indirectly from some of the new spending provisions and can qualify for the new tax credit provisions in varying degrees as summarized below.

Recent legislation has provided nearly $1 trillion toward climate and clean energy investment.[f] A portion of these new spending programs may benefit BECCS deployment with appropriate implementation guidance. In the nearly $1 trillion appropriated or authorized in these programs, there are a number of provisions that could directly or indirectly benefit BECCS deployment. For example, technologies such as direct air capture (DAC) that share common carbon storage needs with BECCS have received multibillion-dollar funding allocations that have been specifically earmarked in legislation.[48] BECCS has received only $500,000 in dedicated spending and only in the form of authorization of annual appropriations.[49] Explicit policy direction for BECCS—including programmatic goals, clarification of funding eligibility, and prioritization in funding awards—is needed to ensure BECCS can benefit from these new authorities and funding.

The new clean energy tax credits incentivize retrofits of carbon capture at existing bioenergy facilities, but the credits remain insufficient for many other potential applications of BECCS absent other policy measures. The IRA established a new framework of tax incentives intended to be technology-neutral with respect to the various forms of clean energy production.[g,50,51,52,53] The new tax credit framework, however, established different eligibility criteria for different energy sources and technologies. The eligibility requirements for each of these credits will have varying incentive effects on BECCS deployment, as well as varying effects on BECCS relative to other clean power and clean fuels technologies. The requirements for some of the relevant tax credits are described below.

The 45V hydrogen production tax credit established a credit level based on the estimated net GHG emissions over the full production life cycle, including carbon capture and storage where applicable. The size of the credit is scaled, with a larger credit for hydrogen that is produced with lower carbon intensity. BECCS projects that produce biohydrogen would need to meet the specified life cycle carbon intensity targets to qualify for the 45V credit.[54] Depending upon the emissions criteria to be applied to the biomass production and conversion stages, biohydrogen could potentially qualify for the full 45V credit without the need for carbon capture and storage. Thus, the 45V credit would not necessarily incentivize biohydrogen with CCUS. Similar requirements—namely a life cycle emissions threshold, a credit that scales based on carbon intensity, and a lack of additional reward for carbon-negative fuels—also apply to the Section 45Z clean fuel production tax credit, which applies to fuels used for transportation.[55]

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[f] Based on EFI analysis of DOE budget data and assessment of IRA, BIL, and CHIPS and Science Acts and the Energy Act of 2020.

[g] Tax credits predating the IRA—such as Sections 40 (alcohol fuels), 40A (biodiesel and renewable diesel), and both 45 and 48 (clean electricity)—could also likely be claimed by BECCS projects. These tax credits, however, are awarded based on technology categories rather than GHG emissions and would provide the same reward to bioenergy regardless of their CCUS use or overall emissions reductions. The Section 48B credit for advanced gasification projects incentivizes lower-emissions projects, but, like Section 45Q, rewards bioenergy projects the same as fossil-based ones. BECCS projects could be eligible for the Section 48C advanced energy project credit, revived in the IRA, but it only rewards individual demonstrations, not large-scale deployment.

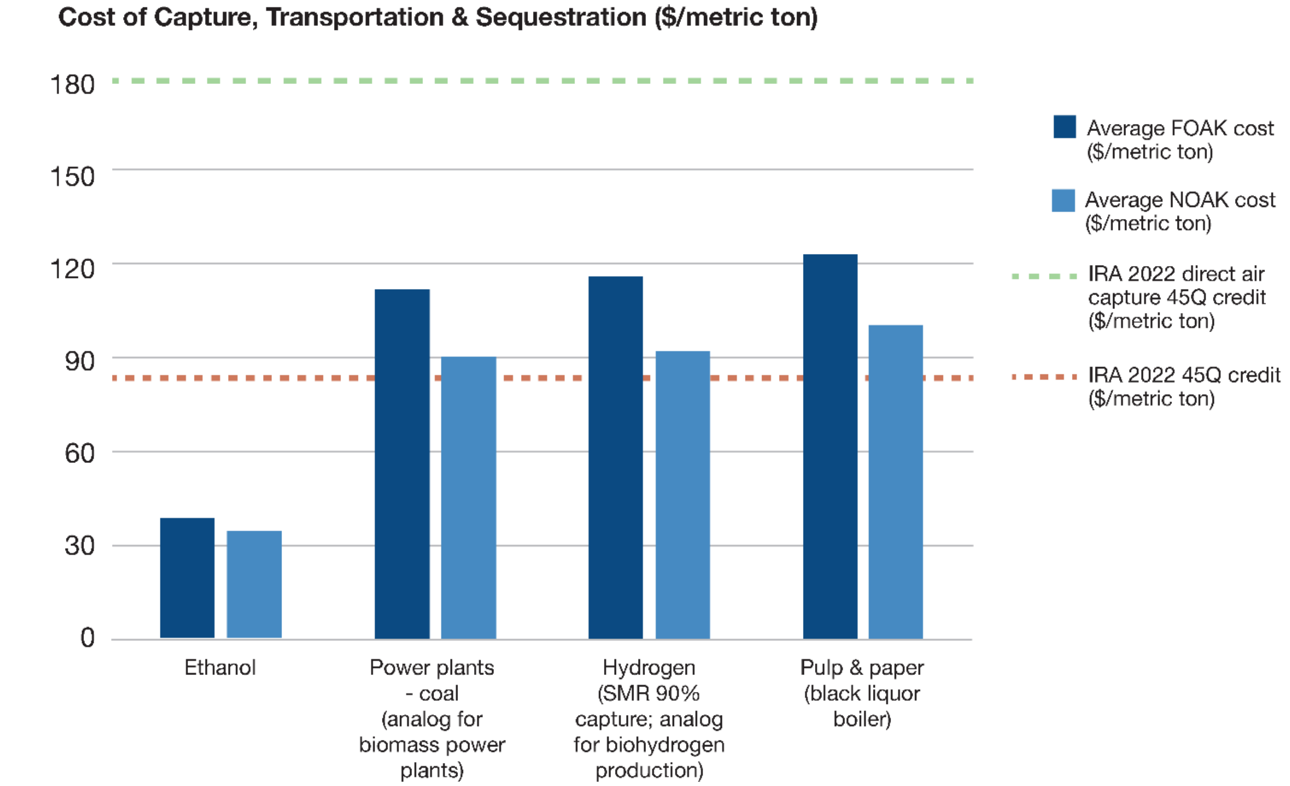
The Section 45Y clean electricity production tax credit does not require a life cycle analysis of net GHG emissions for non-combustion-based technologies. However, clean power generation from combustion-based generation technologies such as BECCs are required to meet a GHG life cycle analysis target.[56] Again, depending on the emissions criteria to be applied to the biomass production and conversion stages, new biopower generation technologies could potentially qualify for the 45Y credit without the need for carbon capture and storage. Thus, the 45Y credit may not incentivize new biopower with CCUS. The same could be true of the Section 48E clean electricity investment tax credit, which follows similar rules to the 45Y credit.[57]

The Section 40B Sustainable Aviation Fuel (SAF) credit provides a production credit for sustainable aviation fuels, depending upon the life cycle GHG emissions associated with SAF production. To qualify, the SAF must meet a minimum GHG emissions reduction of 50%. The maximum credit of up to $1.75 per gallon can be obtained if the SAF achieves 100% GHG emissions reduction (carbon neutral).[58] There is no additional incentive or BECCS-based net-negative GHG emissions.

The Section 45Q credit for carbon oxide sequestration is directly related to the quantity of CO_2 that is captured and stored. The credit does not have a life cycle requirement for the net GHG emissions associated with the carbon capture process that yields the CO_2 for storage.[59] The 45Q credit, although it is focused on the quantity of CCUS and not the production level of the clean fuel, may in fact represent the most effective incentive for BECCS, at least in the short run.[60] Even so, the level of the credit will incentivize only a limited scope of BECCS technologies, as the credit level is insufficient to offset the cost of CCUS for several major bioenergy pathways, and it cannot be stacked with many of the other clean energy credits passed in the IRA.[61] As shown in Figure 10, the new 45Q tax credit will incentivize ethanol with CCUS, and as noted above, there is a substantial level of planning underway for possible CCUS retrofits to ethanol facilities. The new 45Q credit, however, appears inadequate to incentivize CCUS retrofits or new builds for biopower or other bioenergy facilities (e.g., hydrogen production, pyrolysis).

Figure 10

Estimated cost of CCS for various BECCS facilities

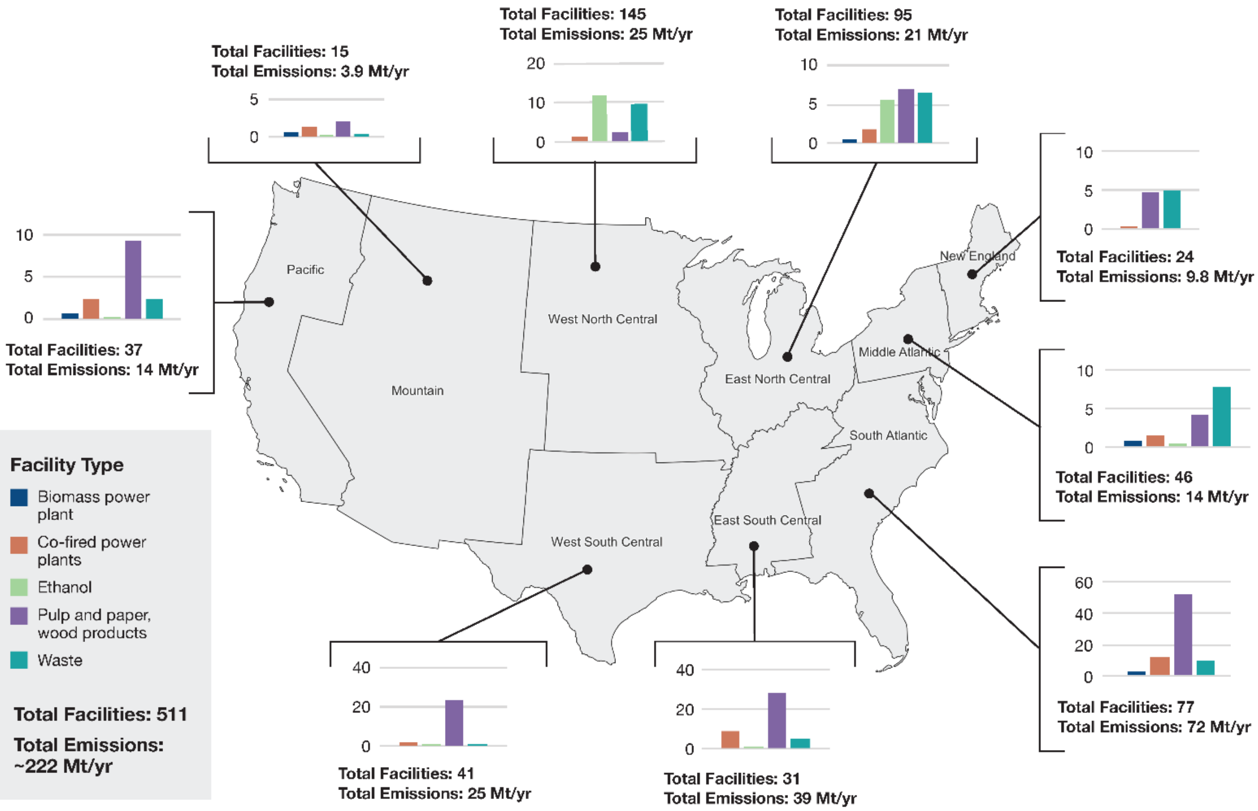


This figure, adapted from EFI Foundation's recent CCUS report, shows the cost of CCS for technolgies relevant to BECCS, either through bioenergy or biofuel pathways. The cost of coal is used as a proxy for biomass, and hydrogen steam methane reformation (SMR) is used as a proxy for biomass gasification, though their costs could be higher or lower depending on the specifics of the process, plant, and feedstock. First-of-a-kind (FOAK) is contrasted with nth-of-a-kind (NOAK) to highlight the particularly challenging financial environment that demonstration and early adopters face. The current estimated cost for most facilities other than ethanol is above the current 45Q credit for which power-producing and industrial facilities are eligible. The $180/ton credit that DAC plants are eligible for is presented for contrast, but none of the facilities would be eligible for it currently. Source: Adapted from EFI Foundation report "Turning CCS Projects in Heavy Industry and Power Into Blue Chip Financial Investments."

The limited effect of the 45Q as an incentive to retrofit existing bioenergy facilities also has an important geographical impact, as shown in Figure 11. The corn ethanol facilities that may now be incentivized to consider CCUS retrofits are located largely in the Midwest. The current 45Q credit does not provide sufficient incentive to retrofit current biopower facilities that are largely located in the Southeast. The availability of potential geologic storage is also an important consideration that will affect the cost of both new CCUS plants and retrofits.

Figure 11

Bioenergy facilities eligible for 45Q carbon sequestration tax credit



This figure focuses on the five types of emitting facilities with the most direct relevance to BECCS: biomass power plants; co-fired power plants, referring to power plants that can use either natural gas or a form of biomass as a fuel; ethanol production facilities; pulp and paper plants, and wood product manufacturing facilities; and waste and wastewater facilities. The emissions totals for each facility included here meet the updated threshold for 45Q eligibility (greater than 12,500 tons/yr for industrial facilities; greater than 18,750 tons/yr for power plants) and have reported biogenic emissions in the past year. Source: Data from "Facility Level Information on Greenhouse Gases Tool (FLIGHT)," EPA Greenhouse Gas Reporting Program (GHGRP), accessed June 16, 2023, https://ghgdata.epa.gov/ghgp/main.do.

Federal acquisition of CDR is another policy avenue with the potential to incentivize BECCS deployment, although the initial demonstration application will be small-scale. Current private sector programs to purchase CDR as credits or offsets have established a monetary value for captured CO_2. Further expansion of the concept could create an additional incentive for deployment of BECCS and other pathways with negative emissions potential. The FY2023 Omnibus Appropriations Act directed DOE to implement a demonstration program for federal purchases of removed CO_2.[62] There is proposed legislation, such as the Carbon Removal and Emissions Storage Technologies (CREST) Act[63] and the Federal Carbon Dioxide Removal Leadership Act, that would expand the size and scope of federal purchasing demonstration programs for removed CO_2 emissions. A 2022 EFI Report, *CO2-Secure: A National Program to Deploy Carbon Removal at Gigaton*

Scale, presented a roadmap for a large-scale operational purchasing program for removed CO_2 from the atmosphere and oceans.[64]

The federal purchasing program would expand on current voluntary efforts by the private sector to invest in CDR as part of corporate commitments to move toward net-zero GHG emissions within their businesses. For example, the Frontier advance market commitment, formed by Shopify, Stripe, Alphabet, Meta, and McKinsey, announced plans to raise $1 billion to invest in CDR projects and sell the carbon credits to other entities seeking to reduce their carbon footprint.[65] While much of this activity has been focused on natural CDR solutions, such as afforestation and reforestation, there is growing interest in acquiring CDR from technological approaches, such as DAC, and considering hybrid approaches, such as BECCS. The Frontier fund organizers are currently developing criteria for eligible investments, targets for CO_2 valuation, and guidelines for net emissions accounting.[66]

Part II: Policy Blueprint for Accelerating BECCS Deployment

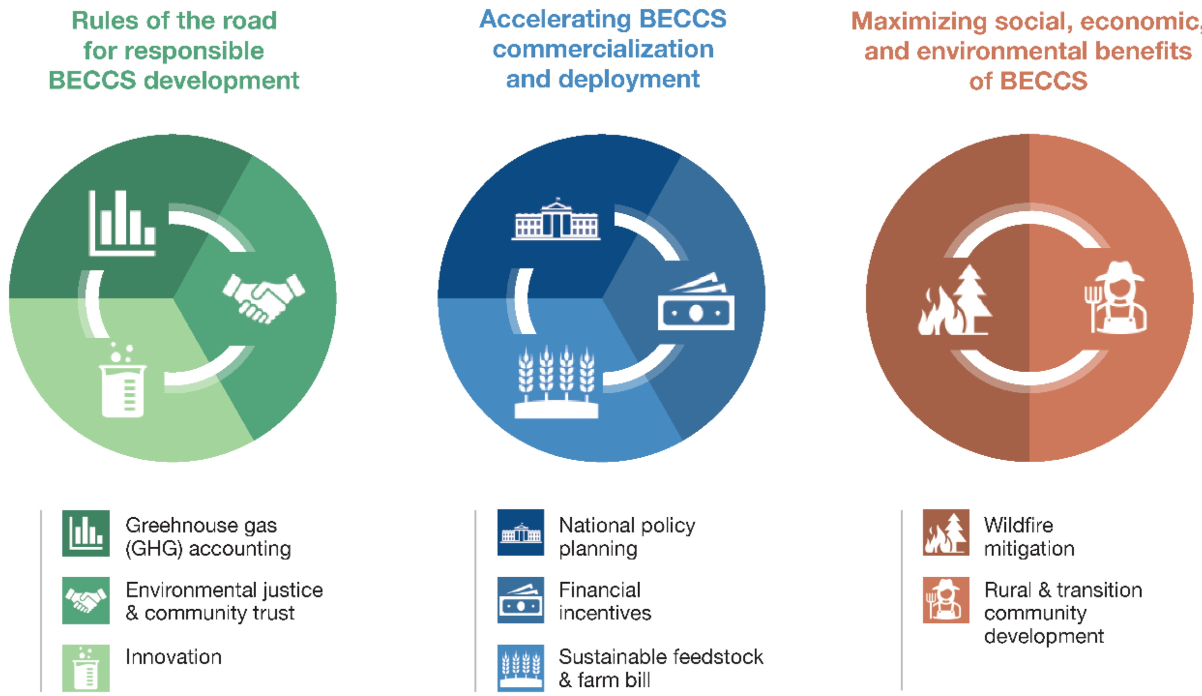
The proposed policy blueprint for accelerated large-scale BECCS deployment consists of a variety of recommendations that fall into three broad themes:

- Accelerating the pace of BECCS deployment
- Maximizing the social, economic, and environmental co-benefits of domestic BECCS deployment
- Establishing rules of the road for responsible BECCS deployment.

The principal areas of recommendations within these broad themes are illustrated in Figure 12. The specific recommendations are summarized in the discussion that follows.

Figure 12

Policy recommendation themes and elements to accelerate BECCS deployment



Source: EFI Foundation, 2023.

Accelerating the Pace of BECCS Deployment

National Policy Planning

Setting national targets for BECCS—focused on both clean energy production and CDR—could be an important step in marshaling the public and private resources needed to advance BECCS deployment. Based on estimates of the potential for sustainable BECCS development in the United States, a reasonable target could be to deploy BECCS at the level that could achieve at least 500 Mt CO2 of CDR annually by 2050. This target is ambitious but achievable. Putting it into perspective, this goal would be equivalent to the current total GHG emissions from aviation and represent a contribution of at least 25% to the total estimated CDR needed to reach net-zero GHG emissions by midcentury, and is equivalent to 9% of the United States' net emissions in 2021.[67,68] The *Sourcing Biomass Feedstocks* white paper estimated that, even in the most conservative scenario, the U.S. could supply enough biomass to produce over 700 Mt CO_2 of BECCS by 2040; thus, the 500 Mt goal could very likely be met with readily accessible biomass resources and without affecting production of food and fiber.[69]

To capture the value of BECCS to both clean energy and carbon removal, this national policy planning should also include an energy target. A reasonable proposal for this energy target would be to produce 1 billion barrels of oil-equivalent (BOE) per year of energy from BECCS (fuels and power combined) by 2050, the equivalent of 8% of 2021's final energy consumption.[70]

The current U.S. national climate strategy, pointed toward a goal of net-zero GHG emissions by 2050, mentions BECCS as a potential solution but does not include a clear target.[71] The establishment of specific goals for BECCS deployment can influence prioritizing actions by federal, state, and local governments, encouraging private investment and convening stakeholder engagement. Having one target focused on CDR and another focused on energy will help align efforts focused on both decarbonization benefits of BECCS—removing carbon from the atmosphere and providing a versatile source of clean power to displace the use of fossil fuels. The current federal offshore wind initiative, centered on a goal of deploying 30 gigawatts (GW) of offshore wind electricity generation capacity by 2030, is a good example of the organizing ability of a national goal.[72]

Financial Incentives

Additional federal financial incentives to complement 45Q should be provided for initial deployments of a variety of BECCS facilities with varying feedstocks and conversion processes. In addition, the federal government should initiate a

demonstration program for federal CDR purchases that include BECCS. The 45Q credit appears adequate to incentivize new or retrofitted ethanol plants with CCUS, but not sufficient to incentivize initial deployments of other forms of BECCS, including, but not limited to: other net-negative liquid fuels such as SAF, biopower with CCUS, and fuels from gasification or pyrolysis. Early deployment of these technologies may require additional financial assistance, such as cost sharing or loan guarantees, to supplement the 45Q credit. For example, a BECCS-biohydrogen project could be eligible for DOE funding as part of a proposed hydrogen hub. The recent EFI Foundation report *Turning CCS projects in heavy industry & power into blue chip financial investments* recommended that DOE "… target BIL commercialization grant funds to the first three-to-five installations to supplement the current $85/metric ton tax credit."[73] The Farm Bill also could become a vehicle to authorize a cost-sharing program in USDA.

In addition, the current planned DOE demonstration purchasing program for CDR could include purchases from qualified BECCS projects, assuming appropriate existing appropriations funding can be reprogrammed. The proposed Carbon Removal and Emissions Storage Technologies (CREST) Act would authorize an expanded CDR purchasing pilot program that would include BECCS as an eligible project pathway.[74] Both efforts could support initial deployment of a variety of new BECCS technologies and pathways.

The federal incentives can be complemented with additional voluntary private sector activity. Inclusion of BECCS within the scope of Frontier advance market commitment investments, for example, can expand the number of early-mover BECCS deployment projects. Another approach is to incentivize BECCS projects in voluntary carbon markets. The "Growing Climate Solutions Act," enacted as part of the Consolidated Appropriations Act for 2023, authorizes USDA to establish a framework of protocols for certification of carbon credits "… derived from the prevention, reduction, or mitigation of greenhouse gas emissions or carbon sequestration on agricultural or private forest land that may be bought or sold on a voluntary environmental market."[75] While the scope of the proposed legislation is much broader than BECCS, the bill creates an additional pathway for creating value for the carbon removals from BECCS.

Sustainable Feedstock Supply and the 2023 Farm Bill

The 2023 Farm Bill presents an important window of opportunity to accelerate BECCS deployment, especially the production of sustainable biomass feedstocks that preserve food and fiber production and contribute to climate and environmental goals. Every five years, Congress reauthorizes and updates many federal agricultural policies and programs as part of the omnibus, multiyear law known as the Farm Bill. The Farm Bill update process in 2023 presents a major opportunity to lay the foundation for accelerating BECCS deployment, especially for feedstock supply adequacy and sustainability. The U.S. has a vast agricultural and forestry resource base capable of supporting large-scale BECCS deployment.[76] Farm Bill programs can provide the necessary framework for ensuring the sustained development of feedstock for BECCS in a manner that does not displace or raise the price of crops for food and fiber, result in net deforestation, or lead to other unintended consequences.

Four separate titles in the Farm Bill—Energy, Conservation, Research and Extension, and Forestry—will have the largest impact on BECCS. The Energy title is particularly important for establishing a stable supply of sustainable feedstocks for BECCS. The current title contains programs that encourage feedstock production and refining of advanced biofuels, bioenergy production in former fossil fuel communities, and wood energy production.[77] A first step would be to increase funding authorizations through mandatory funding to these programs. The current Farm Bill authorized relatively small levels of mandatory spending authority for these programs.[78] Mandatory spending authority could create program longevity and market certainty for landowners and developers.

The 2023 Farm Bill also could target new program initiatives to expand the sources of sustainable biomass feedstocks. For example, the Biomass Crop Assistance Program (BCAP) could provide a higher matching payment—as it currently does for cellulosic crops—to biomass suppliers who grow energy feedstocks with innovative, sustainable practices such as utilizing marginal lands or cover cropping. The Farm Bill could allow biomass cleared from land enrolled in conservation programs (such as the Conservation Reserve Program) and from federal lands consistent with conservation and sustainability requirements to qualify for BCAP or other incentives.[79] Congress also could increase the funding provided for collection, harvesting, storage, and transportation (CHST) activities within the BCAP and the Wood Innovations Programs.[80] Box 1 highlights additional recommendations in the 2023 Farm Bill that could be especially helpful for BECCS and the development of sustainable feedstocks.

Box 1

Additional Recommendations for BECCS Development in the 2023 Farm Bill

- Expand assistance programs in the Energy title that can benefit next-generation bioenergy (e.g., Repowering Assistance Program); authorize grants alongside technical assistance and loans.
- Dedicate funding for BECCS projects where authorized in existing bioenergy infrastructure programs (e.g., Biorefinery, Renewable Chemical, and Biobased Product Manufacturing Assistance Program, Advanced Biofuel Payment Program).
- Maintain funding levels from the Bipartisan Infrastructure Law and Inflation Reduction Act for the Natural Resource Conservation Service and U.S. Forest Service in Farm Bill Conservation and Forestry programs.
- Specify BECCS projects as eligible recipients for relevant programs such as Wood Innovations Grants and Greenhouse Gas Emissions Quantification Program.
- Encourage the use of biomass from wildfire-prone areas in the National Forest System through existing Wood Innovation Programs and wildfire funding.

- Provide dedicated funding to existing programs for assisting disadvantaged landowners to help connect those landowners with biomass markets and biomass-related Farm Bill aid.

USDA or Congress would have to establish eligibility and management standards to govern these programs. This could include refinements to the existing statutory definition of "sustainable agriculture;" existing definitions of sustainability are often inconsistent, overly broad, and difficult to measure and verify.[81] The *Sourcing Biomass Feedstocks* white paper gives four principles that are important for sustainable biomass scale-up: consistent price signals, feedstock specifications, and a level playing field in markets; biomass cultivation as a co-product of integrated systems and enabler of broader land management goals; iterative, stakeholder-driven assessment; and transparent monitoring, reporting, and verification (MRV).[82]

Box 2

Accelerating BECCS Deployment: Recommendations

- The administration should set an explicit national deployment goal for BECCS, as a major component of a CDR strategy, in the next nationally determined contribution (NDC) due in 2025. A goal of at least 500 Mt/yr of net CO_2 removal from BECCS by midcentury appears feasible from a technical, economic, and environmental perspective.
- DOE should include BECCS deployment as a major element in a new National Energy Policy Plan. A BECCS deployment goal of at least 1 billion BOE by midcentury from fuels and power combined would be consistent with the CDR goal.
- EPA should evaluate the feasibility of setting specific targets for BECCS-derived or carbon-negative biofuels within the advanced biofuel category of the Renewable Fuel Standards (RFS), recognizing their carbon negative value. As an initial step, EPA could clarify existing regulations to qualify BECCS under the existing pathways.
- EPA should undertake a comprehensive study of the potential benefits of and implementation pathways for modifying the RFS regulatory framework to recognize the value of biofuels with reduced life cycle GHG emissions, including net-negative emissions, such as a national low carbon fuel standard.
- Congressional consideration of the 2023 Farm Bill should include actions to accelerate BECCS deployment, such as authorizing increased mandatory spending authority across Energy title programs. The Farm Bill also should consider opportunities to increase incentives in Energy title programs for biomass feedstock production activities that incorporate sustainability practices, as well as provide incentives for bioenergy projects that include some form of carbon capture and storage.
- Federal CDR purchasing programs, including the current planned DOE initial demonstration program as well as proposed legislation for broader demonstrations, should include BECCS as an eligible pathway.

Maximizing the Social, Economic, and Environmental Co-Benefits of BECCS

In addition to its primary benefit—reducing atmospheric GHG concentrations by providing clean energy (i.e., mitigation) or CDR—BECCS can have several other "co-benefits," including benefits to the environment, local economies, jobs, and energy and agricultural systems. These benefits can occur all along the BECCS value chain: certain BECCS feedstocks can boost levels of soil organic carbon and improve crop productivity, producing high-capacity factor power from BECCS can provide a backstop that enables deployment of wind and solar power, and carbon transport and storage systems can create jobs for workers displaced from fossil fuel industries.[838485] Co-benefits are not a given, and responsible BECCS development should prioritize policies and projects that can maximize these benefits. This section focuses on two such benefits that were explored in greater depth in this study: wildfire mitigation through use of biomass from wildfire-prone forests and BECCS as an opportunity for rural economic development.

Wildfire Mitigation

The contribution of BECCS in leveraging wildfire mitigation should be incorporated into federal forest and wildfire policies and programs. Wildfires in the Western U.S. have been increasing in number and severity, driven partly by climate change, causing billions of dollars in damage to natural ecosystems, property, and human well-being.[86] This problem has been exacerbated by the presence of "overstocked"h forestland, principally in Western forests, which has increased the risk of number and severity of wildfires.[87]

Much of this overstocked land in Western forests is not statutorily considered to be at risk of wildfire, as shown in Figure 13. This is in contrast to the reality of estimated wildfire risk, as seen in Figure 14. This is partially related to the fact that the majority of forests in the west are controlled by the federal government, as shown in Figure 15. The Forest Inventory and Analysis Program estimates that almost 4 billion tons of forest biomass are in overstocked locations and consequently at higher risk of wildfire and disease.[88] It is estimated that between 265 million and 1 billion bone-dry tons (BDT) of biomass overstock are in wildfire prone counties in five Western states alone (California, Idaho, Nevada, Oregon, and Washington).[89] Wildfire events can lead to substantial CO2 emissions from this overstocked biomass. For example, the estimated overstocked biomass could equate to between 487 Mt and 1,960 Mt CO2 emissions if fully combusted.[90]

BECCS deployment can have a synergistic benefit when combined with improved wildfire management approaches. BECCS creates a value proposition for more active forest wildfire

[h] "Overstocked" forests are those where the density of trees or biomass is so high that it is detrimental to the health of that forest. These health effects include competition for resources, vulnerability to disease, and risk of fire. According to the *Forest Health Treatments* white paper, land and fire management practices have "exacerbated" the buildup of overstocked biomass in Western forests.

management by providing a market for this overstocked biomass. It is estimated that wildfire prevention treatment can vary widely, from $35 to $1,000 per acre.[91] These costs can be shared with BECCS project development, as the wildfire prevention treatments can reduce the net cost of collection and transport of biomass feedstock. The environment also benefits in multiple ways. For example, comparison of treated and untreated plots of forest land in high wildfire risk areas has shown that the former can sequester about 125% more carbon long-term compared to untreated forest land.[92] Integrated wildfire management and BECCS feedstock collection not only will close the carbon cycle; it also will reduce other atmospheric pollution caused by the current practice of thinning and prescribed burning.

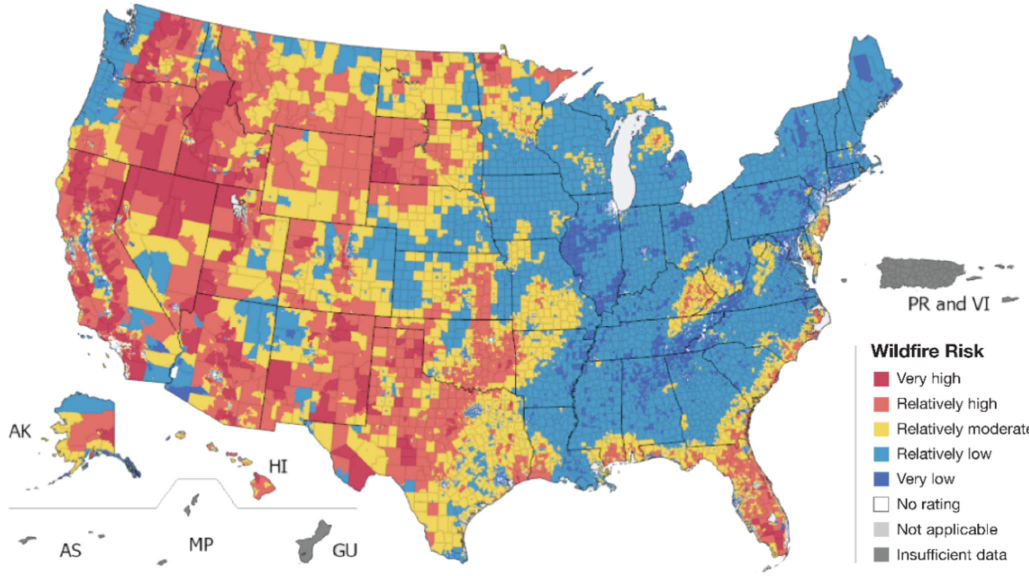
Figure 13

Areas of wildland-urban interface, designated at risk from wildfire according to RFS regulations

Source: Volker C. Radeloff et al., "Rapid Growth of the US Wildland-Urban Interface Raises Wildfire Risk," Proceedings of the National Academy of Sciences 115, no. 13 (March 27, 2018): 3314–19, https://doi.org/10.1073/pnas.1718850115.

Figure 14

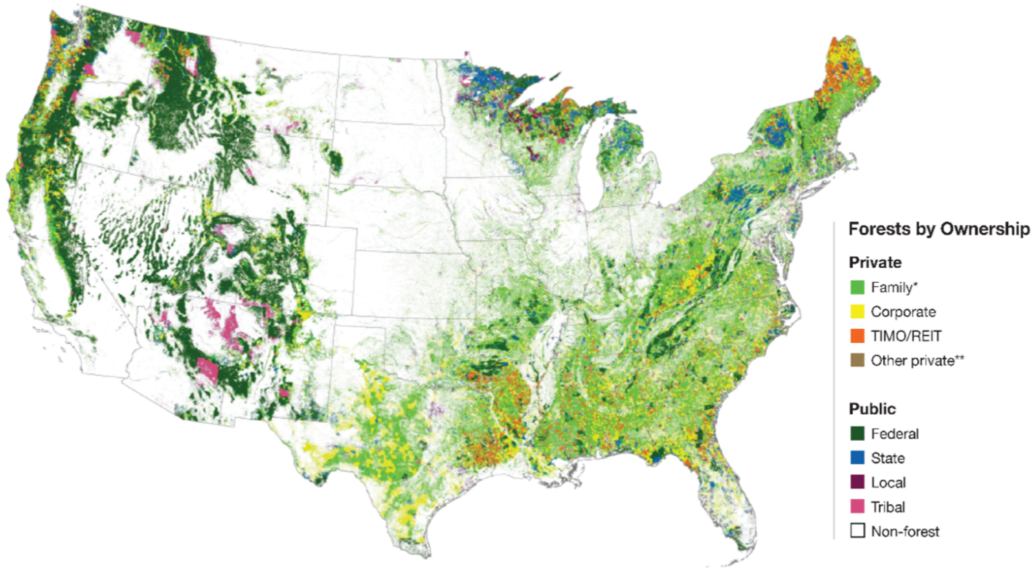
Areas at risk for wildfire as estimated by the Federal Emergency Management Agency (FEMA)



Source: Federal Emergency Management Agency (FEMA), "Wildfire," National Risk Index, June 16, 2023, https://hazards.fema.gov/nri/wildfire.

Figure 15

Forests by ownership class



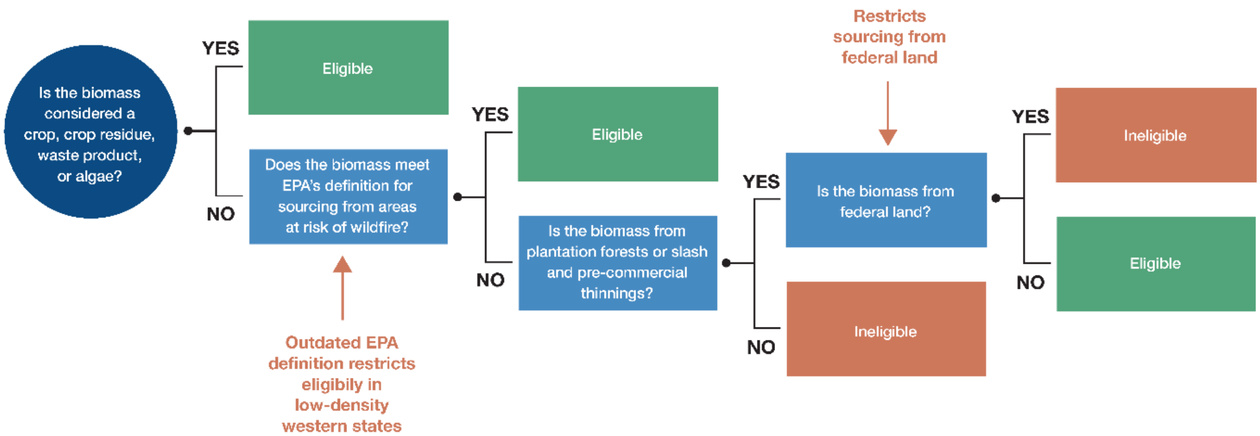
**Family includes individuals, families, trusts, estates, and family partnerships. **Other private includes conservation and natural resource organizations and unincorporated partnerships and associations. The orange ownership category refers to Timber Investment Management Organization (TIMO)/Real Estate Investment Trusts (REIT). Source: Emma S. Sass, Brett J. Butler, and Marla Markowski-Lindsay, "Distribution of Forest Ownership across the Conterminous United States - Geospatial Database" (Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station, 2020), https://doi.org/10.2737/NRS-RMAP-11.*

These three figures highlight the mismatch between areas identified in RFS regulation as "at risk of wildfire" (Figure 13) and actual threats of wildfire (Figure 14). Areas currently qualified for being at risk for wildfire (where biomass is considered "renewable" under the RFS) are primarily located on the East Coast, near densely populated areas, since the definition is tied to wildland-urban interface. Western forests, however, have an equal or higher risk from wildfire, but are not included as "at risk" for purposes of RFS eligibility. The Western forests also are largely federally owned (Figure 15), which excludes them from the RFS and creates an impediment to combining preventative management and bioenergy development.

Current policy poses an obstacle to BECCS deployment, often limiting how biomass from federal lands can be used and restricting its eligibility for clean energy credits. For example, as illustrated in Figure 16, the current requirements for the RFS program restrict eligibility of biofuels produced from forest biomass residues in Western states based on the EPA guidelines for determination of areas "at risk from wildfire." Currently, forest lands with this determination are primarily in the Eastern U.S. located closer to population centers. In addition, under the provisions of the Energy Independence and Security Act, there is a blanket restriction on forest biomass feedstock sourced from federal land from eligibility for the RFS or other forms of federal financial assistance (unless it meets the aforementioned wildfire exemption).[93] These restrictions may have been originally established for well-intentioned purposes, such as to reduce the incentives for timber cutting on federal land and to avoid the inclusion in the RFS of higher cost biofuels produced from lower density biomass sources. The increasing cost of wildfire management, as well as the environmental, social, and economic costs of the increasing number of wildfire events of greater severity, underscore the need for a comprehensive re-evaluation of these requirements.

Figure 16

Types of biomass considered 'renewable' under current law



This flowchart highlights the elements of current law that restrict overstocked forest biomass from Western forests from being considered "renewable" and receiving credits under the RFS. The RFS definition of "renewable" is also used in other federal policies, including certain tax credits. Source: Adapted from Congress House of Representatives, "42 U.S.C. 7545 - Regulation of Fuels" (2010), https://www.law.cornell.edu/uscode/text/42/7545.

Rural and Transition Community Development

BECCS could provide new opportunities for rural areas to participate in the low carbon transition and, in particular, provide an economic engine for communities impacted by economic dislocation. BECCS facilities and supply chains are likely located in or near the farm and forest communities that supply them with biomass. Because of this geography, BECCS provides an opportunity for linking rural job growth, economic development, and infrastructure buildout. In the process of scaling up a new industry, responsible BECCS development also can ensure that its economic benefits are targeted where they can have the greatest impact. For example, as illustrated in Figure 17, the U.S. has experienced continuing job losses in the pulp and paper and wood products industries.

Both the job characteristics and the location of these jobs closely match the human and physical infrastructure needed to support BECCS deployment. The IRA authorized revised clean electricity tax credits that include bonus credits for renewable power generation, including biopower, sited in energy communities.[i,94] This bonus, and similar incentives in other federal funding, could provide a launchpad for BECCS deployment in these communities.

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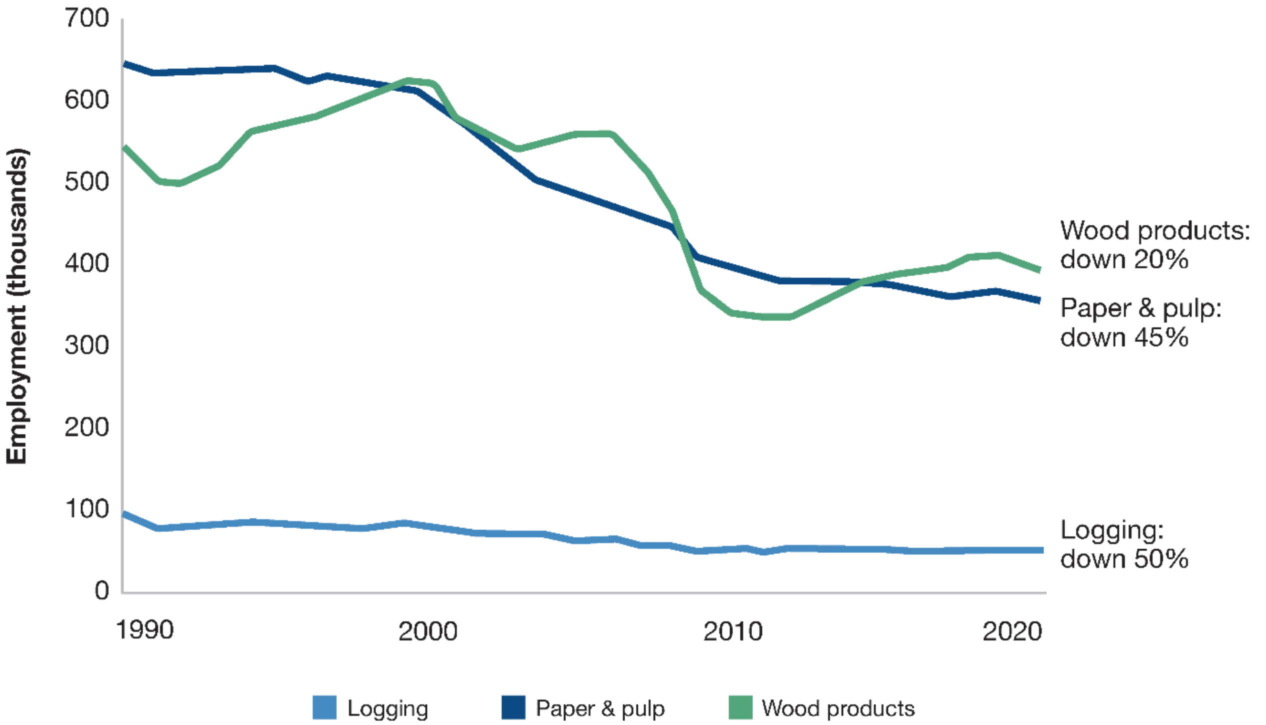
[i] The IRA defines three types of "energy communities": brownfields (vacant sites of polluted former industrial and waste processing facilities); areas that meet certain percentage requirements for rates of employment in fossil fuel activities; and communities where a coal mine closed after 1999 or a coal-fired power generating unit closed after 2009.

Figure 17

Employment in BECCS-adjacent forestry industries in the U.S.



The trends highlight the decline in the workforce in industries related to forestry. Reductions in demand for wood and paper-based products, as well as increasing global competition, have contributed to the downturn of these three industries. The decline has hit hardest rural working-forest communities in the Northeast, Southeast, and Upper Midwest. Source: U.S. Bureau of Labor Statistics, "Data for NAICS Codes 1133 Logging, 321 Wood Products, and 322 Paper Manufacturing," One-Screen Data Search: All Employees, Thousands, Seasonally Adjusted, 2021, https://data.bls.gov/PDQWeb/ce.

BECCS also provides an opportunity to empower underserved farmers and foresters. Small landowners, especially from disadvantaged communities, are less likely to have the financial and technical ability to enter commercial BECCS markets and have difficulties accessing current federal assistance programs.[95] For example, the state of Georgia has an estimated 25 million acres of land used for forestry and most are family owned.[96] Policies and programs to help landowners overcome these structural and financial impediments to obtaining federal assistance would ensure that the benefits of large-scale BECCS deployment are distributed equitably.

Box 3
Maximizing Co-Benefits: Recommendations

- EPA should take administrative action as appropriate to update its methodology for determination of "at risk of wildfire" to address the serious wildfire risk in Western states evident in recent years.
- The administration should work with Congress on legislative amendments to allow biomass from federal lands to be eligible for biofuels production under the RFS program. Eligibility should be based on consistency with federal wildfire prevention and sustainable forestry policies and guidelines.
- The USDA should encourage the utilization of biomass cleared from wildfire-prone land in the National Forest System through shared stewardship agreements and long-term contracts with BECCS developers.
- The USDA should prioritize the use of existing IRA funds for assisting disadvantaged landowners toward connecting those landowners with biomass markets and federal aid.

Rules of the Road for Responsible BECCS Development

Greenhouse Gas Assessments, Reporting, and Accounting

While producing low-carbon energy and CDR from BECCS is certainly feasible under the right circumstances, the question of how to determine the overall net GHG emissions of BECCS projects and policies has been the subject of uncertainty and contrasting perspectives. Large-scale deployment of BECCS will be dependent upon an emissions-accounting methodology that has the support and confidence of policymakers, project developers, investors, and other stakeholders. Incorporating BECCS into climate and clean energy policy planning, emissions inventories, federal incentives, and voluntary carbon markets requires accounting guidelines that are comprehensive, consistent, credible, transparent, and science-based. Such guidelines must account for BECCS at different scales, from the project level to the national or global level.[97] BECCS spans complex systems of agricultural production, forestry management, and energy use, and consists of multiple steps (biomass cultivation, logistics, energy conversion, combustion) that occur in different places, by different operators, and at different times.[98] This complexity leads to uncertainties and continuing debate on what to count and how to count net GHG impacts. No accounting system can fully eliminate ambiguity, but ideally stakeholders could develop guidelines that address remaining uncertainties.

Not all aspects of GHG accounting for BECCS are controversial, nor are they unique to BECCS. Other carbon management, bioenergy, and renewable energy technologies share many of the same accounting challenges; several of the methodological questions centered on feedstock production would be similar for any bioenergy technology. Some parts of the BECCS value chain, such as process and transport emissions, have well-established accounting methods that are common across technologies.[99] Standardized and trusted procedures for measurement and MRV, which are crucial to BECCS GHG accounting, can also be developed to cover multiple technologies or CDR pathways.

The area of BECCS GHG accounting that has been the subject of vigorous debate involves the accounting for biomass harvesting and replanting. Several key issues are outlined in Box 4 below.

Box 4

Methodological Decisions Affecting BECCS Accounting

Estimating BECCS emissions entails several major methodological choices that can affect the life cycle analysis (LCA) of net GHG balance. These include:

Choice of an attributional or consequential accounting approach. According to the *Accounting Considerations* white paper, “Attributional LCA approaches seek to estimate emissions across elements of a supply chain. … Consequential LCA approaches, meanwhile, seek to determine the larger emissions implications of a particular action or decision.”[100] The choice of approach affects the other methodological choices described below. Each approach has its advantages, and both could be used to support different policy objectives. Policymakers should consider which approaches (and what subsequent methodological decisions) are best suited to each policy, as well as how to set best practices that can apply across policies.

Choice of a spatial boundary. Varying accounting approaches can examine biomass feedstock production at different spatial scales. A stand-level (or tract-level) assessment considers the net changes to a spatial area affected by the individual harvest that produces biomass for a BECCS (after accounting for the other market uses for biomass).[101] A landscape-scale assessment considers the GHG impact within a larger working forest area that is being managed for multiple purposes including BECCS, and incorporates the net GHG impact resulting from the interaction among multiple stands that may be at varying stages of harvesting, planting, management, or growth. The net GHG impacts from a landscape-scale assessment may be estimated on the basis of the net change in carbon stock within that landscape. Assessments could also look at market-scale effects, encompassing up to the entire bioeconomy of a region or country.[102]

Choice of a system baseline. In a consequential approach, the determination of net change depends upon the baseline for comparison.[103] The baseline could be the measured conditions of a base year, or it could be a counterfactual reference framework, such as comparison of the change in net GHG emissions relative to a scenario where there is no bioenergy development. The definition of a reference framework can be problematic, as it depends upon assumptions about the counterfactual scenario, such as other possible uses of land employed for feedstock production or other sources of energy that BECCS could displace.

Choice of a temporal boundary. There are several separate methodological when it comes to the timescale for GHG assessment. The net temporal impacts of harvesting and regrowing forest biomass is related to the spatial boundary and baseline; the results may be different for landscape-level and tract-level analysis, and may vary in tract-level analysis based on when the assessment commences.[104] Temporal scales also matter for accounting for aspects of the BECCS process that take place over many years, even beyond a BECCS project's operational lifetime, such as biomass regrowth or carbon storage. The sequencing of BECCS's impacts may make little or no difference over the longer-term timescales, such as the long-term temperature goal of the Paris Agreement, but they may impact the pace at which the climate impacts are realized.

Choice of a system boundary. The question of what elements are "in or out" of BECCS assessment are critical to determining the net GHG balance. Including or excluding elements like land use change, substitution for higher-emitting energy sources, and the downstream impacts of carbon utilization can all greatly affect the GHG calculation for BECCS.[105] Of particular controversy is whether and how to account for market-based or "indirect" effects (i.e., how economic impacts of BECCS affect land use change, forest investment and management, or energy systems).[106] Current accounting policies often draw even narrower boundaries; systems that consider certain biomass resources carbon-neutral by default may exclude even easily measured GHG effects, such as from feedstock processing and transportation.[107] As the boundary expands, it becomes increasingly challenging to maintain consistent accounting methods and propagate uncertainty estimates across the full value chain.

The inability to reach a consensus on the methodology for assessing the net GHG effect of BECCS has led to intervention by policymakers to mandate simplified rules that govern current federal policies and programs, and to uncertainties in the accounting of carbon credits in voluntary carbon markets. For instance, the reporting protocols established by the IPCC for country-level GHG emission inventories track GHG emissions and removals from different aspects of the bioenergy life cycle in different sectors:[108]

- CO_2 emissions from bioenergy are counted in the Agriculture, Forestry, and Other Land Use sectors;
- Non-CO_2 emissions from bioenergy are counted in the Energy sector, as are emissions from fossil fuels used in biomass harvesting, conversion, transportation, etc.;
- GHG emissions from fertilizer use, agricultural soil management, manure management, etc. are reported in the Agriculture sector;
- GHG emissions from waste management and combustion are reported in the Waste sector; and
- GHG reductions from point-source CCUS are generally reported in the Energy and Industrial sectors, but other carbon management pathways, such as DAC, lack a methodology for accounting in inventories entirely.[109]

The result is that there is no crosswalk that reports the full net benefit of BECCS. The fragmentation in the reporting of the net GHG emissions from BECCS can obfuscate the overall value proposition of BECCS.[110] This system of reporting becomes even more complex when various steps in the BECCS process take place in different countries, such as production of wood pellets in the U.S. for export and use in other countries.

In U.S. policy, simplified systems have similarly been implemented to overcome the lack of an agreed-upon accounting framework. An annual rider in recent congressional omnibus appropriation bills states that policies for USDA, DOE, and EPA "reflect the carbon neutrality of forest bioenergy and recognize biomass as a renewable energy source."[111] The rider establishes a blanket carbon-neutral standard for forest biomass harvested and converted into biomass, but it does so with the stipulation that the conversion of forested land does not occur as a result. While these types of measures may provide for a first order estimate of net GHG emissions, they lack sufficient detail and site-specific guidelines needed to provide the necessary longer-term foundation to guide the large-scale investment in accelerated deployment.[112] Building broad-based support for BECCS requires a more robust framework developed through a credible and inclusive process.

U.S. federal policy can look to existing frameworks to inform decision-making on BECCS accounting. The California Low Carbon Fuels Standard and the European Union Renewable Energy Directive II (RED II) have adopted guidelines that provide an initial frame of reference for addressing methodological questions, such as how to treat land use change and market-scale effects.[113] The RED II emissions criteria, for example, include default values for various steps in the bioenergy production process, as well as guidelines on indirect land use change (ILUC) that distinguish between high ILUC-risk and low ILUC-risk biomass sourcing for bioenergy.[114]

Within the U.S., several non-governmental efforts are underway to develop guidelines for estimating the net GHG emissions value of BECCS, including the effort led by the GHG Protocol (a joint initiative by the World Business Council for Sustainable Development and the World Resources Institute) to develop Land Sector and Removals Guidance, and certification schemes in development from organizers of voluntary carbon markets.[115]

Environmental Justice and Community Trust

Successfully accelerating the pace of BECCS deployment will require increased attention to community and environmental justice concerns. BECCS and other bioenergy projects are often sited near feedstock sources in rural areas. The communities in these areas may more likely be disadvantaged in one of more socioeconomic factors. Some of these communities have concerns based on past experiences with bioenergy or other energy or industrial projects that—even if beneficial to the climate—have caused harm to ecosystems and pollution issues in the communities where they are located.[116,117,118,119]

One challenge is that bioenergy plants can emit air pollution, including both criteria pollutants (e.g., particulate matter, volatile organic compounds) and hazardous air pollutants regulated under the Clean Air Act.[120,121,122,123,124,125] Some researchers, advocates, and community groups say that these pollutants disproportionately harm disadvantaged communities that are in proximity to these plants.[126,127,128,129,130] EPA is already pursuing strategies that could potentially help mitigate these concerns, such as updating regulations that control pollution limits and mandatory control technologies, facilitating community input, and integrating pollution burden and "Good Neighbor" policies into regulatory decisionmaking.[131,132,133,134] There is some evidence that adding CCUS to energy facilities could collaterally lower air pollution, but more research is necessary.[135]

The recent initiatives from the administration to support environmental justice, backed by new authorities and funding in the BIL and IRA, aim to avoid community and justice issues by providing tools to project developers, communities, workers, and local governments to ensure that new clean energy projects are engaged in good faith with, and materially benefit, their host communities. One prominent example is the Justice40 Initiative, which is an executive order that directs that at least 40% of the overall benefits from clean energy and environmental investments (along with other specified programs) go to disadvantaged communities.[136] The community benefits and environmental justice provisions spawned by the BIL and IRA include expanded EPA environmental justice programs and the development of Community Benefits Plan (CBP) requirements by DOE to guide DOE-funded clean energy projects.[137,138] While federally assisted BECCS projects will fall under these new requirements, there may be many other BECCS projects developed privately that also would benefit by borrowing from the DOE Community Benefits Agreement framework. In addition, communities that may potentially be the site for future BECCS projects could benefit from federal funding assistance provided through the EPA or USDA community and environmental justice programs.

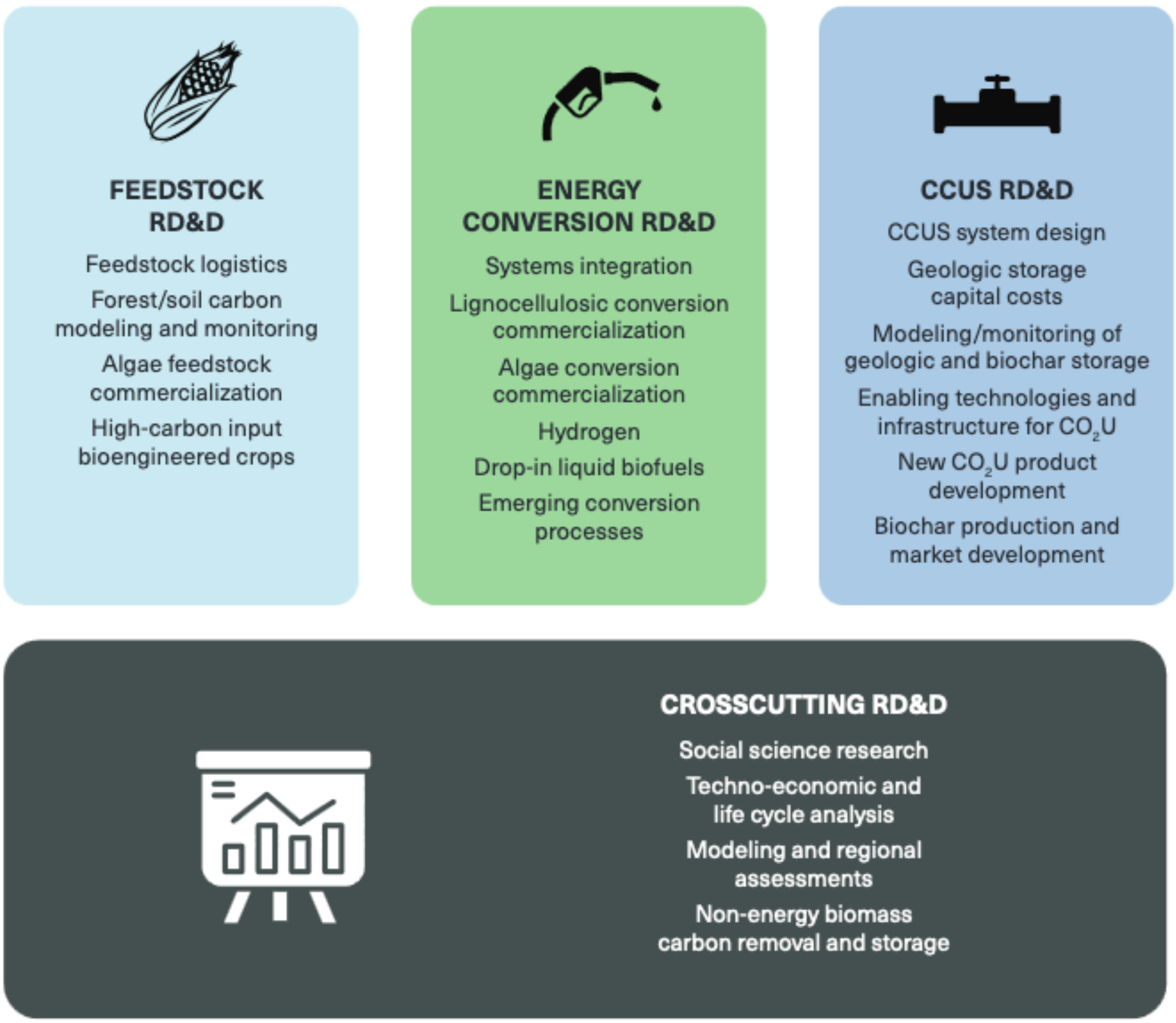
Innovation

BECCS is built on established technologies, but there is a big opportunity for innovation and advancement through targeted research, development, and demonstration (RD&D) programs that are effectively coordinated across the federal agencies. BECCS is most often characterized as a well-established suite of technologies, such as wood-based biopower generation and starch-based ethanol conversion.[139] Further innovation in BECCS conversion technologies, however, can play an important role in enabling deployment at lower cost and greater scale.

As illustrated in Figure 18, investments in R&D could include improvements in biomass collection, processing, and conversion, as well as improvements in the coupling of bioenergy and the carbon capture subcomponents of BECCS. Technological innovation also can improve the ability to downscale BECCS processing and conversion technologies to enable smaller scale deployments in remote locations. Future BECCS conversion technologies could be more closely tailored to the product specifications for new applications, such as aviation, long-haul trucking, and heavy industry. New BECCS technologies also could expand the types of feedstocks, such as cellulosic wastes or algae, to produce biofuels more efficiently or use less land and other resources. BECCS would also benefit from expanded RD&D on carbon management technologies, including further work on underground geologic storage as well as other storage methods. Finally, new and improved tools for modeling, regional assessment, traceability, and MRV can provide benefits across the BECCS value chain.

Figure 18

BECCS RD&D opportunities



Priority areas for BECCS innovation, as identified in the literature review in Phase I of this study. Source: Energy Futures Initiative, "Surveying the BECCS Landscape" (Energy Futures Initiative, January 10, 2022), https://energyfuturesinitiative.org/reports/surveying-the-beccs-landscape/.

The CHIPS and Science Act authorizes expanded funding for innovation in both bioenergy and carbon management. This funding includes the $250 million authorized for the Carbon Sequestration Research and Geological Computational Science Initiative and funding authorization for the DOE Bioenergy Research Center program, including authorization for up to six new research centers.[140] In view of the new caps on discretionary spending included in the recently enacted Fiscal Responsibility Act, prospects for increased appropriations to implement these authorizations will be very challenging over the next several years.

Current federal R&D programs and activities for BECCS are fragmented within DOE, and across DOE, EPA and USDA, resulting in technology silos between bioenergy and carbon management and gaps in R&D coverage, such as in small-scale processing technologies.[141] Additional investments in BECCS RD&D need to be coupled with better coordination in R&D program planning and execution—both within and across the agencies—to advance the pace of innovation needed to support broader deployment.

The DOE Carbon Negative and Clean Fuels and Products "Energy Earthshots" offer the potential to improve R&D planning, prioritization, and coordination of DOE BECCS-related activities.[142,143] The recent memorandum of understanding (MOU) on Sustainable Aviation Fuels (SAF) could serve as a model for collaboration on a broader set of BECCS-related issues.[144] Another approach could be revitalization of the Biomass R&D Board that previously served as a mechanism to integrate biomass-related R&D activities between DOE and USDA.[145] Revitalization of the board could be an item for consideration in the Research Title of the 2023 Farm Bill. Figure 19 shows areas of potential DOE and USDA collaborations as part of a reauthorized Biomass R&D Initiative.

Box 5

Rules of the Road: Recommendations

- The Office of Science and Technology Policy should convene an Interagency Task Force to develop, within 18 months, a set of science-based guidelines for BECCS GHG assessments that can form the foundation for application to accurate and transparent carbon accounting in all federal policies and programs affecting BECCS.
- EPA should consider ways to augment the U.S. GHG Emissions Inventory to capture the full value of BECCS's net GHG emissions on a holistic basis, in addition to sector-specific reporting of emissions where they occur.
- EPA, working with USDA and DOE, should develop model guidelines for stakeholder engagement in all new BECCS projects, including Community Benefits Agreements (CBA) drawn from experiences in implementing similar efforts in other programs authorized in the BIL and IRA.
- EPA should allocate funding through the Environmental Justice Grants and Technical Assistance Services for Communities programs to communities engaging with BECCS and bioenergy projects.
- As part of the Research and Extension title of the Farm Bill, Congress should authorize expanded and new RD&D initiatives focused on next-generation BECCS solutions. These could include expanding the Agricultural Research and Development Authority (AGARDA), adopting the proposed Biochar Research Network Act, and creating a new technology incubator program at the Agricultural Research Service.
- Also, as part of the Farm Bill, Congress should strengthen the responsibilities of the interagency Biomass R&D Board to coordinate planning and implementation of a comprehensive governmentwide BECCS R&D program.

Figure 19

Multi-agency innovation opportunities for new Biomass R&D Initiative

Drop-in fuels
- Example topics: aviation and marine fuels, heavy-duty vehicles, chemical feedstocks, RNG
- Existing initiatives: SAF Grand Challenge, DOE Clean Fuels & Products Shot, SAF tax credit

Bio-hydrogen
- Example topics: gasification with carbon capture, system integration
- Existing initiatives: DOE Hydrogen Shot, Hydrogen Hubs

Bioengineered feedstocks
- Example topics: new cultivars for energy production or carbon storage, synthetic biology
- Existing initiatives: ARPA-E ROOTS, ARS Plant Genetics program

Pyrolysis technologies & biochar
- Example topics: carbon storage in biochar and bio-oil, energy production from pyrolysis
- Existing/proposed initiatives: USDA Climate Hubs biochar research, Biochar Research Network Act

Negative-emissions biomass systems
- Example topics: new conversion technologies, feedstocks, and carbon capture methods
- Existing initiatives: DOE CarbonSAFE and BECCS FEED Studies, DAC Hubs

Converting fossil infrastructure to bioenergy
- Example topics: bioenergy conversion for producers (power plants, refineries) and consumers (buildings, heavy industry)
- Existing initiatives: Biofuel Infrastructure Grants, Energy Infrastructure Reinvestment Financing

Data science
- Example topics: modeling, measurement, monitoring/reporting/verification
- Existing initiatives: National Lab MRV research, USDA Forest Inventory and Soil Survey

The Biomass R&D Initiative, originally authorized in the 2014 Farm Bill, previously consisted of a grant program jointly administered by DOE and USDA. A revitalized Initiative could be funded through the 2023 Farm Bill and could tap into more resources at the two agencies and across the government. This new collaboration could coordinate overlapping research efforts and focus on topics (such as those in the figure, all of which overlap with BECCS) that are most crucial to achieving net zero, similarly to DOE's Energy Earthshots. These topics could integrate work already being conducted under the auspices of Biomass R&D Board, such as SAF innovation, and align with priorities established by current agency programs and recent climate legislation. Source: EFI Foundation, 2023.

Conclusion: Taking Root and Branching Out

BECCS can fill important needs for decarbonization through carbon removal and clean energy production, provide an economic impetus in rural and transition communities, and further establish the U.S. as a global leader in the burgeoning bioeconomy. These attributes are summarized in Figure 20.

Figure 20
Benefits of BECCS

This figure represents a summary of this report's findings on the potential benefits of BECCS. Federal policy should take these potential benefits into consideration, while also establishing rules of the road. Source: EFI Foundation, 2023

New energy and climate legislation—the Energy Act of 2020, BIL, IRA, and the CHIPS and Science Act—are aimed not just at enhancing energy security and lowering emissions, but also at creating jobs, restoring U.S. industry, jump-starting innovation, and championing greater social and economic equity. Accelerating BECCS deployment, with safeguards to ensure sustainability and avoid unintended consequences, could help achieve all these objectives.

The recommendations outlined in this report can have a major impact by leveraging the considerable power of federal policy to accelerate current BECCS deployment activities. These measures will clarify and expand federal incentives for BECCS, help guide the growing voluntary private sector investments in carbon credit purchases, and provide a focal point for action at all levels of government, as well as from stakeholders in industry, agriculture, innovation, and energy communities.

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