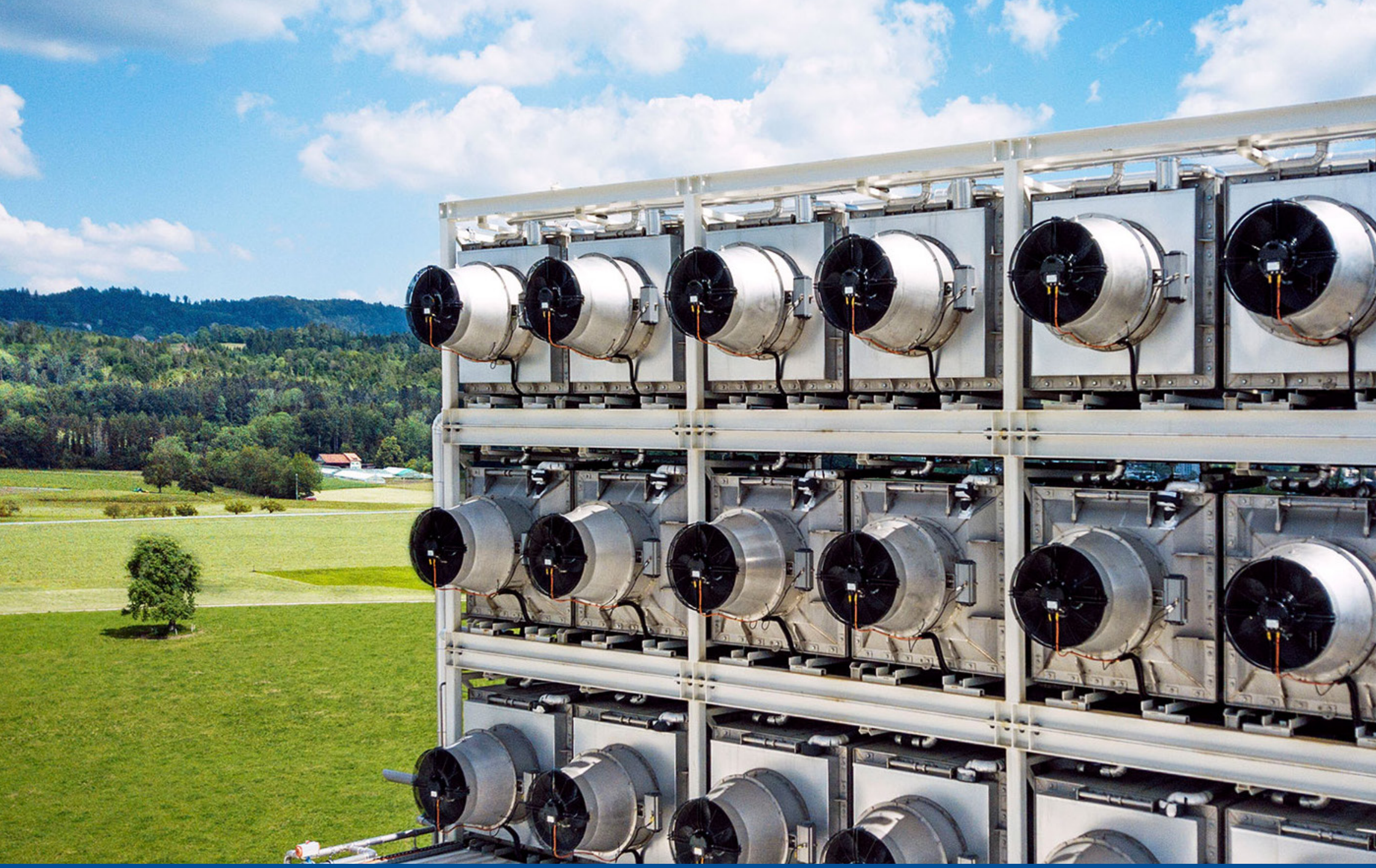

Climeworks direct air capture plant in Hinwil.
Photo credit: Climeworks

Early Deployment of Direct Air Capture with Dedicated Geologic Storage

FEDERAL POLICY OPTIONS

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Executive Summary

To avoid the worst effects of climate change, the world must not only flatten its current greenhouse gas emissions trajectory, but accelerate toward net-zero emissions by roughly mid-century – and most-likely sustain net-negative emissions in the latter half of the century. In recent years, carbon dioxide removal (CDR) technology has moved from theoretical concept to pilot scale, producing a handful of potentially scalable approaches for generating negative emissions by capturing carbon dioxide (CO_2) from the atmosphere. This CO_2 can then be permanently sequestered in the geosphere or put to use in such industrial processes as cement production. There are many technology- and nature-based CDR approaches that have the potential to play a meaningful role in achieving our climate goals. This paper explores just one technology-based approach: direct air capture (DAC) with dedicated geologic storage, also known as direct air carbon capture and sequestration (DACCS). DACCS is an expensive and untested technology today, and like other CDR methods, there is no guarantee DACCS will end up being a central part of the climate solution. However, early action to develop, pilot, and deploy DACCS can help us drive down costs and explore its potential.

Scaling CDR to the massive level required by many models to reach economy-wide net-zero targets – on the order of a gigatonne of annual capacity in the United States by 2050, and tens of gigatonnes globally in the latter half of the century – is a daunting undertaking at best, with major implications for our energy system, land use, supply chains, and more. To add to this challenge, DACCS provides a public good by cleaning up the atmosphere, but there is no obvious private sector market to drive deployment (in contrast to other clean technologies, such as solar energy, which have scaled up quickly through a combination of public incentives and market demand for cheap electricity). Plus, to fully realize the potential climate benefits of DACCS, the technology must be deployed and governed in a manner that does not distract from aggressive mitigation efforts, compete for renewable and low-carbon energy needed for direct decarbonization or serve as a way for companies to justify continued production of fossil fuels and their harmful air and water pollution.

All of this suggests that public policy will play an essential role in driving efforts to mature DACCS into a viable and cost-effective carbon dioxide removal strategy – not merely to get the technology off the ground, but to be able to operate it at scale by mid-century and beyond. In this paper, we seek to understand which policy tools could most effectively drive early deployment of DACCS, which we define as capturing and storing 2-3 megatonnes of CO_2 per year in the U.S. by 2030. While our primary focus has to stay on mitigating existing emissions, beginning to build DACCS plants at commercial scale will help drive price discovery and innovation so that we can determine whether DACCS is capable of growing rapidly in the late 2030s and 2040s.

We describe and evaluate ten policy options for financially supporting deployment, either through capital or operations support. We also discuss three enabling policies that do not directly induce deployment, but are still important pieces of the innovation cycle.

1. **Capital support:** Investment tax credits, accelerated depreciation, loan programs, tax-advantaged financing structures, and public competitions.

2. **Operations support:** Production tax credits, procurement (including reverse auctions and contracts for differences), direct payments, government-owned contractor-operated facilities (GOCOs), and emissions pricing and standards.

3. **Enabling policies:** Federal research, development, and demonstration (RD&D); accelerated CO_2 storage development; and CO_2 transport infrastructure.

We assess these policies against three essential criteria for promoting near-term DACCS deployment:

1. **Financeable:** Does the policy guarantee a predictable cash flow for investors?
2. **Stable:** Is the policy sufficiently long-lasting, and available across a multitude of projects, to support the growth of DACCS companies?
3. **Impactful:** Does the policy offer enough support over the next 5-10 years to actually deploy commercial DACCS facilities?

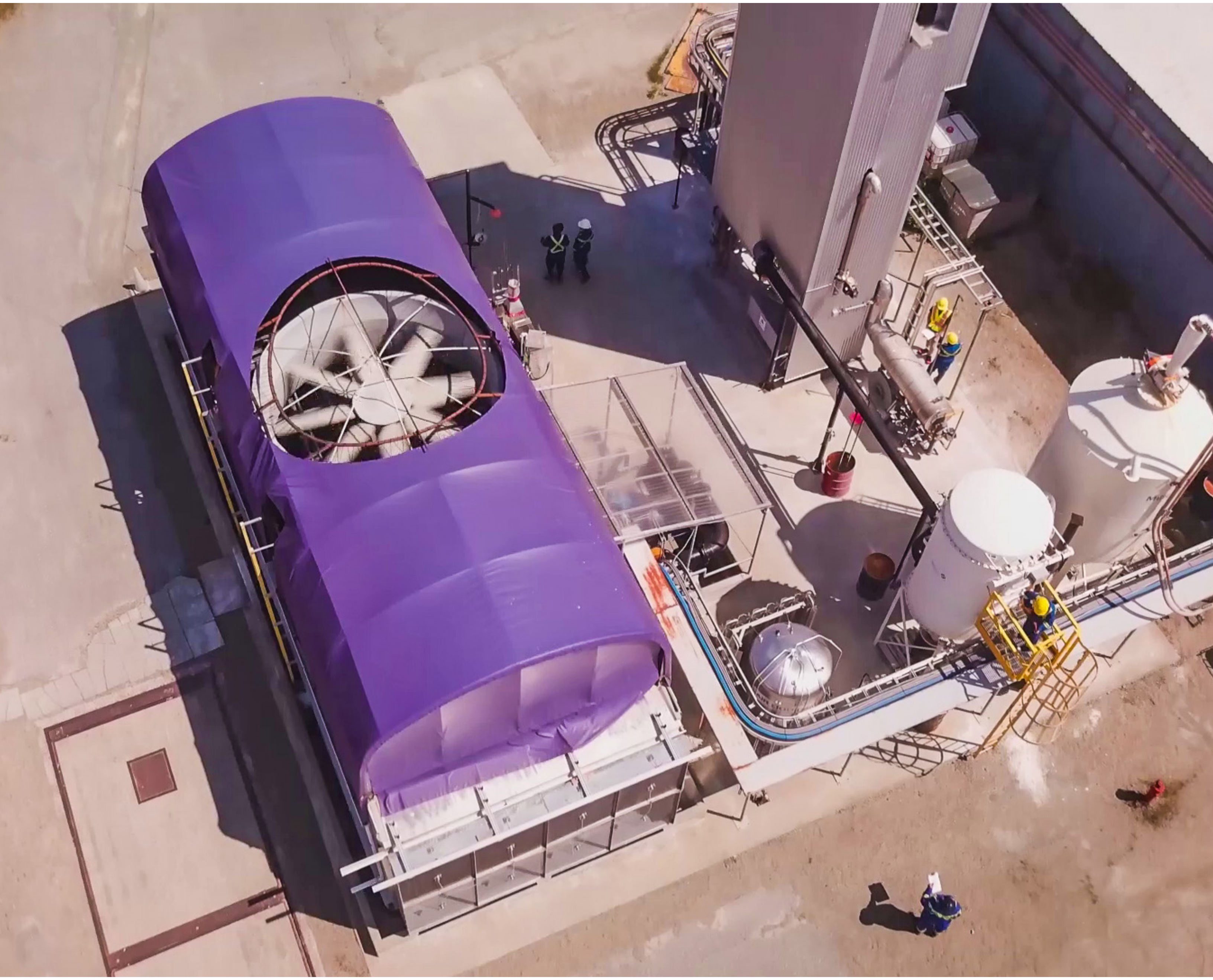
A number of individual policy options ranked well on our criteria. We also present several combinations of policies ("policy packages") that are complementary to one another and sufficiently valuable to drive near-term DACCS deployment. **However, the approach that rises to the top for us is direct procurement via a reverse auction.** Government procurement mechanisms provide a guaranteed market for DACCS developers, driving development of both DAC plants and the necessary infrastructure for permanent geologic storage. When a reverse auction is used, these benefits are combined with a price discovery mechanism that lowers government costs and incentivizes innovation. In a reverse auction, the federal government sets a predictable procurement schedule and solicits developer bids for contracts to build and operate DACCS facilities, generally selecting the lowest cost bid. Beyond covering all upfront and operating costs for DACCS, a reverse auction could demand quantities of DACCS that are aligned with climate targets and offers several other advantages, including the ability to:

- Accommodate first-of-a-kind technologies and encourage innovation without locking in specific DACCS approaches;
- Ensure environmental integrity through robust emissions accounting, including for upstream emissions associated with energy production, such as methane leaks; and
- Pursue other important social objectives, such as community engagement in siting decisions, environmental justice, strong labor standards, and domestic job creation.

If direct procurement of DACCS is not achievable, a second-best option might be a combination of a production tax credit and a 30% investment tax credit, which would help to cover capital and operations costs by replicating and expanding time-tested incentives in the tax code. Ideally, one or both tax credits would be refundable. However, this approach raises concerns about stackability (i.e., whether two tax credits can be combined on the same project) and is unlikely to generate certainty around the level of DACCS deployment we can achieve in a specific timeframe.

Although we believe a reverse auction could be an effective policy to have in place by 2030, realistically, it may take some time to design, introduce, pass and implement such a policy. In the meantime, it is important to maintain momentum on developing and deploying DACCS, so existing policies should be continued or expanded. For example, a reverse auction could overlap with an expanded 45Q tax credit that provides additional value to DACCS projects (such as is proposed in the recent **Clean Energy for America Act**). Other financing or enabling policies such as Department of Energy research and development and loan guarantees can support developers in putting together credible bids.

There are limitations to our analysis. For one, the importance of designing these policies with an eye to other environmental and social considerations, such as ensuring environmental justice and sustainable land use, cannot be overstated. Since many of these factors are likely to vary on a project-by-project basis, we do not include them in our policy comparison, but urge policymakers to design deployment programs in consultation with stakeholders and with these principles in mind. Likewise, we touch occasionally on aspects of policies that may make them more or less politically feasible, but do not provide a whole-cloth assessment of which policies are likely to be most popular or durable.



Carbon Engineering Direct Air Capture pilot plant.
Photo credit: Carbon Engineering Ltd

Introduction

The climate crisis demands that we reduce emissions as rapidly as possible. Unfortunately, globally, we have delayed emissions reduction long enough that, in addition to the transformational changes to our energy system, we also need carbon dioxide removal (CDR) to achieve economy-wide net-zero emissions by roughly midcentury, enabling us to avoid the worst effects of climate change. As the name indicates, CDR approaches remove CO_2 that is already in the atmosphere, providing an opportunity to limit warming and perhaps eventually return our climate to safe levels. This differs from clean energy deployment and other mitigation options that aim to reduce, eliminate, or capture CO_2 emissions before they enter the atmosphere.

According to the Intergovernmental Panel on Climate Change (IPCC), all emissions pathways that limit planetary warming to 1.5°C by the end of the century without overshoot, and 87% of pathways that limit warming to 2°C, rely on large-scale atmospheric CDR, which enables the world to reach net-zero emissions followed by a period of net-negative emissions.[1,2] In IPCC modeling and other peer-reviewed literature, this typically translates to requiring more than 10 $GtCO_2$ of global combined nature-based and technological CDR per year in the latter half of the century. The National Academies suggest that nature-based CDR, such as forest restoration, could feasibly remove up to 5 $GtCO_2$ by 2050, but – as noted in an EDF-penned op-ed in Foreign Affairs – this is likely an optimistic assessment given the risks involved in land use.[3] This implies that, even in this best-case scenario, **at least 5 $GtCO_2$ of annual technological CDR will be necessary by mid-century.**

Multiple analyses have posited that direct air capture (DAC), a technological form of CDR, may be particularly valuable in hitting this goal. CO_2 captured using DAC can be used for multiple purposes. The most clearly beneficial of these purposes from a climate perspective is dedicated geologic storage, also known as direct air carbon capture and sequestration (DACCS), in which the captured CO_2 is injected and safely and permanently stored in dedicated underground formations and does not contribute to fossil fuel extraction.

DAC is not the only CDR technology, and research is also needed into other technological approaches like mineralization and bioenergy with carbon capture and storage (BECCS), as well as nature-based solutions. However, this paper is focused on options to scale and deploy DAC within the next few decades.

Studies that model DAC alongside other CDR technologies and approaches find that gigatonne scale DACCS is necessary in 1.5°C pathways, and often utilized heavily in 2°C pathways:

- Marcucci et. al.: **21-40 $GtCO_2$ of annual DACCS (globally) by 2100** to limit warming to 2°C or lower. Limiting warming to 1.5°C is infeasible without DAC.[4]
- Realmonte et. al.: **600-700 $GtCO_2$ of cumulative DACCS (globally) from 2070 to 2100** to limit warming to 2°C or lower (an average of 20-23 $GtCO_2$ per year). Limiting warming to 1.5°C is infeasible without DAC.[5]
- Rhodium Group: **Up to 1.85 $GtCO_2$ of annual DACCS (U.S.) by 2050** in the 1.5°C compatible pathway and up to 0.74 $GtCO_2$ in the 2°C pathway.[6]

DAC, and especially DAC with dedicated geologic storage, is unlikely to reach maturity or deploy widely without significant policy support. As we discuss below, DAC is expensive and unproven at commercial scale. For now, the permitting process is untested and slow; the only active U.S. site for dedicated geologic storage of CO_2, in Illinois, took 7 years from the initial request to get permitted.[7] More importantly, DACCS provides no market value in the absence of a policy-induced price on removing CO_2 emissions. Unlike clean energy options that, especially early in their technological maturity, may be more expensive than incumbent technologies, but which ultimately provide a market good (electricity or liquid fuel, for instance), or other applications of DAC which sell its captured CO_2 for other purposes such as enhanced oil recovery, industrial processes or use in synthetic fuels, the only value DACCS provides is CO_2 removal (see Table 1 for a discussion of other potential uses of DAC-captured CO_2).

In this report, we examine what policies could be used to spur commercial scale deployment of DAC with dedicated geologic storage in the U.S. over the next decade, which can enable us to drive down DACCS costs and assess its potential role in achieving net-zero emissions – all while making sure it is ready to scale by midcentury if needed. To focus our efforts in this report, we do not consider related CDR approaches, such as nature-based solutions, or point source carbon capture technologies that prevent CO_2 from entering the atmosphere.

We start with an examination of DAC's characteristics and projected costs. Next, we explain our approach to choosing and evaluating policies using consistent criteria – this includes an overview of the different types of support DAC may require and examples of how previous government efforts to catalyze new industries apply to DAC (Box 1). We then examine a series of specific policy options, broken into three main policy categories – Financing Policies (Section 1), Operations Support Policies (Section 2), and Enabling Policies (Section 3). Finally, we compare criteria across policies and provide recommendations on which policies would most effectively drive near-term DAC deployment (Sections 4 and 5).

DAC background

End uses and characteristics

DAC with dedicated geologic storage (DACCS) is underway at small scale today, but lacks an economic driver in the absence of a carbon price or incentive large enough to fully cover DACCS's costs. In contrast, there is an economic value for captured carbon in other end uses – namely injection into oil fields as part of enhanced oil recovery (EOR) and as an input in industrial products (known as carbontech). And in fact, most captured CO_2 today is used for EOR, a process in which oil producers inject CO_2 to extract additional oil. It is likely that the first commercial scale DAC plants will produce CO_2 that is used for EOR, because it has a quicker regulatory timeframe and lower costs than dedicated geologic storage and provides market value for CO_2.[i] But while EOR may allow DAC to scale up more quickly with less policy support, EOR does not provide the direct climate benefit of DACCS, as it leads to marginal increases in fossil fuel production that counteracts some of the benefit of capturing and sequestering the CO_2. Likewise, some carbontech applications, such as synthetic fuel production, may simply recycle the carbon rather than sequester it permanently. These applications may still be useful for reducing emissions relative to conventional oil production or fuels or for commercializing DAC technology, but they are not the focus of this paper.

[i] The existing 45Q incentive provides \$50/ton of CO_2 captured or removed that is stored in geologic saline formations and \$35/ton used for enhanced oil recovery and other end uses. The \$15/ton difference between the two applications is not sufficient to compensate for the economic value of oil produced through EOR.

TABLE 1: DAC end uses and characteristics

End-Use	Description	Maturity	Current Policy Support
DACCS (permanent storage)	Permanent geologic storage of CO2 in underground saline formations.	Demonstration	45Q tax credit of $50/ton; California LCFS
Enhanced oil recovery (EOR)	Injection of CO2 in oil fields for tertiary oil recovery; recycles and stores 90%+ of CO2, but also produces more oil.	Commercial	45Q tax credit of $35/ton; California LCFS
Carbontech: Building materials	Mineralization of CO2 into industrial waste materials and CO2 curing of concrete.	Demonstration early commercialization	45Q tax credit of $35/ton
Carbontech: Synthetic fuels	Catalytic hydrogenation to convert CO2 to fuels.	Lab	45Q tax credit of $35/ton; California LCFS

Costs

Current DAC cost estimates per ton CO_2 removed and stored in geologic formations vary widely. The nascency of various DAC technologies, divergent assumptions of energy demand, and unproven scalability of DAC make it difficult to pinpoint a cost for the first large-scale facility, let alone the Nth. Only a few years ago, estimates of levelized costs for the first megatonne DAC facility were greater than $1,000/ton, but have dropped dramatically since then, despite the fact that this first facility has still not been built.[8] The World Resources Institute (WRI) has been exploring the role of various inputs in the overall cost per ton CO_2 removed; in a January 2021 blog, they summarize costs as between $250-600/ton for early plants, falling to $150-200/ton over the next five years. For the purposes of our analysis, we approximate the middle of these ranges and consider $375/ton to be a conservative estimate of early-stage plant costs. Several additional studies provide alternative ranges – most of which reflect similar results – and can be found in the reference section.[9, 10, 11, 12]

Local and global environmental, energy, and equity considerations

CDR, like all clean energy and decarbonization technologies, comes with tradeoffs. As it scales, DAC will require significant land, energy, and other resources. If deployed at the level most modeling indicates is required, one estimate characterizes DAC as responsible for a quarter of global energy demand by 2100,[13] and another suggests it could account for 9-14% of electricity in 2075.[14]

> "Societies that pursue CDR at too large a scale, adopt the wrong mix of approaches for their circumstances, or govern CDR ineffectively could face serious social and environmental downsides… Civil society organizations, funders, and government agencies can help ensure that CDR plays a positive role in the kind of robust, abatement-focused long-term climate strategy that is essential to fair and effective climate policy."
>
> Morrow, et. al., Principles for Thinking about Carbon Dioxide Removal in Just Climate Policy (2020)

The type of energy used to power DAC matters too – the environmental calculus is very different if DAC plants are powered by natural gas, for instance, than if they are powered by renewable energy. While emissions at the plant could be captured, even natural gas with carbon capture could still lead to upstream methane leaks that significantly reduce the environmental benefits of DAC and could result in local air pollution. On the other hand, renewable energy sources may not be able to provide round the clock power that would keep DAC plants operating 24 hours a day, and, to the extent renewables for DAC power could otherwise be used for grid-connected electricity production, that would also reduce DAC's environmental benefits.[15,16]

Assuming sufficient access to carbon-free energy, DAC may be more scalable than other CDR approaches, such as forest restoration or BECCS, which can be more land- and water-intensive, or biogeochemical approaches like mineralization that rely on availability of reactive source material.[17] However, that does not eliminate the need for researchers and policymakers to grapple with and seek to mitigate the environmental, resource, and energy challenges associated with DACCS - both in aggregate and on a project-by-project basis.[18]

Furthermore, issues of CDR governance and social, economic, and energy justice have begun receiving attention from leading organizations and scholars.[19] Some advocates fear investments in CDR will reduce the urgency to mitigate emissions or could even be used as a justification to perpetuate fossil fuel production. Questions of who shapes CDR policy, who benefits from CDR deployment, and who faces potential adverse environmental and social consequences are increasingly salient as we approach commercial-scale technological CDR. These questions have implications for equity both at a local scale, with individual projects, and at a global scale, particularly when considering whether CDR should be an integral component of wealthy countries' strategies for addressing their historic emissions contributions.

Existing policy support

Research, development, and demonstration (RD&D) at the Department of Energy

The U.S. Department of Energy is the main provider of clean energy research, development, and demonstration (RD&D) funding in the United States,[20] with the main goal of developing, demonstrating, deploying and commercializing socially desirable technologies that may be too financially risky to attract adequate private investment, and which would consequently either fail completely or grow too slowly to meet social needs.[21]

To date, the U.S. has spent just $45 million on DAC RD&D. The first dedicated DOE DAC RD&D investments were not made until fiscal year 2020 (FY20), which accounted for $35 million of that total.[22] Another $50 million in DAC RD&D is being spent in FY21.[23] This increased funding follows many of the budget recommendations made by a 2019 report from the National Academies of Sciences (NAS).[24]

The 45Q tax credit

The Bipartisan Budget Act of 2018 expanded the 45Q tax credit to provide DAC facilities with a credit of up to $35 per ton for carbon dioxide stored through enhanced oil recovery (EOR) or used in other applications, such as industrial processes and greenhouses, and up to a $50 per ton credit for permanent CO_2 storage (DACCS).[25] The spending bill passed by Congress at the end of 2020 included a large energy package, including a two-year extension of 45Q, which made projects that commence construction before the end of 2025 eligible for the credit.[26] By extending the deadline by which DACCS facilities must be constructed, Congress eased pressure on developers and increased the chances of additional DAC deployment.[27] While this is helpful for DACCS, on its own, the 45Q credit is not valuable enough to incentivize DACCS deployment.

California Low-Carbon Fuel Standard (LCFS)

The most substantial deployment incentive for DACCS today is the California Low-Carbon Fuel Standard (LCFS). Under the LCFS's CCS protocol, DAC operators can sell credits in the LCFS market for each ton of CO_2 sequestered permanently in a geologic formation, regardless of whether that DACCS occurs within California. The LCFS allows California fuel providers and refineries to leverage DAC project-based credits to offset the carbon intensity of their fuels.[28] For near-term DACCS deployment, the California LCFS is already a high-impact revenue source. Early DAC developers have noted that they intend to qualify for the LCFS, such as Carbon Engineering, which calls it an example of "effective market-based regulations." [29] However, the LCFS has a floating price based on supply and demand of clean fuels and carbon credits, meaning that DAC projects are not guaranteed a particular value per-ton of CO_2 sequestered. This creates uncertainty for developers, who therefore seek to pair, or "stack," the value of the LCFS with more stable revenue streams, like the 45Q tax credit.

Recently Authorized Federal Competitions

In the spending bill passed in December 2020, Congress authorized several new competitions for DAC. A $35 million prize was established at EPA for DAC, targeting applications that capture at least 10,000 tons per year. A separate prize program was established at DOE, to offer prizes for (1) pre-commercial air capture of CO_2 and (2) for commercial DAC applications, with total budgets of $100 million and $15 million, respectively. The $100 million pre-commercial program is a true public competition, with innovative designs awarded on a competitive basis. The smaller program, despite being called a prize, more closely resembles government procurement, granting equivalent awards – of up to $180/ton CO_2 – to all DAC facilities capturing more than 50,000 tons per year.

These programs all include non-storage applications of CDR (i.e., EOR and utilization) as well as DACCS, although the DOE commercial DAC prize would provide a smaller incentive for EOR than for other DAC applications. None of these programs have received budget appropriations yet.

Approach to policy evaluation

DACCS' unique characteristics make developing effective policy support tricky. First, DAC plants have large upfront capital costs and large operating costs. This means DAC requires incentives to defray both initial *and* ongoing costs. And since DACCS has no market-based revenue stream, the incentive for ongoing operation must be at least as large as the costs to operate the plant. In other words, all costs need to be covered by policy, in the absence of any market value for capturing and storing CO_2. Finally, the novel nature of DACCS may lead to greater caution from stakeholders and financiers, requiring policy to provide guardrails against perverse outcomes, as well as financial certainty and stability.

As discussed above, policies to support DACCS should also consider other environmental tradeoffs and environmental justice concerns that could arise with large-scale DAC deployment, and seek to mitigate them in policy design and implementation, including project-by-project assessment.

This working paper focuses exclusively on federal policy options to deploy DACCS in the next five to ten years. Many of these policy options have been used in the context of other governmental goals (See Box 1). Since DAC costs are expected to drop dramatically over time, the policy mechanisms that may be best suited to drive near-term

Box 1

DACCS isn't the first

Other technologies and industries have been kickstarted with targeted policy support. Although it is not always possible to quantify the exact impact of specific polices, three examples where federal policy support was pivotal include the following:

Scaling wind and solar: Several federal policies including tax credits, loans, and direct payments have supported renewables in the U.S. During the last few decades, wind and solar capacity has grown exponentially. DACCS would benefit from a similar suite of policies. A key difference is that unlike wind and solar, which have high capital costs but low operating costs, DACCS has high upfront and operating costs and will require support on both fronts. DACCS also has no market value today, unlike wind and solar.

Meeting military production needs: During WWII, the government guaranteed purchases and supported operations for production of military equipment. In response, the manufacturing sector reoriented around wartime needs and met unprecedented production quotas. Similar government assumption of private risk would be instrumental for DACCS, but it could be difficult to maintain public support for a large-scale effort for a long-term and intangible threat like climate change as opposed to the immediate and visceral threat of war.

Advancing environmental protection efforts: Carbon prices would incentivize firms to curb carbon emissions, but only a high price would incentivize firms to commit to DACCS. Moreover, deciding who is financially responsible for CO_2 already in the atmosphere would be extremely difficult, if not impossible. In similar pollution cases, the government has assumed the responsibility of clean-up. For example, sewage treatment is now taken for granted as a public service. In addition, through the Superfund program, the government will step in to clean up pollution from old industrial sites if the polluter is unknown or cannot be held accountable.

deployment may not be the ones that are best suited to support the industry long-term. Similarly, policies that could have a bigger impact long-term may not provide much support for DACCS over the next decade.

In this review, we group policies that may contribute to DACCS deployment into three categories:

1. **Capital support:** Includes investment tax credits, accelerated depreciation, loan programs, tax-advantaged financing structures, public competitions.
2. **Operations support:** Includes production tax credits, procurement, direct payments, government-owned contractor-operated facilities (GOCOs), and emissions pricing and standards.
3. **Enabling policies:** Includes federal research, development, and demonstration; accelerated CO_2 storage development; CO_2 transport infrastructure.

Then, we evaluate each policy option with a 1-5 rating on three essential criteria for promoting near-term DACCS deployment:

1. **Financeable:** Does the policy guarantee a predictable cash flow for investors?
2. **Stable:** Is the policy sufficiently long-lasting, and available across a multitude of projects, to support the growth of DACCS companies?
3. **Impact:** Does the policy offer enough support over the next 5-10 years to actually deploy commercial DACCS facilities?

Limitations

These criteria form a relatively crude framework for assessing policy options, and should not be the only factors policymakers consider in designing near-term DACCS deployment support. In this analysis, we do not systematically assess the implications of each policy option on the local or global land use, energy demand, and equity concerns we highlight above. This is largely due to the need to identify these impacts based on specific policy design and on a project-by-project basis, which requires a depth of policy design thinking that is beyond the scope of this paper. However, where possible, we attempt to note when certain mechanisms are by nature more or less likely to influence these outcomes. For instance, when projects are selected by expert agencies on an individual basis, as with loan or procurement programs, there may be a greater ability to engage with stakeholders and address justice concerns than when they are implemented at arms-length, as with accelerated depreciation or other incentives in the tax code. Policymakers should strongly consider environmental risks and justice implications in DACCS deployment policy design.

Our analysis is also limited in its assessment of political feasibility. Again, where possible, we may note where a certain policy might have an advantage – say, because there is strong precedent for Congress passing similar legislation – but we do not and cannot do so systematically, particularly as climate and CDR politics shift rapidly. While our recommendations are based on the criteria above, advocates and policymakers will naturally want to add political economic calculus to the mix. Finally, this analysis is a snapshot of a particular moment of time in the development of CDR approaches. We are limited by what we know about the characteristics, environmental tradeoffs, and capital and operations costs of nascent DACCS technologies – and many questions will remain unanswered until the first DACCS projects break ground. Given this, it is important that early air capture deployment policy be designed to maximize flexibility and promote a diverse set of technologies.

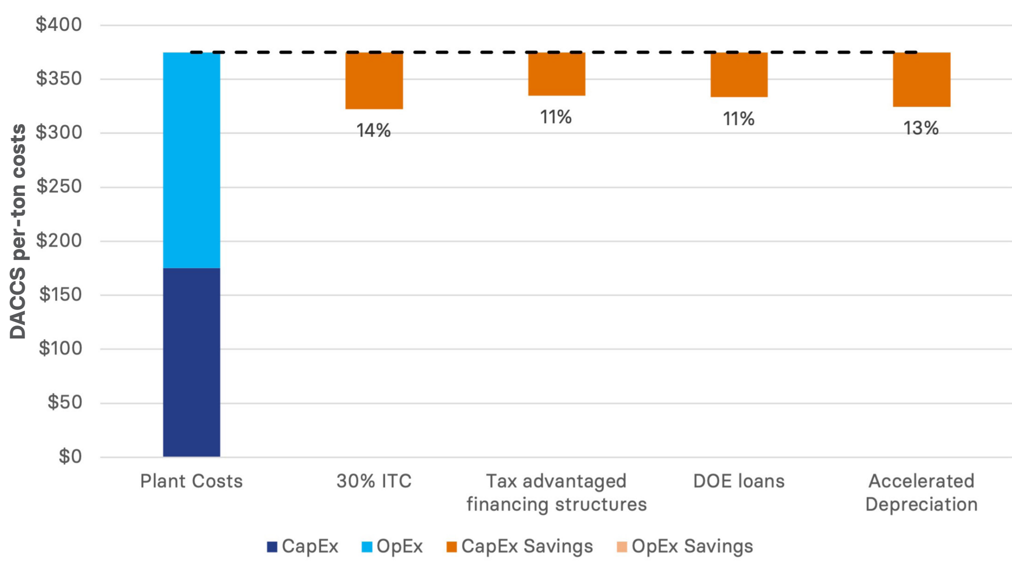
SECTION 1

Capital support

Construction of a commercial scale DACCS facility faces many barriers – they are expensive and capital intensive, the technology is unproven at commercial scale, DAC developers do not yet have any significant revenue stream, and existing policy is insufficient from both an absolute value and stability perspective. The policies discussed in this section aim to reduce the upfront cost barrier to building new DACCS plants. They include:

- Investment tax credits (ITCs)
- Tax-advantaged financing (i.e., private activity bonds)
- DOE loans
- Accelerated depreciation
- Public competitions

FIGURE 1: Projected effect of select capital support policies on per-ton plant costs



Note: The solvent system costs used here are approximations for an average early-stage plant, based on the range of plant costs surveyed by World Resources Institute.[30] Estimates for tax-advantaged financing structures and DOE loans assume a 3% government rate and a 6% corporate rate. All policy options are assumed to be available for all plant capital. These are "best-case scenario" assumptions.

Investment tax credits

Section 48 of the Internal Revenue Code offers an investment tax credit (ITC) for several energy sources. The level of the ITC varies depending on the type of project but many clean energy projects, such as solar and offshore wind, receive dollar-for-dollar credits on up to 30% of their upfront capital expenditure. There is no cap on total amounts and taxpayers receive credits at the time the project is placed in service.[31] An ITC lowers capital costs of a project, and is therefore especially helpful to technologies that have high upfront costs relative to their operating costs. The solar ITC, along with state renewable portfolio standards and research, development and deployment (RD&D) investments that have lowered costs and improved performance, have been instrumental in scaling U.S. solar capacity from just under 1 gigawatt in 2006 to 69 gigawatts today.

A 30% ITC for DACCS is likely politically feasible as Section 48 already exists in the tax code, was recently expanded to offshore wind, and may soon apply to energy storage. Evidence that a 30% ITC boosted solar development may also help build support for this policy.

Additional design features to consider include making the credit refundable and long-term. Refundable credits will streamline development by allowing a company to directly claim the credit, even if the value of the credit exceeds that company's total tax liability. [32] Many clean energy companies have little income, and therefore do not generate enough tax liability to take advantage of the credits without the assistance of a third-party tax equity partner. The small number of tax equity partners—only a few dozen players as of 2017—can constrain the pace and diversity of development.[33] Tax equity can account for up to 20% of the value of 45Q projects for carbon capture and sequestration, for instance.[34]

A long-term or even permanent[35] DACCS ITC may drive DACCS development over the next few decades.[ii] The existing ITC for technologies like solar has been subject to a cycle of expiration and renewal that has contributed to an uncertain investment environment.[36] Such cycles are common with existing clean energy credits, and are usually driven by political factors rather than actual energy sector needs or trends. Permanence can send a strong signal for DACCS support. However, it may be less critical if the goal is simply near-term deployment, as is the focus of this paper.

Policy Option: Provide a 30% credit for DACCS capital costs under the existing ITC.

Financeable	Stable	Impactful
3 of 5	3 of 5	3 of 5
A 30% DACCS ITC would reduce the immediate tax burden of a new project. The policy is essentially cash-on-hand since it applies to upfront costs. However, this upfront support may not assure investors that projects will have enough support for operations. Also, if credits are not refundable, this may make it difficult or expensive for many companies to take advantage, thus reducing the impact of the credit.	The policy would be somewhat stable. Even with potential lapses solar developers have benefited from ITC support for over a decade. The stability would of course increase if the tax credit was offered on a long-term or permanent basis.	A 30% ITC would provide developers with much needed support for capital expenditures, and evidence from the solar industry suggests this can be an effective policy tool to scale new technologies. A DACCS ITC is also likely to be cost-effective, as the credit's value will track with capital cost declines as developers innovate. However, even a 100% ITC—without support from other policies—would not be enough to build DACCS since the facility would have no way to pay for its operating costs.

[ii] At least until an economy-wide carbon price and limit is created.

Tax-advantaged financing structures

The federal government offers tax-advanced financing structures to support private investments that have social benefits, like airports and schools. We focus on three types of tax-advanced financing structures that are relevant to energy infrastructure: Private activity bonds, master limited partnerships, and real estate investment trusts.

Private activity bonds (PABs) are issued to finance construction of several societal goods – currently, there are 27 such "qualified private activities."[iii] Interest on these bonds is tax-exempt, which can make them as attractive to investors as a higher-interest, taxable bond.[37] The volume of PABs that can be issued is capped per state; a 2020 House infrastructure package included provisions to raise the state cap on PABs by more than 50 percent.[38] There is precedent for energy, environmental health, or pollution-related PABs; today, electric and gas facilities, district heating and cooling facilities, waste disposal, and green building and sustainable design projects all qualify.[39]

Master limited partnerships (MLPs) enable private partnerships to raise capital on public markets, without being subject to corporate taxes. This gives private actors the ability to access lower cost capital. MLPs are used primarily for oil and gas development, but there have been several efforts to extend MLP eligibility to clean energy infrastructure.[40] Others argue that the best way to achieve clean energy parity would be to remove the MLP provision from the tax code altogether, as it is functionally a fossil fuel subsidy today. [41]

Real estate investment trusts (REITs) are companies that purchase and operate income-generating real estate, such as timberland or cell towers, and distribute earnings as dividends to shareholders. So long as they distribute 90% of their earnings to shareholders annually, they avoid corporate taxes. To be a REIT, 75% of assets must qualify as "real property" as determined in the tax code. There have been many proposals to expand the definition of real property to include clean energy assets.[42]

Each tax-advantaged financing structure could be adapted to the DAC context. Under PABs, the federal government could add DAC plants, infrastructure, and/or sequestration sites as qualified private activities. MLP eligibility and the definition of REIT "real property" could be expanded to include DACCS infrastructure, giving developers access to lower cost capital. Several advocacy groups and researchers have suggested these expansions.[43,44,45]

DACCS is similar to other qualified tax-advantaged activities and assets; it has large capital costs, environmental benefits, and lack of inherent private value in the absence of climate policy. As such, it is a logical application for these tax advantaged financing structures.

Policy Option: Extend PAB, MLP and REIT eligibility to include DACCs plants or infrastructure.

Financeable	Stable	Impactful
Moderately financeable. PABs, MLPs, and REITs do not provide the cash flow necessary to finance plant construction and operation.	Very stable. These provisions in the tax code are typically not time-limited and would be replicable across projects.	Not very impactful. At best, tax-exempt debt could reduce the lifetime cost of capital by 20% or 30%, but will not finance a DAC plant alone. Tax-exempt financing instruments may complement larger capital or operations incentives, like an ITC.

[iii] These should not be confused with state and local bonds, which the federal government can also issue, to help pay for government projects.

Department of Energy loans

The Department of Energy's Loan Program Office (LPO) administers three direct loan and loan guarantee programs: The Title 17 Innovative Clean Energy Loan Guarantee Program, Tribal Energy Loan Guarantee Program, and Advanced Technology Vehicles Manufacturing Direct Loan Program (ATVM).[iv] LPO was active during the Great Recession, when it received a huge influx in loan authority under the Recovery Act. The Trump Administration tried to zero out the LPO in its initial budget requests, but the Biden Administration appears poised to revitalize the program.

Since 2007, the Title 17 program has issued $25 billion in loan guarantees to clean energy companies. The Tribal Energy program has never been utilized, despite $2 billion in loan authority. The ATVM program saw early success providing low-interest loans to Tesla and other electric vehicle manufacturers, but has dropped in activity since 2009, despite still having nearly $18 billion in direct loan authority and $4 billion in credit subsidies.[46] DACCS is eligible for loans under Title 17 as a technology that sequesters emissions, but no DAC project loan has ever been issued.[47]

LPO has not issued many loans since the ARRA era, partially due to the high cost of access (due to fees) that applicants face. Congress could jump-start investment in DACCS and other clean technologies by making it easier for developers to access loans.[48] As an existing program, it can be expanded and refined by Congress, but does not need entirely new authority to issue DACCS loans.

Title 17 loans can complement new or existing policies that provide revenue for each ton of CO_2 sequestered. Policymakers may enable LPO to fill this complementary role by:

- **Allowing federal contracts to be eligible for LPO programs.** Currently, projects supported by other federal contracts cannot receive LPO loans.
- **Coordinating with other DOE activities.** LPO programs could be follow-ons to other DOE investments, bridging the gap between early-stage demonstration and deployment.
- **Waiving or deferring application fees to the end of the loan process.** By reducing upfront costs to accessing loans, LPO can complement other policy support by requiring fees to be paid only once other revenue sources are in place.

Policy Option: Leverage existing LPO loan authority to finance DACCS projects, and appropriate additional funds to cover administrative costs and application fees for borrowers.

Financeable	Stable	Impactful
Moderately financeable. LPO loans and loan guarantees make low-cost debt more accessible to project developers; however, applicants are subject to fees that can limit program utilization.	Not very stable. The LPO program has existed since 2005, through multiple Administrations, but has not always been active. Loans are also unlikely to be replicable across multiple projects. Further, some high-profile failures of companies that have received loan guarantees (e.g. Solyndra) highlight the risks to the DAC industry if a DAC project funded through LPO fails.	Not very to moderately impactful. LPO loans would only support a few DAC projects, but those projects could help launch the industry. However, previous LPO success stories like Tesla also have other revenue sources. By only reducing the cost of debt for upfront investments, LPO alone will not get DAC projects off the ground.

iv The federal government offers a range of debt options for energy and infrastructure, and it is feasible that similar loans and loan guarantees could be provided by another entity involved in financing energy and infrastructure, such as the USDA's Rural Utilities Service or the U.S. Department of Transportation.

Accelerated depreciation

The federal government provides a tax deduction for assets as they depreciate over the course of their useful lives. Accelerated depreciation allows owners of certain assets to expense (or deduct) depreciation—the normal wear and tear of physical capital—on an accelerated timeline. This allows businesses to frontload expenses, reduce early taxable income, and pay down debt faster. Accelerated depreciation is considered the federal government's largest corporate tax expense.[49]

Through the modified accelerated cost recovery system (MACRS), the federal government groups assets into categories and sets depreciation schedules that are shorter than the assets' useful lives, ranging from 3 to 50 years. After a company exhausts its depreciation deductions, the tax burden will rise again; thus, the benefit of accelerated depreciation is in the time value of money. MACRS provides a 5-year useful life for renewable energy property, including solar, wind, and combined heat and power facilities, as well as carbon capture projects that primarily generate revenue through the sale of CO_2, and has been shown to increase returns on renewable investments.[50]

Bonus depreciation is a temporary provision that allows taxpayers to expense 100% of a purchased asset much faster than the expected life of the asset. It has been altered repeatedly to assist with economic recovery. Companies can only claim bonus depreciation for any remaining investments after exhausting the permanent accelerated depreciation provision, which, as noted above, has a cap of $1 million per year for qualified equipment.[51]

Accelerated depreciation is an established incentive for capital-intensive investments and ensuring DACCS investments are eligible should be politically feasible. In some cases, such as the MACRS provision for facilities that derive the bulk of their revenue from the sale of CO_2, DAC activities may be already eligible. In other cases, clarifications and potential expansions could resolve questions around the eligibility of peripheral aspects of DACCS operations, such as transportation to an injection site and the storage operation itself.

Policy Option: **In legislation or IRS guidance, clarify DACCS eligibility for accelerated depreciation.**

Financeable	Stable	Impactful
Moderately financeable. DACCS developers could leverage accelerated depreciation to reduce upfront costs for machinery, power generation, carbon transportation infrastructure, etc. Although this reduces companies' near-term tax burden, it is not transferrable.	Very stable. Accelerated depreciation is a permanent fixture of the tax code and imposes depreciation schedules that are very predictable for companies and across projects. However, bonus depreciation was established as a temporary measure and could be altered moving forward.	Not very impactful. Accelerated depreciation frontloads the depreciation timeline, so by definition it cannot cover a large share of plant costs. Still, the early timing of this support may make it more impactful than its pure financial value indicates.

Public competitions

The federal government uses public competitions, or prizes, to spur innovation and meet specific technical challenges without bearing high levels of risk, since a federal agency in charge of a competitive program is usually only required to pay out funds if participants are successful.[52] The potential benefits of these competitions are large: policymakers can set ambitious goals, inspire public imagination and attract a larger, more diverse set of participants.[53] Public competitions can also stimulate private sector investment on a much larger scale than the value of the policy itself.[54]

The annual number of active prize competitions across the federal government rose from about ten to over one hundred since 2010.[55] In the 116th Congress, legislators introduced at least thirty prize proposals.[56] Given this popularity, prizes are sometimes used to describe programs that do not quite meet our definition of a public competition. For instance, a $115 million air capture prize program authorized in the FY21 spending package includes $100 million in awards for innovative pre-commercial designs, which is a public competition; however, the remaining $15 million would offer equivalent sums, up to $180/ton, for qualifying commercial DAC facilities, which we see as more like procurement than a prize. Prizes that are truly public competitions are considered most useful as a complement to more traditional support mechanisms.[57] Moreover, a recent analysis notes that there is limited information regarding the impact of prizes.[58] A systematic evaluation of prizes is needed to determine if they are cost-effective drivers of additional growth for a given sector or technology.[59]

The FY21 spending package also authorized (but did not appropriate funds for) a public competition at the Environmental Protection Agency for DAC with a total budget of $35 million.[60,61] The prize would support direct air capture projects designed to capture over 10,000 tons of CO_2 per year and that could be commercially viable in the "foreseeable future."[62] When this provision was first introduced in a much more narrow bill (the USE IT Act), it received bipartisan cosponsors and support, suggesting a bigger prize might be politically feasible. Prizes are sometimes run by the private sector as well. Elon Musk's XPrize recently announced a $100 million program for CDR that offers a $1 million reward for the top fifteen competitors.[63] These teams must then develop full-scale demonstration projects to compete for a reward of $50 million (1st place), $20 million (2nd place) or $10 million (3rd place). Although even the smallest prize could be impactful, the time and effort required to win the reward highlights the uncertainty facing potential competitors.[64] Further, if XPrize is successful, it raises a question as to the value-add of additional prize programs run through the federal government.

Policy Option: Design a public competition that rewards DAC developers with scalable technologies.

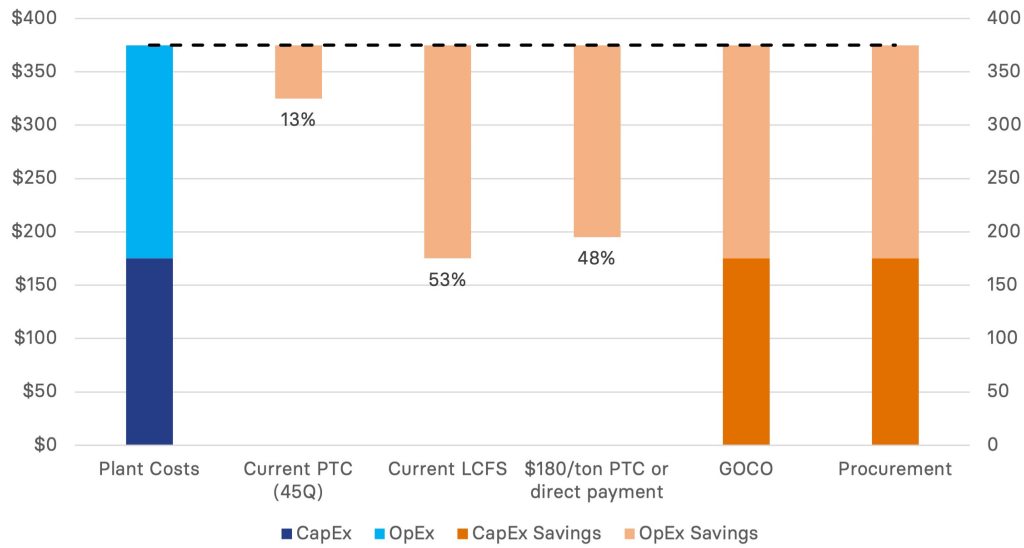
Financeable	Stable	Impactful
Not very financeable. Public competitions guarantee some financial support for a project from the government. However, it is unclear if a competition would attract private investors as there is uncertainty around who will win the prize. Public competitions may also not convince investors that there is long-term political support for DACCS.	Not very stable. Without clear guarantees around magnitude and duration, public competitions may not provide individual operators with long-term support and could be perceived as an unstable one-off deal.	Moderately impactful. A large reward could support capital costs for a few projects, and perhaps even future development efforts for these winners. Competitions can also inspire public support in ways that traditional policies do not. However, competitions are designed to reward early innovators, not sustain DACCS deployment and operations.

Operations support

Getting a DACCS facility built is only half the problem – these facilities are also expensive to operate. Each incremental ton of CO_2 pulled from the air, transported to a saline reservoir, and injected underground represents an incremental cost to the DACCS operator. An effective DACCS policy will therefore provide value to DACCS operators not just for upfront costs but for operating costs, on a per ton captured and stored basis. That is the goal of the policies discussed in this section. These include:

- Production tax credits (PTCs)
- Cash grants and direct payments
- Government procurement (e.g., reverse auctions)
- Government-owned, contractor-operated facilities (GOCOs)
- Emissions pricing and standards (e.g., California's low-carbon fuel standard)

FIGURE 2: Projected effect of select operations support policies on per-ton plant costs



Note: The solvent system costs used here are approximations for an average early-stage plant, based on the range of plant costs surveyed by World Resources Institute.[65] Assumes procurement and GOCOs would cover the full cost of the system.

Production tax credits

Section 45 of the Internal Revenue Code offers a production tax credit (PTC) for several energy sources.[66] The wind PTC is one such well-known and longstanding production credit. Qualifying firms receive support for each kilowatt-hour (kWh) of electricity generated over a ten-year period. The wind PTC was first implemented in 1992 and several studies credit it with being a leading contributor to wind investment and growth.[67] Another study suggests PTCs are more effective at scaling new technologies than ITCs.[68] DACCS is eligible for a credit under 45Q today, but the value of the credit, at $50/ton, does not cover a meaningful portion of costs.[69]

Unlike investment tax credits, discussed above, production tax credits incentivize operation of eligible technologies, but do nothing to directly ameliorate construction costs. Some sort of incentive for ongoing production is essential for DACCS, which has no market value. Without an incentive to continue to capture and sequester carbon, operators would lose money on every ton of CO_2 captured.

While the existing 45Q credit provides needed ongoing operating support to DACCS, a higher PTC would be required to meaningfully drive deployment. The Rhodium Group estimated that an incentive of $180/ton would be enough for the nth DACCS plant to break even, but an even higher credit may be needed for the earliest plants.[70] Current policy requires DAC plants to capture 100,000 metric tons or more of qualified carbon per year to be eligible for the tax credit. Decreasing this size threshold could allow for different technologies and developers to participate. Climeworks' Hinwil facility, for instance, one of the largest DAC plants in operation, captures fewer than 1,000 metric tons per year.[71]

Legislators could help remove non-cost barriers to DACCS by creating a DACCS-specific tax credit, instead of keeping it lumped in with CCS and EOR applications. There is political risk to DACCS of being associated with the fossil fuel industry, which is an integral player in EOR as well as CCS. As with an ITC, policymakers might also consider implementing a DACCS PTC over long time horizons and making the credit refundable, so that developers benefit regardless of their tax liability.

Finally, political feasibility will play a role in policy design. The existence and recent extension of 45Q may provide a strong foundation for a more robust DACCS credit.

Policy Option: Increase the 45Q tax credit to $180/ton and expand eligibility to small plants.

Financeable	Stable	Impactful
Very financeable if refundable. Somewhat less financeable if non-refundable. It may be difficult to attract tax equity partners who are willing to take on the ongoing risk and high costs of project operations. However, investor concerns may be alleviated after the first few plants demonstrate performance.	Moderately stable if credits are not offered on a long-term or permanent basis. Although a long-term driver of capacity, the wind PTC lapsed twelve times between 1992 and 2016. The on-again off-again support noticeably stalls wind capacity additions every time it occurs.[72]	A $180/ton credit would provide significant support for the high operational costs associated with DACCS. Moreover, since upfront investments are financeable against this operations incentive, a PTC could also cover CapEx costs. However, even a $180/ton credit may not be enough for the first few DACCS facilities to break even; some additional policy support would be needed to fill any remaining gap. It is possible that revenue from the California LCFS could fill the gap.

Cash grants or direct payments

Federal direct payment programs provide grants or cash assistance to private companies to deploy a technology or service. Direct payments reduce the cost of projects for developers and are similar to refundable tax credits, which are not limited by the taxpayer's tax liability. However, direct payments provide more timely financial assistance than refundable credits, as the recipient need not wait until they file taxes the following year to recoup the value of the incentive. Grants or cash payments also differ from government procurement, as they do not necessarily require a government contract to acquire the good or service.

Direct payment has been utilized for climate mitigation in the past, including for the deployment of solar, wind, and other clean energy projects. A prominent example is the Section 1603 Program under the American Recovery and Reinvestment Act (ARRA), which provided cash grants in lieu of tax credits to support clean energy developers by offsetting a portion of the cost of installing equipment.[73] The National Renewable Energy Laboratory estimates that the 1603 Program delivered $26 billion on more than 100,000 projects, which in turn supported up to 75,000 jobs and generated up to $44 billion in economic output.[74,75] The U.S. Department of Agriculture also administers a number of direct payment programs to promote resource conservation, including the Environmental Quality Incentive Program and Conservation Stewardship Program.

Although clean energy advocates have been unsuccessful at securing direct payments since ARRA, this policy option may be more politically feasible at present. The current economic crisis has led many clean energy advocates to raise the Section 1603 program as a top stimulus priority.[76] The Congressional Research Service has examined the potential for direct payments to play a role in the COVID-19 context, though not specific to energy or DAC.[77]

Direct payments could supplement or augment the existing 45Q tax credit—in the same manner that Section 1603 payments changed the delivery of solar and wind tax credits—or exist independently. Regardless, a DACCS direct payments program could function similarly to a production tax credit. A key advantage of a direct pay program is that there is no requirement for large and long-term tax liability. Whereas providing tax equity on the 45Q credit is only tenable for a handful of the largest financial institutions, direct payments can allow more small and novel DACCS players to move quickly, compete, and innovate. However, direct payments have not historically benefitted from the same political support as tax credits, and may require an annual appropriation. Passing a new direct payment program, particularly outside of a temporary stimulus context, could be challenging.

Policy Option: **Offer federal direct payments for a portion of upfront and operational DACCS costs.**

Financeable	Stable	Impactful
5 of 5	3 of 5	4 of 5
Very financeable, as they are predictable cash flows and not dependent on tax liability.	Very replicable across projects and companies, as all qualifying projects typically receive payments. However, these programs typically have fixed budgets, unlike tax credits; historically, they have been short-lived and/or used for temporary stimulus.	Moderately to very impactful, depending on the value of the payment and how long the cash grants are offered. Large payments could allow developers to finance the initial construction of DAC plants. Performance-based payments would ensure environmental integrity while covering the cost of each incremental unit of CO_2 removal.

Government procurement

The U.S. government procures more than $550 billion in goods and services each year,[78] using its purchasing power not only to buy equipment but also to establish new markets. The FY21 spending bill funded dozens of procurement efforts across various agencies, including creating a CDR task force directed to consider procurement, and authorizing a "prize competition" that would procure DACCS at up to $180/ton.[79] Since DACCS provides a public good that has no market value today, there is a strong case for the government to procure it directly. We consider two forms of procurement: reverse auctions and contracts for differences.

A reverse auction is a process by which the government solicits bids from private companies to provide a good or service, typically selecting the lowest qualifying cost option, thereby encouraging competition and innovation.[80] In contrast with other models, such as Requests for Proposals (RFPs), a reverse auction can simplify the federal bidding process and maximize efficiency. This makes them a relatively popular tool: according to the GAO, reverse auctions saved federal agencies $100 million in 2016.[81] In a reverse auction for DACCS, vendors could compete to secure a long-term contract for carbon sequestration. The reverse auction could be run out of an existing agency like DOE, or a new entity, like a national green bank.

A contract for differences (CFD) is an agreement that states that the buyer of a good or service will pay the seller the difference between the market value of that good or service at time of sale and its price when the contract is signed. Governments can use CFDs to incentivize investment in innovative technologies with high risk profiles. The federal government could procure DACCS by entering into multi-year CFDs with private developers. These contracts would set a price for one ton of CO_2 removal, then pay developers the difference between that price and what they can get from the market. There is precedent for this, with multi-year clean energy CFDs in the U.S. and U.K.[82,83]

As a major purchaser of DACCS, the federal government could set CO_2 removal quantity schedules that are aligned with scientific targets. Since the government may also be promoting DAC research, overseeing the permitting of storage reservoirs, or incentivizing DAC manufacturing, they can synchronize procurement with these other activities. Additionally, reverse auctions are often used to promote other social and economic objectives, such as domestic labor standards.[84]

Politically, procurement of DACCS may face opposition, either due to the uncertain scale of spending or concerns of conflict with existing policy. For instance, a CFD would create an unusual situation by which a federal incentive's value hinges on state incentives like the LCFS. However, the inclusion of direct procurement for CDR in the FY21 omnibus spending bill suggests decent political appetite, and design choices – such as a reverse auction to drive cost savings – could ameliorate opposition.

Policy Option: Create a reverse auction for public procurement of DACCS.

Financeable	Stable	Impactful
Very financeable, assuming a contract is for a significant term length (10-20 years) and is accessible before or during facility construction.	The contracts themselves are stable if for a significant term length, but no particular company is guaranteed to win bids, so contracts are not necessarily replicable across multiple projects.	Very impactful, as procurement would provide revenue certainty for early movers that might otherwise be hamstrung by a complex policy and market environment. It can also help drive newer and more expensive technologies down the cost curve.

Government-owned, contractor-operated facilities (GOCOs)

GOCOs are public-private partnerships in which the government owns a particular asset while a private contractor carries out its operations. One benefit of a GOCO is that it can speed up the buildout of a new technology or industry by reducing private sector risk. For example, during World War II, the federal government could not afford to wait for private investors to decide if certain activities, such as manufacturing aircrafts, would be economically beneficial. Instead, the government used GOCOs to ensure that production quotas were met.[85] With the government taking on the risk and providing contractors with capital, factories scaled up on very short time frames.[86]

Another potential benefit of the GOCO framework is that it allows each party to play to its respective strengths: the federal government sets missions and the private sector applies business best practices or scientific expertise to carry them out.[87] Sixteen of the seventeen Department of Energy laboratories are GOCOs and the model is cited as providing support for projects in the national interest, while helping insulate scientists and engineers from political pressure.[88]

While it is unlikely that there is near-term public appetite to support DACCS GOCOs on the scale of a war-time economy, a smaller scale may be feasible. GOCOs received renewed attention as a potential tool to combat coronavirus, so the approach may be more viable today than it has been in decades.[89] That said, a climate-specific GOCO has not received attention from policymakers, so the potential political opposition to such a proposal is difficult to predict.

In principle, DACCS GOCOs could promote both the public interest and private innovation. However, private contractors' reliance on the government may discourage private sector risk-taking and innovation that might otherwise occur as a new company develops.[90] Although the government can attempt to implement technology-neutral GOCOs, there is also a risk that this this policy would lock in incumbent technologies. This could be mitigated with a GOCO contract solicitation process designed to ensure a variety of technologies are eligible.

Policy Option: Implement a DACCS GOCO that covers upfront and some or all of operating costs.

Financeable	Stable	Impactful
Very financeable. By taking on much of the risk, the government would provide private companies with reassurance that the plants would get built and that they would be given assistance on production costs. By paying directly for the operation of DACCS facilities, a GOCO would drive DACCS deployment despite the lack of direct market incentive. This was the case for GOCOs during WWII, which received set and modest profits in return for their production.	Moderately stable. Even though many of the GOCO companies established during WWII retained government support through the mid-1950s, there are risks. The biggest stability risk is that companies are captive to government interests and the government's decision to renew a contract or not.	Moderately to very impactful, depending on the level of overall support provided. The potential to support upfront and ongoing costs makes this an attractive policy option. Such an ownership model could kickstart deployment by mitigating risk. This ownership model could also offset some of the risks with other related activities, including government buildout of pipeline infrastructure or government assumption of permanent CO_2 storage liability.

Emissions pricing and standards

Emissions prices and standards that aim to drive reductions in climate pollution, including both economy-wide and sector-specific approaches, can provide a framework to enable deployment of carbon dioxide removal (CDR). CDR can be used by covered entities as an alternative way to comply with the program's requirements. Historically, this has been seen with nature-based offsets under carbon pricing programs, such as California's cap-and-trade regime.[91] However, CDR has been included or proposed as eligible to offset emissions in other technology-neutral climate policies, such as carbon taxes, low-carbon fuel standards (LCFS), and clean electricity standards (CES). DACCS could also receive financial support through voluntary offset markets, such as those that some companies participate in as a way to claim carbon neutrality.

Climate policy that explicitly targets emissions will likely be a key element of any strategy to decarbonize the U.S. economy. Although comprehensive federal climate policy, or even federal sector-specific policy like a CES or LCFS, has been far harder to pass than individual technological incentives, it is very likely DACCS would be allowed within any policy that does pass. In addition to the existing California LCFS, DACCS would be eligible to generate credits—or as a potential use for generated revenue—under several CES and carbon pricing bills introduced in the 116th Congress.[92]

As near-term DACCS' costs will likely be higher than those of many other compliance options, policies will need to be designed to provide extra incentives to drive buildout of early DAC plants. Policymakers could offer a bonus credit for permanent CDR to reflect the additional social value of developing a robust DACCS industry. This could drive down DACCS' costs and make it competitive as compliance costs rise. However, bonus credits beyond actual reductions would weaken the stringency of a carbon policy. Alternatively, policymakers could allow DAC developers to stack the revenue from their climate policy with other policies (i.e., sell credits in multiple markets). Today, DAC developers can stack California LCFS revenue with non-market incentives, such as the 45Q tax credit. However, allowing the same emissions reduction to receive credit under two different policies double counts reductions. This erodes the integrity of the climate policies and favors DAC over other mitigation efforts. Stackability also hinges on clarity around DAC eligibility for compliance credits. This includes whether a DAC facility may operate outside of the policy jurisdiction, as is possible under California's LCFS.

Policy Option: Allow DACCS to provide emissions or carbon intensity credits under an emissions-based climate policy, such as a price or standard.

Financeable	Stable	Impactful
Moderately financeable. The price of credits or allowances can fluctuate significantly. Policies can reduce or increase financer confidence by stabilizing market prices through design elements such as price floors or ceilings. There is also uncertainty about the ability to "stack" revenue from different climate policies. However, DAC financers are surely accounting for at least some value of California LCFS credits when evaluating projects.	At the state level, broad climate policy has proven more stable than technology-specific incentives. However, market-based approaches will cause revenue available to DACCS developers to fluctuate over time and, historically, U.S. carbon prices have remained low – far lower than the cost of DACCS today. Markets subject to climate policies are typically quite large (California, for example, emitted over 425 million tons of CO2e in 2018), so there is capacity to deploy the first DAC plants without straining the compliance market.	Moderately impactful. Over the long-term, it is essential to pass emissions-based climate policy to avoid the worst effects of climate change, and these policies are very likely to allow CO_2 removal approaches to qualify. Covered entities have flexibility to develop DACCS or purchase credits from a DAC operator. DAC facilities would receive revenue on a per-ton basis, but the scale of the incentive from will likely start off relatively small.

Enabling policies

The policies discussed to this point are designed to incentivize construction and operation of DACCS facilities. In this section, we look at policies that promote DACCS by lowering technology or regulatory costs or enabling infrastructure to capture, transport and store CO_2.

This section summarizes three non-deployment policies that may nevertheless serve an important function in enabling deployment: (1) Federal research, development, and demonstration (RD&D) programs; (2) accelerated CO_2 storage development; and (3) CO_2 transportation infrastructure. We do not evaluate these against the same criteria as other policies, since they do not directly support plant construction or operations, but discuss their role in unlocking near-term DACCS deployment.

1. Federal research, development and demonstration programs

As discussed in the Existing Policy Support section above, research, development and demonstration (RD&D) programs funnel public support to technologies that may be too financially risky to attract adequate private investment.[93]

If Congress continues to provide funding for DACCS RD&D, DOE should carefully consider program design. DOE should lean into the experimental nature of RD&D by embracing a certain risk of failure, focusing on proving concepts on a small scale and targeting technologies where more information is necessary.[94] At the same time, DOE can take steps to reduce risk. For example, DOE can fund front-end engineering design (FEED) studies, which reduce performance risk and cost over-runs.[95] FEED studies often have cost sharing requirements,[96] but these could be waived.

Finally, policymakers should continue to provide funding for R&D in any DACCS funding package. The technology is nascent, and it is likely that R&D will identify alternative technologies and methods. The more potential tools we explore, the more potential there is for a robust DACCS sector in the long-term.

2. Accelerated CO_2 storage development

At time of writing, there are only a handful of carbon capture projects in the United States with dedicated geologic storage – and most of those are in the FEED stage.[97] There are no operable DAC facilities with dedicated geologic storage. Storage is a limiting factor not due to geologic capacity, but due to a lack of operational carbon storage wells.[98] The process of regulating and approving these wells is managed by the Class VI program at the U.S. Environmental Protection Agency (EPA), which requires developers to characterize the local geology, monitor well integrity, and more.[99] These rules are crucial to minimize environmental harm, but can make it challenging to obtain permits.

Given the relatively small scale of most DAC plants to date, it is likely to be cost-prohibitive for a DACCS project to develop a new Class VI well that would have significantly more capacity than the DAC plant would need. Government programs to develop and put into operation Class VI wells could therefore be very impactful in defraying these infrastructure costs for DAC plants.

Federal policy that accelerates the development of CO_2 storage could pave the way for near-term DACCS deployment. Recent proposals from lawmakers and advocacy groups have included:

- Expediting Class VI well permitting by increasing resources at EPA and state agencies. (States can apply for "primacy" to administer injection control rules, but just two states, North Dakota and Wyoming, have primacy today.) The only active Class VI site, in Illinois, took 7 years from the initial request to become active.[100]
- A $250 million per year investment in research and development for secure geologic storage operations and engineering, as recommended by the National Academy of Sciences.[101]
- Increasing funding for DOE's CarbonSAFE program, which aims to develop 50 million tons of operational CO_2 storage capacity by 2026. EDF supports increasing the CarbonSAFE annual budget from $30 million to at least $150 million.[102]
- Government mapping and/or pre-approval of sites for secure geologic storage.
- Resolving challenges associated with surface owners' legal rights to subsurface pore space.[103]

Access to subsurface storage is a necessary condition for the operation of any DACCS project. Class VI wells are subject to strong federal regulations and have a long permitting process today – though hopefully this will shorten as EPA gains experience. While the solutions above do not result in DACCS deployment on their own, we consider them "no regrets" policies that would expand development of CO_2 storage without compromising environmental integrity.

3. Transportation infrastructure

CO_2 transportation infrastructure, particularly pipelines, is among the most mature of the tools needed for geologic storage. It is considered a key enabler of point-source CCS, which requires CO_2 to be moved from its source to a storage location. However, it is less clear the extent to which pipeline infrastructure is critical for the near-term deployment of DACCS. Today, there are roughly 5,000 miles of CO_2 pipelines in the U.S.[104] Developers may be able to site the first few commercial-scale DACCS plants close to storage reservoirs or existing infrastructure, thereby limiting the need for new pipelines.[105] Eventually, though, it is likely that additional CO_2 transportation infrastructure will be needed to deploy DACCS at scale.

Policy can improve the conditions for infrastructure development, reduce costs, or pool risks. Some proposals include:

- Developing regional infrastructure hubs, through coordination with states and multiple operators.
- Optimizing existing right-of-way corridors to designate land for CO_2 infrastructure.
- Providing support for routing and logistics to mitigate over- or under-building and ensure access for smaller DAC plants, which have high per-ton transportation costs.[106,107]

For the first few DAC plants, federal policy to improve planning and siting of carbon dioxide transportation infrastructure may provide some modest financial and logistical relief for developers, but is unlikely to be essential for deployment, since these first few facilities could rely on existing infrastructure. Likewise, to the extent that pipelines help to deploy point-source CCS for industrial facilities, and CCS improves CO_2 storage and utilization, they may indirectly benefit DACCS. When and if additional pipeline infrastructure is needed, it will be essential for the pipelines to be developed in close coordination with affected communities, to ensure the pipelines have minimal environmental impact and do not exacerbate environmental justice issues.

SECTION 4

Comparison

In Section 3, we describe and evaluate 10 different policy options – 5 capital support and 5 operations support policies, as well as three enabling policies – that could drive near-term deployment of DAC with dedicated geologic storage; i.e., establish the first few commercial-scale facilities in the U.S. before the end of the decade. But which policies rise to the top? In Table 2, we compare each near-term DACCS deployment policy option against our three main criteria: Financeable, Stable and Impactful. Several insights emerge. We also highlight a few important caveats that may not be apparent due to the relatively crude criteria used in this paper.

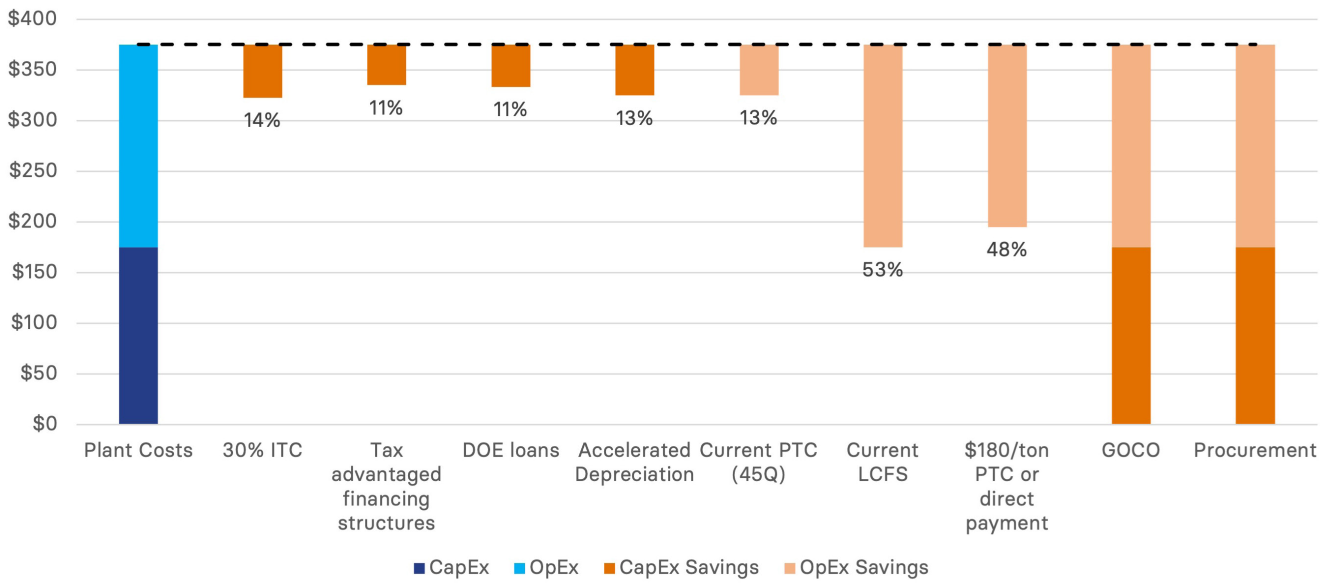
TABLE 2: Comparison of criteria ratings across policy options

Policy Mechanism	Type	Financeable	Stable	Impact
Investment tax credits	Capital	3	3	3
Tax-advantaged financing	Capital	3	5	2
Department of Energy loan programs	Capital	3	1	2
Accelerated depreciation	Capital	3	5	1
Public competitions	Capital	2	1	3
Production tax credits	Operations	4	3	5
Cash grants or direct payments	Operations	5	3	4
Reverse auctions and CFDs	Operations	5	4	5
GOCOs	Operations	5	3	4
Emissions pricing and standards	Operations	3	5	3

First, the only policies that score 4 or 5 on Impact are those that directly incentivize operations of DACCS facilities on a per-ton basis. While other policies may reduce the costs of debt or improve technological performance, no DAC will be deployed and operated without an ongoing incentive for each ton of removal. Yet a single operations incentive, if robust enough, can help to cover the capital investment in building a DAC facility. **This leads us to conclude that any policy package to deploy DACCS must include one or more operations incentives.** However, these operations incentives may be more politically challenging to pass, given the magnitude of the per-ton incentive necessary to deploy the first few facilities and the relatively limited precedent for many of these approaches, such as reverse auctions. If it proves difficult to pass these policies in the near-term, advocates should also pursue easily attainable short-term financing benefits (such as DACCS eligibility for private activity bonds), while slowly building the political coalition for more robust operations incentives. On the other hand, the near-term political climate may present the best opportunity to pass ambitious policy for the foreseeable future.

Second, our comparison table provides some insight into how hybrid policies or policy packages could emerge. **Policymakers should look for groupings that balance the relative advantages and disadvantages of different support mechanisms.** For instance, direct payments and production tax credits are both impactful incentives for DACCS operations, but the former is more financeable given its simplicity and lack of reliance on tax equity, while the latter is an established piece of the tax code and does not require annual appropriations. Approaches that enable refundability for a production tax credit – as with the 1603 program under ARRA – could capitalize on the benefits of both policies. Similarly, for the first few plants, an incentive that is difficult to access, such as securing a DOE loan, might be best complemented by a policy that is widely and consistently accessible, such as an investment tax credit, to hedge against risk.

FIGURE 3: Potential policy impact on early DACCS plants



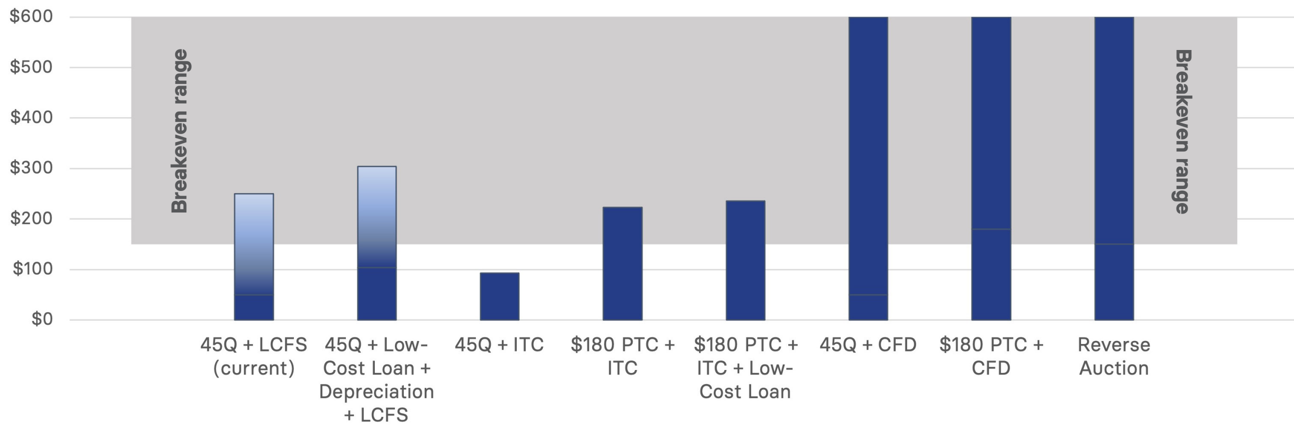
Note: These impacts reflect optimistic assumptions to illustrate "best case" scenarios for policy impact, including a 6% corporate rate and a 3% tax-exempt or government rate for loans and tax-advantaged financing structures.

Third, as shown in Figure 3, some policies that score as high-impact in our criteria may still need complementary policies to cover the full cost to developers. For example, despite the fact that procurement, PTCs, and direct payments all score highly on impact, only procurement is likely to cover the entire cost of DAC facilities and respond dynamically to changes in cost, making them capable of funding expensive but promising early-stage technologies. In contrast, fixed incentives, such as PTCs or direct payments, may not cover the cost of emerging technologies, thereby limiting innovation.

Based on the above three points, we compiled a few different policy package options, as shown in Figure 4. The chart starts on the left with current U.S. policies: The 45Q tax credit and the California Low-Carbon Fuel Standard. Light blue bars indicate some uncertainty as to the exact value of the incentive to the developer, due to a floating price. The exact value of procurement policies is also unknown, but that is by design and should not represent uncertainty for the developer.

From this analysis, we conclude that the existing 45Q and California LCFS could provide enough financial support for near-term DACCS deployment. However, this policy combination may not provide developers with the certainty needed to raise sufficient funds to build DACCS facilities. DACCS plants with costs above $250/ton would need support beyond the existing 45Q and LCFS; this could limit viability for smaller-scale projects, remote locations, or more innovative approaches. Furthermore, potential fluctuations in the floating price of the California LCFS could challenge the finance-ability of even the lower-cost DACCS projects. In other words, if developers or financers could be confident that the California LCFS would continue to provide a $200 per ton subsidy over the next 10 years, that might be enough to finance new plants. Without that certainty, the risk profile for financers changes significantly.

FIGURE 4: Financial support provided to DACCS by different policy combinations



Note: Lighter blue gradient indicates when uncertainty kicks in with respect to the total value of the incentive (LCFS only).

Fourth and finally, some enabling policies or capital and operations supports that appear low-impact for the first few plants may still be essential for the growth of the industry long-term. This reflects the limits of taking a purely financial view on deployment policy. For instance, some policies that appear small in impact have outsized value due to the *timing* of their interventions, as with DOE loans that can help early-stage companies bridge the "valley of death" from R&D to commercial viability. These policies may be worth pursuing despite their understated near-term deployment impact. Likewise, important enabling policies are not captured in our comparison table; accelerated carbon dioxide storage development will be instrumental in eventually pushing CDR to gigatonne scale.

Climeworks direct air capture plant.
Photo credit: Climeworks,
Photo by Julia Dunlop

SECTION 5

Policy recommendations

Based on our analyses in Sections 3 and 4, we believe the first-best option for driving near-term DACCS deployment is direct federal procurement with a reverse auction, which we ranked as Very Financeable, Moderately Stable, and Very Impactful. This policy would cover early-stage plant costs in full and, if well-designed, could stimulate a competitive yet diverse DACCS market. A procurement policy could be equally valuable if combined with the existing 45Q and LCFS policies as a CFD, or as a standalone reverse auction. In the former case, government procurement would simply provide the difference between the existing policy support and the funding needed to build DACCS facilities. However, since having a federal policy like a CFD that depends on the fluctuations of state policy would be complicated and unusual, **a reverse auction is our preferred policy approach.**

Reverse auction - design and implications

We recommend that the U.S. government establish a reverse auction for DACCS with a procurement schedule aligned with climate targets, sufficient value to accommodate innovative approaches, and cost-effective implementation through competition and price discovery. A federal reverse auction proposal should include the following specific design elements:

- **An upper price limit that reflects the high-end of current DACCS estimates, which could be up to $600/ton.**[108] Both the real costs and the auction price caps will ratchet down over time as developers gain experience and more companies enter the market.
- **Contracts, granted to those with the lowest credible bids, that guarantee the dollar per ton value of the bid for multiple years.** While DAC facilities are expected to have average useful lives spanning several decades, we propose locking in the auction price for a ten-year period, though previously winning projects would be eligible to rebid in subsequent auctions. Presumably, if the policy does not exist after those ten years, it is because it has been replaced with some other form of policy support, or because DACCS is no longer seen as a crucial decarbonization tool.
- **Flexible design that can maximize competition, innovative approaches, and capacity additions.** This could include tweaking the design to facilitate participation of small developers or separating different DAC technologies during the bidding process. On an even broader level, a reverse auction for DAC could be implemented in parallel or as part of a wider CDR auction program. Flexible design could also apply to the way the capacity and price caps are set. For example, instead of pre-defining the price limit and demand schedules for a decade, the Department of Energy could be required to establish a new schedule before each auction period, decreasing the price limit and increasing the quantity by a certain amount compared to the prior cycle.
- **Conditions on contracts to pursue other social or economic objectives.** One advantage of procurement over more hands-off approaches, like tax credits, is that the government can ensure the projects it funds maximize social benefits. Policymakers can require environmental justice safeguards, high-road labor standards, prevailing

wages, domestic manufacturing (i.e., "Buy America") stipulations, local or regional job creation, and more. As DACCS is increasingly evaluated for its potential social and economic effects,[109] policymakers may wish to use procurement to target those opportunities.

We showcase these principles in an illustrative DACCS reverse auction design (Box 2).

Box 2

Illustrative DACCS reverse auction design

There are many different possible design options for a reverse auction that could provide sufficient funding to catalyze the DACCS market while encouraging competition and minimizing costs. We present one potential policy design below, which we believe could address some of the challenges a reverse auction could face.

To ensure we capture the high range of potential current DACCS costs, we suggest the first auction have a maximum clearing price of $600/ton.

We also propose having price caps and demand schedules in three-year periods for the first decade of the program rather than setting an annual schedule. Having multi-year schedules will allow the program to accommodate both a large plant and several smaller facilities. Single year auctions, which would by definition have smaller caps, could be totally captured by one plant, or, conversely, be dramatically undersubscribed if no developer bids a large project.

Table 3 shows one potential schedule that, if implemented in 2023, would result in 2.5 million tons of capacity by 2030. This proposed schedule requires initial bids at some point in the first year of each auction period, with winning bids required to be built by the end of each auction period. If the demand cap for a given auction period is not fully subscribed by the bids received during the auction in the first year of that period, a subsequent auction for the remaining tons would take place in the second year of the period. If after this second auction there is still outstanding capacity, a third auction deadline would take place in year three of the auction period.

To maximize competition and cost efficiency, we would expect auction periods to become shorter after Years 7-9.

Table 3 Proposed Reverse Auction Schedule

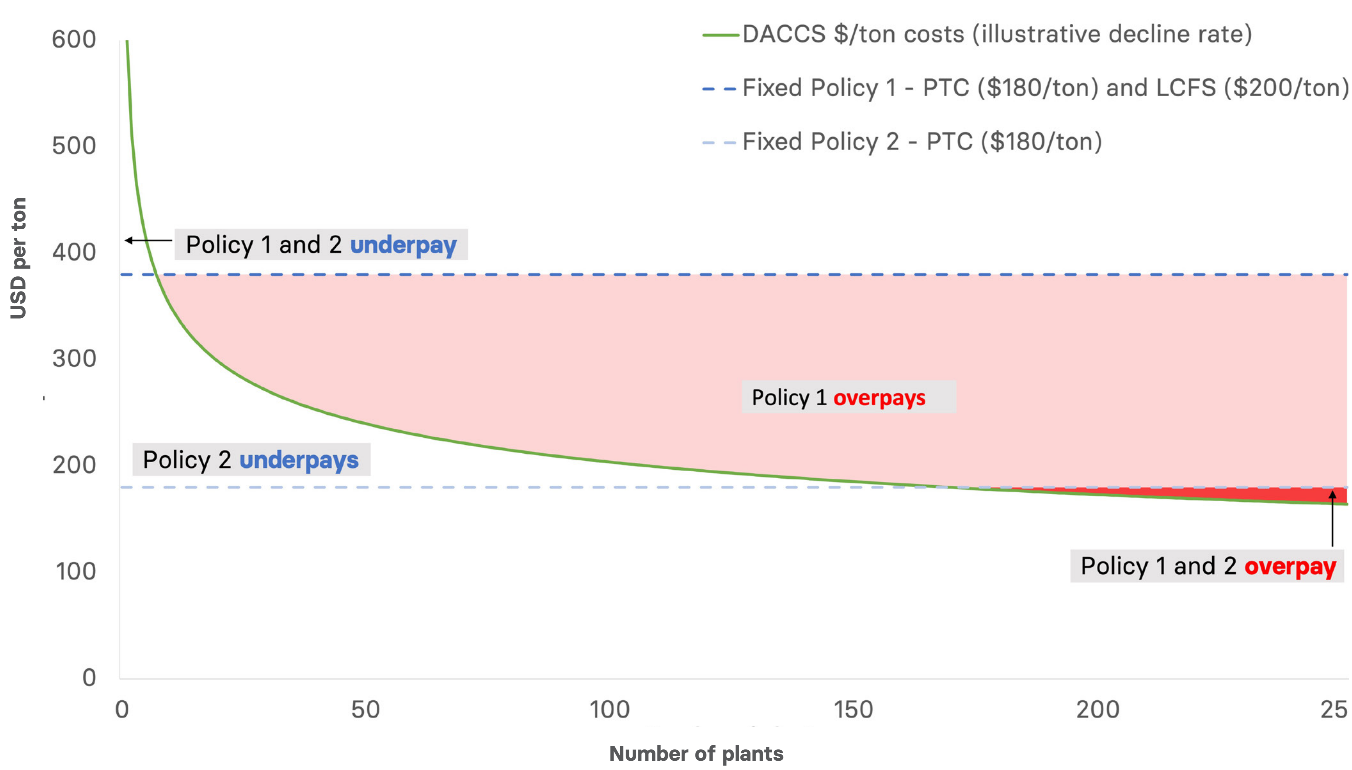
Auction Period	Auction Price ($/ton)	Capacity Cap per period (tons)	Max Cumulative Capacity (tons)	Max Cost ($)	Max Cumulative cost ($)
Years 1-3	600	550,000	550,000	275,000,000	275,000,000
Years 4-6	350	750,000	1,300,000	455,000,000	730,000,000
Years 7-9	250	1,200,000	2,500,000	625,000,000	1,355,000,000

The price and demand schedule are based on our understanding of the DACCS market, the minimum level of growth over the next ten years we think is necessary to make DACCS a viable mid-century climate solution, and some simple assumptions regarding the cost improvements we would expect to see due to learning as the DACCS market grows. For detailed assumptions, please see Appendix A.

One possible critique of our procurement principles is the price ceiling of $600/ton, which is quite high relative to other climate strategies and could be seen as diverting funding from options with lower marginal abatement costs. However, it is important to note this price represents the highest costs the government could end up paying, while actual prices could be considerably lower. A key advantage of reverse auctions is that the bids are competitive; they respond to (and drive) decreases in DACCS costs as the industry scales, innovates, and gains experience. By starting with a high price, the government can enable expensive, emerging approaches to qualify, while being confident costs will decline as a robust DACCS market emerges. If we start with a low ceiling on bids, we could lock in one existing approach, at precisely the point when we need to be spurring innovation.

As demonstrated in Figure 5 below, the rate at which costs fall will play a large role in the number of DACCS plants deployed under any given policy. Competitive bidding processes, such as those employed by reverse auctions, will respond to these cost declines automatically. This in turn can help them to capture more CO_2 per dollar. In contrast, fixed incentives cannot respond to changes in DACCS costs and would risk overpaying for deployment, when that money could be better served driving emissions reductions elsewhere. Moreover, a policy mechanism that provides information about the rate at which DACCS costs fall may help policymakers understand how much effort to spend on DACCS relative to other CDR approaches.

FIGURE 5: Illustration of a DACCS learning curve vs. fixed policy incentives



Note: This chart illustrates a potential decline in the dollar per ton cost of DACCS for the first 250 plants. The solvent system costs used here are approximations for an average early-stage plant, based on the range of plant costs surveyed by World Resources Institute. The fixed $18000 PTC and $380 PTC with LCFS policies demonstrate how such fixed approaches will likely underpay for early DACCS and then overpay as costs decline. Cumulative overpayments are shaded in red for both policies.

Competition will create uncertainty for developers and financers, as reflected in the Stability ranking for this policy. It is also true that other individual policies (e.g., cash grants or direct payments) and policy packages (e.g., any of the options with an expanded PTC presented in Figure 4) would provide more price certainty in the near-term. However, given the urgent need to scale large quantities of DACCS, we think this uncertainty is outweighed by a mechanism with the potential to add new capacity cost-effectively. Moreover, as noted in Box 2, a reverse auction will take time to design and implement. 2023 is probably the earliest feasible start date for a robust program. In the meantime, other policy options should be pursued. For example, a reverse auction could overlap with an expanded 45Q tax credit. Other financing or enabling policies could also support developers in putting together credible bids. Such complementary roles are discussed further below. Ideally, decisive action in the next two years would help to continue driving down costs, demonstrating technologies, and financing a few DACCS facilities, laying the groundwork for a robust set of bids in the first auction period by expanding the pool of ready participants and technologies.

Finally, should DACCS reach maturity, minimize land use and energy impacts, and emerge as an important and viable tool for large-scale CDR, it makes sense for government to take a central role in shaping a robust DACCS industry. As we have noted several times in this paper, there is no market value for capturing and sequestering CO_2, but there is an immense social good.

Second-best policy options and considerations

Nearly every other policy package presented in Figure 4 could support some DACCS deployment, and some even provide similarly high value to developers when stacked together. However, there are potential feasibility and legality hurdles that lead us to believe these options are less viable. For example, one such option would be an expanded 45Q incentive (of up to $180 per ton) plus a 30% ITC. This policy combination has the benefit of building off an existing policy (45Q) and a very familiar policy approach (a 30% ITC). However, even if each policy has political support, there are not many examples in law today of firms being able to claim both a PTC and an ITC. Under the 2009 Recovery Act, for example, renewable energy projects were able to claim an ITC in lieu of the PTC, but not both. Similarly, the recent FY21 omnibus spending bill allows offshore wind projects to choose between the PTC or the ITC.[110] Unlike a reverse auction, this approach would not provide built-in cost efficiency, running the risk that the government would end up overpaying for any facilities built using these incentives, thus leaving additional emissions reductions on the table.

This does not mean that policies that cannot fully support DACCS construction and operation costs would not be helpful, particularly if these are the only politically feasible options in the near-term. Policies that enable DACCS developers to access low-cost debt – such as private activity bonds or DOE loans – or otherwise reduce capital costs can get plants off the ground and reduce the pressure on developers to finance their plants fully against future, and perhaps uncertain, revenue streams.

Enabling policies can also play an important role in unlocking the potential for other policies to drive deployment. With RD&D, we can drive down the costs of DACCS toward the bottom of the current break-even range shown in Figure 4, making more policy combinations tenable for developers and politically feasible. For instance, Figure 4 only represents a $50 PTC (45Q) and a $180 PTC, but it is possible that the politically achievable price point falls somewhere between the $50/ton value today and the $180/ton value discussed here. That value is more likely to be impactful if RD&D can buy down the cost of emerging DACCS technologies. Likewise, reducing barriers to accessing the subsurface and transporting CO_2 can maximize the near-term impact of financial incentives.

Finally, there is no real limit to the number of policies that could be combined to support near-term DACCS deployment. We recommend the following to policymakers pursuing other packages:

- **Reduce complexity.** The larger the number of policies required to provide enough revenue to deploy DACCS, the more complicated it is to juggle different revenue streams and political risks. This is particularly true when there are state, federal, or even local policies in play. This is an argument for just one or two high-value incentives, like a PTC, or for the government to pay for DACCS directly and remove the need for private-sector financing.

- **Use complementary tools.** With multiple incentives at play, it is important for companies – and for governments – to understand how they work together. If designed poorly, a policy package could generate a windfall for developers, phase in or out at different times, or create redundancies. A strong policy package will promote and coordinate complementary tools. An example of this could be synchronization of early stage R&D, DOE loans, and direct payments; as a DACCS technology leaves the lab, DOE loans can follow-on to finance the construction of first-of-a-kind facilities, then direct payments can ensure the project is commercially viable. This would be far more effective than, say, a developer piecing together a state LCFS, federal tax incentive, and international compliance credits to cover costs.

- **Make policies stackable – but don't double-count emissions.** In policy arenas with multiple tools in play at once, it can be hard to understand whether they can add together or if one must choose between them. For instance, the IRS may not allow a certain facility to claim multiple tax credits, or laws may be written at the federal level that preempt state incentives. Wherever possible, policymakers should look to design policies that are stackable and clearly communicate the conditions for doing so, so long as this does not undermine environmental integrity (i.e., by double-counting CO_2 in multiple markets).

Climeworks direct air capture and storage plant in Iceland.
Photo credit: Climeworks

Conclusion

Although we are far from gigatonne-scale CDR, and the appropriate set of CDR approaches remains uncertain, there are tested policy tools that can help to mature and deploy promising approaches, such as DACCS. Each of the policies explored in this paper could provide some level of short-term support. Some of these policies, such as an expanded PTC or government procurement programs, could provide critical funding for ongoing DACCS operation costs. Others, such as public competitions or DOE loans, might have less overall impact in driving deployment but could cover some of DACCS' upfront capital costs. Finally, enabling policies, such as RD&D and accelerating storage development, may only indirectly support DACCS deployment today, but should not be overlooked for their ability to lay the foundation for continued deployment tomorrow.

Our top recommendation is a reverse auction—a simple and efficient means of providing financial support for near-term DACCS growth. With a predictable procurement schedule and suitably long-term contracts to cover DACCS operations, a reverse auction can provide developers and the government with certainty as to the quantity of added DACCS capacity. Well-designed auctions could encourage competition between developers, which would likely minimize costs over time.

A second-best option is a combination of a production tax credit and a 30% investment tax credit, which would cover capital and operations costs by replicating and expanding time-tested incentives in the tax code. Ideally, one or both tax credits would be refundable. However, this approach raises questions about stackability and would be less likely to lead to a predictable level of DACCS deployment in a specific timeframe.

While we do not tackle them here, the importance of designing these policies with an eye to other environmental and social considerations, such as land use conflict or environmental justice concerns, cannot be overstated. And, beyond the near-term deployment policies, sustaining large-scale DACCS operations well into the latter half of the century may require DACCS and other CDR approaches to align with economy-wide climate policy.

Climeworks direct air capture plant.
Photo credit: Climeworks, Photo by Julia Dunlop

Appendix A

Reverse Auction Design

We built a simple tool to estimate the scope and budget for a reasonable first decade of a reverse auction program that offers 10-year contracts to DAC developers. Winning bidders would receive $/ton support for DACCS for the duration of the contract.

The tool relies on the following assumptions:

Air capture costs for the nth ton = Initial cost* [(1 – learning rate) ^ (ln(n)/ln (2))]

This function states that the $/ton capture costs will fall by a certain percent for every doubling of capacity. This is based on a modified version of Rhodium's 2019 analysis where cost declines are tied to the number of plants deployed. Additional parameters, such as a cost floor, are not included in our function, and would be important to consider when modeling later years of the auction policy.

We further assume that these cost declines will be reflected in the $/ton prices bid into the auction. If competition is successful, there should be some degree of price discovery.

Function inputs:

- Initial cost: $600/ton
- Learning rate:10% (Rhodium's most conservative rate).
- Initial existing capacity: 1,000 tons.

The supply of new capacity is determined by investor support

In order to estimate a timeline over which air capture costs could move down the cost curve, we assume a fixed annual budget of external investment. We then estimate how much additional capacity can be supplied at that budget by estimating the NPV of capital cost investments on a per-ton basis at a specific $/ton cost and discounted over a 10-year contract period. This allows us to estimate a justifiable growth rate for the industry that is high in the early years and levels off in later years.

Assumed annual investment budget: $100 million

NPV input:

- Discount rate: 5%
- Contract period: 10 years (as specified in reverse auction)
- Capital cost factor: .30 (i.e. the share of revenue goes to paying off capital costs.)

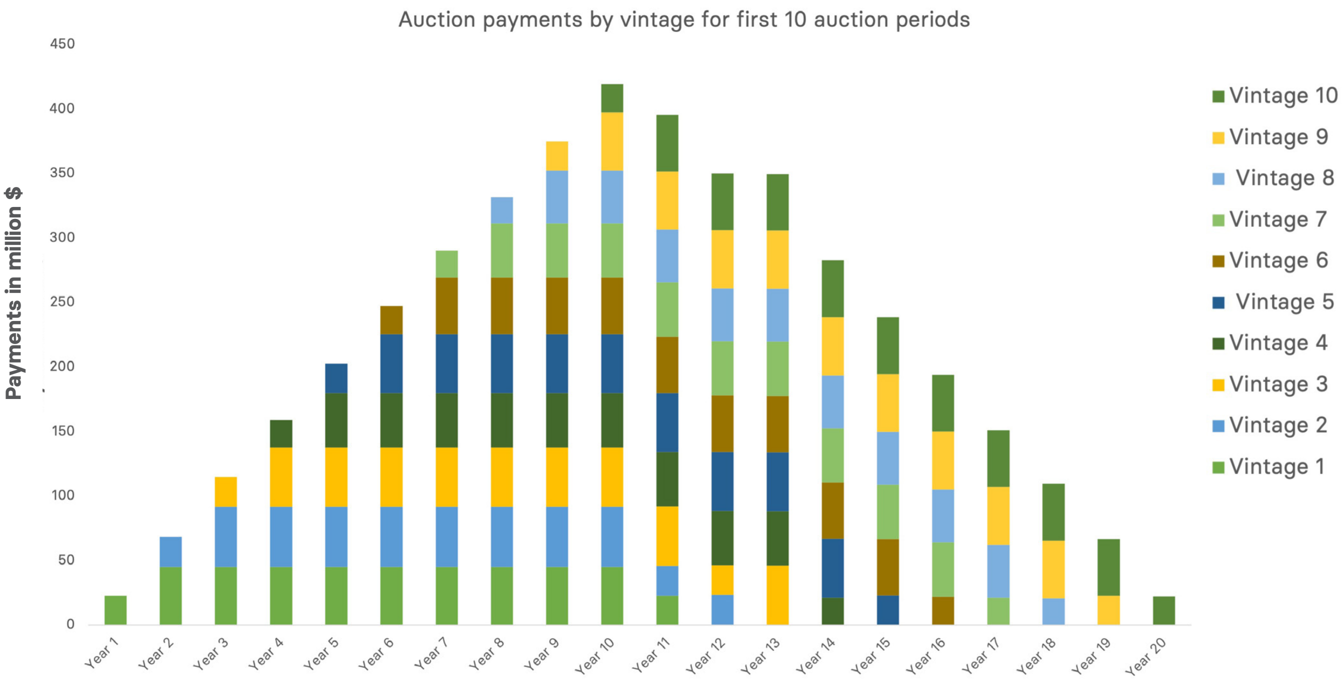
The following table summarizes the output of our tool:

Table A1: Auction program for first 10 years

Year	Auction Price ($/ton)	New Capacity (ton/end of year)	Cumulative Capacity (tons at start of year)	Annual Reverse Auction payments for new capacity (million $)	Cumulative Reverse Auction payments (million $)
Year 1	600	75,000	1,000	45	23
Year 2	311	150,000	76,000	47	68
Year 3	263	175,000	227,000	46	115
Year 4	241	175,000	402,000	42	159
Year 5	228	200,000	577,000	46	203
Year 6	218	200,000	777,000	44	247
Year 7	211	200,000	977,000	42	290
Year 8	205	200,000	1,177,000	41	332
Year 9	200	225,000	1,377,000	45	375
Year 10	195	225,000	1,600,000	44	419

These results are illustrative and assume annual auctions are perfectly subscribed based on our assessment of annual new capacity available at the projected $/ton cost of DAC. The annual reverse auction payments indicate how much the reverse auction program will pay out for each new vintage of capacity additions. The cumulative payments offer an estimate of how the total auction payments might be spent out. For simplicity, our tool assumes half of the awarded plants are built and operating by mid-year of the auction they won. Figure A1 summarizes these payments by vintage for the first 10 auctions.

Figure A1: Reverse auction payments by vintage



Note: This chart illustrates how auction payments will rise as contracts accumulate across auction periods and then fall as contracts phase out. The chart illustrates payments for the first ten vintage years, but the program could continue after that.

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