Clean Energy and Sustainability Accelerator

OPPORTUNITIES FOR LONG-TERM DEPLOYMENT

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Executive Summary

The year 2021 opens with urgent public policy imperatives to 1) address the economic ravages of COVID-19 in the immediate near term, particularly for low and moderate income ("LMI") communities that have suffered the most from both the direct and indirect impacts of the pandemic, and 2) concurrently and beyond, to resume efforts to decarbonize the economy within the next three decades. These goals are separate, but materially intertwined and mutually reinforcing, as policy makers have recognized for many years. As described further below, the proposed Clean Energy and Sustainability Accelerator (the "Accelerator") would be a federally funded, non-profit NGO with a mandate and the necessary financial resources and flexibility to pursue these goals at great speed and at large scale. The Coalition for Green Capital has sought the input of energy industry experts to help develop priorities and approaches that would optimize the Accelerator's ability to meet its short-term and long-term missions.

The Accelerator will pursue complementary short- and long-term missions in parallel, both beginning immediately. The **short-term mission** will be to provide immediate liquidity for economic recovery via clean energy investments. These investments will be chosen, where possible, to also improve equitable, social justice-restorative participation in the benefits of the clean energy transition (which has often missed LMI communities, upon whom climate and environmental quality burdens fall disproportionately). The short-term mission is described in detail in a complementary white paper prepared by economists at the Analysis Group led by Sue Tierney and Paul Hibbard entitled "Accelerating Job Growth and an Equitable Low-Carbon Energy Transition: The Role of the Clean Energy Accelerator." This white paper describes the Accelerator's long-term mission.

The Accelerator's **long-term mission** focuses on accelerating the rate of decarbonization over a period extending from as soon as possible to as many as 10 to 30 years in the future, through targeted financial support and risk-mitigating facilitations of commercially proven clean energy technologies. The logic is that as the economy returns to "normal" – presumably within a couple of years – and certainly thereafter, the most important thing we can do for decarbonization is accelerate adoption of currently available clean energy technologies that quickly reduce GHG emissions. "Decarbonization" would also be defined to continue prioritizing social justice goals over the long-term.

While much political debate about decarbonization policy involves setting very long-term goals like "80 by 50", in fact, early reductions in GHG emissions are in many ways more important than the eventual depth of reductions, because cumulative GHGs in the atmosphere are what cause warming, not the rate at which they are emitted in any given year (though both are important), as GHGs persist in the atmosphere for decades or longer). Accelerating decarbonization by a few years can result in less cumulative emissions than a slower decarbonization process that eventually resulted in lower annual emissions by 2050.

The pressure of time leads to another precept of the Accelerator's mission: a focus on commercially proven clean energy technologies. Basic research, pre-commercial R&D and the invention/ commercialization of new technologies will undoubtedly play a key role in achieving deep decarbonization. However, by definition, pre-commercial R&D is an uncertain process with little applicability to near- and medium-term decarbonization efforts, and generally not much, if any, near-term economic impact.[1] By contrast, many highly effective clean energy technologies exist today (or are close to commercialization), but we need to deploy them more quickly to obtain the near-term and long-term benefits of accelerated decarbonization. Many technologies are currently available that have a positive expected net present value, despite the fact they are not always being actively deployed and/or are being pursued well below the pace and level of adoption that is needed for material climate decarbonization.

To some degree, these impediments are due to classic economic failures (which are ultimately also matters of public policy)—e.g., decarbonization benefits are frequently not priced or even understood. Recent examples include lack of appetite for economy-wide or sectoral carbon taxes and considerable evidence that automotive customers are not generally aware of the cost and performance benefits of electric vehicles, likely delaying their adoption.

In the context of commercially proven technologies, the Accelerator would address remediable situations of under-investment that are due to frictional *institutional and financial* barriers, e.g., that are limiting how available benefits are perceived or shared or that involve untenable levels of risk relative to the risk tolerances of potential sponsors and private, for-profit financing entities. These types of barriers complicate the realization of the benefits of decarbonization investment, and are amenable to reconfiguration via a sophisticated intermediary like the Accelerator. The Accelerator could help by bearing certain risks that for-profit entities are unwilling to bear, offsetting side-effect transaction costs, and redistributing benefits in new ways, to "debottleneck" private capital investment in otherwise attractive or nearly attractive clean energy projects.

[1] As it turns out, R&D is also already well-supported from an institutional standpoint, such as via the U.S. Department of Energy's ARPA-E.

Through these approaches, the Accelerator could more cost-effectively accelerate decarbonization than by simply subsidizing clean energy technologies to the point where they would reach a positive NPV or fast payback. By finding such niche opportunities that primarily need "debottlenecking" or are near a tipping point of readiness for wider use, the Accelerator can be used to leverage other private capital that is already available and interested but reluctant to dive in.[2]

We have identified a number of institutional and financial barriers that we have observed in our energy market consulting experience. For instance, there are "chicken or egg" situations whereby complementary clean technologies are waiting for each other to take off — such as electric vehicles and charging infrastructure — yet both are needed and well understood. The chicken or egg problem can also manifest itself as an apparent lack of demand that may consist equally of a lack of willingness to supply, such as in the case of technology deployments that have not yet achieved required economies of scale. Building retrofits in low-income communities may face this kind of barrier. Several such barriers, their associated effects, and their potential mitigation via the Accelerator are examined in a series of examples presented below in section IV. They are all amenable to relief by flexible and creative uses of an Accelerator and its financial resources.

The Accelerator would be a new kind of publicly-backed NGO with a defined mission and a finite life (perhaps up to 20-30 years, but with the majority of its projects established in the next few years, followed by administrative monitoring in the out-years) to foster more rapid, ready for immediate or very near-term deployment, socially conscious decarbonization. The Accelerator would accomplish its defined mission by such mechanisms as targeted financing, creating financial guarantees/insurance, fostering complementary projects to offset distributional imbalances, and providing hedging – all aimed at removing bottlenecks and nudging select projects over "tipping points" to unlock private capital for near-term decarbonization opportunities.

Again, the intent of the Accelerator would be to 'lever' or 'crowd-in' private capital investment with targeted funding and support from the Accelerator, rather than just having the Accelerator assume the full or partial cost of a project to improve its economics. This means that the projects supported by the Accelerator should have financial multipliers of sorts, in addition to their other indirect economic benefits. Where possible, the Accelerator's goals will be pursued via market-based solicitations for decarbonization projects that can be evaluated not only by cost metrics

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[2] Importantly, catalyzing available technology adoption (at industrial and individual scale) will also have continuing early recovery benefits and may facilitate more rapid innovation and cost reductions (e.g., from learning curves and reaching commercial scale) in the underlying technologies.

but also for size and timeliness of environmental and economic benefits measured along several dimensions of decarbonization, social justice, risk, developer financial and strategic commitments, as well as equitable considerations of benefits accruing widely throughout the economy. In this way, the Accelerator would be somewhat similar to already existing "Green Banks" at the state and local levels, but with key differences, including:

- Much larger scale (perhaps $100B vs. about $3B in aggregate Green Bank financing to date), and ability to address multi-state impediments;
- Research capabilities to evaluate marginal, facilitating capital needs (not total project needs);
- Ability to make investments based on whether a project will provide significant public benefits (e.g., reduced or avoided emissions of GHGs and other pollutants harmful to public health); not constrained to earning a return of and on every dollar invested; and
- Some administrative capacity to help price and manage market and policy risks over time (e.g. trading desks).

In particular, while we expect the Accelerator would reinforce the existing role of state and local Green Banks, its distinctive mission would be to dramatically expand beyond the typical Green Bank mandate —in dollars as well as scope — seeking out and promoting larger scale step-changes in clean technology deployment and decarbonization.[3]

In summary, the Accelerator is expected to be a powerful mechanism for gaining several kinds of complementary benefits, in economic recovery, decarbonization, social justice, and market enhancement. The design below is not meant to be an explicit plan for its operational approach or priorities, but rather to demonstrate how and why it is an important policy vehicle for the current situation.

[3] Most of the activity of existing state and local Green Banks appears to be targeted at the end-use consumer or small project level, which definitely has needs including some, which the Accelerator could also address. However, these applications tend to exclude the larger utility scale, commercial and industrial applications that might give larger GHG impacts sooner. E.g., the New York Green Bank, by far the largest and best funded of the existing Green Banks in the US, has a limit of $50mm per project. (See New York Green Bank Annual Business Plan 2020-2021 (https://greenbank.ny.gov/Resources/Public-Filings)

I. Overview and Motivation

The proposed Accelerator has two broad missions – overlapping but over different timeframes – and somewhat different criteria for investment.

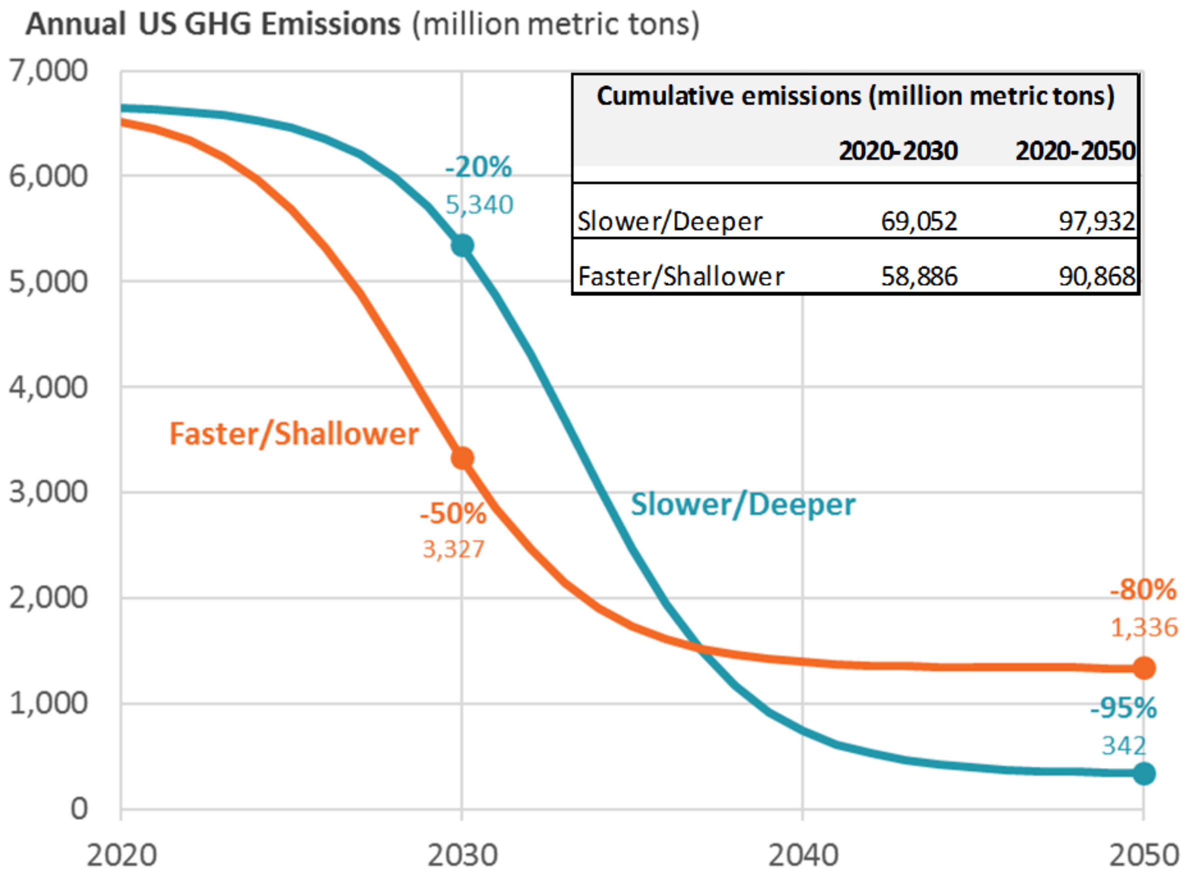
The first mission is to provide immediate liquidity for economic recovery via clean energy investment. This investment will also improve equitable, social justice-restorative participation in the benefits of green technologies (which have often missed low-income communities, or worse, climate and environmental quality burdens have fallen disproportionately on less affluent citizens). Investments should provide substantial macroeconomic multipliers to help repair the economy within the next two years. This mission is evaluated in a separate white paper prepared by Analysis Group, entitled "Accelerating Job Growth and an Equitable Low-Carbon Energy Transition: The Role of the Clean Energy Accelerator."

The parallel second mission is to accelerate the rate of decarbonization over a longer period through targeted financial support and risk-mitigating facilitations of available technologies. As and after the economy returns "back to normal" – presumably within a couple of years – the most important thing we can do for climate protection is rapid adoption of clean technologies that quickly reduce GHG emissions. **This white paper focuses exclusively on how the Accelerator can serve this longer-term purpose**.

Why focus on accelerating decarbonization, rather than, for example, supporting novel, "infant" technologies that may be needed to reach net zero emissions? In short, this is because slowing the rate of climate change depends more so on decarbonizing *more rapidly* than eventually decarbonizing *more deeply*. Cumulative GHGs in the atmosphere are what cause warming, not the rate at which they are emitted because they persist in the atmosphere for decades or longer. Accelerating decarbonization by a few years can result in less cumulative emissions for many of the years between now and a "decarbonized" 2050 end state.

FIGURE 1 illustrates this important prioritization by comparing the impact of two decarbonization trajectories on cumulative emissions: one with a faster decarbonization trajectory but more end-state emissions, and a second slower decarbonization but a more deeply decarbonized end state. The faster of the two decarbonization efforts produces a 7% reduction in cumulative GHGs in the atmosphere (from the US) by 2050, despite a higher end-state emissions rate.

FIGURE 1: ILLUSTRATING THE BENEFITS OF ACCELERATING DECARBONIZATION
IN THIS EXAMPLE, ACCELERATING DECARBONIZATION RESULTS IN 7% FEWER CUMULATIVE EMISSIONS DESPITE INCREASED EMISSIONS BY 2050

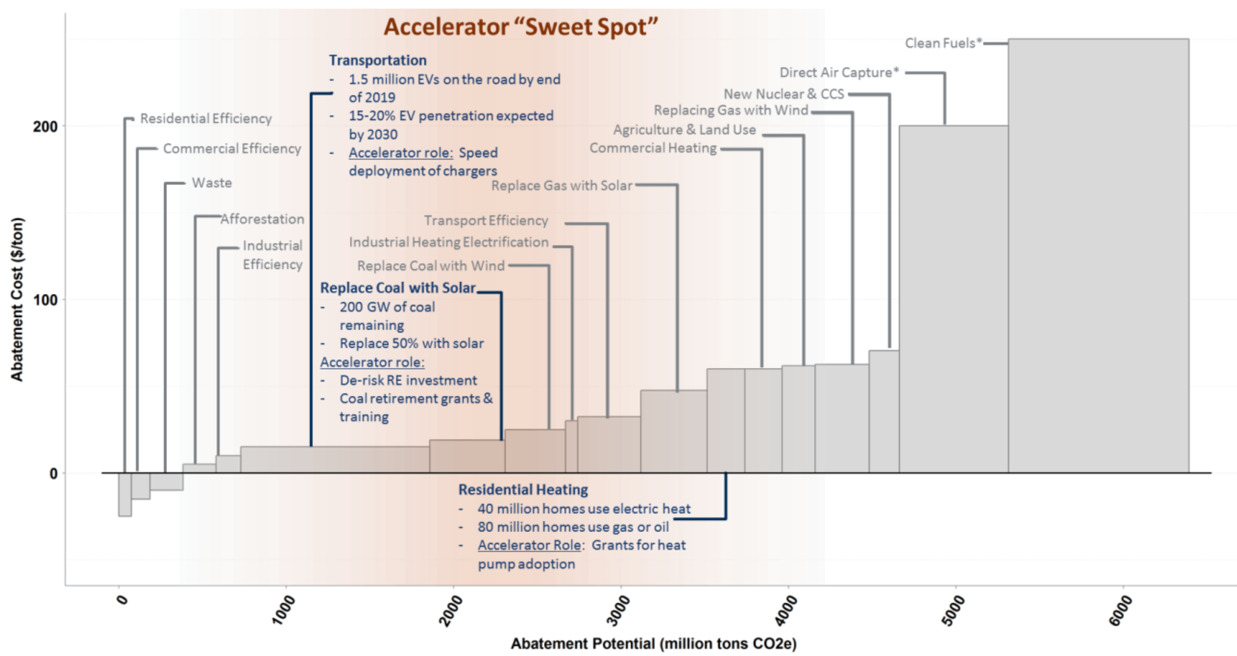


Another virtue of accelerating decarbonization is that it does not require much pre-commercial R&D or inventing of new technologies – we have much of the necessary technology, but we need to deploy it more quickly. Many decarbonization technologies are available today that have a positive expected net present value but are not being deployed at a pace sufficient to achieve material climate protection. Catalyzing available technology adoption (at industrial and individual scale) will also have continuing early benefits in economic recovery and may facilitate more rapid innovation and cost reductions (e.g., from learning curves and reaching commercial scale) in the underlying technologies.

A key question is how the Accelerator could most effectively deploy its capital and resources to speed decarbonization. That will require identifying not just the technical opportunities but determining which are constrained from significant adoption, as well as how much and what types of financial support may be needed to "debottleneck" those promising technologies. To appreciate the diversity of the technology and cost landscape, Brattle has developed a rough supply curve for visualizing the potential opportunities for decarbonization, ordered by cost per ton of abatement, that add up to 96% of the current level of annual US CO_2 emissions (about 6.4GT/year CO_2 from the US, around 1/6th of about 38GT/year for the world). These results are shown in

FIGURE 2 below.

FIGURE 2: ILLUSTRATIVE U.S. GHG ABATEMENT COST CURVE
ILLUSTRATING THE ACCELERATOR'S "SWEET SPOT" IN SPEEDING DECARBONIZATION



* These technologies have highly uncertain costs, with uncertainty of $100/ton or more (e.g. clean fuels sometimes estimated at around $600/ton).

Sources: See appendix for assumptions and sources

First, a few caveats. The shape of this curve should be understood to be very approximate and indicative (and amenable to future refinement) rather than precise or prescriptive. Each "bar" in the curve for a given supply technology or activity depicts rough average costs and potential, when in fact each is composed of numerous different activities having widely varying costs per ton of abatement. For instance, there are many types of energy efficiency (EE) widely differing costs and benefits. The high end of the curve becomes more speculative; however, these measures are the least likely to be applicable to the Accelerator given their high costs. For instance, air capture's cost per ton avoided will be based on the future cost of natural gas, which is uncertain in the long- run. Perhaps a more interesting example is the replacement of coal-fired generation with renewables, shown roughly in the middle of this graph. On average this might involve some net cost, as is shown in the chart, but in some instances coal-to-solar switching may reduce costs, i.e., the replacement power is cheaper than the to-go costs of the retired asset.

Another simplification in this supply display is that several of the supply options are interdependent. In particular, electrification of end-uses will create a new requirement for some combination of clean electricity, clean fuels, or direct air decarbonization. Here those conversions are shown with the implicit assumption of clean electricity as the replacement (while what is shown for decarbonizing the electric sector is only for existing generation, before new, large-scale electrification.).

However, the general shape of this abatement curve is indicative of the environmental and economic situation that the Accelerator could face:

- At one extreme, there are a few activities (mostly associated with conservation) which are often so economical that they would save money rather than impose net new costs.
- At the other extreme are activities or technologies that are more novel and speculative as to their effectiveness and/or cost. They may be in research stages or have yet to be commercialized at scale.[4] These technologies may be needed to completely decarbonize the economy, but are not needed (or available) to accelerate decarbonization.
- In the middle is a broad swath of approaches that have relatively modest abatement costs, generally involving proven technologies, which may provide the lion's share of GHG abatement over the next 10–20 years.

We have shaded the middle portion of this curve; abatement measures in this "Goldilocks Zone" are most likely to be of interest to the Accelerator, as they are (1) ready for immediate or very near-term deployment, (2) significant in scale, and (3) perhaps amenable to leverage-able "nudging" of potential investors.

Why is the Accelerator needed to accelerate deployment of these Goldilocks abatement measures? What is insufficient about conventional financing? Although some activity is occurring in these areas, institutional and financial bottlenecks are often slowing the clean energy transformation. As was noted above, and which is studied below for a few specific case studies that could be attractive early targets of the Accelerator, several currently available clean energy

[4] Several promising decarbonization technologies are emerging at the RD&D stages, currently with few prototypes but often quite poor economics at these early, pre-scale levels of adoption. These include RNG, H2, CCS, and direct air capture, shown at the far right of Figure 2 above. These technologies are likely to be quite important in the long run (particularly, for reducing the reliability and resilience performance problems and high cost issues that could arise with only reliance on very deep stacks of wind and solar plus storage for the last 10-20% of decarbonization). However, at present they are mostly not "shovel ready" or likely to support economic recovery or significant GHG savings in the near term. Accordingly, these will be largely ignored here as belonging to the purposes of other public policy and venture financing effort. That is not to say they could not be part of the Accelerator's purview, but that we would not expect them to be central to it.

technologies have sufficient social and even private net benefits to be economically justified but are not being pursued significantly.

To some degree, these impediments are due to classic economic failures – especially positive social externalities of benefits not being priced or privatize-able, or lack of good customer (or even developer) information/understanding of the costs or benefits of the alternatives. Recent examples include lack of appetite for economy-wide or sectoral carbon taxes and considerable evidence that the automotive customers are not generally aware of the cost and performance benefits of electric vehicles, hence delaying their adoption.

These classic externality problems are often amenable to public policies like pricing of carbon emissions and information campaigns (although these measures have yet to be widely adopted). We assume (hope) that carbon pricing may happen, though that is not taken as a premise in this analysis. Even if it is widely adopted, it is most likely to be effective in encouraging electric industry conversions, with much less impact on transportation, personal and commercial energy end-uses, and agricultural – which are now the sectors responsible for the large majority of US GHG emissions.[5] The proposed role for the Accelerator is not to simply fill that externality gap for decarbonization technologies or to directly subsidize their deployment. Such funding may be socially appropriate, but is not an innovative or multiplicative use of the Accelerator, unless/except occasionally where there may be some nearly economical alternatives that simply need a nudge to cross over some tipping point.

In contrast to those classic economic failures, there appear to be many other situations of under-investment that are more due to institutional and financial barriers that limit how available benefits are perceived or shared, or that involve untenable levels of risk relative to the risk tolerances of potential sponsors and private, for-profit financing entities. *These are amenable to reconfiguration via a sophisticated intermediary like the proposed Accelerator*. In this role, the Accelerator can "debottleneck" private capital investment in otherwise attractive or nearly

5 GHG pricing is likely to be much more impactful in the electric industry than elsewhere because electricity generation is extremely carbon-intensive when fossil fuels are used (making carbon prices a substantial part of the cost of power). In contrast, fuel use for commercial and personal purposes is very low in carbon intensity relative to the value of those activities, products, and consumption behaviors. As a result, an enormous, politically implausible carbon price would be required to induce much investment or behavioral change in these non-electric sectors. (For instance, a \$100/ton CO_2 price would raise the price of gasoline by only about \$1.00/gallon, still well within the range of normal gasoline price variation.) This is important to the Accelerator because it means a great deal of the incentive for non-electricity decarbonization will come from legal mandates, tax incentives, and technology standards that will require or involve substantial, possibly complex financing as well as costly and controversial transitions from old to new. Even a very broad carbon tax will not eliminate the kinds of barriers discussed infra that arise from risk, uneven distribution of costs and benefits, and liquidity problems for installing green infrastructure.

attractive clean energy projects by bearing certain risks that for-profit entities are unwilling to bear, offsetting side-effect transaction costs and redistributing benefits in new ways. Ideally, this can be done at a much lower cost than the cost of simply subsidizing the cost to deploy clean energy technologies to the point of them reaching a positive NPV or fast payback. By finding such niche opportunities, the Accelerator can be used to leverage other private capital that is already available and somewhat interested but reluctant to dive in.

II. Barriers Amenable to Debottlenecking

A. Barrier 1: Limited Risk Tolerance

Sometimes the pool of willing investors and developers may be small and/or have limited ability to bear the full risk of a project even where its economic return at the expected value of future conditions is favorable. Typically, in such situations, the range and uncertainty of possible outcomes is wide, they are difficult to forecast or hedge, and often they are dependent on the evolution of future public policies that could alter priorities or mechanisms abruptly. Such high-risk conditions strongly dampen willingness or even ability to invest.

Examples include:

1. **Community solar developers** have sometimes expressed unwillingness (or inability) to develop sites absent long-term subscriptions from customers. However, that form of subscription is not well aligned with the likely population interested in community solar, such as individual and commercial renters with uncertain horizons of commitment to the local area.
2. **Merchant utility-scale PV** often appears valuable against projected marginal costs for energy, capacity and RECs (if available), but developers—and in particular their lenders—are frequently reluctant to pursue these projects absent backing from a long-term utility PPA.[6]
3. **Energy storage** may be under-invested by private developers absent economic assurances. This is largely due to the fact that it is very complex to optimally use and its value in markets

[6] A few large solar and wind projects are being financed on a merchant basis (with medium term hedges) in some RTO regions, but not in vertically integrated markets without wholesale price visibility. https://solarmagazine.com/merchant-solar-projects-rise-as-contract-prices-record-lows/

is very sensitive to risk factors such as over/under-development of other, competing storage assets and the extent of entry by renewables, dynamic fuel prices, and public policies that could change market conditions (such as GHG price management).

Affected sectors could include end-use customers, renewable energy and storage developers, and utilities.

B. Barrier 2: Insufficient Liquidity

Some decarbonization and efficiency investments have good expected benefits for the private owner/user, but they involve large upfront financial investments to execute. One well-established example is residential solar PV, where the installation costs that might deter homeowner adoption have been increasingly mitigated by financing via securitization of bundled solar PPAs. Another important example with increasing relevance is end-use electrification, which will be a huge and necessary component of decarbonization, e.g., of home or small commercial HVAC and water heating, as well as transportation (electric vehicles). Conversion to these technologies can be extremely capital-intensive for the necessary equipment like heat pumps or new electric hot water heaters replacing viable gas units. Upgrades to the building envelope may be needed in some circumstances, e.g. to create air ducts in a home with forced hot water heat. Financing on favorable terms (or partial subsidization) from the Accelerator might nudge these into material adoption. It may also help establish the supply industry for bulk provision of these technologies.

Affected sectors could include residential & small commercial end-use customers, the municipal, university, school and hospital (MUSH) sector, and energy service companies.

C. Barrier 3: Misalignment of Benefits and Costs, or Adverse Side-Effects

Some green projects have benefits that are diffused or not readily shared with all affected parties, especially where some of the implementation costs are more localized than the benefits, and/or the attractive project involves adverse side effects. This can create disincentives for the host parties to pursue those projects, even where they are net beneficial to them. Examples include:

1. **"Premature" coal retirements, replaced with renewables, storage and peakers before the coal plants reach engineering obsolescence and are fully depreciated.** This opportunity is among the "low hanging fruit" of decarbonization, possibly having negative costs and large amounts of GHG abatement. However, coal retirements create stranded costs for the

owner-utility, and it impose unemployment for plant employees (as well as the associated social disruption to their townships). Those side effects may be enough to discourage both plant owners and regulators from pursuing retirements. These constraints can be especially problematic for non-IOU utilities like municipalities and coops that rely heavily on debt capitalization. The Accelerator might help absorb training and relocation costs for displaced workers, or extend stranded costs mitigation financing terms (such as low interest rates, or credit enhancement for utility securitization of those costs).

2. **Transmission lines to reach remote renewables.** In order to interconnect large quantities of renewables from the most productive regions, transmission lines may have to span huge distances across areas that will not be consuming the clean power. These transmission lines can create NIMBY problems for affected residents and communities that do not directly share in the benefits. Large-scale offshore wind may involve the related problem of forcing huge grid adjustments on the distribution scale power systems where the power would be landed (exacerbated where landing regions function as more of a gateway than where that wind power will be primarily used).

Affected sectors could include IOUs, coops, municipal utilities, transmission developers, end-use customers, and affected communities.

D. Barrier 4: Chicken-or-Egg Problems

Chicken-or-egg problems arise when multiple types of changes have to occur in order to gain critical adoption, where each of the needed changes is dependent on the others. A good example is electric vehicles, where supply and demand are held back in part by lack of charging infrastructure – while that infrastructure will not be built in the needed quantities absent more EV ownership. This conundrum can be solved in principle by public support for some of the infrastructure (or utility development and ownership), but even that involves costs being imposed socially for the benefit of a portion of society who will be the immediate users.[7] The Accelerator could help socialize that problem more broadly.

Some types of distributed energy resource (DER) infrastructure support may have similar problems. The type and timing of system upgrades needed (such as voltage reinforcement or flow controls) are not economical unless/until a large portion of customers on a given circuit

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7 EV owners will increase the load on the electric system and will pay more for electricity, but not necessarily their share if some of the associated capital investments are socialized in ratebase. In contrast, those customers will enjoy fuel savings for their automobile that more than offset their incremental electric expenses, while the other non-EV customers will not have that benefit.

participate, but a critical mass of customers may not be yet ready to do so. In the meantime, the upgrades are too expensive to be justified for a small number of participants. Carbon capture and storage (CCS) technologies discussed below in Barrier 6 may also have chicken-or-egg development hurdles, whereby the offtake pipelines and storage will not be developed until there are several CCS power plants, and vice versa. Likewise, some aspects of clean energy development for low-income neighborhoods may be impeded by chicken/egg problems. For instance, those communities may be perceived by developers as unlikely to achieve commercial scale, or too risky, or having other economic and infrastructure needs that supersede the new energy technologies in priority – even though those customers would benefit economically from the upgrades. As a result, there may be few first movers aspiring to overcome these perceptions.

Affected sectors could include end-use customers, renewable and transmission developers, utilities, governments, and engineering technology providers.

E. Barrier 5: Underserved Market Sectors

In nearly all decarbonization opportunities, we begin with the presumption that competitive markets can and will supply a considerable portion of the necessary infrastructure. However, there are likely to be sectors of the customer base that will tend to be bypassed or overlooked by competitive markets, especially low-income customers and those in economically depressed regions that may appear to have too many unrelated (non-energy) risks for developers. A 2020 LBNL report finds that households with incomes below the national average are almost three times less likely to adopt rooftop PV than those with incomes above the average.[8] Additionally, they conclude that interventions like LMI-targeted incentives and property-assessed clean energy financing (PACE) are associated with more equitable PV adoption, illustrating another example of the Accelerator's potential to increase renewable adoption across income levels.[9] Incentive lending or contract backup-guarantees to developers willing to confront these circumstances would be a possible helpful use of the Accelerator.

8 There are many reasons for why low-income customers may not consume as much energy improvements technology, despite energy being a larger part of their budget burden, including less home ownership. However, a study in several countries of the EU shows that that tendency to under-consume persists even when home ownership is corrected, but that support mechanisms can help remedy that imbalance. *See* Joachim Schleich, "Energy efficient technology adoption in low-income households in the European Union – What is the evidence?" *Energy Policy*, Volume 125, February 2019, pages 196-206, https://www.sciencedirect.com/science/article/abs/pii/S0301421518307158?via%3Dihub.

9 Eric O'Shaughnessy, et al., "The Impacts of Policies and Business Models on Income Equity in Rooftop Solar Adoption," Lawrence Berkeley National Laboratory, December 2020, https://eta-publications.lbl.gov/sites/default/files/cesa_ne_webinar.pdf.

Another circumstance that markets tend to underserve is where the benefits of the needed assets are "peak" in nature, such as resiliency or reliability to address rare conditions. Absent policy support, such benefits are too infrequent and idiosyncratic in size and value to fund development. For instance, some portion of electric charging sufficient to handle Thanksgiving weekend traffic will have a low average utilization factor except under those extremes. Here again, funding subsidies could be a beneficial Accelerator use.

Community initiatives that provide public benefits—such as addressing urban "heat islands" by reducing dark surfaces and adding vegetation[10]—may also be overlooked, owing to ambiguity about ownership and return on investment.

Affected sectors could include LMI and/or low-density households/ communities.

F. Barrier 6: Long-Run Value Needing Near-term Market Priming

Right now, decarbonization of the electric power sector is enjoying an economic renaissance because large-scale renewable generation has fallen in cost so much, while older fossil plants are experiencing high maintenance and upgrade costs. However, even if renewables and storage continue to decline in costs for many years, they have a pending, inherent disadvantage for deep decarbonization: They tend to produce power at roughly the same time and are not controllable (except by curtailment). This means that they decline in marginal value to the power system, the more of them there are. They begin to crowd each other out and they push the peak load for power to off-renewable hours, such as early evening after the sun has set. Storage is a good technical fix for this, but to fill it there must be a comparable amount of renewable capacity in excess of immediate load available for filling the storage, so it becomes a 2-for-1 MW overbuild which can be expensive. Worse, we do not currently have storage technologies that are suitable or economical for very long periods of renewable unavailability, such as a few days of time that may occur with low wind and solar. In those times, dispatchable clean energy with an unlimited energy reservoir (i.e. a conventional power plant with cleaned up emissions or with cleaned up fuel) would be very attractive.

This "resiliency" problem during "renewable droughts" is very difficult to evaluate and also costly to solve, as it involves maintaining adequate capacity for rare but very consequential periods of a few days or more when power demands may be high but renewable power output very low.

10 These "smart surface" initiatives are described in more detail in the white paper prepared by Analysis Group.

Several recent studies have shown that as we approach 80% or more decarbonization, having clean dispatchable power can be much cheaper than relying on deeper layers of renewables and storage. For instance, The Brattle Group has recently found for New England that a system with dispatchable clean power resources could have annual costs roughly half as great as a system composed entirely of intermittent renewables plus storage.[11] (This topic is explored in more detail in Section IV.F below.)

The best available clean dispatchable solutions currently known are carbon capture and storage (CCS) at coal and gas plants (which can achieve 99% decarbonization, and at gas plants barely altering the flexibility of the units for load following and cycling), renewable gas (RNG from biowaste and agricultural processing), hydrogen (H^2), and potentially, small, advanced modular nuclear reactors (AMRs). Some of these are in their technological infancy, hence not so well suited to the Accelerator (esp., AMRs and H^2). Some technologies such as CCS and RNG are sufficiently proven to attract considerable commercial interest, but they remain impaired because their current economics are out of the money compared to renewables – even though their long run economics are already in the money, even at current costs.[12] In a study on maintaining reliability for the New England power grid while decarbonizing the region by 80% by 2050, E3 and EFI found that "the availability of low-carbon firm generation technologies – such as advanced nuclear or natural gas with CCS – could provide significant cost savings and reduce the pressure of renewable development on New England's lands and coastal waters." Specifically, their modeling showed that the incremental cost to move from 50% clean electricity to 95% fell roughly in half if natural gas with CCS were available, and it declined further if advanced nuclear technology were also available at scale.[13] However, a gap between their current and future value persists and is preventing them from being developed; but *if they are neglected now they will not be present later when we need them most.*

CCS and RNG may also be especially important politically to gaining support for a national decarbonization infrastructure policy, because they provide a mechanism for fossil-fuel intensive regions to embrace and participate in clean energy goals without loss of jobs. They may also help avoid very large electric transmission buildouts (very costly and very unpopular, as noted

[11] Frank Graves, Kasparas Spokas, Katie, Mansur, and Shreeansh Agrawal, "Opportunities and Challenges for CCUS in the Power Sector," November 16, 2020, https://brattlefiles.blob.core.windows.net/files/20506_opportunities_and_challenges_for_ccus_in_the_power_sector.pdf.

[12] These emerging technologies experience the type of chicken-or-egg problems discussed above.

[13] E3 & EFI, "Net-Zero New England: Ensuring Electric Reliability in a Low-Carbon Future", E3 & EFI, November 2020, https://www.ethree.com/wp-content/uploads/2020/11/E3-EFI_Report-New-England-Reliability-Under-Deep-Decarbonization_Full-Report_11-17-2020_Release.pdf.

elsewhere herein) that would otherwise be required for broad geographic diversity to help overcome the renewable resiliency difficulties. Thus, the Accelerator may be useful in helping nudge climate-skeptical regions to retrofit some of their fossil plants, rather than have them be displaced by renewables. This could help end the "red-blue" divide in climate policy. Both RNG and CCS are also suitable for decarbonization of the high-heat portions of the industrial sector of the economy (such as cement, refining, and chemical processing), which are responsible for almost as much CO_2 emissions as the electric power sector itself, and which cannot readily be switched over to electric power for their manufacturing processes.

Affected sectors could include engineering technology providers, electric utilities, gas LDCs and midstream pipelines, and fossil fuel suppliers.

FIGURE 3 below summarizes this diversity of needs and barriers along different links in the supply chain of decarbonization. It is worth re-emphasizing that a significant challenge for the Accelerator will be identifying which types of barriers are most amenable to cost-effective mitigation. *This determination will require a fair amount of institutional knowledge and economic evaluation expertise, perhaps considerably more than a conventional lender would bring.* By the same token, that expertise will also allow the Accelerator to be more than just a large, Green Bank-style lender, but also a risk-bearing participant and advisor in the success (or tribulations) of some of its ventures.

FIGURE 3: DIVERSITY OF NEEDS AND BARRIERS ACROSS DECARBONIZATION SUPPLY CHAIN

BARRIERS	DESCRIPTION	SUBOPTIMIZED CLEAN ENERGY INVESTMENTS	AFFECTED SECTORS	POTENTIAL ACCELERATOR ROLE
1 **Limited Risk Tolerance for Full Investment**	*Market volatility outweighs expected benefit.* **End-users or investors may have limited ability to bear risk** even if economics make sense. This may result from scale mismatches, lack of hedging or insurance, or exposure to public policy shifts.	Community solar absent long-term subscriptions. Merchant utility scale renewables facing long-term REC and energy value uncertainty. Storage operating in highly volatile market conditions without long-term contracting opportunities.	End-use customers, renewable energy and storage developers, energy service companies, and utilities.	Reduce frictions through acquisition, standardization, and risk-subsidization. Firm up revenue streams; supply credit enhancement; provide low-cost risk bearing capital. **See Example A:** De-Risking Community Solar **See Example B:** De-Risking Merchant Renewables
2 **Insufficient Liquidity**	*High front-loaded investment requirements.* **Conversion to clean energy technologies can be extremely capital-intensive** for residences or small commercial, and government entities. Investment may include building modification as well as equipment itself.	End-use electrification (home or small commercial HVAC and water heating, as well as electric vehicles). Commercial building envelopes/ smart surfaces. Distributed energy resources like rooftop solar, especially for LMI customers.	Residential & small commercial end-use customers; municipal, university, school and hospital (MUSH) sector; energy service companies.	Finance or subsidize upfront costs. Help rationalize (e.g. scale up) equipment supply industries. **See Example D:** Building Retrofits and Electrification
3 **Misalignment of Benefits and Costs, or Adverse Side-Effects**	*Socialized benefits incur local costs.* **Some green projects have benefits that are diffused or not readily shared with all affected parties**, esp. where some of the implementation costs are more localized than the benefits, and/or the attractive project involves adverse side-effects.	Early coal plant retirements. Long-distance transmission for renewables.	IOUs, Coops, munis, commercial customers, transmission developers, end-use customers, affected communities.	Distribute grants to recover stranded costs and mitigate Design programs to redistribute benefits or induce complementary, additional projects that offset adverse side effects. **See Example C:** Coal Retirement **See Example E:** Transmission Expansion

BARRIERS	DESCRIPTION	SUBOPTIMIZED CLEAN ENERGY INVESTMENTS	AFFECTED SECTORS	POTENTIAL ACCELERATOR ROLE
4 **Chicken-or-Egg Problems**	*Critical mass of infrastructure to support adoption.* **Problems arise when multiple types of changes have to occur in order to gain critical adoption**, where each of the needed changes is dependent on the others. Investors may not take "build it and they will come" risk.	EV charging infrastructure Distribution system upgrades for extensive DER penetration and improve grid resiliency System upgrades for utility scale renewable interconnections Transmission serving offshore wind	End-use customers, renewable and transmission developers, utilities, governments, engineering technology providers.	Target threshold infrastructure requirement, underwrite initial costs, and transition to market. **See Example D:** Building Retrofits and Electrification **See Example E:** Transmission Expansion
5 **Underserved Market Sectors**	*Applications that lack economic compensation* There are likely to **be sectors of the customer base that will be bypassed or overlooked** by competitive market participants because costs or risks are too high.	Infrastructure (such as EV charging) requiring overbuild, peaking characteristics, or subsidies. Smart surfaces (reducing dark surfaces and adding vegetation in urban "heat islands").	LMI and/or low-density households/ communities.	Grants and subsidies to support investment in LMI communities and for locations that could experience occasional extreme peaks but not much routine traffic **See Example D:** Building Retrofits and Electrification
6 **Long-Run Value Needing Near-term Market Priming**	*Low-carbon supports for renewable intermittency* Renewables, even if they produce cheapest energy, are intermittent and tend to produce power at concentrated times of day. **As renewables gain more market penetration, this will require developing the best supporting technologies to address renewable downtimes.**	Long duration storage. Carbon capture and storage. Renewable natural gas. Repurposed gas delivery infrastructure.	Engineering technology providers, electric utilities, gas LDCs and midstream pipelines, fossil fuel suppliers.	Support to help achieve closer cost parity with renewables and storage today, as well as repurposing infrastructure, taking into account the present value benefits in the future. **See Example F:** CCS and RNG Facilitation

III. The Accelerator Solution

The Accelerator would be a new kind of publicly-backed NGO to foster more rapid, ready for immediate or very near-term deployment, socially conscious decarbonization. The Accelerator would have a defined mission and a finite life (perhaps up to 20-30 years, but with the majority of its projects established in the near and medium term, followed by administrative monitoring in the out-years). The Accelerator would accomplish its mission by providing targeted financing, creating financial guarantees/insurance, and providing hedging, all aimed at removing bottlenecks and nudging select projects over ”tipping points” to unlock private capital for near-term decarbonization opportunities. The goal of the fund would be to ‘lever’ or ‘crowd-in’ private capital investment with targeted funding and support from the Accelerator, rather than just having the Accelerator assume the full or partial cost of a project to improve its economics. This means that the projects supported by the Accelerator should have financial multipliers of sorts, in addition to their other indirect economic benefits. In this way, the Accelerator would be somewhat similar to already existing “Green Banks” at the state and local levels, but with key differences, including:

- Much larger scale (perhaps $100B vs. about $3B in aggregate Green Bank financing to date), and ability to address multi-state impediments;
- Research capabilities to evaluate marginal, facilitating capital needs (not total project needs);
- Ability to make investments based on whether a project will provide significant public benefits (e.g., reduced or avoided emissions of GHGs and other pollutants harmful to public health); not constrained to earning a return of and on every dollar invested; and
- Some administrative capacity to help price and manage market risks over time (e.g. trading desks).

In particular, while we expect the Accelerator would reinforce the existing role of state and local Green Banks, its distinctive mission would be to dramatically expand beyond the typical Green Bank mandate—in dollars as well as scope--seeking out and promoting larger scale step-changes in clean technology deployment and decarbonization.[14]

[14] Most Green Bank activity seems to be targeted at the consumer or small project level, which definitely has needs including some which the Accelerator could also address. However, these applications tend to exclude the larger utility scale, commercial and industrial applications that might give larger GHG impacts sooner. E.g., the New York Green Bank has a limit of $50mm per project. (*See* New York Green Bank Annual Business Plan 2020-2021 (https://greenbank.ny.gov/Resources/Public-Filings).)

In order to identify good candidates for debottlenecking, the Accelerator will need significant financial and energy industry expertise as well as administrative means to employ a variety of screening and competitive procurement mechanisms, such as auctions and competitive solicitations. Such mechanisms can help to harness competition and appropriately allocate risk, rather than strictly relying on bureaucratic, 'top-down' approaches to leveraging funds.

There will be challenges and limitations in constructing competitive mechanisms, because the goals of the Accelerator are multifaceted and the economic context complex (and evolving). Primary among these will be measuring and verifying the promises of what the Accelerator would procure or support, in order to ensure the outcomes of any competitive process are efficient as well as fair and transparent. In its overall mission, the Accelerator will cast a wide, economy-wide net for solutions to debottleneck decarbonization and create jobs. In principle, they could be ranked on a "tons-of-GHG avoided per dollar of funding basis" – but in fact, comparing these solutions on an "apples-to-apples" basis will be difficult. For example, how should competitive procurement and value emission reductions be measured due to accelerated coal retirements, some of which may shift a portion of their fossil fuel use to other locations in the power system? Some retirements may also have additional health benefits if they are close to population areas, which would not be captured by ranking solely on emissions reductions. How should retirements be compared to early adoption of carbon capture technologies, which will tend to have option value in addition to their direct carbon displacement? And how should carbon emission reductions be valued versus job creation? These challenges are exacerbated by complicating factors, including that some of the Accelerator's objectives, such as leveraging private capital while seeking equitable investment by socioeconomic group and geography, may be difficult to quantify and solicit.

While challenging, these nuances of project selection are not new to the energy industry. One approach to these challenges could be to selectively use standardized, single-stage auction formats, which are effective at soliciting competition from a range of potential solutions when procuring specific and measureable goods. In the Accelerator context, these could take the form of uniform "products"—not unlike the renewable energy credits commonly subject to auction today--but with additional pre-defined criteria to reflect policy outcomes sought by the Accelerator. Participation criteria could include sectoral definitions (e.g., utility scale infrastructure vs. end-use electrification), technology specifications, intended societal and geographic impact, and/or degrees of private sector mobilization. Bids could be evaluated based on cost per unit (or the inverse, units of improvement to be accomplished per dollar of funding sought), which might be defined in terms of decarbonization capacity deployed, tons of carbon displaced, or the present value of carbon reductions. Standardized, single-stage auctions could be optimized per techniques well-established in theory and practice, such as the REC auctions mentioned above, energy market capacity auctions, or spectrum auctions.

The multiplicity of needs and uses for the Accelerator funds will likely require that many different types of auctions or procurement methods be pursued. Another approach would be to evaluate candidates for Accelerator support in a more bespoke manner, such as, might be accomplished by a multi-stage Request for Proposal ("RFP") process. RFPs are a good procurement mechanism when attempting to competitively procure goods with multiple attributes (such as those listed above) when they prove too unwieldy to package in standardized products, as RFPs are more amenable to handling a "scorecard" of multiple objectives on an iterative basis. Such multi-stage RFP processes have ample precedent—such as when utilities or state agencies conduct solicitations to satisfy the requirements of integrated resource plans.

Regardless of whether auctions, multi-stage RFPs, grant applications, or targeted proactive outreach by the Accelerator are used, expert oversight will be needed to ensure solicitations remain effective and aligned with the Accelerator's (potentially evolving) mission. Investments that are not effective in achieving the fund's objectives should be quickly flagged, and funding priorities and mechanisms should be shifted to reflect lessons learned and evolving socioeconomic and technical realities. We are at the threshold of making important changes to the norms of energy production and usage in the economy, so it is not appropriate to expect perfection in performance from a new catalyst like the Accelerator. Indeed, much can be learned from what does not work as planned, when we are in this stage of development.

IV. Examples

There are doubtless hundreds of possible bottlenecks that the Accelerator could address. Here we make no effort to exhaust that list of possibilities, nor to prioritize them. Instead, we present a handful of case studies that illustrate the opportunity for a few different technologies, constituencies, and types of barriers. These include:

A. De-risking of community solar investments

B. De-risking of utility scale renewable investments

C. Addressing stranded costs from coal shutdowns (especially for non-IOUs)

D. Capital investments in electrification technologies like heat pumps

E. Peak EV charging stations

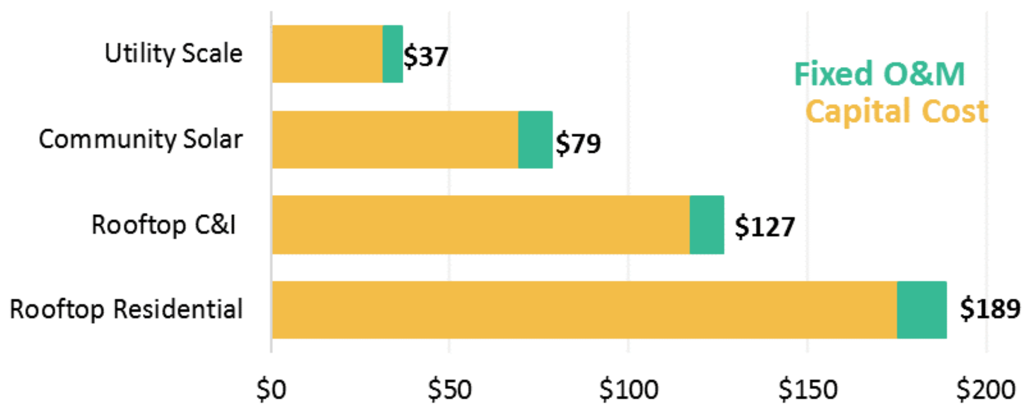
F. CCS and RNG facilitation

A. De-Risking Community Solar Investments

Observed Problem: Despite strong economics, uptake of community solar has been limited by market frictions including site acquisition difficulties, lack of standardization in ownership models, and concerns about market risks.

Despite attractive economics, community solar has been slow to take off. It is typically about half as expensive per watt to install as rooftop solar, due to larger scale plus tax benefits under some arrangements, and it can often achieve a better capacity factor of solar output than rooftops (hence have even more advantages in $/MWh). Approximate Community Solar (CS) economics are summarized below in **FIGURE 4** in relation to other types of solar power.

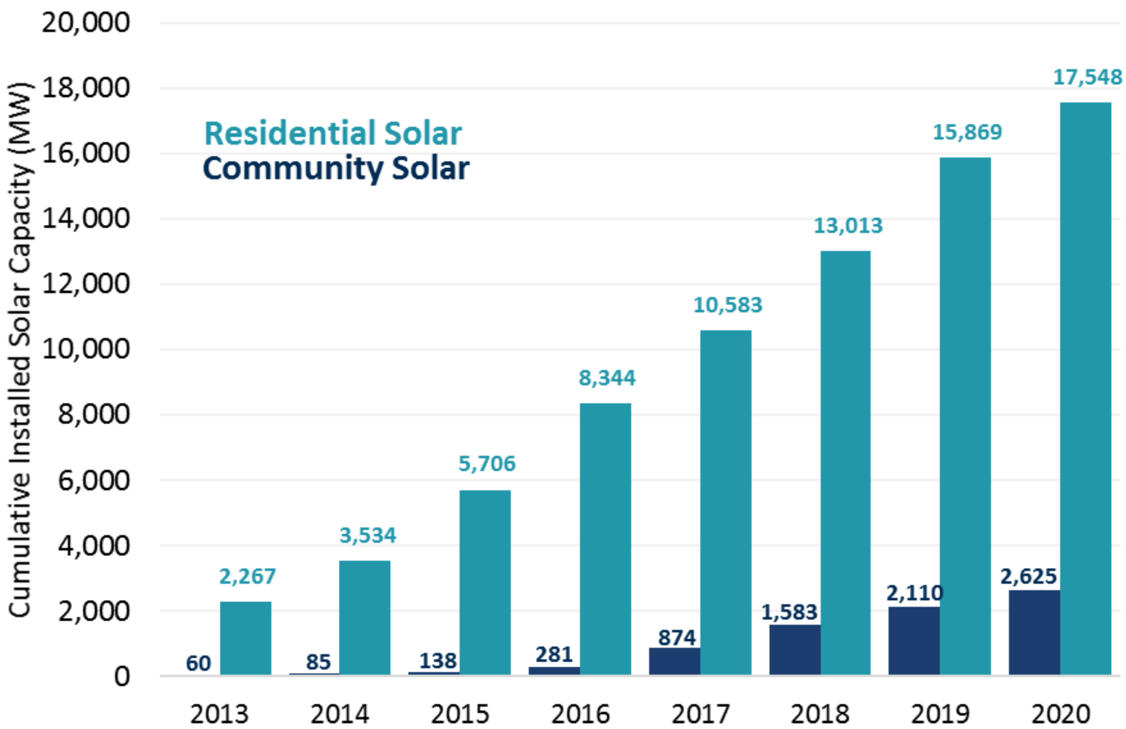
FIGURE 4: SOLAR LEVELIZED COST OF ENERGY



Sources: Lazard, "Lazard's Levelized Cost of Energy Analysis - Version 14.0," October 2020, https://www.lazard.com/media/451419/lazards-levelized-cost-of-energy-version-140.pdf

Notwithstanding these economic advantages, there were only about 2,600 MWs of community solar in the US by mid-2020 (concentrated very heavily in four states: MN, MA, NY and CO) and of this, only about 21 MWs are in low income neighborhoods for those customers (with another 155 MWs under development). In contrast, there are about seven times as much (almost 18,000 MWs) of the more expensive and less productive rooftop solar. (Those are beneficial resources, but it is surprising how much they have surpassed CS given the economics, highlighting how institutional barriers can overwhelm economic advantages.) This situation is shown in **FIGURE 5** below.

FIGURE 5: CUMULATIVE SOLAR INSTALLATIONS



Sources: SEIA, "Community Solar," 2020, data available at https://data.nrel.gov/submissions/149; SEIA, "Solar Industry Research Data," 2020, https://www.seia.org/solar-industry-research-data.

Note: 2020 data through June 2020.

Potential Role of Accelerator: Reduce frictions through acquisition, standardization, and risk-subsidization of community solar projects

- Direct acquisition of site properties, perhaps to deed them over to NPOs (like local churches) to be the owner; alternatively, subsidized (top tier investment grade) lending or loan guarantees to potential NPO owners;
- Standardization of project structures, perhaps via the Accelerator staff serving as transaction advisors to NPOs and NGOs hoping to arrange a facility in their neighborhood, leveraging expertise in risk analysis to help design optimal terms and conditions;
- Subsidizing "anchor clients" who would take a large share of the CS output for most of the life of the asset; or

- Securing the long-term price of the RECs the CS facility will create so that there is a revenue basis for securely covering the debt financing.[15] This approach has in fact been considered by some utilities, esp. for LMI CS facilities, but to our knowledge, it is not yet being adopted. It could also apply to utility scale renewables, as discussed next.

B. De-risking Merchant Utility-Scale Renewable Investments

Observed Problem: To date, utility-scale renewable investment has been largely limited to resources with long-term contracts (often satisfying RPS obligations) due to market and regulatory risk.

Utility-scale renewables are well established, with almost one-half of the new U.S. wholesale generation capacity brought online in 2019 coming from wind or solar sources. As a result, those renewables now comprise about 12% of the nation's generating capacity and 9% of electricity generation in 2019.[16] We have reached this level of green energy in part due to a blend of regulatory mandates, tax benefits, and market incentives -- which in turn have helped foster dramatic reductions in wind, solar and battery technology costs.

Notwithstanding the progress to date, the potential (and need) for deep penetration of utility-scale renewables remains unfulfilled, with large gaps between attainment and where it would be economical, and even larger gaps compared to advancing it at the necessary (rapid) long-term pace for deep decarbonization. (This is in part the flip side of the coal stranded cost question, where many more fossil plants could be retired and replaced with renewables than has so far occurred. But the need also includes supplying electrification of other energy markets with clean power, a huge challenge that could involve more renewable power than our entire fleet of plants of all types.) Challenges to reaching these goals include the following:

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[15] Note that REC swap price hedging would require the Accelerator to be in the intermediation business, settling at periodic intervals with its sponsored CS projects for the difference between actual and intended (initially expected) REC prices. This active involvement in facilitating risk-bearing could be a big difference between the Accelerator and GBs to date. It also has material implications for the administrative scale and expertise needed at the Accelerator compared to a pure lending institution.

[16] This does not include hydro resources, which produce about the same amount of carbon free energy as wind, but they have not been materially expanded in the US for the last few decades.

- **Uncertain revenue streams:** A large number of utility-scale renewable generation projects have been developed under long-term PPAs or REC price guarantees associated with RPS regimes. These help secure the debt financing and profitability of those renewable projects. A recent study by LBNL reports that "[r]oughly half of all [renewable energy] capacity additions over the past decade serve RPS compliance needs." Many of these targets have been met (though new targets are being mandated in some places).[17] Utilities that have satisfied their RPS targets and/or have relatively modest requirements going forward may be reluctant to continue entering into long-term contracts because they fear (probably correctly) that those positions could end up looking expensive and imprudent in a few years as renewable costs fall further. Indeed, their own marginal energy costs (or market prices) will tend to fall as more renewables are put under contract. Also, as current RPS targets are achieved, market REC values will logically collapse. In any event, the LBNL study forecasts that currently visible state RPS targets would aggregate to only 12% of U.S. retail electricity sales by 2030, far below the level needed for meaningful climate protection.
  - Separately, utility PPAs based on PURPA obligations, while recently increasing in some geographies, are highly contentious, have been marginally weakened under recent FERC policy, and cannot be counted on to materially support renewables development going forward.
  - Some merchant renewable development has occurred, especially in RTO regions with very favorable solar or wind conditions, and while large tax incentives have been available, many developers claim that they need some form of revenue assurance to obtain financing and to be economical. While merchant projects have been helped by falling renewable technology costs, they may ultimately be the victims of that success as greater renewables penetration occurs and marginal wholesale energy prices drop.
- **Erosion of tax equity:** Utility scale renewables have customarily been heavily reliant on substantial federal and state tax incentives as well as so-called "tax equity" to optimally monetize the benefits of credits and deductions. The market supply of tax equity -- which can comprise more than 50% of the capital investment in large wind and solar projects -- is currently reduced for 2021 compared to past levels of investment due to COVID-19 raising doubts about the loan performance (hence taxable income) of many of the traditional tax equity suppliers (mostly banks). In addition, many of the favorable tax advantages for

[17] Galen Barbose, "U.S. Renewable Portfolio Standards, 2018 Annual Status Report," Berkeley Lab, November 2018, https://eta-publications.lbl.gov/sites/default/files/2018_annual_rps_summary_report.pdf

renewables are scheduled to be phased out soon (wind PTC in 2021, solar 30% ITC in 2024), further dampening tax equity supply.

- **Lack of standardized financing:** The investment community often says that it sees solar and wind investments as conceptually a low risk investment that could be funded via standardized financial products such as "green bonds." Standardized, and presumably more efficient financing techniques will likely become more important as and if tax equity becomes less viable. However, few financial instruments have yet to emerge to accomplish this. One barrier may be that in aggregate, renewable generation investments are probably not very risky, but one by one they can involve a fair amount of regulatory and performance variance, requiring case-by-case project finance underwriting.

Potential Role of Accelerator: Reduce investor and developer risk and address logistical challenges

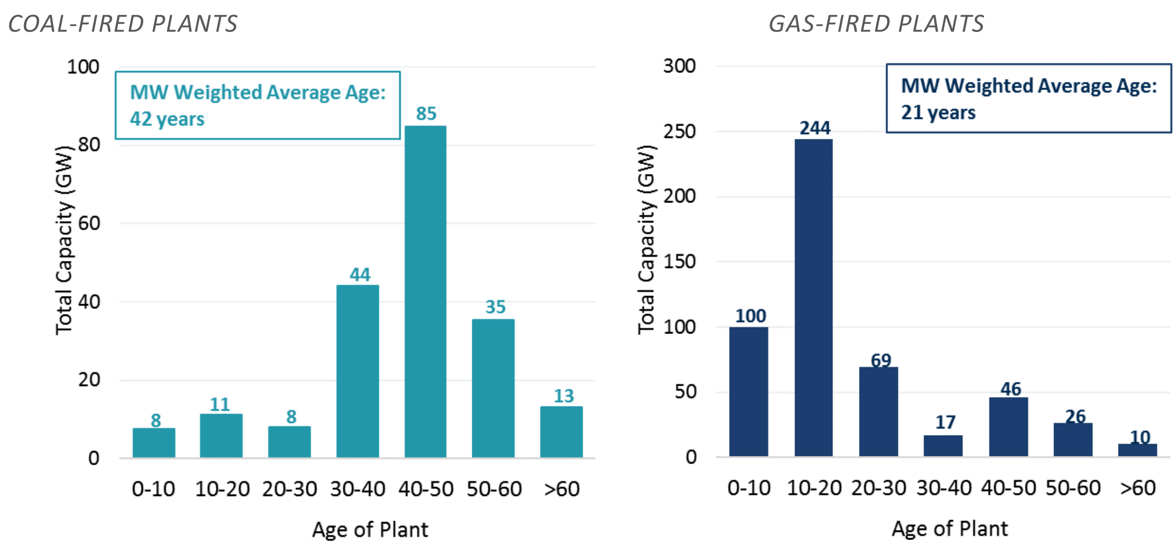
- **Firm-up revenue streams:** The Accelerator might step in and guarantee REC prices for a while, essentially writing a CFD between realized and fixed prices, for enough of the output of new renewable plants to secure their financing. The utility would transact with the supplier at marginal REC costs, changing over time, while the Accelerator would mark those (one way or the other) to a breakeven price for the developer. This would involve no immediate financing by the Accelerator, but it would require collateral as well as some energy administrative skills to deal with the realized risk outcomes.
- **Augment or replace tax equity:** The Accelerator might play a role in providing temporary substitute financing on concessionary terms, as part of the initial economic recovery portion of its goals. This could serve to smooth temporary disruptions in tax-equity markets.
- **Support standard financing structures:** Prospects for standardized financing structures might be improved by using public funding to help de-risk investments by creating layered portfolios of contracts from renewable projects and having the Accelerator buy the riskiest, top 'tranches' of these stacks. Lower layers of the stack would then be available for better financing terms, if pooled into portfolios of high priority. This would be similar to what the U.S. Government did during the 2008 financial crisis to help clean up the collateralized mortgage crisis. This would require coordination with financial entities that would manage the collateralization. For the Accelerator there would not be much net cash flow unless/until these top stacks felt the aggregate risk of the pool spilling up to it.

C. Coal Retirement Grants, Re-training and Transition Cost Mitigation

Observed Problem: Many coal plants are uneconomic but still operating

Approximately 230 GW of coal plants are currently operating in the United States. In 2019, these plants generated 966,000 GWh of power, responsible for approximately one billion tons of CO_2 emissions, or 15% of total U.S. emissions.[18] A large portion of these coal plants are either unprofitable or barely profitable, and many are quite old (average age >30 years), as seen below in **FIGURE 6**.[19] (By comparison, most of the gas fleet is much younger, hence less amenable to retirement despite having carbon emissions. These plants also tend to play an important role in balancing of the system to offset the intermittency of renewables.)

FIGURE 6: U.S. UTILITY-SCALE ELECTRIC GENERATING CAPACITY BY INITIAL OPERATING YEAR



Sources: Velocity Suite

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[18] EIA, "U.S. coal-fired electricity generation in 2019 falls to 42- year low," May 11, 2020, https://www.eia.gov/todayinenergy/detail.php?id=43675. Assumes 1 ton CO_2 emissions per MWh

[19] Anna Duquiatan, "Average age of US power plant fleet flat for 4th-straight year in 2018," S&P Global, January 16, 2019, https://www.spglobal.com/marketintelligence/en/news-insights/trending/gfjqeFt8GTPYNK4WX57z9g2.

In part due to this longevity, Rocky Mountain Institute has estimated 80–90% of existing coal plants are uncompetitive relative to their replacement with renewables and storage producing equivalent time patterns and reliability of output.[20] However, several factors are slowing the pace of coal retirements, especially recovery of stranded costs and concerns about impacts to local communities. More specifically, the typical problems are:

- Even when the retired units have higher to-go costs (fuel, variable O&M, fixed O&M and future capacity adds) than the all-in costs of the renewable replacements, the utility is often accused of having been imprudent to be in a situation where that occurs, and
- There can be severe adverse side effects on local employment and property taxes for the communities where the retired plant resides. Both of these could be mitigated in part with interventions by the Accelerator.

Potential Role of Accelerator: Distribute grants to recover coal-stranded costs and mitigate economic disruption issues from the plant retirements

Accelerator funding could be distributed as utility "grants" contingent upon the retirement of coal plants to help limit or recoup any stranded costs, as well to retrain power plant staff for new green jobs. This might be especially useful for electric cooperatives and municipalities, which tend to have a lot of coal in their fleets and which do not have an equity base to transfer risk or costs – they must absorb all of the stranded costs (i.e., the customers are on the hook for all the costs, or at least all of the debt, of both the old and the new plants). The Accelerator might absorb the excess of such costs that would cause or necessitate a rate increase to make the conversions rate-neutral to customers.

Regardless of being an IOU vs. a coop or muni, the Accelerator could also help guarantee (or underwrite) the securitized financing for buying out the abandoned assets' book value and carrying it in the future at lower costs than would have otherwise been collected had the plant stayed in rates under conventional cost of service financing and pricing. If the Accelerator wished to commit less capital, it could simply provide guarantees to any SPEs created to host the securitization (to offset any concerns about customer payments for the securitized bonds).

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[20] Paul Bodnar, *et al.*, "How to Retire Early: Making Accelerated Coal Phaseout Feasible and Just," Rocky Mountain Institute, 2020, https://rmi.org/insight/how-to-retire-early.https://rmi.org/insight/how-to-retire-early.

Additional possible roles for the Accelerator include providing funds for jobs training of displaced workers, and providing transitional mortgage protections for displaced workers and lease protections for small commercial entities who lose business due to plant shut downs.

D. Building Retrofits and Electrification Support

Observed Problem: Building electrification is a large source of decarbonization opportunity, but it has large upfront costs and slow paybacks that discourage retail adoption.

A critical step in deep decarbonization will be conversion of existing fossil fuel end-uses (such as home HVAC and water heaters) to clean electricity. This will not be an easy or welcome transition for many customers, because of their comfort with the existing technologies and the large up-front capital cost and slow paybacks from the conversions, e.g., to heat pumps.

A recent Brattle study for the state of Rhode Island Office of Energy Resources estimated the following installation costs for ground source heat pumps (GSHP) and air source heat pumps (ASHP) vs. conventional gas and oil heating systems for residential and small commercial facilities.

FIGURE 7: INSTALLED COSTS IN 2050 OF HEAT PUMPS VS. CONVENTIONAL HEAT (2018$)

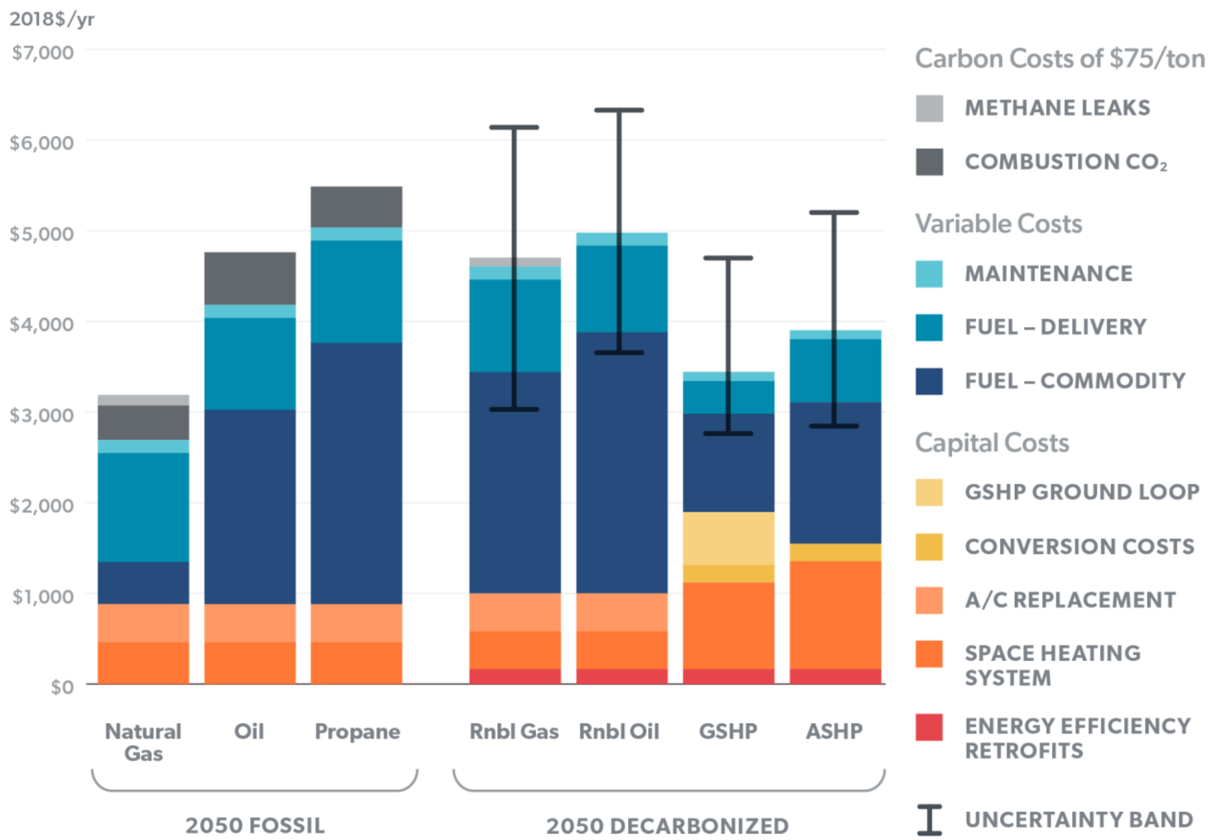
	Residential			Commercial		
	Fuel-based	GSHP	ASHP	Fuel-based	GSHP	ASHP
Primary Heater (2050)	$6,200	$14,200	$14,200	$32,700	$100,500	$100,500
Primary Heater (2020)	$6,200	$19,200	$19,200	$32,700	$135,900	$135,900
Annual Cost Decline	0%	-1%	-1%	0%	-1%	-1%
Secondary Heater	n.a.	n.a.	$500	n.a.	n.a.	$1,500
Ground Loop	n.a.	$15,000	n.a.	n.a.	$71,200	n.a.
Electrical and Ducting	n.a.	$5,000	$5,000	n.a.	$15,000	$15,000
A/C Replacement	$5,000	n.a.	n.a.	$15,000	n.a.	n.a.
Total	$11,200	$34,200	$19,700	$47,700	$186,700	$117,000

Ground-sourced heat pumps are considerably more expensive than air-sourced to install due to needing a "ground loop" (at around $15,000) for the heat sink. However, in cold winter-peaking regions, they can considerably reduce electricity costs because they do not lose efficiency at cold temperatures, while ASHP becomes much less effective. Heat pumps can also involve tens of thousands of additional dollars in building infrastructure upgrades if air ducting and other improvements are needed. On the other hand, they avoid the cost of air conditioning equipment, since they operate in "both directions" (heating and cooling).

These large capital costs may be a huge impediment to HP investment, even though the annualized costs for the HVAC services may be fairly comparable to other technologies we are likely to be using as we approach deep decarbonization. **FIGURE 8** below shows these estimates, from the same study using the above capital costs.[21]

[21] Dean Murphy and Jurgen Weiss, "Heating Sector Transformation in Rhode Island," The Brattle Group, 2020, http://www.energy.ri.gov/documents/HST/RI%20HST%20Final%20Pathways%20Report%204-22-20.pdf.

FIGURE 8: ANNUALIZED COST OF SPACE HEATING IN 2050 FOR A REPRESENTATIVE SINGLE FAMILY HOME



This figure shows that heat pumps (last two bars on the right) are likely to involve considerable savings on variable costs (blue shading), and on an all-in basis they could be competitive with conventional heat sources (gas, oil, propane – shown in the three bars on the left) depending on what fuels and electricity then cost.[22] These are highly uncertain factors, strongly dependent on the climate protection policies adopted between now and then.

Thus, *both liquidity and risk issues are likely to impede rapid adoption of electrification technologie*s. Even if a mandate were to be legislated, the transition costs for a state or city could be very large. For instance, a city aspiring for full decarbonization by 2050 with 500,000 single or multi-family homes might require converting 3% of those per year starting immediately, or about 15,000 homes per year at perhaps $0.3–.4 billion per year of installations.[23]

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22 Some studies show that today ASHP systems in the Northeast US can save customers almost $500/year against electric space heating and almost $1000/year against the widely used oil heat. https://www.energy.gov/energysaver/heat-pump-systems/air-source-heat-pumps

23 For more details on heat pump potential, see http://www.energy.ri.gov/HST/

Potential Role of Accelerator: Financing and technical support to overcome liquidity and risk barriers to residential and commercial electrification

1. Providing financing support to reduce customers' upfront costs and accelerate payback periods. Anecdotal evidence of customer adoption of other new energy technologies suggest that a fairly fast payback of 3-5 years is often needed as a threshold matter to attract much adoption, likely far faster than heat pumps currently offer.
2. Possibly, providing manufacturing supply expansion support (favorable lending) for the heat pump industry, so that it has production capacity and staffing adequate to the potential demand. In 2009, US EIA reported that there were 27 active manufacturers of heat pumps in the US, producing about 120,000 units per year. That would only serve eight medium size cities decarbonizing at the above pace.[24] The entire heating equipment industry in the US had about $3billion of revenues in 2015, of which about 1/3 came from heat pumps. That sector has grown but not doubled by now, and even $2B would only serve four cities of the size evaluated above.
3. Another kind of electrification that may benefit from the Accelerator is achieving sufficient electric vehicle (EV) charging infrastructure for conversions from internal combustion engines to EVs to take off. Here again there are known and economical solutions for both the EVs and the charging technology, but there is a chicken-or-egg problem of chargers waiting on vehicles and vice versa. Some of this will be cured naturally by the market as technology (especially battery size and cost) improves, but some aspects may be intrinsically underserved. Specifically, charging for low-income neighborhoods and for locations that could experience occasional extreme peaks but not much routine traffic will not be attractive to market developers. For instance, major arteries out of large cities may need extra chargers for holiday traffic, but these sites will normally have low utilization. In fact, all civic charging may tend to have low utilization to the extent that most charging occurs at homes. The Accelerator could provide funding to communities or NPOs that want to install charging to fill these gaps.

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[24] EIA, "Geothermal Heat Pump Manufacturing Activities," 2012, https://www.eia.gov/renewable/annual/geothermal/

Grand View Research, "U.S. Heating Equipment Market Size, Share & Trends Analysis Report by Product, 2018-2025," March 2017, https://www.grandviewresearch.com/industry-analysis/us-heating-equipment-market.

E. Transmission Expansion over NIMBY Concerns and Lack of Uniform Local Benefits

Observed Problem: Very substantial transmission build-out will reduce decarbonization costs and foster reliability, but capital and institutional barriers are large.

It is likely that we will need a very large amount of transmission to bring renewables from their best production areas (e.g. wind in the Midwest, offshore along the Atlantic, or solar in the Southwest) to distant market areas. Recent studies by The Brattle Group have found that in order for New York and New England regions to achieve electrification and decarbonization of their economies by 2050, they will need approximately $7 billion and $4 billion of capital expenditures, respectively, for new transmission to connect corresponding amounts of 7,200MW and 3,600MW of offshore wind.[25] The national story is comparable. Below in Figures 9 and 10 are some of those results.

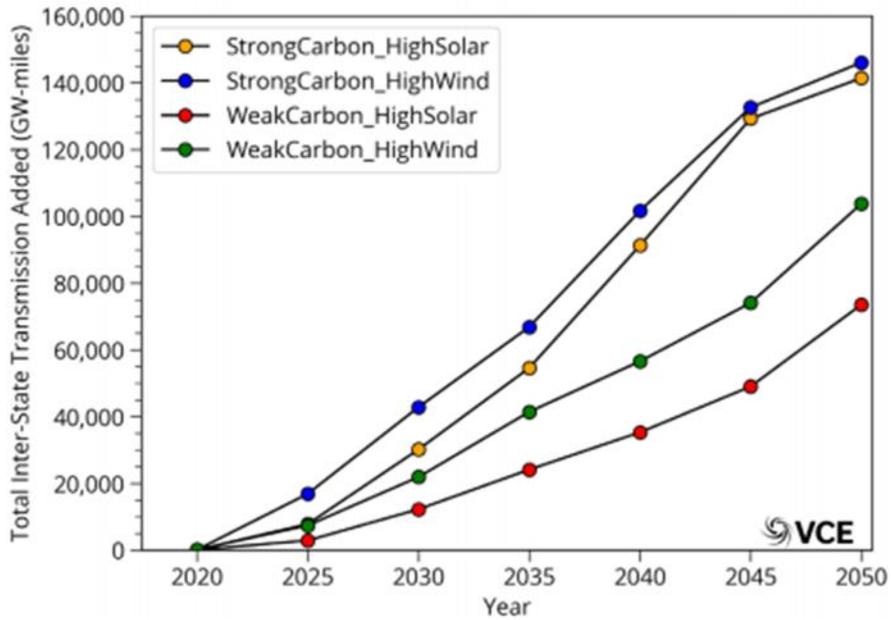
First, in

FIGURE 9 we see that depending on the pace and approach to decarbonization, the US would need about 70,000 to 150,000 circuit miles of very high voltage transmission expansion to achieve geographically diversified (and economically justified) interconnection of remote renewables, based on VCE modeling scenarios.

25 $3.9–4.4B to connection next 3,600 MW of offshore wind in New England *(See,* Johannes Pfeifenberger, Sam Newell, and Walter Graf, "Offshore Transmission in New England," The Brattle Group, May 2020, https://brattlefiles.blob.core.windows.net/files/18939_offshore_transmission_in_new_england_-the_benefits_of_a_better-planned_grid_brattle.pdf.)

$6.6 – 7.1B to connect next 7,200 MW of offshore wind (*See,* Johannes Pfeifenberger, et al., "Offshore Wind Transition: An Analysis of Options for New York," The Brattle Group, August 6, 2020, https://brattlefiles.blob.core.windows.net/files/19747_offshore_wind_transmission_-_an_analysis_of_options_for_new_york_lcv_virtual_policy_forum_presentation.pdf).

FIGURE 9: SCALE OF TRANSMISSION EXPANSION FOR NATIONAL DEEP DECARBONIZATION SCENARIOS



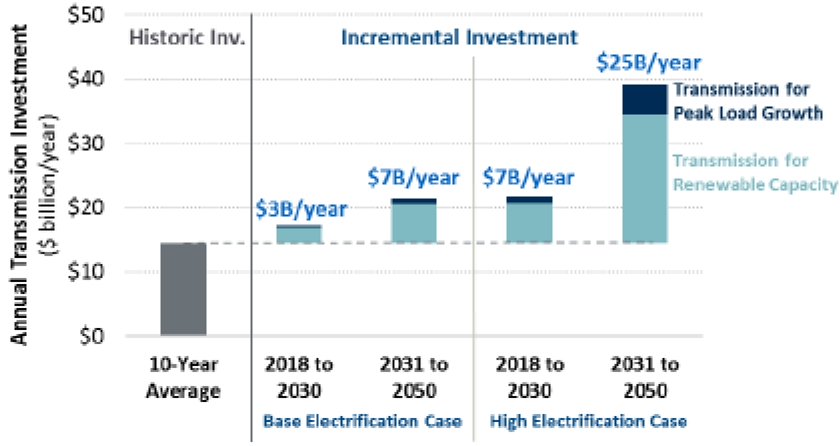
Source: Clack, et al., "Consumer, Employment and Environmental Benefits of Electricity Transmission Expansion in the Eastern U.S.," Americans for a Clean Energy Grid, October 2020, https://cleanenergygrid.org/wp-content/uploads/2020/10/Consumer-Employment-and-Environmental-Benefits-of-Transmission-Expansion-in-the-Eastern-U.S..pdf

This graph shows what is needed on top of the existing transmission, which as of 2018, was estimated at 152,000 GW-miles.[26] This extent of transmission expansion would create geographic production diversity that significantly reduces the extent of over-building and storage that would otherwise be needed if only local resources were to be used. However, there is massive institutional resistance to transmission expansion.

Financially, this scale of investment could require tens of billions of dollars of expenditures per year, as seen here:

[26] Clack et al., "Transmission Insights from 'ZeroByFifty'," Vibrant Clean Energy, LLC, November 11, 2020, slide 16.

FIGURE 10: NATIONAL ANNUAL EXPENDITURES ON TRANSMISSION TO SUPPORT CLEAN ELECTRIFICATION



Notes: The historical average reflects transmission investments from 2006 to 2016 based on transmission capital expenditures reported on FERC Form 1.

Source: Weiss et al., "The Coming Electrification of the North American Economy," WIRES, March 2019.

The historical average expenditure is about $12 billion per year, while this scale of decarbonization would require another two times that amount. (Even just cleaning up the entire existing power system, not expanding it for electrification, would require $3–7 billion incremental spending per year from now to 2050).

These results are of course approximate, but they dramatize the huge scale of infrastructural expansion needed to decarbonize. This will involve both significant funding and debottlenecking challenges to realize these improvements in a timely manner.

Potential Role of Accelerator: Providing support for complementary projects to accompany transmission may offset the uneven distribution of benefits

This problem is no doubt largely political, but it does have an economic element of need for redistributing benefits or for inducing complementary, additional projects with benefits that offset some of the adverse side effects of the transmission line itself. For instance, it might be possible to entice an intermediate state along the transmission expansion path to support the line if it was going to obtain an in-state RNG production facility that would both take off some of the power (so that the RNG is created with clean electricity) and provide a boost to local agriculture and new employment. The RNG project could be tied to accepting the line.

F. CCS and RNG Facilitation

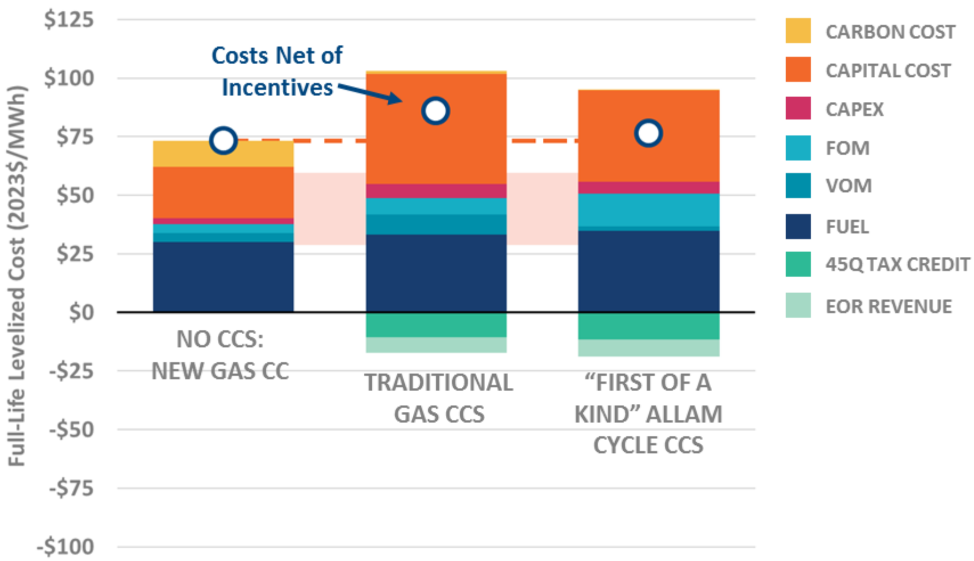
Observed Problem: Fossil-fuel intensive regions of the country are often very opposed to renewables and other decarbonization policies because of loss of jobs and stranded infrastructure. CCS and RNG present a means for them to preserve both, to diversify their clean energy base, and to create decarbonization options for industrial sectors that are not amenable to electrification.

Right now, CCS and RNG are mostly more expensive than renewable generation and storage, MWh for MWh. For instance, Lazard estimates that the levelized cost of energy produced by a coal CCS unit is around $159/MWh, while the levelized cost of energy produced by a "solar + storage" system may range from $80–$140/MWh.[27] However, with recent tax incentives (45Q) and the right combination of other local opportunities (EOR, ability to reuse existing transmission infrastructure, proximity to pipelines), CCS can be as economical as current operation of existing coal plants.[28] There is also an emerging technology for CCS at gas plants (the "Allam Cycle," shown below) that may make them barely more expensive than existing new technology, even without material tax incentives.

27 https://www.lazard.com/perspective/levelized-cost-of-energy-and-levelized-cost-of-storage-2020/. *See* slides "Levelized Cost of Energy Comparison – Unsubsidized Analysis" and "Unsubsidized Levelized Cost of Storage Comparison – Energy ($/MWh)."

28 Kasparas Spokas, Katie Mansur, and Frank Graves, "Emerging Value of Carbon Capture for Utilities: From Retrofits to Deep Decarbonization," *Public Utilities Fortnightly* 158(12) (October 2020): p. 38.

FIGURE 11: COSTS OF CCS AT NEW GAS PLANTS[29]



The engineering scope of opportunity for CCS is also vast – the US has enormous geologic storage potential for CO_2 (over 2,000 gigatonnes, which is roughly equal to 2,000 years of current coal emissions). There is also high confidence that the stored GHGs would be stable essentially indefinitely.

Some states are already forcing their utilities to consider CCS vs. renewables for new power supply, and this trend may increase if/as a few successful projects are undertaken:

- In November 2019, the New Mexico Public Service Commission required a utility to evaluate CCS retrofit before retiring its coal plant to comply with state environmental regulations.[30]

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[29] Frank Graves, Kasparas Spokas, Katie, Mansur, and Shreeansh Agrawal, "Opportunities and Challenges for CCUS in the Power Sector," November 16, 2020, https://brattlefiles.blob.core.windows.net/files/20506_opportunities_and_challenges_for_ccus_in_the_power_sector.pdf.

[30] The utility ultimately determined that replacing the plant with renewables was a cheaper alternative than retrofitting the plant with CCS. Catherine Morehouse, "PNM: Carbon capture would raise San Juan transition cost of $6B, as PRC, legislator battle rages," *Utility Dive*, November 25, 2019, accessed December 21, 2020, https://www.utilitydive.com/news/pnm-carbon-capture-would-raise-san-juan-transition-cost-to-6b-as-prc-le/567937/.

- In March 2020, the Wisconsin House Legislature passed a bill that would allow utilities to recover their investment in CCS in rate base.[31]
- The Wyoming Public Service Commission has recently asked PacifiCorp to reevaluate its planned shift away from coal plants towards renewables, storage and peakers by comparing those options to CCS retrofits at its current coal plants.[32]
- Over the past decade, several states have also passed authorizations for utilities to recover CCS investments in their rate base or enjoy tax benefits.[33]

However, there have been very few CCS projects at utility scale, and some of those have had high development costs[34] or have run up against viability problems because of declining marginal costs for power. Those low power market costs are beneficial for the US and for the economy, but they are also mis-informative about the need for other clean technologies -- in part they rely on natural gas that has to be eventually decarbonized or abandoned, and in part because they mask the relative value of clean dispatchable power vs. renewables when taking a long-term view.

As we approach deep decarbonization (as we must, by 2035 or so), the cost per MWh advantage of renewables tends to disappear, not because they become expensive, but because they become too similar in performance to cover the system needs reliably. As a result, vast redundancy in their construction and backup with storage become essential to offset their production coincidence and the related risk of several days of "renewable droughts" when output conditions are poor. These droughts are more common than is generally appreciated. For

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31 Andrew Graham, "Stripped of $1 billion, Gordon carbon capture bill clears house," *Gillette News Record,* March 4, 2020, accessed December 21, 2020, https://www.gillettenewsrecord.com/news/wyoming/article_4cc95f23-cd0a-5f5c-b291-c5bea6a5be15.html.

32 Emma Penrod, "Wyoming PSC: Socioeconomic impact of coal retirements not within the purview of an IRP," *Utility Dive*, October 13, 2020, accessed December 21, 2020, https://www.utilitydive.com/news/wyoming-psc-socioeconomic-impact-of-coal-retirements-not-within-the-purvie/586884/.

33 Virginia allows utilities to recover an "enhanced" return on certain types of clean technologies, including coal CCS plants. Other states, including Kansas, Texas and Louisiana, provide various tax incentives to encourage CCS development. "U.S. State Energy Financial Incentives for CCS," Center for Climate and Energy Solutions, February 2019, accessed December 21, 2020, https://www.c2es.org/document/energy-financial-incentives-for-ccs/.

34 The two CCS projects with notably high cost overruns are Petra Nova (2017, 240 MW) and Boundary Dam (2014, 105 MW). David Schlisse and Dennis Wamsted, "Holy Grail of Carbon Capture Continues to Elude Coal Industry," Institute for Energy Economics and Financial Analysis, November 2018, accessed December 21, 2020, https://ieefa.org/wp-content/uploads/2018/11/Holy-Grail-of-Carbon-Capture-Continues-to-Elude-Coal-Industry_November-2018.pdf.

instance, a recent study used 40 years of historical data in Germany to determine that a 5-day period with wind capacity factors less than 10% (for the country as a whole) happens about every year, and an 8-day period with wind capacity factors less than 10% happens about every 10 years.[35] Even a hypothetical fleet with 9 towers at widely dispersed and poorly correlated wind-speed locations across the entire US could have a hundred hours every year in which the total fleet output is below 15% of wind nameplate capacity.[36] Likewise solar power, even over a very large area, can be afflicted by widespread outages if there is protracted cloud cover from a very large storm, as happens with hurricanes and major winter storms. This problem can be offset somewhat by interconnecting renewables over a very large area, but it likely has to be an extremely large area (a substantial portion of the US) and it will entail very expensive and locally unwelcome transmission expansion.[37]

Stated more positively, the cost of clean power can be made much lower with dispatchable clean power, even though that costs much more per MWh than renewables. Below, **FIGURE 12**shows the savings The Brattle Group found for New England by 2040, along with the dramatic differences in resource mix that would be needed with or without dispatchable clean power like CCS.

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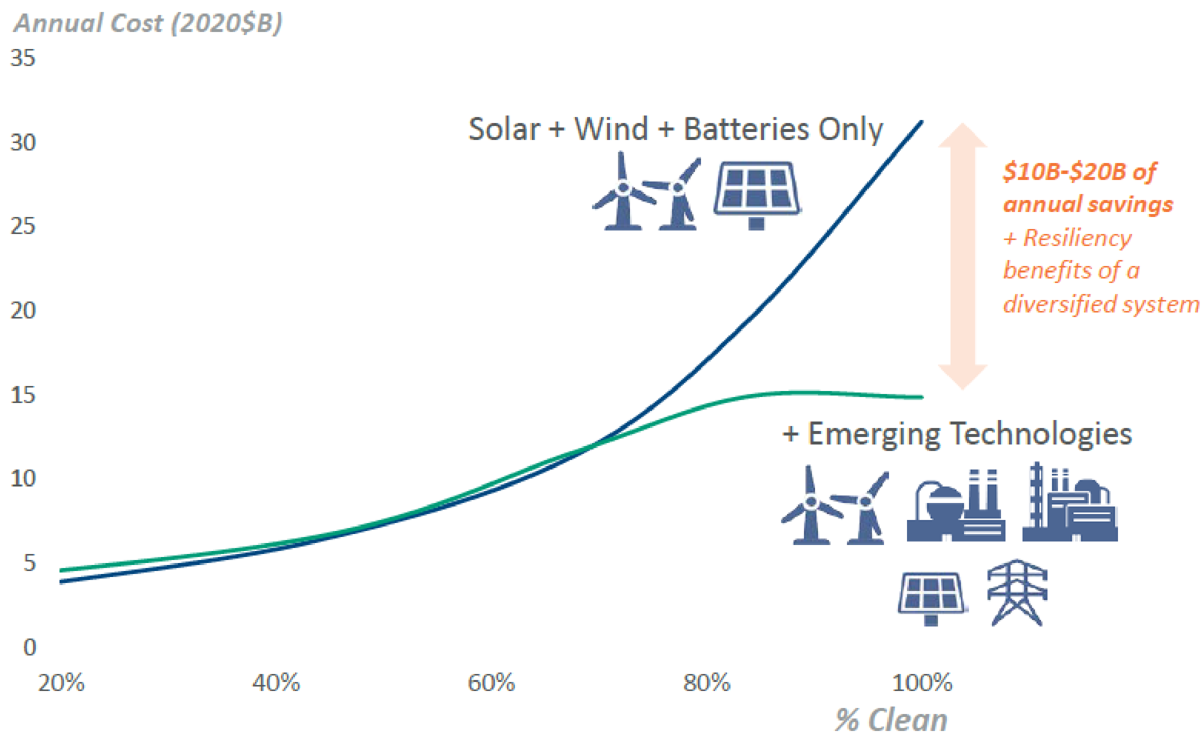
35 Nils Ohlendorf and Wolf-Peter Schill, "Frequency and duration of low-wind-power events in Germany," *Environ. Res. Lett.* 15(8) (August 2020), https://iopscience.iop.org/article/10.1088/1748-9326/ab91e9.

36 Mark Handschy, Stephen Rose, and Jay Apt, "Is It Always Windy Somewhere? Occurrence of Low-Wind-Power Events over Large Areas," *Renewable Energy* 101 (February 2017): pp. 1124-1130, https://www.sciencedirect.com/science/article/abs/pii/S0960148116308680. Note that results depend heavily on how the statistical distribution of wind is modeled, a difficult problem for "tail events" that are unlike normal conditions. A few non-contiguous hours of such deep outage could be handled with storage, but days at a time, though much more rare, require more robust backup like CCS or RNG.

See also, Paul Leahy and Eamon McKeogh, "Persistence of low wind speed conditions and implications for wind power variability," *Wind Energy* 16(4) (May 2013), pp. 575-586, https://onlinelibrary.wiley.com/action/showCitFormats?doi=10.1002%2Fwe.1509.

37 Jesse Jenkins, Max Luke, and Samuel Thernstrom, "Getting to Zero Carbon Emissions in the Electric Power Sector," *Joule* 2(12) (December 2018), pp. 2506-2507, https://www.cell.com/joule/fulltext/S2542-4351(18)30562-2.

FIGURE 12: MODELING OF DECARBONIZATION NEW ENGLAND ELECTRICITY SYSTEM[38]



RNG currently appears to be somewhat more expensive than CCS, though it too is not yet pursued at commercial scale or scope, so it could become much cheaper. It appears to have technical potential to replace much or all of the gas used by the high-heat industrial sector[39] – a very difficult sector to decarbonize via electrification. As a result, its role in future power systems may be limited to extreme peak events.

The construction and few-of-a-kind risk of these technologies are preventing them from taking root as much as we are likely to need them within a few short years. Supplemental support from the Accelerator to help them achieve closer cost parity with renewables and storage today, taking into account the present value benefits they provide in the future, could be a very good use of

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[38] Frank Graves, Kasparas Spokas, Katie, Mansur, and Shreeansh Agrawal, "Opportunities and Challenges for CCUS in the Power Sector," November 16, 2020, https://brattlefiles.blob.core.windows.net/files/20506_opportunities_and_challenges_for_ccus_in_the_power_sector.pdf.

[39] The American Gas Federation estimates that the low, high, and technical resource potential for RNG production in 2040 is approximately 1,910, 4,510, and 13,960 tBtu/year, respectively. Based on current U.S. industrial sector natural gas consumption of approximately 7,652 tBtu/year (2009-2018 average), this RNG resource potential would equate to 25%, 59%, and 182% of current U.S. natural gas consumption in the industrial sector, respectively. *See* "Renewable Sources of Natural Gas: Supply and Emissions Reduction Assessment," American Gas Foundation, December 2019, accessed December 21, 2020, pp. 11-15, https://www.gasfoundation.org/wp-content/uploads/2019/12/AGF-2019-RNG-Study-Full-Report-FINAL-12-18-19.pdf.

the monies. It would not only help establish more tools in our decarbonization tool kit, but it would also help overcome regional political and sectoral barriers (red vs. blue states, fossil producing vs. mostly energy consuming states, industrial vs. agricultural, etc.) that need to be addressed so that our carbon solutions are national not regional, and benefits redound to all. As noted in the discussion of transmission buildout, it is also possible that CCS and RNG funding could be used as "offsets" to help through-regions feel some benefits of supporting the otherwise undesirable line.

V. Preliminary Takeaways

One of the two key missions of the Accelerator will be to materially increase the rate of decarbonization in the US economy through strategically targeted financial support and risk-mitigating facilitations of available technologies. Accelerating decarbonization by a few years can result in less cumulative emissions for many of the years between now and a "decarbonized" 2050 end state, thereby mitigating climate change. We therefore need to accelerate deployment of shovel-ready projects, finding those with large "financial multipliers" whose incremental involvement of the Accelerator frees up private investment. The Accelerator can serve as an agency that "debottlenecks" institutional constraints that limit otherwise (or nearly) economic adoption of available clean technologies.

Although significant clean energy and decarbonization activity is occurring, it is often patchy, not systematic, and by no means optimized relative to potential or needs. Tens of trillions of dollars in investment will be needed over the next three decades to address the decarbonization problem, but current investment levels are far smaller and not systematic.[40]

The Accelerator will be well positioned to leverage public sector dollars in a manner that is cost-effective, engages the private sector, and reduces risk. The Accelerator could be directed to help remove impediments that are slowing the flow of capital, allowing market mechanisms to expand in places where uneven sharing of costs and benefits, adverse side effects, or extreme risk exposure make the market reticent or slow to participate. This is illustrated in the examples above to highlight the variety of barriers that can slow decarbonization and to demonstrate how

[40] Cost estimates vary widely, but generally are in the tens of trillions. For example, *see* https://www.morganstanley.com/ideas/investing-in-decarbonization and https://www.oecd.org/environment/cc/climate-futures/policy-highlights-financing-climate-futures.pdf

the Accelerator could remove some of those frictions. These examples are not intended to be an exhaustive set, and they may not even be the best opportunities. Rather, we believe they are indicative of a few different types of many such opportunities that the Accelerator should explore.

The complexity of the decarbonization challenges drives home that *the Accelerator will need to be more than a lending agency* (e.g., a new Green Bank) to fill these more nuanced roles. Speeding decarbonization will require more than public funds – it will require expertise, careful planning, and transactional infrastructure to identify the most leverage-able alternatives, as the case for needing a new Accelerator should be premised on more than just the large cost of the needed infrastructure. The fund will also need to harness competition to ensure its objectives are achieved cost effectively. If the Accelerator is to foster decarbonization by curing impediments and bearing risks that tend to persist over time, it will have to have the capability to both identify the best investment opportunities and how to enhance them, plus the managerial and administrative capabilities to stay with the mitigations it supports over time.

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GHG Abatement Curve Assumptions and Sources

FIGURE 13: SOURCING FOR U.S. GHG ABATEMENT CURVE

	Abatement cost ($/ton)	Citation
Ag & Forestry		
Agriculture & land use	$62	Gillingham, Kenneth & Stock, 2018
Waste	-$10	TBG Assumption, assumed to be -$10/ton
Afforestation	$5	Gillingham, Kenneth & Stock, 2018
Alternative Energy Sources and Carbon Capture		
Direct air capture	$200	TBG Assumption, assumed to be $200/ton
Clean fuels for power	$630	TBG Assumption, $50/MMBTu of RNG - $5/MMBTu of natural gas = $45/MMBtu fuel price x 7 MMBtu/MWh = $315/MWh/0.5 tons CO2/MMWh = $630/ton
Power Generation		
New nuclear or CCS	$71	Gillingham, Kenneth & Stock, 2018
Replace Coal with Solar	$19	Bodnar et al., 2020
Replace Coal with Wind	$25	TBG Assumption, assumed to be $25/ton
Replace Gas with Solar	$48	TBG Assumption, assumed to be 2.5x the cost of replacing coal with solar
Replace Gas with Wind	$63	TBG Assumption, assumed to be 2.5x the cost of replacing coal with wind
End-User Efficiency and Conservation		
Industrial EE	$10	TBG Assumption, assumed to be $10/ton
Residential EE	-$25	TBG Assumptions, assumed to be -$25/ton
Commercial EE	-$15	TBG Assumptions, assumed to be -$15/ton
Transport efficiency	$33	Gillingham, Kenneth & Stock, 2018
Electrification		
Electrifying transportation	$15	MJB&A, 2018
Residential heating electrification	$60	Mahone et al., 2018
Commercial heating electrification	$60	Mahone et al., 2018
Industrial heating electrification	$30	TBG Assumption, assumed to be $30/ton.

"Electric Vehicle Cost-Benefit Analysis", MJB&A, December 2018, page 5, https://www.swenergy.org/pubs/azevstudy.

Kenneth Gillingham & James Stock, "The Cost of Reducing Greenhouse Gas Emissions," *Journal of Economic Perspectives*, August 2, 2018, page 9, https://scholar.harvard.edu/files/stock/files/gillingham_stock_cost_080218_posted.pdf.

Mahone *et al*., "Deep Decarbonization in a High Renewables Future," Energy & Environmental Economics, May 2018, page 52, https://www.ethree.com/wp-content/uploads/2018/05/E3_2050Pathways_Draft_FullDeck_20180522.pdf.

Paul Bodnar, *et al.*, “How to Retire Early: Making Accelerated Coal Phaseout Feasible and Just,” Rocky Mountain Institute, 2020, page 14, https://rmi.org/insight/how-to-retire-early.