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INDUSTRIAL DECARBONIZATION INVESTMENT STRATEGY

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An Analysis of the National Climate Bank Act of 2019 on the Decarbonization of the Industrial Sector

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ABOUT THIS DOCUMENT: This analysis suggests potential ways in which the Climate Bank can offer financial support to the industrial decarbonization sector- it is in no way a definitive guide. The investment committee will need to conduct further in-depth analysis, as market conditions change, and modify accordingly. This analysis is conducted under a regular scenario without the impact of COVID-19.

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EXECUTIVE SUMMARY

In the United States, emissions from the industrial sector make up almost a quarter (22%) of total greenhouse gas emissions, making it the third largest emitting sector (EPA, 2019). Thus, the industrial sector is a critical target in order for the US to abate their emissions. However, current financing from both the public and private sector lacks the financial commitment and requires an extra push toward significant emissions reductions. Thus, the National Climate Bank Act of 2019 is a proposed tool by which the federal government invests USD $35 billion, within 30 years, in seed capital toward the creation of the National Climate Bank, a non-profit that will stimulate financial investments in clean energy solutions. The Climate Bank is also expected to trigger private sector investment of up to USD $1 trillion into sustainable projects. The Climate Bank primarily focuses on investments in innovative clean technologies that would otherwise be unable to progress in the current financial markets, and with the current financial mechanisms.

This analysis reviews existing policy support, technological advancements and financial mechanisms for five technologies: 1) carbon capture, utilization and sequestration (CCUS); 2) biomass; 3) hydrogen; 4) energy efficiency; and 5) electrification. Additionally, the analysis describes the investment feasibility by the National Climate Bank to maximize emissions reductions and to provide potential strategies for investment.

Based on the analyses, carbon capture, utilization and sequestration (CCUS), biomass and energy efficiency have high emissions reductions potential, while hydrogen and electrification may not, as they are still developing. CCUS is expected to reduce about 90% of emissions, biomass up to 86% and energy efficiency reduces energy consumption by 15-32%. In addition, these technologies are commercially viable or currently operate at a large-scale, indicating more widespread adoption, less constraints and higher emissions reductions. In terms of financial feasibility and return on investment, CCUS is unlikely to produce any returns as the investment calls for offsetting the high operational costs of two kinds of CCUS technologies: direct air capture and post-combustion CCUS. However, over time the operational costs of CCUS are expected to decrease and may no longer need Climate Bank support once the industrial plants are able to absorb the costs themselves, along with existing tax incentives. Biomass and energy efficiency, on the other hand, have potential returns depending on the project. Biomass suggests capital investment in large-scale advanced boilers, as operation and maintenance costs would be low, and biomass is competitive in the renewable energy market. Thus, biomass investments will likely be paid back. Finally, energy efficiency incentive programs already have a return rate of 15-25% with a payback period of 3-5 years and the Climate Bank may want to replicate these programs. In conclusion, investment in these three technologies will likely result in maximized emissions reductions at varying levels of return.

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ACRONYMS

45Q Credit	Operational subsidy for CCUS
BOF	Blast oxygen furnace
BPA	Bonneville Power Administration
CapEx	Capital Expenditure
CCUS	Carbon capture, utilization and storage
CEFC	Clean Energy Finance Corporation
CFB Boilers	Circulating fluidized-bed boilers
CGB	Connecticut Green Bank
CHP	Combined heat and power (cogeneration)
CTS	Clean Technology Scenario
DAC	Direct Air Capture
DOE	US Department of Energy
DRI	Direct-reduced Iron (process)
EIA	US Energy Information Administration
EIA	US Energy Information Administration
EOR	Enhanced oil recovery
EPACT 2005	Energy Policy Act of 2005
EPA	US Environmental Protection Agency
ESI	Energy Smart Industrial (program)
FERC	Federal Energy Regulatory Commission
GHG	Greenhouse gas(es)
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
LCOE	Levelized cost of energy
MassCEC	Massachusetts Clean Energy Center
NOAA	National Oceanic and Atmospheric Administration
NREL	National Renewable Energy Laboratory
NYSERDA	New York State Energy Research and Development Authority
O&M	Operations and maintenance
PPP	Public-private partnership
R&D	Research and development
SEE Action Network	State and Local Energy Efficiency Action Network
SMR	Steam methane reforming
UCSUSA	Union of Concerned Scientists USA

INTRODUCTION

Anthropogenic climate change risks overall human productivity and well-being, with detrimental changes to food systems, water resources, human health, and ecosystems (Pachauri et al., 2015). Hence, the Intergovernmental Panel of Climate Change (IPCC) have determined three global emissions reductions targets to mitigate the effects of climate change: maintaining temperatures below 1.5°C from pre-industrialized levels, achieving a 40-60% reduction in global greenhouse gas (GHG) emissions from 2010 levels by 2030, and achieving global carbon neutrality by 2050 (Pachauri et al., 2015).

The United States is the second most polluting nation by total emissions and per capita, emitting 15% of global GHG emissions (EPA, 2018). Despite this jarring statistic, this ranking can be an opportunity for the United States to invest in climate mitigation solutions that contribute to the global reduction targets. Financing such solutions will be no small feat, it is estimated that the switch to 100% renewable energy would cost the nation USD $4.5 trillion in capital investment (Holden, 2019). The public sector in the United States is unlikely to commit this level of funds for clean energy investment on its own. Private sector investments in clean energy are increasing, but are also not on track to reach climate goals without substantial changes. However, there is a potential solution proposed, one that would require mobilizing both public and private sector involvement.

The National Climate Bank Act of 2019 proposes the federal government reduce national GHG emissions by financing USD $35 billion in seed capital toward the creation of the National Climate Bank (Climate Bank), a non-profit which seeks to match public dollars with private investment toward clean energy solutions. The bank's seed capital is estimated to stimulate up to USD $1 trillion dollars in total investment over a thirty-year period, within the timeline of global targets set by the IPCC. The bill proposes a policy solution that reduces emissions by accelerating financial investment on innovative clean technologies that would otherwise be unable to progress in the current financial markets, and with the current financial mechanisms.

The bill encourages private sector investment at a reduced risk as the Climate Bank also shoulders some of that investment, while taking the public dollar further.

The National Climate Bank’s scope includes:

- Indirect investing by supporting existing, local green banks and creating new ones
- Direct investing by financing projects
- Prioritizing 20% of investments toward climate-impacted communities, defined as communities of color, low-income, minority, rural groups and communities most impacted by climate change
- Transitioning the nation to a low-carbon economy without increasing costs to end users, while maximizing emissions reductions per public dollar
- Ensuring the consumer credit protection and labor protection mandate

The sectors eligible for National Climate Bank's financial investment include:

- Renewable energy
- Building energy efficiency, fuel switching, and electrification
- Industrial decarbonization
- Grid technology, including transmission, distribution and storage
- Agriculture and forestry
- Clean transportation
- Climate-resilient infrastructure
- Any other key areas that complies with emissions reductions, environmental justice, consumer credit protection and labor protection mandate

This analysis is part of a series that looks at how the Climate Bank can alleviate any existing financial barriers and accelerate the transition to renewables in any of these sectors. This analysis will focus specifically on industrial decarbonization by analyzing the current situation in industry and proposing potential investment strategies for emissions reductions. It will also reveal how the Climate Bank would accelerate the development of clean energy by integrating public and private capital. The Climate Bank's main financing criteria would be supporting any technology that is able to maximize and accelerate emissions reductions, while also considering the returns on investment. This would mean prioritizing technologies that will have the highest emissions reductions and with the largest return on investment. Thus, technologies that are already or will be mature for commercialization, with Climate Bank support, should be the Climate Bank's first priority. Commercial-ready technologies will have the highest emissions reductions as it is more likely to be adopted by many in industry, has seen extensive research and development leading to faster deployment, and leads to increased efficiency and potential offset or returns. However, the Climate Bank is also ready to shoulder the costs of investments that may yield no returns, if it means the highest emissions reductions.

OVERVIEW OF SECTOR

The industrial sector is an indispensable part of both a nation's economy and the global economy. Industry accounts for one-quarter of global GDP and total employment based on a report by the consulting firm McKinsey & Company (De Pee, 2018). Unfortunately, this comes at a cost to the environment as about 28% of global GHG emissions come from this sector, and is 90% carbon dioxide (CO2) emissions (De Pee, 2018). For the US, industry's share of total GHG emissions is 22%, making it the third largest emitting sector for GHG emissions, with the electricity sector at 27% and transportation at 28% (EPA, 2018). This means that the industrial sector emitted about 1.47 billion metric tonnes of CO2 in 2018 alone (EPA, 2018). Additionally, about 44 percent of industry's primary energy source comes from natural gas, and approximately 40 percent comes from petroleum (EIA, 2020). Thus, in total, 84% of industry's energy is derived from fossil fuels. This indicates an opportunity for renewable energy to develop and ease the reliance on fossil fuel. Hence, to combat climate change and meet the global transition toward clean energy, decarbonizing the industrial sector must be a key player for carbon reduction.

There are many strategies to promote industrial decarbonization (decarbonization) and this can be seen as both an opportunity and a challenge. This analysis will explore five potential technologies: 1) carbon capture, utilization and sequestration (CCUS); 2) biomass; 3) hydrogen; 4) energy efficiency; and 5) electrification. Each technology alone will not be able to reduce all of industrial emissions in the US. Hence, a combination of decarbonization strategies is needed to achieve the goal of emissions reductions in this sector.

INDUSTRIAL DECARBONIZATION TECHNOLOGIES

CARBON CAPTURE, UTILIZATION AND STORAGE (CCUS)

CCUS, though one concept, has many different types of capture and storage methods that are at varying levels of development. Additionally, CCUS can be expected to reduce emissions up to 90%. However, due to high operational costs there is potentially little to no return on this investment.

The capture process of CCUS traps CO_2 emissions either from direct sources, such as factories emitting CO_2, or indirect sources, such as ambient air, and then undergo chemical reactions. The captured CO_2 can then either be used or stored, depending on the resources available. Utilization repurposes the captured CO_2 toward chemical production, fuel production, and raw material such as feedstocks, thereby creating a closed loop system if the carbon continues to be captured and reused. The storage process involves its injection into the subsurface, either deep underground or in the ocean. The two main technologies for CCUS depend on the source of CO_2 and are called: direct air capture (DAC) and point source capture. DAC captures indirectly sourced CO_2 from the atmosphere, whereas point source capture technologies capture emissions from direct sources. Point source capture includes pre-combustion, post-combustion and oxy-combustion capture. CCUS can help US industries reach carbon neutrality and even carbon negativity, when combined with lower-carbon power sources like offshore wind and biomass.

Federal and state policies have begun incentivizing investment in all kinds of CCUS technology since 2018. This is because CCUS has become a popular solution for industry as adopting CCUS technologies does not require huge overhauls or systemic changes in operations (Temple, 2018). At the state level, fifteen states have implemented policy incentives such as direct financial assistance, tax incentives, setting clean energy standards, and more, each covering varying costs of a CCUS project (see Appendix A for more information). Additionally, a notable federal policy known as Section 45Q Credit (45Q) is a tax credit that provides an operational subsidy for CCUS at a rate of USD $35-50/t- CO_2, depending on what the captured CO_2 will be utilized for, and for up to 12 years (Waltzer, 2018).

The primary challenge of CCUS investment has been its high operational costs for all forms of CCUS technologies. However, DAC facilities are becoming increasingly efficient with lower operational costs and the annual capacity of sequestering up to 1 Mt of CO_2 (Keith, 2018). Costs of DAC technology are expected to reach as low as about USD $54/t- CO_2 captured by 2040 (Fasihi, 2019; Keith, 2018). As for post-combustion CCUS, the carbon capture costs decrease as technology develops and ranges from about USD $50-70/t- CO_2 abated, shown in Figure 1 below. However, the operational costs of post-combustion CCUS presents a significant part, driving up an additional 80% of total project costs (DOE, n.d.). Thus, both DAC and post-combustion CCUS technologies operate at a cost higher than the USD $50/t- CO_2 abated subsidy and it will still set large economic burdens on industries to sequester carbon, even with the tax credit.

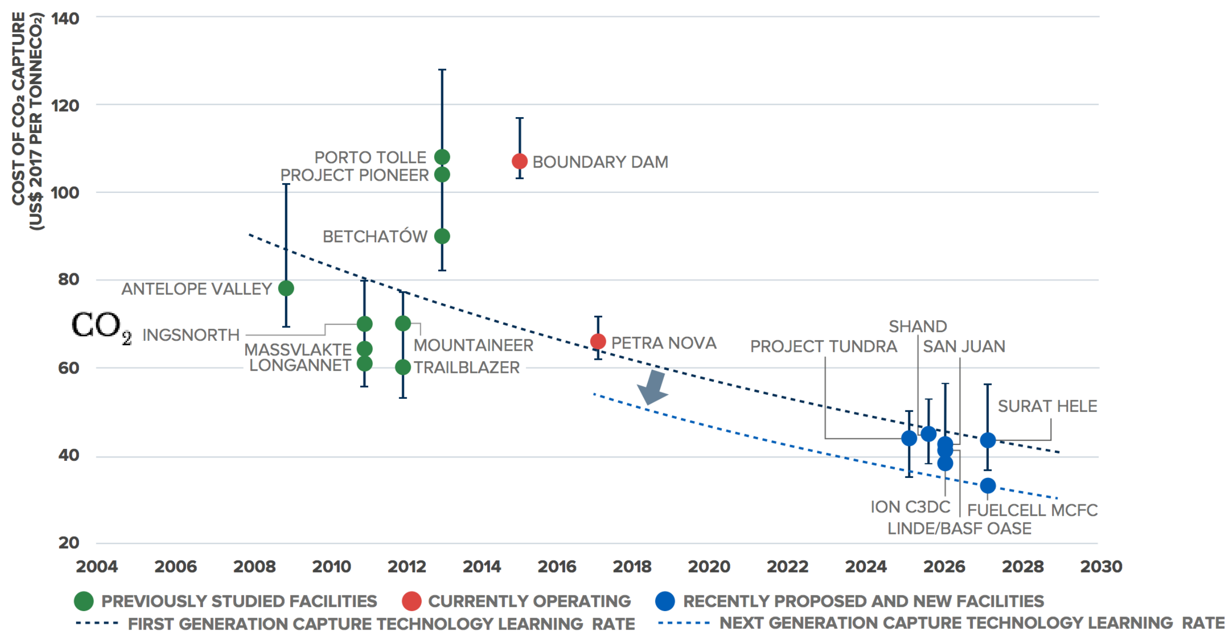


Figure 1. Levelized cost of captured CO_2 (per Mt) for large-scale post-combustion CCUS projects over time. Source: Global CCS (Carbon Capture and Storage) Institute

INVESTMENT POTENTIAL

Modeling scenarios based on presently available technologies often rely on CCUS to meet long-term emissions targets (Temple, 2018). DAC, which is currently operating at small-scale, is expected to scale up and lower costs as the technology develops (Quartz, 2019). DAC pilot plants are already being operated in the US and around the world to reduce carbon footprint. The Swiss company Climeworks runs a demonstration DAC plant in the US, sequestering 8kg of CO_2 per day or 3.12 Mt of CO_2 per year. The primary difficulty with DAC is that CO_2 is only available in ambient air in concentrations of approximately 400ppm and requires mass amounts of air to move through the device every day. As a result, the energy required for this process ramps up the operational cost (House, 2011). Additionally, Norway has instituted a DAC project within a waste-to-energy industrial plant which utilizes the heat waste from the plant to power DAC fans, which then capture CO_2 from the air. The best industrial sites for this kind of technology will be those with heat waste in the form of steam or other kinds of flue gas. This project captures up to 90% of the CO_2 in flue gas (Fortum, 2018).

It will likely result in little to no returns if investments were only offsetting operational costs. However, if there is enough investment to offset the operational costs such that DAC becomes widely adopted, emissions reductions would be greatly achieved. It is also important to note, investments in offsetting costs would not be forever. As operational costs decrease and come within the tax credit range of USD $35-50/t- CO_2, investments would no longer be needed.

Post-combustion, a point source technology, on the other hand, is a more mature technology relative to the other CCUS options. Pilot projects have begun since the early 21st century, such as Boundary dams in Canada and Petra Nova Plants in the US. Three-generation technology development allows post-combustion technology to be practiced in multiple sectors, including power, natural gas processing and chemicals production. It is also proven to reduce emissions up to 90% for a single plant (DOE, n.d.). This kind of technology can also be retrofitted for existing industrial plants, which makes it even more flexible to be applied. While it is not a carbon negative technology, if all industries were to adopt this method for all their emitting plants, the industrial sector would only emit 2.2% of total US emissions, instead of the 22% it currently emits. Hence, post-combustion CCUS are of great potential as there is little capital infrastructure costs, yet great emissions reductions potential.

Additionally, there is incentive to promote utilization before storage as the carbon can be reused or sold as a source of revenue to cover operations and maintenance (O&M) costs. For example, the captured CO_2 from DAC can be utilized to make fuel or can be transformed into other marketable products (Sutherland, 2019). However, one major concern is that CCUS provides a license for fossil fuel and other industries to continue polluting (Sutherland, 2019). In this case, utilization has the potential to negate carbon sequestering efforts, even when it is reused, if the carbon is not continuously recaptured. Regardless, there is currently a lack of profitability for carbon utilization without systematic carbon trade as well as carbon pricing. Because of this, the federal government introduced the enhanced 45Q tax stimulus in 2018, pushing power plants and industrial facilities to retrofit their infrastructure with CCUS (IEA, 2019).

In addition, there is potential investment in carbon capture projects combining biomass, which is known as Bio-CCUS. In Mississippi, Velocys Inc. announced a project at the Bayou Fuels facility that uses woody biomass forest residue converting waste to cleaner sustainable fuels for either aviation or heavy-duty road transport. By integrating with CCUS, the Bayou Fuels facility will save about 70% of net CO_2 emissions for each tonne of replaced conventional fuel, and therefore potentially avoid 550,000/t- CO_2 annually (Lane, 2019). According to the data from Carbon Engineering on Joule report, the levelized cost of capture has a range of USD $94 - 232/t- CO_2 (Keith, 2018).

ROLE OF THE NATIONAL CLIMATE BANK

Investment in Direct Air Capture and Post-Combustion

With existing financial policies, the primary need for the Climate Bank in the CCUS context could be to provide capital investment, likely needed for both construction and development of DAC and post-consumption technologies, but mainly to offset their operational costs until they fall within the 45Q tax credit. Additionally, if capital investment is needed, the Climate Bank could offer zero- or low-interest senior debt loans to the project sponsor, which could allow the projects to bear lower financial risks while attracting more participants.

Investment in Bio-CCUS

The Climate Bank could potentially help developers invest in Bio-CCUS projects, like Bayou Fuels project, as their waste-to-energy model decreases the costs and deepens emissions reductions further. In some cases, CCUS can be applied to power plants and industrial facilities, as the least-cost decarbonization option, at a cost as low as USD $15-25/t- CO_2 captured to reach carbon neutrality or carbon negativity for industrial operations (IEA, 2019). The waste-to-energy model will become the mainstream of the US industry since it has great market potential to address both economic and emissions concerns.

Future Outlooks

According to the US Energy Information Administration (IEA), more than 28Gt CO_2 is expected to be captured from the industrial sector by the period of 2060, mostly from the cement, steel and chemical subsectors. As one of the most cost-effective decarbonization solutions for large-scale emission reduction, CCUS could address approximately one-fifth of the emissions reductions needed across the industry sector; in particular, CCUS is expected to help realize 15% of the emissions cuts needed in both cement and steel subsectors, and up to 38% in the chemical sub sector (IEA, 2019). Backed by the 45Q stimulus only, USD $1 billion of fresh capital is expected to be raised for CCUS projects over the next six years, for potentially increased carbon capture capacity that ranges from 10-30Mt CO_2 (IEA, 2019).

BIOMASS

Biomass refers to pretreated woody, cellulosic, and vegetable fat feedstocks or inputs to produce energy. It can either be converted to fuel or used as combustion feedstocks to provide low-carbon heat. While biomass is mainly for residential use in developing countries, in the United States it is mainly for transportation (31%) and industrial (44%) use (DOE, 2011; IEA, 2013). Biomass has the potential to reduce up to 800 million metric tonnes of CO_2 can be carbon neutral in the long-term with proper planning, and is a low-cost renewable option as they are already competitive in the renewable energy market.

While the current US biomass generation plants use a combination of different types of biomass (depending on availability), cellulosic biomass holds the most emissions reductions potential of 800 million metric tonnes of CO_2 per year. This could lead to emissions reductions of up to 86%, whereas other biomass types such as corn ethanol only reduce 52% (DOE, 2007).

Biomass technology, however, also has its drawbacks, including combustion-related GHG and other harmful pollutants. While burning biomass does create emissions, it is relatively smaller compared to emissions from fossil fuels. Additionally, according to the US Energy Information Administration (EIA), the rate of burning can be offset by regrowth of plant material (EIA, 2019). This could mean that biomass can achieve carbon neutrality when planned properly, though this outlook is only achievable in the long-term, as the rate of burning is much faster than plant regrowth (Harvey and Heikkinen, 2018). In addition, harmful pollutants such as carbon monoxide and particulate matter are released, which can result in a potential health risk at high concentrations (EIA, 2019). Other drawbacks include the relatively large area required for biomass plants, and the uneven distribution of locations for raw materials, making it costly to collect and transport (University of Wisconsin-Stevens Point, 2017).

Biomass has benefited from extensive federally-funded R&D and initiatives, leading to its commercialization. In 2000, for example, the Department of Energy conducted jointly funded projects with the Department of Agriculture on biofuels and bio-based products' research, development, and demonstration, as part of Biomass Research and Development Act (H.R. 2559). The act has led to progressive development and provided analysis on the benefits of biomass production and biobased industrial products (H.R. 2259). A total of 225 state incentive programs have promoted the use of biomass since 2015 (Roni et al., 2017). Present funding for bioenergy still exists as DOE recently announced an investment of USD $100 million for R&D of bioenergy technologies in January 2020 (DOE, 2020).

Currently, conventionally pretreated biomass is a mature and commercially viable clean technology. It is either cheaper or as competitive as other renewables, at about USD $15/GJ, while other options such as green hydrogen are priced at USD $40/GJ and electrification at USD $11-17/GJ. Depending on the type of biomass used, the price of biomass can sometimes reach as low as USD $3.7/GJ and can be even less costly than traditional fossil fuel, which is priced at $4.4/GJ (EIA, 2019; IRENA, 2012). While total

While total installed costs of biomass power generation plants vary significantly by size and location, the levelized cost of electricity usually falls between USD $0.8 to $0.15 per kWh (IRENA, 2012; Whole Building Design Guide, 2016). Thus, biomass is a competitive option in the renewable energy market.

INVESTMENT POTENTIAL

There are four potential methods to eliminate emissions from biomass combustion. These methods consider different stages of the biomass combustion process and include: greener pretreatments to prep the biomass, more efficient boilers to process the biomass, combining biomass with other emissions reductions technologies to maximize emissions and to consider the type of biomass with the highest emissions reductions.

Biomass must be pretreated before combustion. Conventional chemical pretreatment strategies are unsustainable as they require high energy and reduce biomass efficiency. One possible direction for investment is on the improved pretreatment of biomass known as green pretreatments such as microwave, ultrasound and high-pressure homogenization. This method has a higher cost because of additional constructions, but it is more environmentally-friendly and can raise the energy efficiency of biomass through reducing wastes during combustion (Hassan et al., 2018). However, green pretreatments are currently in the research phase and are not currently viable for commercialization (Hassan et al., 2018). Thus, an investment at this stage in its development will lead to little to no return on investments.

Another option is to invest in new infrastructure such as advanced boilers. For instance, circulating fluidized bed (CFB) boilers are the most recent technology that can enhance energy conversion efficiency and lower the NOx and SO2 emissions during biomass combustion (Roni et al., 2017). Currently, the majority of American biomass plants use the co-firing method, burning a combination of coal and biomass, and pulverized coal-fired boilers, both of which are not optimal for biomass combustion because they cannot deal with the variances in biomass materials, such as particle sizes and moisture content (Roni et al., 2017). Commercial CFB boilers are currently more widespread in Europe than in the US, due to their high capital cost and limited supply (EPA, 2015). Regardless, US plants with CFB boilers still exist, such as Virginia City Hybrid Energy Center, which also uses them for co-firing, allowing up to 20% of biomass fuel input (Peltier, 2012).

A third option would address the carbon neutrality issue of biomass. If a short-term solution is required, biomass generation plants may be combined with CCUS known as Bio-CCUS, such as DAC to further offset emissions.

Finally, investment in cellulosic biofuels should also be considered. Cellulosic feedstocks are an important consideration for investment because they have the highest emissions reduction potential, and do not displace food production like corn, though they are more expensive. Again, if used at maximum potential for all US industry, this could be up to a cumulative elimination of more than 800 million metric tonnes of CO_2 (DOE, 2007).

ROLE OF THE NATIONAL CLIMATE BANK

According to the Environmental Protection Agency (EPA), two major barriers impede the adaptation of renewable energy; a lack of information and education on renewable heating technology options, and managers' hesitation to make a complete overhaul. Circulating fluidized-bed boilers, which can maximize biomass efficiency and minimize side environmental impacts, are not commonly used in the US, as industrial companies are not sure whether it's worthwhile to completely replace coal with biomass (EPA, 2020). Additionally, biomass-fueled power plants and industrial companies mostly use biomass as a supplement for coal, not as the main heating resource. Thus, in many cases, biomass heating projects might only "scratch the surface" of a facility's total heating energy use, and therefore have small impacts on emissions reductions (EPA, 2020). Hence, Climate Bank support may give them the push they need toward biomass, such that their ratio of coal to biomass decreases until there is no longer reliance on fossil fuels. The Climate Bank may help accelerate the application of CFB boilers in industrial heating by providing capital support to existing power plants. According to EPA, the average capital, operational and maintenance costs are lower for large-scale CFB boilers projects, compared with small and medium scale (Table 1). Thus, the Climate Bank should invest in large-scale CFB boiler facilities by supporting the upfront infrastructure capital costs. Once the technology is installed, operating and maintenance costs will decrease. This technology is well beyond the deployment phase, so the risk associated with this investment is very low (EPA, 2017).

CFB Boiler Size	Small	Medium	Large
Total installed boiler costs	$697,000.00	$24,510,000.00	**$32,250,000.00**
Total installed steam system costs	$9,610,000.00	$29,940,000.00	**$39,360,000.00**
Unit capital cost ($/lb steam)	$480.00	$171.00	**$151.00**
Non-fuel Operations and Maintenance cost ($/1000lb steam)	$4.19	$1.09	**$0.74**

Table 1. Costs of Circulating Fluidized-Bed Boilers at various scales (in USD). Adapted from the Environmental Protection Agency

The installation of CFB boilers can increase the efficiency of biomass, and lead to the complete replacement of coal. While biomass is not completely clean compared to other decarbonization options, it is a relatively mature and economical option for the Climate Bank to consider.

HYDROGEN

Hydrogen is utilized in two different ways within the industrial sector. Industry either produces hydrogen as a product or uses hydrogen during industrial processes. For example, in the United States, hydrogen is commonly used by industry for refining petroleum, treating metals, producing fertilizer and processing food (EIA, 2020). To reduce emissions, both types of plants (hydrogen-producing or hydrogen-using plants) should make or use green hydrogen, respectively. Green hydrogen is hydrogen produced using 100% renewable sources and applications of green hydrogen can reduce up to 30% of emissions in the industrial sector (de Pee et al., 2018). Since hydrogen has many applications, green hydrogen production and use could benefit from further investments. Additionally, the emissions reductions potential could be even greater with more widespread adoption of green hydrogen.

About 95% of the hydrogen made in the US today is created through a process called steam methane reforming or SMR (DOE, 2017). This process reacts steam with methane sources like natural gas in the presence of a catalyst at high temperatures (700°C–1,000°C) and pressure (3–25 bar). This form of hydrogen is also called grey hydrogen, as it is produced from fossil fuels. The output generates a significant amount of CO_2 if the carbon byproduct is not captured (Abraham, 2017). Fortunately, another process, known as electrolysis, allows industrial plants to make hydrogen greener. This process uses electricity to directly split water molecules into hydrogen and oxygen. In addition to producing no CO_2, electrolysis can operate even more cleanly if the electricity used to power it is derived from renewables to make green hydrogen (Hight, 2019).

Currently, cost has been a barrier to adopting electrolysis in industry despite extensive R&D in hydrogen production. In Europe, hydrogen produced through SMR can be as cheap as approximately USD $1.65 per kg depending on the cost of natural gas, while green hydrogen is usually priced between USD $3.85-$5.5 per kg (van Hulst, 2019). Although limited electrolysis capacity is part of the reason why green hydrogen is costly, the most critical factor is the price of the renewables, used as electricity in the electrolysis process (van Hulst, 2019).

In the past, state and federal policies have significantly supported the R&D of hydrogen and fuel-cell technology for industrial use, though hydrogen for electric vehicle applications were more popular. Policies such as the Energy Policy Act of 2005 (EPACT 2005) promoted the development, innovation and commercialization of hydrogen; the federal program H2@Scale has expanded their financial support for R&D, increasing their hydrogen projects every year; the DOE has also increased their number of projects every year (from 20 projects in 2018 to 29 in 2019) following their USD $40 million investment to focus on production, storage, transport, and utilization (EPACT, 2005; DOE, 2020). Overall the policies have focused research on two methods of hydrogen production: SMR with CCUS and electrolysis.

INVESTMENT POTENTIAL

One promising adaptation of hydrogen is in the steel industry. The pioneering Swedish company HYBRIT has been developing technology to completely replace coal with hydrogen in the blast oxygen furnace (BOF) process during steel production since 2017. According to the company's research, this "fossil-free fuel steel" technology can reduce the carbon emission of steel production from 1600kg CO_2 per ton of steel to 25kg CO_2 per ton of steel (Rocky Mountain Institute, 2020). Despite its great potential in decarbonization, this technology is still in the R&D stage, and therefore cannot yet be commercialized.

In the longer term, DOE hopes to deploy commercial-scale production and establish green hydrogen as a substantial commercial supply. With future green hydrogen pricing expected to decrease, there will be even more incentive for producing and using green hydrogen. Operating costs for producing hydrogen will likely reduce over the next ten years as green hydrogen becomes more competitive in the energy market. As for utilization, for steel-producing companies, replacing traditional fuel sources with hydrogen fuel can abate as much as 30% of their production emissions (de Pee et al., 2018). Thus, there is potential investment in accelerating toward commercial-scale production through methods such as offsetting operational costs or subsidizing the price of green hydrogen in the long-term.

ROLE OF THE NATIONAL CLIMATE BANK

Electrolysis is currently operating at small-scale and needs further R&D. Hence, it is unlikely that investment through the Climate Bank would effectively reduce significant GHG emissions while achieving returns.

Additionally, hydrogen investment and development has seen greater emphasis and is more mature in the transport sector, due to the commercialization of hydrogen-fuel cell batteries for electric vehicles. Thus, much of the research in hydrogen has been deviated to that area instead of the industrial sector. Regardless, hydrogen fuel production may be more applicable as a future investment for the Climate Bank, as electrolysis matures and passes its R&D stage. Hence, in the future, the Climate Bank may be able to offer financial support toward commercializing green hydrogen production and electrolysis through the methods mentioned previously. However, even if the Climate Bank does not invest directly in green hydrogen, the Climate Bank's overall investment in renewables would help drive the price of hydrogen down as renewables become more competitive with fossil fuel.

ENERGY EFFICIENCY

Energy efficiency is the strategy of building or retrofitting to high performance, such that less energy is needed to perform a given function. It has great environmental benefits, projected to result in a 15-32% decrease in industrial energy consumption. The Intergovernmental Panel on Climate Change (IPCC) states that energy efficiency can help reduce the energy intensity of current processes by up to 25% (Lechtenböhmer, 2017). The American Council for an Energy-Efficient Economy (ACEEE), also points out that enhancing energy efficiency can halve greenhouse gas emissions in US energy use by 2050 (Ungar, 2019). It can lead to sufficient energy cost savings in both the short and long terms as well (SEE Action Network, 2017). Additionally, investments in energy efficiency are also expected to have a 15% rate of return in 3-5 years (SEE Action Network, 2017).

Energy efficiency projects are often undertaken by the owner of a capital asset. Government support for industrial energy efficiency include programs such as the Industrial Energy Efficiency Program and the Ratepayer-Funded Energy Efficiency Program. According to the DOE, these programs have an average cost of saved energy of USD $0.03/kWh in 2012

(Department of Energy, 2014). The levelized cost of commercial and industrial program savings is from USD $0.018/kWh to $0.024/kWh based on the existing rate of Ratepayer-Funded Energy Efficiency Programs (See Action Network, 2017). Also, the cost of energy savings in the industrial sector is $0.029/kWh, lower than that in the residential industry of USD $0.05/kWh (Department of Energy, 2014). Most of the energy efficiency programs, such as the Ratepayer-funded Energy Efficiency Program above, are in the public-private partnership (PPP) mode, involving local agencies and corporations. Under this model, most energy efficiency programs have payback periods of 3-5 years with over 15% or even 25% internal rate of return over the useful life of the projects (SEE Action Network, 2017). This implicates a remarkable return potential.

INVESTMENT POTENTIAL

The primary driver of energy efficiency investment is the expected returns. Reducing a single plant's energy costs by 25% with the strictest energy efficiency measures will result in serious cost reductions to the plant owner, which thereby can increase profits and productivity. This investment strategy can appeal to industrial operations owners who are not necessarily motivated by cutting emissions, but are driven toward their bottom line. High potential for industrial energy savings in the steel, cement, and pulp and paper industries are suggested by IPCC as their high energy intensity and feasibility to improve energy efficiency through heating process improvement and fuel switching (IPCC, 2007).

The Bonneville Power Administration (BPA), a federally-owned interstate electric power utility in Portland, Oregon, instituted an Energy Smart Industrial (ESI) program which offered "project development, marketing, technical service, proposal consultant contracting, and implementation of industrial sector energy efficiency acquisition for all BPA-offered industrial sector programs to improve regional consistency from 2010 to 2014" (SEE Action Network, 2014). BPA's ESI program had a benefit-cost ratio of 7.3:1 in 2011, which illustrates the cost-effectiveness of this program.

A case under BPA's ESI program is a large paper mill in Washington State, called NORPAC. The company, BPA and local government helped fund an initiative to add a new wood chip pretreatment and screening process, which would realize 100 million kWh per year in energy savings, around 12% of annual energy consumption (SEE Action Network, 2014). These kinds of applications show how investment in energy efficiency yields both energy savings which would lead to cost and emissions reduction in the long-run.

The New York State Energy Research and Development Authority (NYSERDA) offers financial incentives, flexible technical assistance, manufacturing technology development and incentives for combined heat and power systems to local commercial and industrial customers for energy efficiency improvement. Irving Tissue, a company that built a new pulp processing paper machine and additional supporting infrastructure, was funded by NYSERDA with an incentive of USD $1.8 million to institute energy efficiency measures into the new manufacturing infrastructure. The incremental cost was USD $4.3 million and the energy savings compared with a standard paper machine installation was 14,800,000 kWh per year (SEE Action Network, 2014).

In all, the cost-benefit analysis of energy efficiency varies by programs. Yet, based on the considerable energy-saving, return rate, and emissions reduction, investments within industrial energy efficiency projects still yield positive results in emissions and cost reductions.

ROLE OF THE NATIONAL CLIMATE BANK

The Climate Bank can serve as a provider of investment and technical assistance to promote increasing numbers and scale of energy efficiency projects. Particular attention should be paid to steel, cement, pulp and paper industry to better enhance emissions reduction. Furthermore, US Green Banks across states have projects and strategies relating to energy efficiency that the Climate Bank may take as a reference, including Connecticut Green Bank (CGB), California CLEEN Center, and the Clean Energy Finance Corporation (CEFC). They have plenty of financial instruments in energy efficiency investments, including direct loans, bond funding, public financing and among others (see Appendix B for more information). Additionally, the Climate Bank may want to evaluate energy efficiency upgrades for sector-specific technology resources in industry, coupled with one or more additional decarbonization strategies as energy efficiency cannot decarbonize a whole industrial operation. However, it does reduce the burden on any complementary system that is currently operating. Hence, the industrial sector may be more receptive to energy efficiency changes as it doesn't require huge infrastructure and systems overhauls and can work with existing infrastructure.

ELECTRIFICATION

Electrification is defined as the shift from the nonelectric source of energy, like coal and natural gas, to electricity in the end use (McMillan, 2018). There are two pathways to electrify the industrial sector. The first is to directly substitute fossil fuels and petroleum-based fuels in the powering and heating processes. The other indirect way is to use hydrogen in a "direct-reduced iron (DRI)" process of energy storage or load (Lechtenböhmer, 2017). Regardless of which pathway, if a plant were to electrify using 100% renewable sources such as wind and solar, this could lead to 100% emissions reductions. However, investments would be needed as electrification leads to infrastructure and systems overhauls and may require government support as well.

Electrification can reduce combustion-related GHG emissions and the full value of emissions reductions will be subject to the primary energy for electricity supply. If the power grid were based on clean energy this could mean a near-complete reduction in emissions within the energy sector. The 100% electrification scenario results in a 3.6% savings in primary energy (Deason et al., 2018). Therefore, the co-development of renewable energy sources, such as wind and hydrogen, can also play a role in the future of electrification. Currently, the application of electricity shares a smaller proportion than non-electricity fuel in the industrial sector and the portion

portion of end-use electricity consumption is projected to be fairly stable from 2015 to 2050, as shown in Figure 2 (EIA, 2020). Most notable increase in electricity application can be seen in industries producing glass products, machinery, primary metals, and other manufacturing.

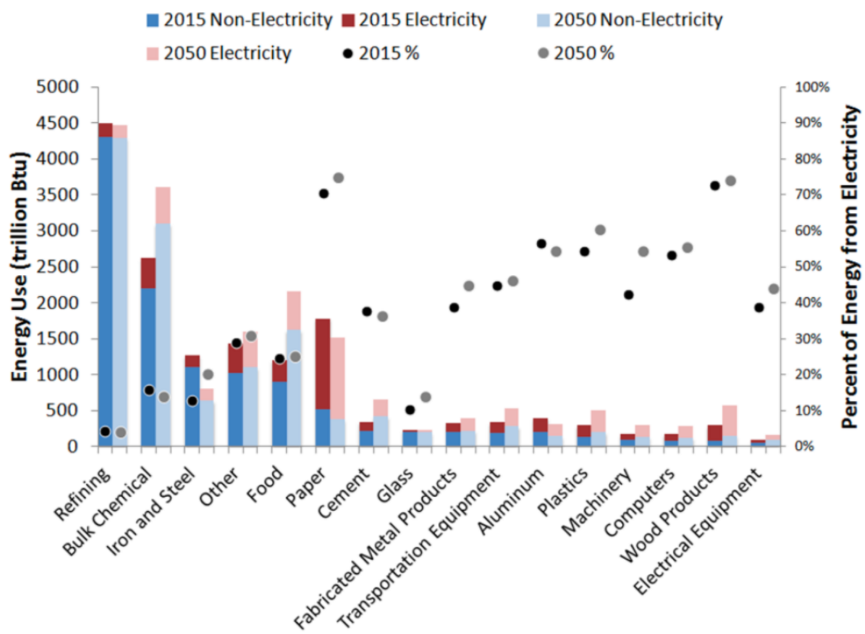


Figure 2. Electricity and non-electricity fuel use by the industrial sector in 2015 and projected demands in 2050. Source: Energy Information Administration

Although the National Renewable Energy Laboratory (NREL) expects that all conventional boilers will be converted to electric technologies by 2050, few policies directly support industrial electrification (Steinberg et al., 2017). Since electrification is a systematic process which is closely related to infrastructure upgrade and electricity price, EPACT 2005 helps accelerate electrification by offering a framework to coordinate among federal agencies with authority to site electric transmission facilities (DOE, n.d.; EPACT, 2005). EPACT 2005 includes provisions at expanding the electric grid and issuing a rule on electric transmission pricing reforms (Federal Energy, 2006). This rule increases the power grid reliability and lowers delivery costs by reducing transmission congestion and promoting electric transmission investment. The upgraded infrastructure and decreased electricity costs further facilitate electrification.

Environmental benefits of electrification can be huge, while costly. A report from the Brattle Group, a consulting group, shows that it can achieve an 80% reduction from 1990 levels if the States can fully decarbonize the electric power sector in 2050 (Weiss, Hledik, Hagerty, & Gorman, 2017). However, the advanced industrial technologies in electrification will require billions of dollars in transmission investment in the next several decades. The transmission investment of electrification will need around USD $90 billion by 2030 and over USD $600 billion by 2050 (Institute for Energy Research, 2019). At that time, electrification will increase U.S. annual electricity demand by 5%-15% by 2030 and up to 85% by 2050 (Institute for Energy Research, 2019). However, it is difficult to measure the cost of financing for industrial electrotechnologies as little data or projects were made publicly available.

INVESTMENT POTENTIAL

Several studies in the US and Europe found that the technical potential for fuel-switching in industry is broad and significant for long-term decarbonization, particularly with a low-carbon primary energy supply like offshore wind (European Climate Foundation, 2010; Long et al., 2011; Wei et al., 2013; Williams, 2012). According to the breakdown of non-electricity fuel use by the industrial sector, heating dominates fuel use in producing industries, such as petroleum and coal products, primary metals, iron and steel and nonmetallic mineral products, while the use of conventional boilers shares a relatively small fraction of overall fuel use (see appendix C). This is an important implication of where electricity can substitute fossil fuel and thus, heating and boiler systems are of great potential to be electrified. Although there are limited data, the best estimates are up to 100% electrification for industries including cement, paper, and glass manufacturing (Deason, Wei, Leventis, Smith, & Schwartz, 2018). What is more, in 2014, nearly 62% of fuel used in the manufacturing came from fossil fuel and steam, a 12,394 TBtu oil equivalent, which presents the potential of electrification as well. (EIA, 2019; see appendix D).

Despite the technological opportunities for electrification, the costs of investment in electrification is a major barrier. Deason et al. indicates that the technical potential for industry electrification is high, but faces challenges in cost and investments (Deason, Wei, Leventis, Smith, & Schwartz, 2018). High cost of electrification consists of large-scale electric infrastructure upgrade as well as less competitive price of renewable energy based electricity. Due to the current low price of natural gas, electric heating is less favored than natural gas-fired heating. In 2017, industrial prices for natural gas were USD $0.014 per kWh-thermal while the price for industrial electricity was USD $0.053 per kWh (Deason, Wei, Leventis, Smith, & Schwartz, 2018). As a result, the price of natural gas is four times cheaper than industrial electricity. For industry processes, this means the cost of energy will be 4.2 times higher for the electric boiler with 100% end-use efficiency than the gas-fired boiler with 80% efficiency. We will not go into detail about renewable electricity prices but it is definitely an indispensable factor in electrifying the industry.

ROLE OF THE NATIONAL CLIMATE BANK

Investment in heat pumps

Heat pumps serve as an energy-efficient way to meet heating and cooling needs and are usually placed in air conditioners, furnaces or water heaters. They are powered by electricity, are quieter, conserve energy and can endure longer-lasting temperature adjustments (DOE, n.d.). Incentive programs for heat pumps are generally offered through loans, rebates or tax incentives. The Massachusetts Clean Energy Center offers rebates of USD $2,500 to $30,000 for residential utility customers' purchase of certain heat pumps. This is to promote the application of heat pumps in residential buildings and the program has rebated over USD $5.8 million for 4,000 units from 2014 to 2016 (MassCEC, n.d.). The Tennessee Valley Authority (TVA) has also lent loans since 1997 for heat pumps to customers in the service territory of their electric distribution companies (SEE Action Network, 2014). In the industrial perspective, there is a possibility for the Climate Bank to offer low-interest loans to manufacture, upgrade or change new heat pumps. These heat pumps can be applied to air conditioners in factories or furnaces during the heating process to improve the working environment as well as production efficiency.

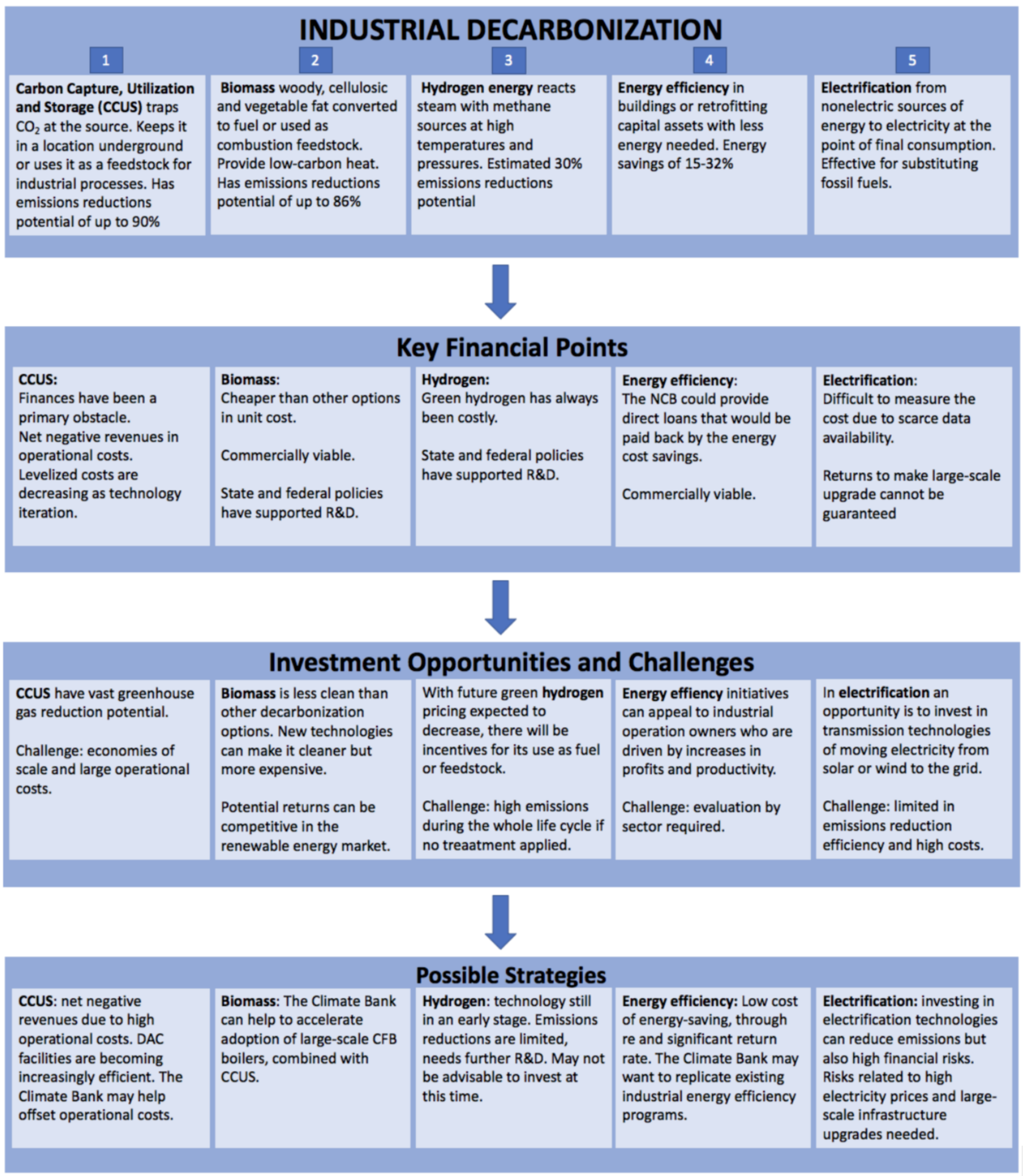
Investment in electric boilers

Electric boilers are likely to be the simplest industrial electrification implementation. They can be environmentally-friendly when powered by renewable energy, however, as the natural gas price continues going down, electric boilers become less competitive against gas-fired ones. One possible direction is to develop hybrid gas-electric boilers, which can be used whenever natural gas or electricity is cheaper. There are estimates that huge quantities of renewable energy are coming online in the future and outstripping demand may lead to falling electricity prices (California ISO 2016; Denholm 2015). The Climate Bank may consider investing in electric boilers in conjunction with renewable energy promotion. Such programs can be conducted through direct loans as well.

If the Climate Bank were to invest in electrification technologies, the investment can largely reduce emissions with renewable energy supply, though there may be little to no returns. The Climate Bank may bear huge costs due to the high electricity prices and large-scale infrastructure upgrades. Retail electricity sales in industry have been quite stable since 1990 at about 1,000 TWh/year (EIA, 2020). Many sectors are not originally designed to use electricity or large-scale application of electricity, therefore, upgrades in delivery infrastructure are necessary and expensive so it is hard to obtain a positive return with such huge initial inputs. What is more, sub-sectors and process heating modules vary across the sector, which requires application-specific designs and sets complex for electrified processing. Lastly, in 2014, the electricity generation from noncombustible renewable energy was only about 1% of the total amount of electricity generated onsite in US manufacturing and this portion remains relatively stable. Thus, investment in this process may face a lot of technical, financial and implemental constraints (EIA, 2020).

SUMMARY

The following figure shows a summary of the technologies in this analysis including the current status, investment potential and the suggested financial strategies for investment.



CONCLUSION

The National Climate Bank would open many opportunities for further investment in the industrial decarbonization sector. Thus, it is important for the Climate Bank to make sound and effective investments that maximize emissions reductions with a return on investment. However, if there are significant emissions reductions involved and a return on investment is unlikely, the Climate Bank may re-prioritize and fund these projects. The analysis looked at five technologies: 1) CCUS; 2) Biomass; 3) Hydrogen; 4) Energy Efficiency and 5) Electrification in the industrial sector that could benefit from the Climate Bank's support, given their respective technological, political and financial status. Hence, it is suggested that investment in a combination of three technologies: CCUS, biomass, and energy efficiency would yield the most promising results. DAC and post-combustion technologies from CCUS would result in emissions reductions of up to 90%, biomass could reduce up to 86%, and energy efficiency measures could decrease energy consumption by 15-32%. While CCUS technologies are unlikely to yield any returns, biomass through investment in CFB boilers and energy efficiency through different incentive programs have potential returns depending on the project. In short, it is important to have the National Climate Bank's involvement in making the necessary steps toward emissions reductions. The participation of the Climate Bank can provide capital, share project risks, and boost market confidence to attract increasing private investment in clean energy solutions.

APPENDIX

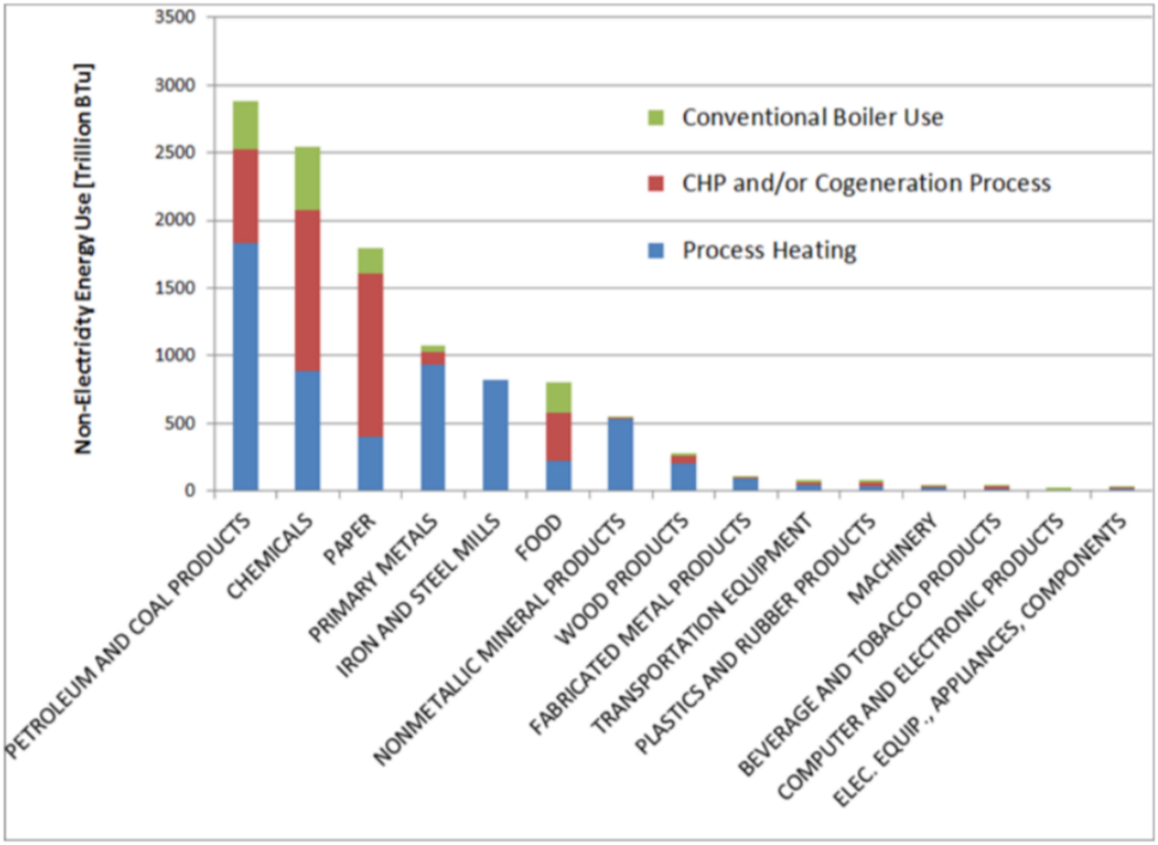
Appendix A. Types of State Policies supporting CCUS Technologies

	TYPES OF POLICIES IMPLEMENTED FOR CCUS					
State	**Direct financial assistance**	**Off-take agreements**	**Utility cost recovery mechanism**	**Clean energy standard**	**State assumption of long-term liability**	**Tax incentives**
Michigan				X		
Illinois	X	X	X	X	X	X
Indiana		X				
Kentucky					X	X
Virginia			X			
Montana					X	X
North Dakota	X				X	X
Wyoming	X					X
Utah				X		
Colorado			X			
Kansas					X	X
Mississippi			X			X
Texas	X				X	X
New Mexico			X			
California				X		

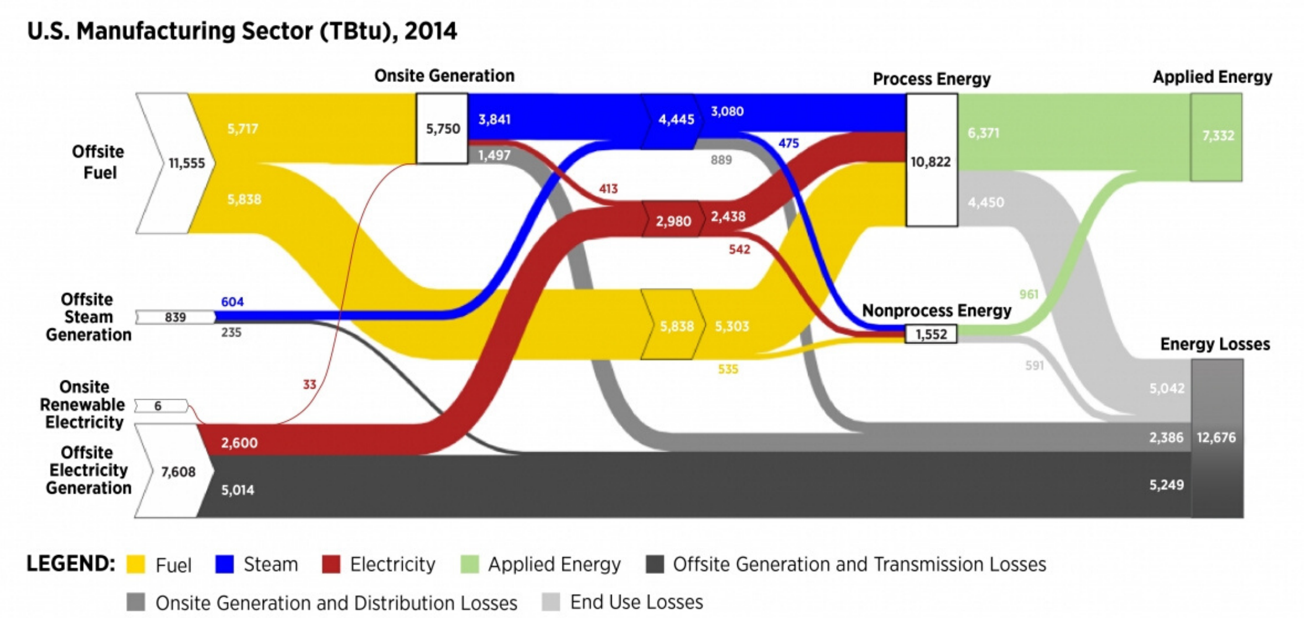
Appendix B. Comparisons between Green Banks and Recommendation to CGC

	Strategy Summary/Financial Instruments	Strategy Benefits	Recommendation
Connecticut Green Bank (CGB)	- Portfolio Investment Target: setting an investment target (i.e., amount, interest, risk and maturity) - Leverage Ratio Target: determining a reasonable leverage ratio target - Investment Criteria: defining and prioritizing investment criteria to serve as a screen for supporting the investment strategy	- Reducing burden of energy cost. - Achieving 20% electricity production from renewable energy by 2020 - Borrow working capital up to 50% of project costs for CGB program projects. - Competitive interest rate -Social benefit (employment, fringe benefit)	**Recommend it for similar energy efficiency project, because:** More than 30 states have adopted enabling legislation because of investment opportunities, energy and cost savings, and job creation.
Montgomery County Green Bank (MCGB)	- Partner with private financial institutes to provide commercial loans to eligible contractors and businesses (defined by the Green Bank) - Make loan payments less than or equal to energy savings - Scopes include energy efficiency improvement, solar, etc.	- Mature loan systems provided by commercial banks - Motivate private market to invest in green technologies in the long run - Loan amount can be relatively small (10,000 to $250,000)	**Recommend MCGB's strategies for energy efficiency projects, because:** - Green Bank bears low risks. - Mature loan systems are available from commercial banks. - Flexible, case-by-case interest rate and loan term are provided.
California CLEEN Center	- Direct loan or tax-exempt bonds - Up to the project's useful life or 30 years - Finance 100% of project costs - A 25% general subsidy, plus additional subsidy - Its own Interest Rate Methodology	- Providing direct loans - Adjusted interest rate - Supporting local small business - Immature loan system than commercial banks	**Recommend CLEEN's strategies for energy efficiency projects, because:** - Direct loans from the IBank offers total costs below the public offerings. - It provides better credits and loan structures although a mature loan system is not fully guaranteed.
Green Investment Group (GIG)	Equity Investments: - Direct investment - Equity buy-in - Collaboration with other partners for co-investment	- Not applicable to non-profit organizations at the current stage given no prior cases - Risk tolerance levels are different from non-profits - Unknowns in non-profit equity investment makes possibilities for exploration - Policy differences exist between Asia, Europe and Australia and the US	**Consider GIG's investment strategy, because:** -Although National Client Bank would likely by giving out loans, it is important that we consider the possibilities of employing equity investment
The Clean Energy Finance Corporation	*Mechanisms*: - Commercially-rigorous approach - Structured governance approach - Portfolio diversification strategy - Well-developed risk management framework - Partnerships with other investors *Financial Instruments*: - Senior debt - Subordinated debt - Preferred equity/convertible debt - Common equity - Interests in pooled investment schemes, trusts and partnerships - Net profits interests, royalty interests, and entitlements to volumetric production payments	- Structured Governance - Supportive external advisors available - Strategic risk management - Financing solutions provided	**Recommend CEFC's strategies for energy efficiency projects, because:** - The CEFC provides federal financial support to initiate renewable energy projects. - In FY 2017-18, the CEFC invested in 10 commercial-scale renewable projects, with the goal of producing an additional 1,100 MW of clean energy across Australia. - The CEFC has similar goals but more developed strategies and management frameworks compared to CGC.

Appendix C. Breakdown of Non-electric Uses by Industrial Sectors. Source: Energy Information Administration



Appendix D. Sankey Diagram of US Manufacturing Sector, 2014. Source: Department of Energy



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