Options for Industrial Businesses Toward Achieving Carbon Reduction Targets

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ABSTRACT

There are a growing number of factors that are fueling business interest in establishing carbon reduction targets and energy transition. These factors include: the acceleration of local policy, shareholder resolutions, technology advances, low carbon and renewable energy standards and tax incentives, favorable economics, corporate interest in 'going green,' as well as other stakeholders, including employees. Businesses are challenged to consider rapid changes in complex and urgent environmental, natural resources and infrastructure issues that affect their current operations and future plans. Many are looking at carbon reduction strategies to manage their risk, improve their carbon footprint and capitalize on opportunities that are emerging from a changing energy supply mix and pricing, new technologies and new incentives. Carbon reduction strategies are often also part of a company's overall sustainability Environmental, Social and Governance (ESG) strategy.

This paper will:

- Cover some of the most effective types of carbon reduction opportunities, including: energy efficiency improvements, renewable energy, fuel switching, efficient use and recycle of materials, carbon capture and storage, and investment in carbon sequestration or natural resource solutions;
- Include examples of how these approaches have benefitted the businesses and reputations of energy consumers, producers and distributors; and

- Provide an overview of how an integrated energy strategy can help in a transition to lower carbon or 'net zero' commitments, starting with the importance of accounting for Scope 1, 2 and 3 greenhouse gas (GHG) emissions, establishing effective targets and implementing informed changes to business practices, design, equipment, energy, fuel, and material supplies that have resulted in progress toward these targets.

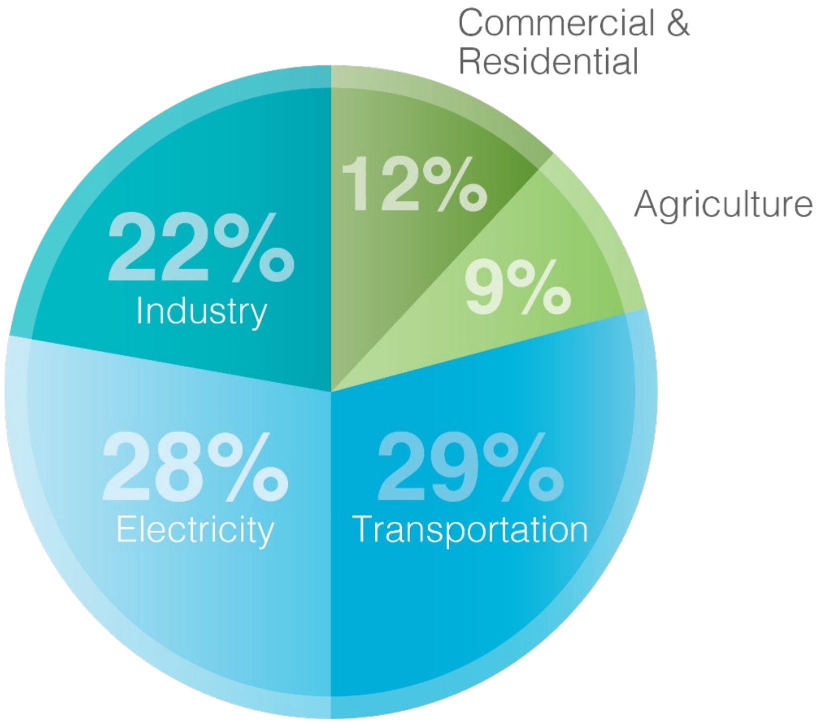
INTRODUCTION

The threat of climate change, as experienced by more extreme weather events/conditions and climbing concentrations of GHG in the atmosphere, is a risk that businesses are acknowledging. Society is in the midst of an energy transition to lower carbon or renewable fuels and lower carbon or renewable electricity generation. Climate change is viewed by policy makers, investors, business owners, employees, and other citizens as one of the most important challenges of our time, and one that presents both significant risk and opportunities. To understand the risks to businesses for the purposes of financial disclosure, the Task Force on Climate-related Financial Disclosure (TCFD) was established to develop voluntary disclosure recommendations. The final recommendations were made in June 2017[1] and have been used by many of the largest corporations worldwide. The 2019 TCFD Status Report[2] found that 78 percent of large companies in 2018 disclosed information aligned with at least one of the TCFD recommendations. The recommendations, which address climate-related risks and opportunities, are made around four core elements: governance, strategy, risk management, and metrics/targets. As businesses disclose the transition risks, many are tracking metrics, setting targets and goals, and considering carbon reduction strategies, often as part of corporate sustainability ESG planning, to manage risk, improve the carbon footprint, and capitalize on opportunities.

Meanwhile, policies related to climate change, carbon reduction, and energy transition are being proposed and adopted in multiple jurisdictions globally and across the United States (U.S.) to address risks from climate change. Many of the policies in the U.S. are adopted at the local city, county, and state level and include a variety of low carbon technology incentives, GHG reduction programs, renewable portfolio standard mandates, energy efficiency targets, low carbon fuel standards, and even carbon neutrality goals.

Industrial businesses in the U.S. make up a substantial share of the GHG inventory and are responsible for providing goods and services, economic vitality, and jobs in a clean, safe manner that align with the laws and regulations within the jurisdictions and communities where they operate. In the U.S., the three largest contributors to the overall GHG are the transportation sector at 29 percent, the generation of electricity at 28 percent, and the industrial sector at 22 percent. (Figure 1).

Figure 1. Total United States Greenhouse Gas Emissions by Economic Sector in 2017 (adapted from data from EPA, 2019).[3]



The challenges for industrial businesses are many. Changes to business practices, processes, equipment, sources, supplies, fuel, energy use, emissions, and waste recovery are necessary and driven by multiple objectives, including:

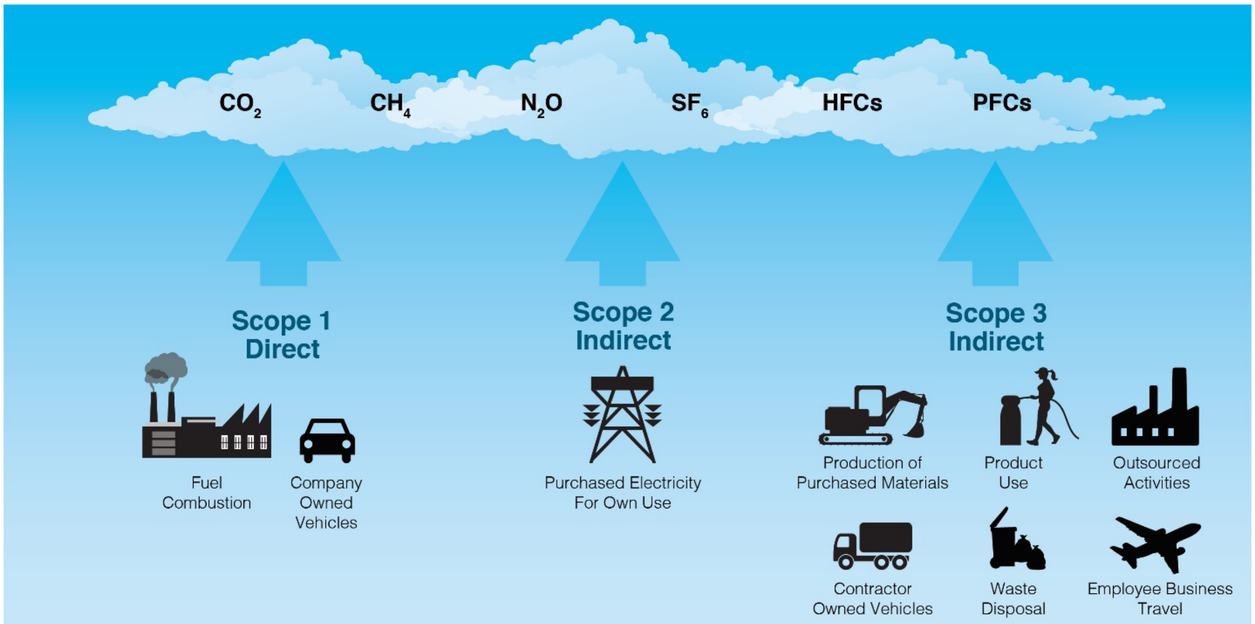
- Sustainability program goals;
- Low-carbon regulations, mandates from local jurisdictions;
- Supply-chain mandates;
- Cost savings and investment;
- Incentive programs;
- Reputation and market; and
- Risk reduction.

The scope of this paper focuses on the industrial sector in the U.S., with some examples from businesses operating in regions of the country and elsewhere in the world where policies, incentives, and opportunities have given rise to approaches that have demonstrated ways to reduce carbon emissions.

BACKGROUND

To gain an understanding of their relative position, risks, and opportunities to inform a carbon strategy, businesses must, at a minimum, have a clear picture of: i) their current carbon emissions, including where they are located; ii) how they define operational boundaries; and iii) the most significant sources of emissions. Companies that report their emissions under a mandatory program will report on their direct and indirect emissions, referred to as Scope 1 and Scope 2 emissions, respectively. While GHG reporting programs have very specific accounting requirements, standard practice follows the principals in The Greenhouse Gas Protocol.[4] Scope 1 emissions are direct GHG emissions from sources owned or controlled by the company, such as process emissions or combustion emissions from boilers, engines, or vehicles. Scope 2 emissions are indirect emissions from sources not owned by the company and occur due to the demand for the company's consumption of purchased electricity, heat, steam, or cooling (Figure 2).

Figure 2. Emission Scopes in GHG Inventories.



Some companies choose to include Scope 3 emissions in their corporate inventories. Scope 3 emissions are other indirect emissions that occur within the company's supply chain and provide a more complete picture of a carbon footprint. Such emissions would include GHG from the production of purchased materials, transport of purchased materials, end use of the product (for example, a fuel), ultimate waste disposal or material reuse, or sources outside the company's control (e.g., aircraft emissions from employee travel). Some factors to consider in whether to account for Scope 3 emissions might include:

- Availability of reliable data;
- Supply chain relationships; and
- Degree of responsibility or influence desired.

For example, IKEA, the international home furnishings retailer, decided to include Scope 3 emissions from customer travel in its inventory as it became clear that these emissions were large relative to Scope 1 and 2 emissions.[4] This provided useful information for developing public transportation options and home delivery services for its stores.

A company's GHG inventory will both inform and be influenced by the kind of carbon reduction strategy and targets it chooses to set. Companies set targets aligned with their sustainability program goals and the policies of the relevant countries and local jurisdictions. They also benchmark themselves against competitors, suppliers, and customers. Companies can also elect to set science-based targets (SBT) that are aligned with the level of decarbonization required to keep global temperature increase to below 2 degrees Celsius compared to pre-industrial temperatures. For example, Proctor & Gamble Company set very near-term SBTs for 2020[5] to achieve 30 percent reductions in GHG from a 2010 base year and included other sustainability measures across its value chain, such as doubling use of post-consumer plastic packaging, supporting zero deforestation in palm oil supply chain, and innovating its washing detergent design to increase effectiveness of cold-water washes to allow consumer energy reduction.

This paper will cover some of the most effective types of carbon reduction opportunities, including: energy efficiency improvements, fuel switching, renewable energy, efficient use and recycle of materials, carbon capture and storage, and investment in carbon sequestration or natural resource solutions, with examples of how these approaches have benefitted the businesses of energy consumers, producers, and distributors.

RESULTS AND DISCUSSION

Examples of implementing informed changes to business practices, design, equipment, energy, fuel, and material supplies that have resulted in progress to reduction targets are included below. The following carbon reduction options are covered:

1. Energy Efficiency Improvements.
2. Electricity Supply/Generation (Green Power Purchasing and Green Power Generation).
3. Fuel Switching.
4. Material Procurement and Efficient Use.
5. Capturing Carbon Emissions.
6. Carbon Sequestration.

Energy Efficiency Improvements

Perhaps the most obvious and most cost-effective means to decarbonize industrial operations is to find ways to do more with less fuel and electricity. Because energy efficiency is not a new concept, it is perhaps not as exciting or capable of drawing attention as other strategies. Identifying energy efficiency improvements at industrial facilities can sometimes be met with a belief that all good or cost-effective solutions have already been implemented. Taking a second look at ideas that were not economic in the past can result in identifying additional or new improvements to invest in. This is quite often true, particularly given: i) changes to processes over time; ii) advances in technology; iii) lower cost energy pricing; and iv) new alternatives.

> **"Energy-saving technologies keep improving faster than they're applied, so efficiency is an ever larger and cheaper resource."**
> --Amory Lovins,
> Rocky Mountain Institute

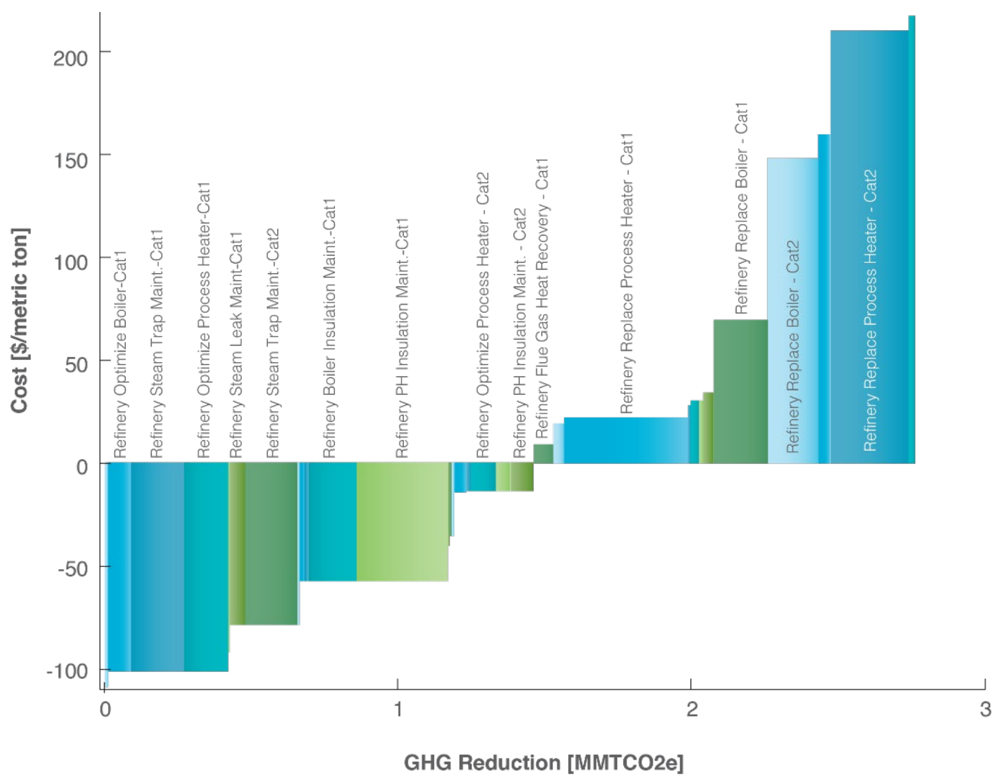
Energy efficiency projects can account for a substantial part of business sustainability solutions for carbon reduction. In the U.S., energy efficiency solutions are credited with the potential to account for as much as 50 percent of the GHG reduction potential to meet climate goals.[6] On a more practical level, studies have found that most companies can reduce the overall energy use (and associated GHG emission potential) of their operations by 10 percent or better with relatively small investments and up to 35 percent by making substantially larger investments. This takes a real commitment, generally involving:

- Review of the process design and equipment;
- Identifying opportunities within the production system to improve; and
- Driving funding and execution of projects to implement solutions and realize the benefits.

This is much easier said than done. Many companies maintain a list of good energy efficiency projects that await the right timing and budget cycle to be executed. Planning and scheduling these projects can often be done incrementally and as part of other planned expansions, maintenance, or improvements. For example, when a facility must propose GHG mitigation to be granted permit approval or public acceptance of a proposed project, energy efficiency projects can often be included in a project scope as a useful measure to mitigate other GHG increases.

One way to visualize the attractiveness of energy efficiency projects in creating a GHG reduction strategy, is to create a marginal abatement cost curve (MACC) for the suite of GHG reduction opportunities (Figure 3). This could be identified through surveying experts familiar with the facility energy systems or by conducting an energy audit. The energy efficiency projects are often the projects showing a cost savings.

Figure 3. Example Marginal Abatement Cost Curve (adapted from California Environmental Protection Agency Air Resources Board, 2010).[7]



Types of successful energy efficiency measures that can be applied across multiple types of industrial operations include: i) optimizing steam system (reduce steam use); ii) replacing motor drives with higher efficiency or variable speed drives; iii) optimizing pumping and compressed air systems; iv) waste heat recovery; v) using combined cycle turbine equipment; vi) upgrading heating and cooling systems; and vii) investing in instrumentation and controls. Additional examples of energy efficiency projects implemented were identified by California industrial facilities under the AB32 GHG program. The California Air Resources Board[8] (CARB) summarized these measures for several industry sectors (electricity generation, cement, oil and gas production, mineral production, refineries, and hydrogen facilities) in a series of Energy Efficiency and Co-Benefits Assessment of Large Industrial Sources. The measures included boiler projects, electrical systems, process equipment, combustion systems, steam systems, and thermal equipment improvements.

Other measures could involve programmatic approaches such as implementing an energy management system. For example, a company could consider using the 1SO 50001 standard or U.S. Environmental Protection Agency (EPA)'s Energy Star program. For all these measures to be successful, it is important to invest in skilled and trained technical personnel to identify, implement, maintain, and monitor the effectiveness of the energy saving measures and meeting program goals.

Another recently developed programmatic framework to engage for an energy strategy in alignment with sustainability goals follows the guidelines that are established by the World Business Council for Sustainable Development (WBCSD) as part of an Integrated Energy Management Strategy.[9] The solutions and guidance offered for reducing energy and fuel consumption through energy efficiency measures focuses on three areas:

- Engaging with your workforce and value chain partners to improve energy efficiency;
- Using smart controls to improve energy and fuel efficiency; and
- Upgrading and replacing equipment and assets to improve energy efficiency.

The guidelines provide examples and building blocks for success for businesses to use in creating their own approach and solutions for energy efficiency. The examples are in the context of a broader energy management strategy and includes some of the other decarbonization approaches discussed in this paper.

Electricity Supply/Generation

The GHG Protocol Scope 2 guidance[4,10] standardizes how corporations measure emissions from purchased or acquired electricity, steam, heat, and cooling. Nearly 22 percent of U.S. GHG emissions are from the industrial sector, trailing transportation and electric power generation (Figure 1). Changing the source of electricity to renewable sources is one way the industrial sector can achieve significant reductions in reported GHG emissions.

Companies changing to renewable sources purchase Renewable Energy Certificates (RECs), which are market-based instruments that represent each one megawatt-hour (MWh) of electricity generated and delivered to the grid from renewable energy sources. RECs convey the property rights to the environmental, social, and other non-power attributes of renewable electricity generation and provide a key role in accounting, tracking, and assigning ownership to renewable electricity generation and use.[11] All renewable energy supply options involve a REC. However, electricity and RECs are distinct products and can be sold separately as unbundled products or together as a bundled product.[12]

Green Power Purchasing

Industrial companies have options for offsite or onsite renewable and green power generation through contract vehicles such as Physical Power Purchase Agreements (PPAs), Virtual PPAs (VPPAs), or self-generated renewables. In recent years, the incorporation of renewables plus storage such as lithium ion or vanadium flow batteries has affected the makeup of green power generation. The price of four-hour utility scale lithium ion battery storage systems is expected to drop 20 to 80 percent for the next 30 years.[13]

Physical PPAs are contracts for renewable power where the corporate buyer is purchasing the electricity generated and RECs at a certain renewable energy project. The buyer is responsible for the electricity and typically sells the energy into the electricity market. Corporate buyers of physical PPAs agree to offtake power for a fixed amount of time while also locking in stable energy rates for the renewable energy purchased over the contract term. In direct PPAs, the electricity produced needs to be physically used by the buyer. Thus, the project size needs to be tailored to the load, which places an upper limit on the GHG benefit. Direct PPAs often require the generating facility and the company's operations to be located within the same grid region. Operations may need to be in deregulated retail states for direct PPAs to be viable.[14] Physical PPAs were the most common form of transaction in the early years of the corporate renewable energy market.[15,16]

Many corporations are using Physical PPAs for large scale solar photovoltaics (PV)[17] to meet renewable energy goals. As reported by the National Renewable Energy Laboratory (NREL), from 2014 to 2017, corporate procurements increased from 1 to 17 percent of annual installed utility scale capacity. Projections are that corporate procurement will rise to more than 20 percent of new solar additions in the next five years and will overtake wind as the renewable resource of choice for corporate buyers. The growth in solar is in part due to:

- More companies adopting renewable strategies and sustainability goals;
- The step down of federal tax credits for wind energy; and
- The incorporation of battery storage into new renewable energy projects.

Large corporations are leading the way with offsite PV contracts such as computer and data management companies, health care companies, retail, and governments.

Wind energy has used PPAs for the majority of commercial scale projects to date. Data from 2018 shows continued additions of wind at historically low prices and investments of over $11 billion. In 2018, wind energy contributed 6.5 percent of the nation's electricity supply, with newer projects proposed that are paired with storage. The price of wind energy dropped from around 7 cents per kilowatt-hour (kWh) for PPAs executed in 2009 to a 2019 average price of below 2 cents per kWh. Prices are dominated by projects in the lowest-priced interior region of the country and compare favorably to the projected future fuel costs of gas-fired generation.[18]

Virtual PPAs (VPPAs) have grown in use for corporate buyers where PPAs are not viable. Virtual PPAs are sometimes referred to as financial PPAs. This occurs when the corporate buyer does not own and is not responsible for the physical electrons generated by the project but does still receive RECs. Instead of routing renewable power directly to the corporate buyer, the generation facility sells their renewable power directly to the grid and receives the open market price. The project developer pays the difference to the corporate buyer when the agreed upon PPA price is below the market price, and vice-versa. This is why VPPAs are also known as contracts for differences.[15,16]

VPPAs have become the fastest growing transaction structure today. This allows smaller buyers and companies without energy trading expertise to participate, because they are easily scalable and enable buyers to satisfy a large portion of their sustainability goals with a relatively small number of deals. They also allow buyers that have highly distributed electricity loads to meet their renewable energy goals quickly and efficiently. For example, Fifth Third Bank was able to meet its 100 percent renewable energy goal with just one VPPA.[15]

Corporate offtakers of both PPAs and VPPAs can opt for a bundled PPA deal and retain RECs associated with the project's energy production. With this option, corporations with sustainability targets in addition to financial savings goals can address both outcomes using a PPA.[14]

VPPAs are often more flexible than direct PPAs. VPPAs appeal to many corporations because:

- Buyers in regulated states have the choice to lock in a long-term PPA price at below market rates;
- Buyers with multiple load centers across grid regions can satisfy renewable energy needs using fewer transactions;
- Corporate buyers avoid affecting their utilities and transacting in the wholesale market only;
- Technical risk and engineering problems are mostly mitigated since electricity is not delivered and developers take on most operational risks;
- A short position on future power can often be an effective hedge against rising energy costs; and
- They typically require less complicated market awareness to return the greatest benefits.

Green Power Generation

Self-generated renewables often take the form of onsite PV solar panels or small wind turbines. These onsite renewables are often considered distributed generation and are located behind the meter with the utility. Distributed generation solar PV may be located on rooftops or on the ground. Grid connected systems allow users to power their operations with renewable energy with a net meter, where the excess electricity generated 'turns back' the electricity meter as it is fed back into the grid. If more electricity is used than self-generated systems provide, the user pays the utility for the difference between what was used versus what was produced (net meter). Again, all electricity generated is carbon-free and reduces or eliminates the amount supplied by the grid and the associated GHG emissions.[19]

Grid-tied systems require interconnection agreements with power providers outlining requirements such as liability insurance, other fees, and charges. If the system generates more electricity than is used, the electricity goes onto the grid for the utility to use elsewhere. The Public Utility Regulatory Policy Act of 1978 (PURPA) requires power providers to purchase excess power from grid-connected small renewable energy systems at a rate equal to what it costs the power provider to produce the power itself.[19]

The following are several examples of the emissions reduction benefits for industries as more renewable energy projects are brought into their portfolios.

Oil and Gas Industry: In 2018, ExxonMobil entered into PPAs to purchase both wind and solar power in West Texas to power the oil and gas company's expanding operations in the Permian basin.[20] The oil and gas company and renewable developer signed two PPAs of 250MW each to develop and use low cost clean electricity generated in essentially the same region where the oil fields are located.

Power Generation Industry: Xcel Energy[21] has been successful in reducing their carbon emissions by over 35 percent (roughly 31 million tons) from the period 2005 to 2017 through a combination of increased renewable energy, energy efficiency, use of nuclear power, and coal retirements/repowering. Their goal is to reduce carbon emissions by 60 percent by 2030. To accomplish this, the utility planned to shutter coal-fired capacity at a generating station and replace it with lower carbon alternatives. A competitive Request for Proposal was issued to request proposals for wind, solar, natural gas, and storage. The responses resulted in unprecedented low costs for renewable energy and storage. The median price bid for wind-plus-storage projects in the solicitation was $21 per MWh, and the median bid for solar-plus storage was $36 per MWh. Previously, the lowest known bid for similar solar resources was $45 per MWh in Arizona, a full $9 per MWh cheaper than the lowest contract amount in the prior year.

Computer Industry:[22] Google is an example of a corporate leader in carbon free energy, accomplishing it through an aggressive portfolio of renewable energy agreements and PPAs throughout the United States and world. Per their 2019 annual report, they have signed 34 PPA agreements totaling more than 3.75 gigawatts (GW) of renewable energy, allowing them to operate on 100 percent renewable energy. They have been carbon neutral for 12 years through renewable energy and carbon offset programs such that their net carbon emissions during the period were zero. They have committed $2.5 billion in investment commitments since 2010 with a total combined capacity of 3.7 GW. To date, they have purchased nearly 26 million MWh of renewable energy through PPAs, VPPAs, and other purchasing models. In 2018, their gross Scope 1 and 2 GHG emissions were 4.4 million metric tons of carbon dioxide equivalent (tCO_2e) but renewable energy purchases reduced their net GHG emission by 3.7 million tons. Since 2011, their renewable energy purchase has resulted in emissions savings of nearly 11 million tCO_2e, a cumulative 52 percent reduction in Scope 1 and 2 emissions over the period.

Manufacturing Industry: Cummins is an American Fortune 500 manufacturing company that produces engines, generators, and associated components, headquartered in Indiana. They use VPPAs to meet their targets to reduce and offset GHG emissions. Cummins' 2016 goal was for a 32 percent reduction in energy use and GHG intensity by 2020. Cummins considered the purchase of several alternatives including unbundled RECs, Utility Contract, direct PPA, or VPPA. Of these, Cummins chose the VPPA option for a wind energy project being constructed near its load center in Indiana. The Indiana Meadow Lake project took advantage of a practice, known as 'REC swapping' between two adjacent markets to improve the economic outlook of the VPPA, and Cummins was able to sign the deal. The electricity generated is planned to be equal to the amount of Cummins' usage in the state of Indiana, which is approximately 25 percent of its total company GHG footprint. Cummins' GHG reduction plan by 2020 is to result in an over 56 percent overall reduction in GHG footprint.

Fuel Switching

Reducing process fuel use and thermal energy needs is intuitively the best place to start for decreasing industrial source GHG emissions. It goes hand in hand with improved process efficiency, lower cost, and reduced environmental liability. This creates a "win-win" situation for the business. Yet when the low-hanging fruit has been picked and facilities have already been optimized and upgraded with new and more efficient equipment, more fundamental processes or thermal energy changes may be necessary to meet low carbon goals. What is not intuitive or easy in highly integrated manufacturing processes is the substitution of process fuels with renewable or low carbon alternatives. This opens up another dimension of challenges and opportunities for manufacturing design and optimization. Many large manufacturers (steel, cement, chemicals, petroleum, and petrochemicals) and manufacturing sector collaboratives[23] are weighing their options.

Fuel switching is a significant step in a carbon reduction strategy. As depicted in Figure 4 and Figure 5, a majority of carbon dioxide (CO_2) emissions related to fossil fuels, such as gasoline, diesel, jet fuel, residual fuel oil (RFO), liquified petroleum gas (LPG) and coke, occur during the combustion phase, where carbon contained in the feedstock is released (up to 99 percent for coal in particular). Therefore, moving from coal to less carbon intensive natural gas could result in significant carbon reduction. The shift to low carbon renewable fuels or electrification (from renewable energy sources) could result in a considerably greater reduction of carbon emissions.

Figure 4. GHG Emissions of Petroleum Fuels.[24]

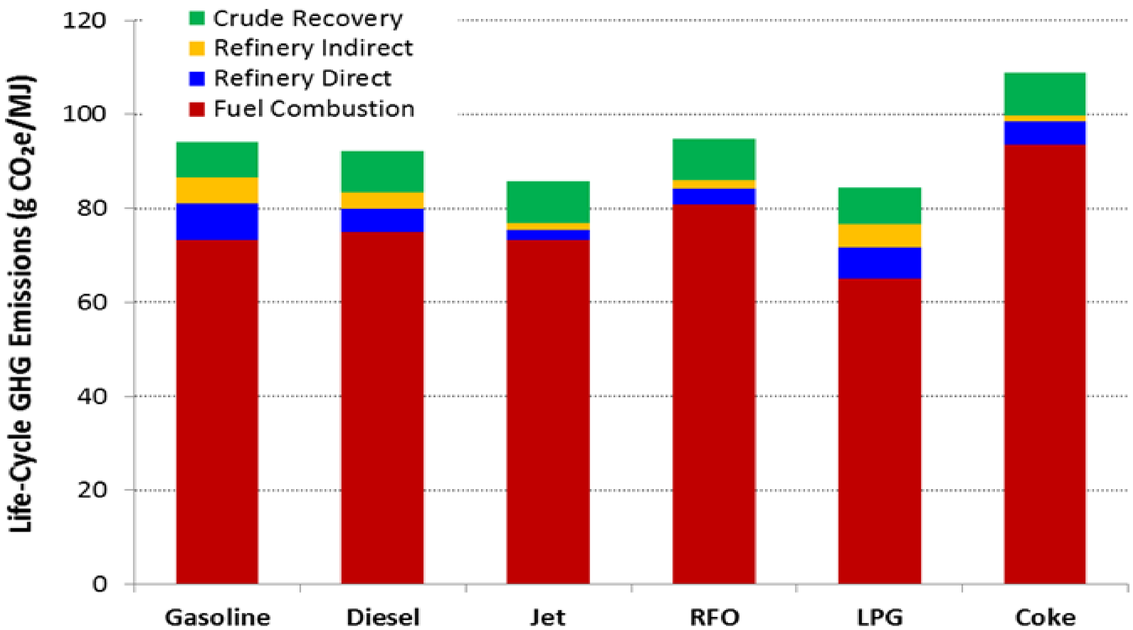
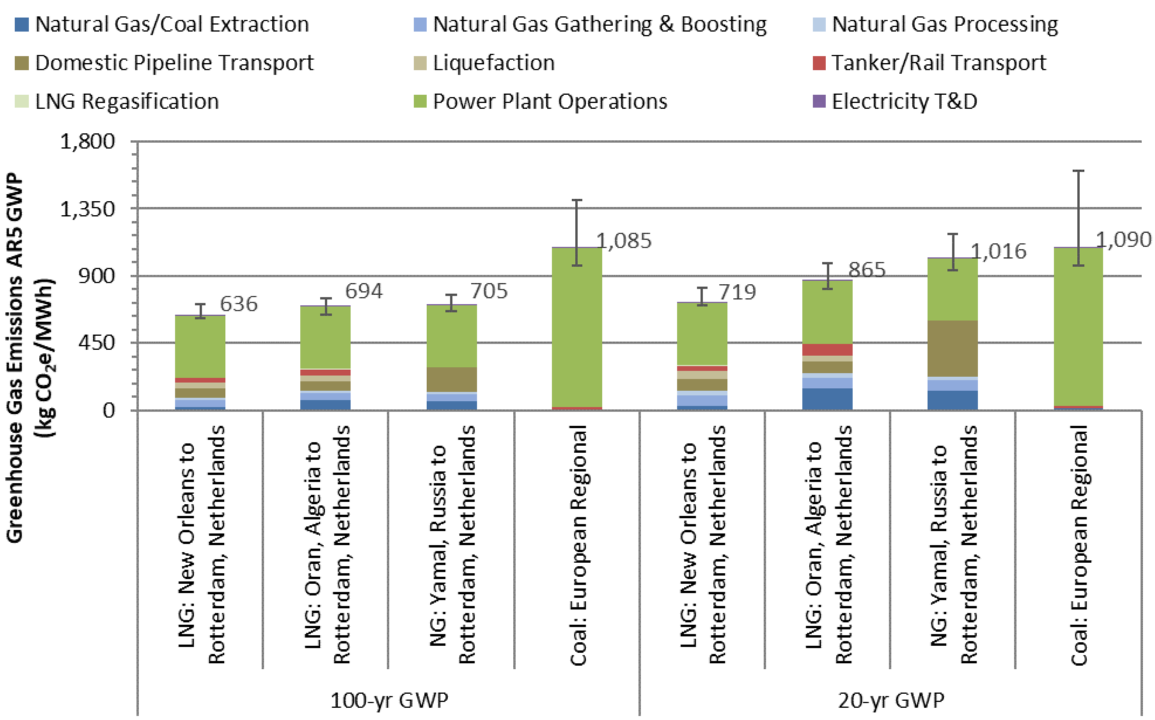


Figure 5. Life Cycle GHG Emissions for Natural Gas and Coal Power in Europe.[25]



Fuel switching options include direct substitution of fossil-based process fuels (gasoline, diesel, liquefied petroleum gas [LPG], and natural gas) with renewable liquid fuels: gasoline, diesel, biodiesel, or renewable gases. This includes LPG, natural gas, and hydrogen. It could also mean replacing high carbon intensity fuels with lower carbon alternatives (e.g., switching from burning coal, diesel, and fuel oil for process heat to natural gas or woody biomass-fired systems). One example is using biomass energy in a Brazilian sugar cane ethanol plant. The tables below show the process energy and GHG emissions for the registered sugarcane ethanol pathway under the California Low Carbon Fuel Standard. More than 99 percent of the process energy was provided by burning the biomass byproduct (bagasse), which results in a nearly carbon free process, and in this case, a final product with a very low carbon intensity. Many ethanol plants in the U.S. are also utilizing the same strategy.[26]

Table 1. Brazilian Sugarcane Ethanol Production Energy Use.

Fuel Type	**Total Energy Use**
From Residual Oil (BTU/gal)	279
From Bagasse (BTU/gal)	83,132
Total Energy Input for Ethanol Production (BTU/gal)	**83,411**
Total Energy Input for Ethanol Production (BTU/mmBTU)	1,093,320

Notes:
BTU/gal = British thermal units per gallon
BTU/mmBTU = British thermal units per million British thermal units

Table 2. GHG Emissions for Brazilian Sugarcane Ethanol Production.

GHG Species (gCO_2e/MJ)	**GHG Emissions**
Residual Oil (gCO_2e/MJ)	0.03
GHG from Bagasse Burning (gCO_2e/MJ)	124.93
Credit for Bagasse Burning (gCO_2e/MJ)	-122.9
Total GHG Emissions (gCO_2e/MJ)	**2.1**

Notes: gCO_2e/MJ = grams of carbon dioxide equivalent per megajoule

In the past decade, the U.S. grid has transformed significantly to decarbonize itself, and some of this success has been enabled by fuel switching. Base-load fossil generation (coal and oil) that has retired and been replaced by efficient combined cycle natural gas fired peaker plants allow power grids to balance more intermittent renewable fuel mix (i.e., wind and solar). In addition, research is being funded for development of advanced batteries and energy storage solutions to allow even further penetration of intermittent renewable energy sources and eventually replace dependence on natural gas. Renewable fuels such as hydrogen have received attention to store surplus energy. Hydrogen can be produced by electrolysis using excess power created when intermittent sources produce more power than demand. It is then used as a fuel to create power at another time. As the electricity grid becomes ‘greener’ (power generated from renewable or carbon-free sources), the option of switching away from fuel to electricity (Scope 2) as the primary source of energy to power processes and equipment provides a way to decarbonize operations (Scope 1). Even the traditional fossil energy industry is taking advantage of these opportunities to lower carbon emissions. In 2016, Total was the world’s first company to test all electric subsea drilling.[27]

However, there are numerous challenges to make this happen. The lifetime of an industrial facility is often on the order of 50 years, so making significant changes to accommodate a new feedstock or fuel type that requires fundamental redesign could be a slow process. Additionally, the current choice of fuel and design is influenced by availability and economics. Fuel switching or electrification only becomes feasible for manufacturers in a competitive, commoditized global marketplace if the quantity of alternative fuel needed is priced competitively. For many manufacturers, production using low-carbon fuels, if feasible, available, and reliable, will likely come at a higher cost, at least in the interim.

Availability is another issue. While conventional natural gas is plentiful and currently a very economical fuel choice, large volumes of renewable diesel, biodiesel, or renewable natural gas or hydrogen may not be currently available in the quantities required at a cost that would make them feasible.

The feasibility challenges of producing renewable fuels could potentially be solved by turning to other low carbon solutions. For example, one of the most cost-effective ways identified to produce large quantities of renewable hydrogen is via traditional steam-methane reforming with carbon capture, utilization, and storage (CCUS) of the CO_2 byproduct. This is known as 'blue hydrogen.' By contrast, 'green hydrogen' is produced in generally lower quantities by hydrolysis of water using electricity from a renewable energy source (for example, solar or wind), and traditional 'grey hydrogen' is produced by traditional steam-methane reforming without CCUS and has a high carbon intensity.

Material Procurement and Efficient Use

There are many examples of how industrial businesses are looking at their entire manufacturing process, including procurement of materials up the value chain from suppliers (Scope 3 emissions). This involves making changes to feedstock or materials that directly reduce the plant's GHG emissions (Scope 1) and developing ways to reduce waste.

Tackling the problem of the carbon emissions from cement manufacturing[28] is an example of a complex issue requiring consideration of multiple approaches such as the materials used and the manufacturing process itself. Since cement manufacturing alone accounts for about 7 percent of all global carbon emissions[29] and is essential in infrastructure and buildings, international collaborative efforts are underway to develop decarbonization solutions. Everything from energy efficiency, to using alternative fuels, to CCUS, to new formulations reducing clinker content and alternative binding materials is being attempted. Manufacturing cement requires high temperatures, which requires a large amount of fuel, but it is the decomposition of the limestone (in the formation of clinker) that generates at least half or more of the CO_2 emissions of cement manufacturing. Thus, cement operations are attempting to use recycled materials (steel slag, fly ash, clays) to replace some or all of the clinker.

Other researchers[30] are even looking into ways to use captured CO_2 emissions from other processes (such as power plants) to produce a cement-like alternative building material. Concrete also has CO_2 absorbing properties that could be exploited if production facilities were paired with carbon capture. Challenges include[31] cost-competitiveness compared to Portland cement, regulations and engineering standards, a conservative business sector, and willingness of construction industry to adopt use of new products.

Capturing Carbon Emissions

The transition of many industrial sources to low carbon or non-carbon alternatives will require: i) years of additional planning; ii) retirement of critical energy sources; iii) infrastructure development; and iv) additional technological solutions. Because of this and the desire to hasten decarbonization progress, both companies and jurisdictions that have ascribed to net-zero or carbon neutral goals within the next couple of decades have become increasingly supportive of including carbon capture or natural carbon removal strategies resulting in 'negative emissions' in carbon reduction strategies. This is accomplished by capturing CO_2 or methane (CH_4) from both industrial and biogenic sources, and also by removing CO_2 directly from the atmosphere. By incorporating negative emission measures into a carbon strategy, carbon emission sources can be balanced by a complimentary number of sources generating negative emissions in an inventory, providing in a net-zero result.

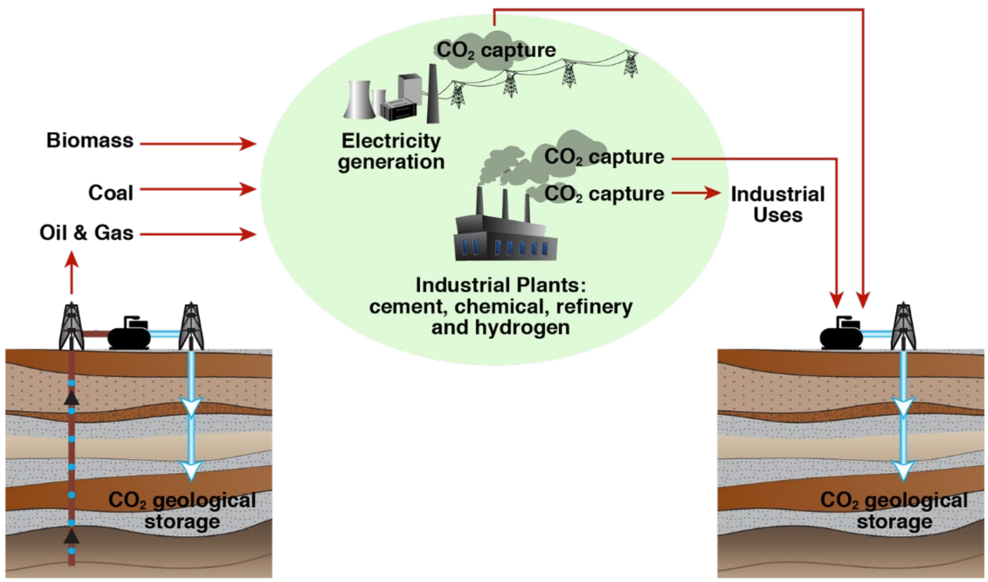
There is growing acceptance and recognition in global energy transition scenario planning that reliance on carbon capture and use, storage or natural carbon removal, including biomass conversion strategies, is essential to achieve aggressive 'deep decarbonization' targets. Implementing many of these measures is expected to have co-benefits in: i) air and water quality; ii) land and resource management; and iii) energy resiliency.

Industrial businesses have been reporting their CO_2e emissions under mandatory reporting programs for several years and have identified their largest direct CO_2 and CH_4 emission sources. Reduction opportunities consider ways to prevent or minimize these emissions through some of the strategies already discussed (fuel switching, energy efficiency). They can also reduce fugitive emissions from leaks or minimizing direct stack emissions, venting, or flaring. In the case of CH_4 emissions (which has a high global warming potential 25 times higher than CO_2), carbon capture by leak prevention and reduction has been addressed through toughening regulatory standards for leak detection and repair (LDAR) for methane in many industries (especially oil and gas production and gas distribution systems). However, there are still industrial, waste, and biogenic sources of methane that are large contributors to GHG emissions on a regional and global scale.[32,33] For example, the largest contribution of CH_4 emissions in California is from landfills.

At the same time, demand for renewable natural gas and biogas (CH_4 from biogenic or waste sources) is growing due to recognized low carbon intensity. This has value in certain jurisdictions (like California and Oregon, that have low carbon fuel standard programs), or with companies that are accounting for emissions from fuels toward their carbon targets. This is providing additional incentive and a market for capturing waste and biogenic emissions of CH_4 (e.g., landfill gas and dairy digester gas)[34] for use as a renewable fuel, instead of allowing direct releases or flaring the gas.

When other reduction options are not feasible or sufficient, capturing the CO_2 emissions from the emission point for use or storage is an option that is gaining acceptance and adoption. Called CCUS, large industrial CO_2 emitters such as cement plants, power plants, hydrogen plants, refineries, and oil and gas production facilities are determining feasibility, developing plans and implementing projects where location to use or storage options exist. Figure 6 depicts possible CCUS applications, showing relevant sources, transport and storage options for CO_2. As of January 2020, there are: i) 19 large-scale CCUS facilities in commercial operation; ii) four more are under construction; and iii) another 28 are in development, not counting numerous demonstration and pilot projects.[35]

Figure 6. Possible CCUS Systems.



There are also innovative approaches to carbon capture called direct air capture (DAC), or the direct removal of CO_2 from the ambient air by using fans and separation technologies. While these are still undergoing commercialization and scale-up, they provide some unique advantages that are getting attention and support for their 'negative emissions' potential. A Canadian-based energy company (Carbon Engineering Ltd.)[36] has developed an example of this approach and has received support from industrial businesses with interest in new technology development. A Silicon Valley start-up company, Prometheus,[37] has developed a DAC system that then dissolves captured CO_2 in water and produces liquid renewable syn fuel by an electrolysis process. Such renewable fuels could be used in industrial and transportation applications that are otherwise difficult to decarbonize.

Carbon Sequestration

Companies have invested in numerous types of sequestration approaches, including:

- Sequestering emissions captured from their own processes;
- Partnering to sequester emissions from other sources for operational benefits as in the case of enhanced oil recovery or to generate carbon credits; and
- Investing in nature-based sequestration, such as forest or soil management (e.g., tree-planting), either on their own lands or that owned by others.

Once CO_2 is captured, what is done with it? The CO_2 is generally compressed and transported for storage in geological formations, in the ocean, in mineral carbonates, or for use in industrial processes. The most mature storage technology is geologic storage. In fact, CO_2 has been injected into geologic formations for many years for enhanced oil recovery (EOR), a means to extend the production life of oil fields. This technique has been practiced since the 1970s in the U.S.[38] The CO_2 storage had originally been regarded as incidental, and the technique was economical because the significant cost of capturing, transporting, and storing CO_2 is offset by the value of the incrementally produced oil. Such conditions exist in the Permian Basin, where over 60 million tons per year of CO_2 is used for EOR.[39] More recently incentives such as the 45Q tax credit, and policies such as California's low carbon fuel standard and Cap-and-Trade Program which monetize carbon, are now establishing accounting systems and providing reward for the climate benefits.

Reservoir characteristics, location, CO_2 source and transport (pipeline) options, funding, collateral benefits, and means to account for and credit the CO_2 reduction (as well as many other factors) must align for implementation of CCUS to be economical and successful. An example of large-scale CCUS for EOR is a project being developed for California Resources Corporation (CRC), who has partnered with Electric Power Research Institute (EPRI) and Fluor to design and permit by 2030 California's first CCUS project[40] and largest in the U.S. at its Elk Hills oil field. The project will capture and store 1.5 million metric tons of CO_2 emissions from its nearby Elk Hills power plant.

Studies have identified suitable storage zones in California's Central Valley alone comprising a minimum of 17 billion tons of CO_2 storage capacity,[39] though much additional evaluation of geologic, seismic conditions, as well as man-made penetrations must be investigated carefully to confirm storage suitability. Other critical considerations for additional future CCUS projects is expansion of pipeline infrastructure to transport CO_2 from large sources and to the fields and long-term monitoring of these projects to prevent or quantify any leakage.

There are other ways to use or sequester CO_2 for beneficial use. For example, fermentation of sugars from energy crops, such as corn, sugar cane, and switchgrass in ethanol production produce CO_2 as a byproduct. This is relatively pure and is often sold for use in the beverage industry. Climeworks[41] is a European company formed in Zurich, Switzerland, that commissioned the world's first commercial-scale DAC plant in 2017. They collect CO_2 from air and sell it to beverage manufacturers, farmers (for greenhouses), or others for products such as renewable fuels.

The CO_2 captured from some industrial sources, such as combustion stacks, may not be suitable for use in beverages and fuels. However, there are some innovative uses for captured CO_2, particularly in building materials, such as cement. Carbon Cure[42] is one company that has developed a business of imbedding CO_2 in concrete. Their process injects CO_2 into wet ready-mixed concrete to form calcium carbonate (limestone) mineral. CO_2 is sourced from industrial emissions collected by gas suppliers who purify and distribute it as liquid CO_2. This building material has won awards for innovation and is finding a market with green building developers as a more sustainable concrete product. Calera[43] operates a demonstration pilot plant project at the Moss Landing, California, power plant for a similar process of absorbing and mineralizing the CO_2 captured from the power plant and sequestered as carbonate. Depending on the application, this process can also potentially capture other metals and sulfur pollutants and bind them into the mineral product.

Since carbon sequestration takes place every day in the natural environment, the business community is also taking cues from natural processes to develop approaches. This includes investing in solutions and programs aimed at natural processes and land use management that improve carbon sequestration by maintaining vegetation, trees, soil, and wetlands. Projects with goals of restoring and protecting forests, soil, and wetlands needing funding are finding corporate partners.[44] An average cost for opportunities of $11.40 per ton of CO_2e was estimated in a recent California study; this can be more economical than other sequestration methods. These projects have attractive co-benefits to air and water quality, ecosystems, soil health, resilience to climate change, and wildfire protection.

European oil and natural gas companies are leading the way incorporating such plans in their company carbon strategies. In 2019, Eni SpA,[45] a major Italian energy company, announced its plan to offset emissions by developing and funding forestry projects in Africa through the UNFCC REDD+ program. Shell[46] announced plans to invest $300M over three years in natural ecosystem-based projects, initially focusing on reforestation partnerships in Europe.

Additionally, while tree planting and forest management are important to managing the global carbon balance, soil management to prevent depletion of soil organic carbon is getting attention as well. Some report that the earth's soils[47] contain more than three times more carbon than is stored in the atmosphere and four times more than the amount in all living plants and animals. But programs to assess the potential for carbon sequestering land management and farming practices are still in the research stage, and protocols for accounting are in the pilot stage.[48] While soil carbon sequestration may have enormous potential and co-benefits, some of the challenges are in quantifying the reductions, accounting for effectiveness over time, demonstrating the permanence of the reductions, and uncertainties such as resilience to weather events.

SUMMARY

Companies in the U.S. are setting carbon reduction targets aligned with their sustainability program goals and the policies of the relevant local jurisdictions. Energy efficiency solutions are credited with the potential to account for as much as 50 percent of the GHG reduction potential to meet climate goals, and are often cost-effective, but take commitment. Changing the source of electricity to renewable sources is becoming more attractive due to more competitive pricing of wind and solar resources. Fuel switching is a significant step in decarbonizing but may be challenging to implement in existing facilities. Alternative fuels or electrification options will need to be feasible, available, reliable, and priced competitively for a given industrial process and location. Complete redesign of manufacturing and infrastructure changes are being considered in some cases and will take time and additional research. Meanwhile, measures to prevent leaks are being implemented. Further demonstration of negative emission techniques is advancing. Feasibility of carbon capture in industrial, biogenic, and atmospheric applications is improving and finding application. Carbon sequestration in geologic applications is getting attention and new concepts and investments in enhancing natural carbon sequestration processes in ecosystems with attractive co-benefits are being tried but may need years of further development and means of accounting for the benefits.

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