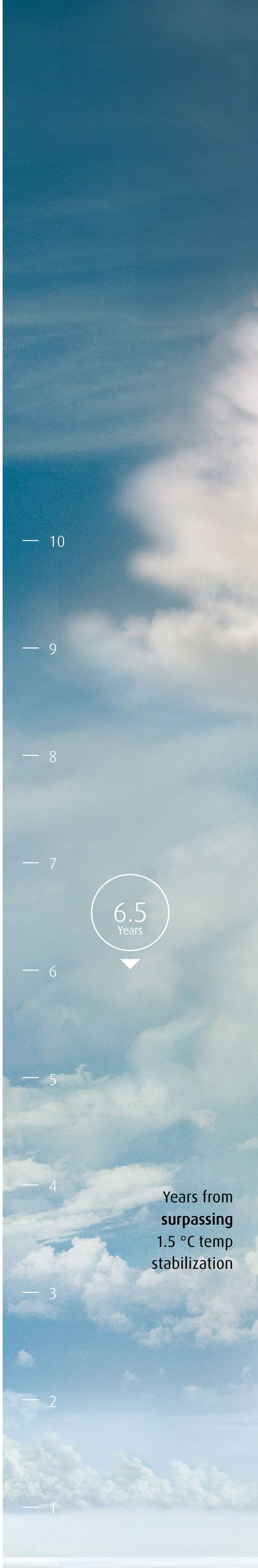
Making our world more productive

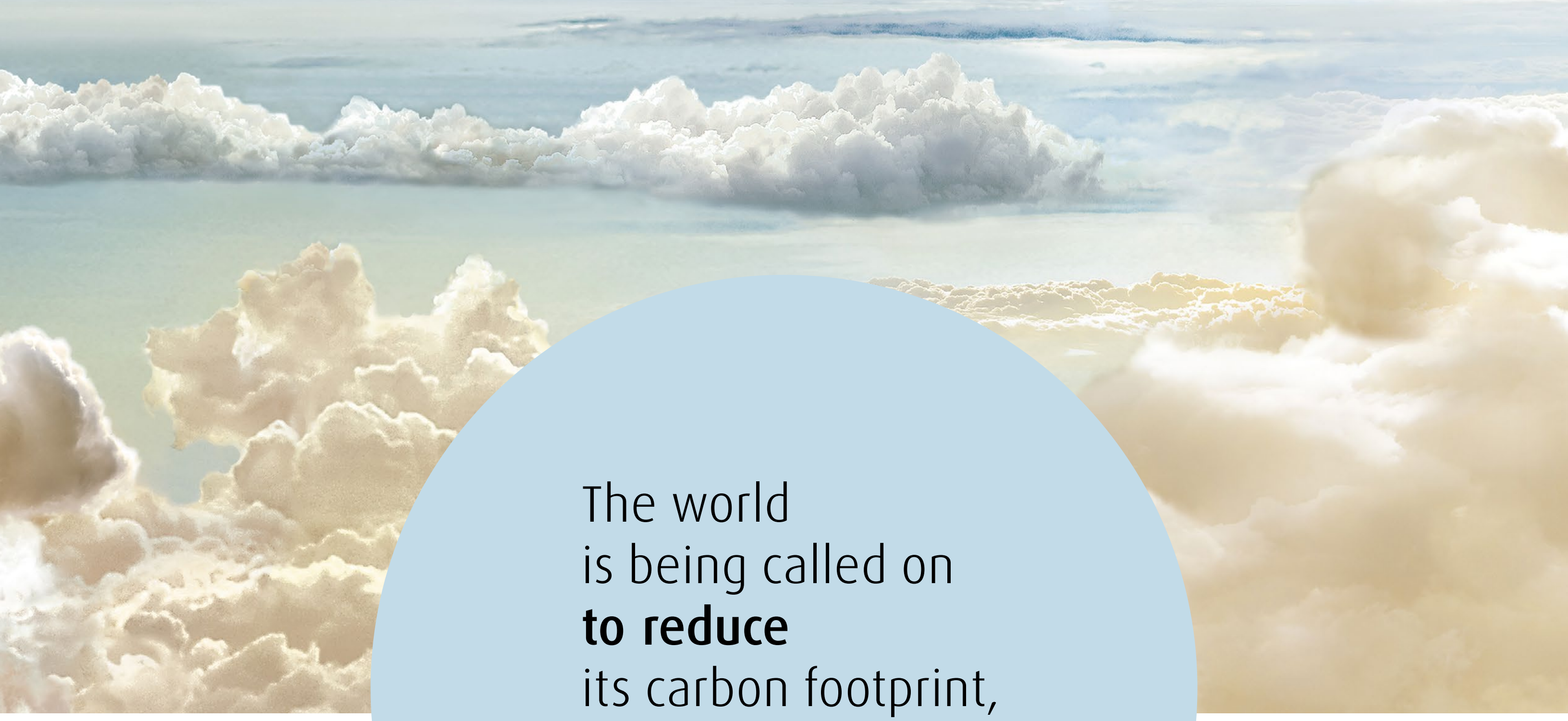
How to Efficiently Reduce Your CO_2 Footprint

Carbon dioxide (CO_2) has been in the public eye for a while now. Though essential to photosynthesis and respiration, its role as a greenhouse gas dominates many discussions.

The Mercator Research Institute on Global Commons and Climate Change's online Carbon Clock shows the amount of CO_2 released into the atmosphere.[1] According to the clock, the world emits approximately 1,331 tons of CO_2 per second – or 42 gigatons (Gt) each year – and is only 6.5 years away from surpassing a 1.5 °C degree temperature stabilization scenario recommended by experts around the world to limit global warming. This scenario calls for limiting emissions to no more than 420 additional gigatons (Gt) of CO_2 into the atmosphere for the remainder of this century.

One gigaton = 1,000 megatons or 2.2 trillion pounds





The world
is being called on
to reduce
its carbon footprint,
and everyone
has a role
in that quest.

Here’s the challenge

The more extensive your footprint,
the harder it is to reduce CO_2 emissions.

Climate Change and CO_2

Opinions differ on global warming and its effect on climate change. Competing views aside, the scientific community generally agrees that climate-warming trends observed since the genesis of the Industrial Age have roots in human activities and require a coordinated human response to mitigate.

Global warming

The Earth's rising temperature

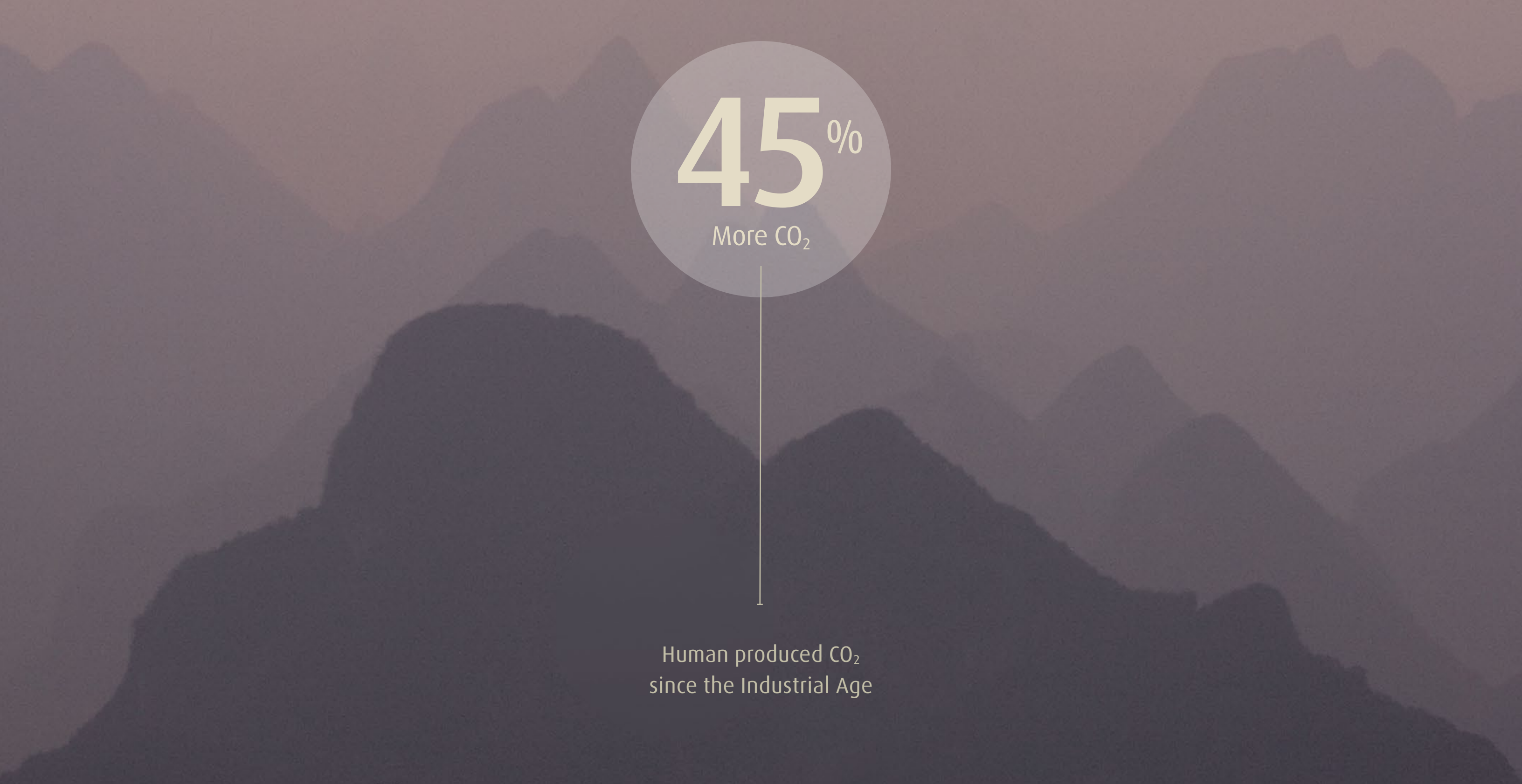
The Earth's temperature is not static, nor has it ever been. Our 4.5-billion-year-old planet has weathered several ice ages – "glacials" – interspersed with warm periods – "interglacials" – where the average global temperature at times approached a considerably warm 90ºF (32.2 ºC).

For an interglacial period, the Earth has been relatively "cool" during the current Holocene Epoch or "Age of Man" with the average global surface temperature hovering around 58 ºF (14.4 ºC), according to the National Oceanic & Atmospheric Administration (NOAA).[2] Still, an approximate 1.8 ºF (1 ºC) increase in the Earth's average surface temperature since the early 1800s has caught the attention of scientists, industry, and world leaders, as well as individuals. The early 19th Century is a reference point for temperature change because the Industrial Revolution was gearing up in Europe, transforming the continent from one of primarily agrarian pursuits to an industrial economy. New energy sources, mainly coal, fueled progressively larger engines and machines, which amplified the production of various materials and finished goods. As industrialization migrated across the globe, so too did the demand for coal. Recognizing its finite quantities, pioneers discovered new fossil fuels – like oil and natural gas – to create the electricity needed to power burgeoning industry. These fuel sources changed the world.

According to The Center on Global Energy Policy at Columbia University SIPA, the Earth's carbon cycle was effectively balanced until the Industrial Revolution.[3] Since 1800, fossil fuel combustion and other human activities have released approximately 2 trillion tons of CO_2 into the atmosphere. CO_2 does not dissipate quickly like reactive gases – ozone and nitrous oxides, for example – and it works alongside other anthropogenic greenhouse gases (GHGs) to absorb solar energy and reflect it to Earth. Overall, the greenhouse effect is beneficial to humankind, as, for centuries, it has created warmer and more habitable living conditions. However, the increased concentration of GHGs, mainly CO_2, traps and reflects more heat, and this phenomenon is believed to be at least partially responsible for rising global temperatures.

> "Humans have increased the abundance of carbon dioxide by 45 percent since the beginning of the Industrial Age. That's making big changes in our environment, but at the same time, it's not going to lead to a runaway greenhouse effect or something like that. So, our atmosphere will survive, but, as suggested by UCLA professor and Pulitzer-Prize-winning author Jared Diamond, even the most advanced societies can be more fragile than the atmosphere is."

David Crisp
Science Team Lead for NASA's Orbiting Carbon Observatory-2 (OCO-2 and OCO-3) satellites[4]



Change is in the air

The IPCC and Paris Agreement

The United Nations' Intergovernmental Panel on Climate Change (IPCC), which assesses the science related to climate change, has referenced the potentially harmful effects of increasing global temperatures in several reports through the years including:[5]

Global weather patterns
that exacerbate drought, heatwaves, floods, wildfires, and storms, including hurricanes.

Rising temperatures
that melt ice caps, glaciers, and permafrost layers, which can lead to rising sea levels and coastal erosion.

Impacts on fresh water
and food sources, particularly in less climate-resilient areas and where staple food crops are critical for survival.

To stem these impacts, the IPCC has called for "substantial and sustained reductions in greenhouse gas emissions" to stabilize the global average temperature over time. It has analyzed several GHG emission reduction scenarios, some of which target zero CO_2 emissions and some negative emissions by 2100. Several also recommend reducing methane (CH_4) and sulfur dioxide (SO_2) emissions.

The 2015 Paris Agreement marked a turning point in the international climate change arena. At the United Nations Framework Convention on Climate Change's (UNFCCC) 21st annual Council of Parties (COP) in Paris, France, on December 12, 2015, more than 190 nations signed a legally binding international treaty on climate change. The agreement calls for participating nations to do their part to reduce global greenhouse gas emissions in a collective effort to limit the global temperature increase to 2 °C above preindustrial levels while striving to limit the rise to 1.5 °C above preindustrial levels. They agreed to cut their pollutants over time, participate in transparent monitoring and reporting, and continually elevate their climate goals.

Spotlight on Net-Zero Decarbonization

A growing number of experts, scientists, and organizations devoted to studying and analyzing global warming and climate change believe reducing or eliminating CO_2 emissions – decarbonization – plays a central role in stabilizing our global temperature.

Before and after the signing of the Paris Agreement, there was a significant movement to identify and develop CO_2 emission reduction methods and technologies that help reduce the carbon footprints of the industrial and power generation sectors, two of the largest CO_2 emitters.

The two main concepts are:

1. Achieving zero emissions by switching to clean energy sources that do not release CO_2.

2. Achieving net-zero emissions by removing the equivalent amount of CO_2 emitted through power generation and industrial processes from the atmosphere through removal or sequestration.

> “Carbon dioxide is the greenhouse gas produced in the largest quantities, accounting for more than half of the current impact on the Earth’s climate. Depending on emissions rates, carbon dioxide concentrations could double or nearly triple from today’s level by the end of the century, greatly amplifying future human impacts on climate.”

National Academy of Sciences (United States)[6]

Many argue the zero-emissions scenario is difficult, if not impossible, to achieve in the near term. The National Academies of Sciences, Engineering, and Medicine points out that energy systems and industrial assets last for years or even decades.[7]

It is far less expensive to allow these assets to reach the end of their useful lives and then replace them with zero-emissions alternatives. Business and industry could work toward achieving net-zero emission-reduction goals through other methods, which include:

Applying carbon capture, utilization, and storage (CCUS)

There are CO_2 emitters that are difficult to decarbonize. Carbon capture, utilization, and storage – also termed sequestration – (CCUS) technologies capture and compress CO_2 (CC) from stationary sources that burn and convert fossil fuels to other energy forms, like heat and/or electricity. The captured CO_2 can be used (U) to create products, such as chemicals, fuels, and building materials, or can be transported to a permanent underground storage (S) location in geological formations.

Switching to renewable energy sources for buildings and transportation

The transportation sector generates approximately 30 percent of greenhouse gas emissions and another 13 percent is emitted by buildings and homes that burn fossil fuels for heat, according to the U.S. Environmental Protection Agency (EPA).[8] Businesses and individuals can migrate to clean energy source-powered vehicles for transport and construct new homes and buildings – or renovate or retrofit existing structures – with carbon-neutral energy systems and materials.

Decarbonizing power generation

The power sector produces approximately one-third of global CO_2 emissions, according to the International Energy Agency (IEA).[9] Fueled mainly by coal- and gas-powered systems, electricity producers could capture and sequester their CO_2 emissions to reach net-zero. As their facilities reach the end of their operational lives, they could shift to clean energy sources.

H_2

Producing low-carbon hydrogen at scale to help decarbonize hard-to-abate sectors

Low-carbon hydrogen can be used as a feedstock and alternative fuel for transportation, manufacturing, as well as, electricity and heat generation for buildings and communities. It can also be used as a long-term electricity storage solution and to balance variations in electricity demand.

The clock is ticking

Focus on Energy and Industry

The industrial and energy sectors power our global economy – they are responsible for generating electricity and manufacturing materials and products vital to the everyday lives of billions of people, businesses, and organizations across the globe. The COVID-19 pandemic provided a real-world example of what can happen when the wheels of industry slow. Even relatively small and short events like the recent Suez Canal blockage can have major impacts on the industry.

As the world population increases, so will the demand on these sectors. And, as demand grows, so will emissions. For example, the IEA estimates industry CO_2 emissions will rise by 11 percent to 6.7 gigatons of CO_2 per year, as reported in the Center on Global Energy Policy at Columbia University SIPA's Net-Zero and Geospheric Return: Actions Today for 2030 and Beyond.

Though not solely responsible for the increase in global CO_2 emissions, the industrial and energy sectors have been identified as vital participants in the CO_2 emission reduction effort because of their use of fossil fuels to power their facilities and processes. The call is out for industry to remove CO_2 from flue gases typically released into the atmosphere.

Sources of CO_2-containing off-gas streams:

- Fossil fuel power plants
- Industrial plants - iron and steel, cement, pulp and paper, etc.
- Chemical plants - ammonia, ethanol, etc.
- Refineries
- Hydrogen plants

The search for solutions

Carbon Management Technologies

Industrial and utility companies are answering the call for decarbonization actions. Many companies adopt climate-friendly policies and invest in technology to reduce CO_2 emissions to help meet global targets outlined in the Paris Agreement. There are many ways they can reduce their carbon footprint. Still, the option that promises the most significant results for hard-to-abate industries with emission-intensive facilities is carbon capture, utilization, and storage (CCUS or CCS).

> "In the fight against climate change, carbon capture and storage (CCS) is a game-changer. Its ability to avoid carbon dioxide (CO_2) emissions at their source and enable large-scale decreases to CO_2 already in the atmosphere via CO_2 removal technologies make it an essential part of the solution."
>
> **Global Status of CCS Report 2020[10]**

CCUS

How it works

Approximately 40 megatons of CO_2 are captured and stored each year. That needs to increase substantially to help meet goals outlined in the 1.5 °C and 2 °C temperature stabilization scenarios. Facilities with CCUS technology can capture almost all CO_2 emissions.

Deployment generally entails three steps:

1 Capture and processing

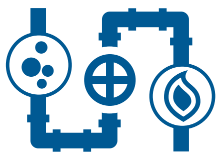
2 Transportation

3 Utilization or storage

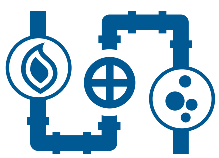
Step 1

Carbon capture

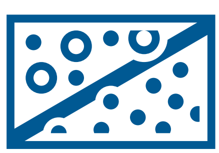
The first step entails capturing carbon at the source. Carbon capture technologies fall into three categories:[11]



Pre-combustion technologies separate CO_2 before the combustion process.
Reforming and gasification processes react fossil fuels with air or pure oxygen to create a synthesis gas comprised of hydrogen (H_2), carbon monoxide (CO), and carbon dioxide (CO_2). The CO_2 molecules are separated out of the syngas stream before combustion or further downstream chemical use of the syngas takes place.



Post-combustion technologies separate CO_2 from the exhaust after the combustion process.
This is the most widely used CCS technology for retrofitting industrial and power generating facilities. During the post-combustion process, flue gas resulting from burning fossil fuels passes through an absorber column with circulating liquid solvent, which absorbs the CO_2 molecules. A heating medium like steam enables the adjacent regeneration column releases the CO_2 from the solvent,and the CO_2 is captured and piped away before it reaches the atmosphere.



Oxy-fuel combustion technologies burn fuel in an almost purely oxygenated environment.
Oxygen is separated from air and then combusted with a fossil fuel to produce CO_2 and water vapor. This combustion, for example, drives turbines and generates electricity, then the water vapor is cooled, condensed, and removed while the CO_2 is captured, purified and piped away.

Step 2

Transportation

After the carbon is captured and processed (purified and liquefied or compressed) for downstream permanent storage or utilization in other processes, it can be transported by pipeline, ship, train, or other vehicles to its destination. Transportation mode depends on amount of CO_2 captured, distance to destination, required CO_2 specification, distribution requirements, regulations and existing or new infrastructure possibilities.

Step 3

Utilization or storage

Once captured, CO_2 can be compressed, purified, liquefied, and used in various applications from horticulture and welding to cryogenic cleaning and carbonated drinks. When not used for feedstock or commercial applications, it is stored permanently in geological formations to mitigate the climate impact of industrial and power generating processes. A geological formation must be deeper than 0.5 miles (800 meters), porous enough to hold the CO_2, and protected by impermeable rock formations that prevent it from escaping.

Examples of qualifying formations include:

- → Oil and natural gas reservoirs
- → Unmineable coal seams
- → Saline aquifers
- → Shale formations
- → Basalt formations

According to the Global CCS Institute, available global storage resources are estimated at more than 5 trillion tons of CO_2 capacity, which exceeds the amount needed to reach the 1.5 °C and 2 °C temperature stabilization scenarios. However, the compilation of a global portfolio of qualified storage sites with their capacities, accessibility, risk, technical feasibility, and environmental sustainability requires further development.

Emerging carbon removal technologies

Several emerging carbon removal technologies offer sustainable means to remove CO_2 directly from the Earth's atmosphere and oceans. These will not negate CCUS technologies' role in reducing CO_2 emissions in the industrial and energy sectors and promise to work in tandem to enhance global climate protection efforts.

Emerging carbon removal technologies

Mineralization

Mineralization technologies speed up naturally occurring CO_2 reactions with silicate minerals to make carbonate minerals, removing large volumes of CO_2 from the Earth's atmosphere. Mineralization is considered nature's way of storing CO_2, so it, too, is a long-standing carbon removal method, but naturally is a prolonged process. Mineralization technologies can increase the exposure of minerals to CO_2 by pumping underground water to the surface to react with the minerals, moving air through old mining shafts so that rocks leftover from those operations react with CO_2 in the air, or incorporating CO_2 into the production of cement and aggregate to form carbonates.

Biomass Energy with carbon capture and storage (BECCS)

Biomass Energy with Carbon Capture and Storage (BECCS) technologies combine CCS with bioenergy to capture CO_2 from air and water. Biomass materials – renewable organic material from plants and animals – are converted to heat, electricity, or fuels. The CO_2 emissions are captured and stored in geological formations or used to produce products. The carbon removal component results from the bioenergy crops (that become biomass) drawing CO_2 from the atmosphere as they grow. Biomass materials include wood and wood processing waste, crops and waste, animal manure, and human sewage.

Direct-air capture with carbon storage (DACCS)

Direct-Air Capture with Carbon Storage (DACCS) technology removes CO_2 from the air and compresses it so that it can be transported to a geological storage facility or used to manufacture products, such as cement. Direct-air capture technology is not new, having been used since World War II to operate submarines and in the 1960s to operate spacecraft. DACCS methodology uses chemicals to bind with CO_2 in the air and releases it when heated, or uses electrical charges to capture and release CO_2.

CCUS

Reduce Your Business' Carbon Footprint

The demand for the industrial and power generation sectors to reduce GHG emissions is growing, so companies are looking for flexible and cost-efficient solutions to improve their carbon footprint. This complex process requires extensive research, detailed cost-benefit analyses, and careful consideration of available carbon-reduction options.[12]

If your business is new to this process, start by examining the different carbon reduction methods and determine which are most feasible for your operation – on all levels, including:

Avoiding CO_2 emissions

Industry avoids emissions by incorporating emissions-free infrastructure in operations, such as building a solar- or wind-powered plant instead of a natural gas power plant. This alternative is adopted most often.

Capturing and storing CO_2 emissions

CCUS entails constructing or retrofitting a plant with equipment and infrastructure that captures and separates CO_2 from flue, fuel or process gases and transports it in gaseous or liquid form, or as supercritical fluid for further use or permanent underground storage.

Reducing CO_2 emissions

Reducing CO_2 emissions can be accomplished in various ways, including using lower-carbon materials in manufacturing processes, reclaiming and reusing materials, and introducing efficiencies into operations. These techniques are often employed in tandem with other emission reduction technologies.

Removing CO_2

Carbon dioxide removal – often referred to as CDR or carbon drawdown – is accomplished by capturing CO_2 through mineralization, direct-air capture, or biomass energy technologies and storing it in plants, oceans, minerals, saline aquifers, or depleted oil wells. These technologies are in the early stages of research and development.

Evaluate your infrastructure to determine the options that make the most sense for implementation from financial, operational, logistical, and environmental standpoints. For example, it might be financially feasible to implement a clean energy combustion system into plans for a new project instead of retrofitting an entire plant already in operation. And you might incorporate carbon reduction methods into everyday business processes and find that you need a larger-scale effort like CCUS technology to meet big picture goals.

When evaluating CCUS technologies, logistical considerations include your plant's proximity to viable geological storage facilities and transportation options. Is there a readily available carbon hub nearby? Are you located near an existing CO_2 pipeline network, or will you have to help front the infrastructure cost? Can you transport captured CO_2 by other means, such as a barge or train? Transport by truck is an option, but does it make sense for your business?

The decision-making process warrants time, attention, and expertise. Consider partnering with an engineering and consulting company with years of expertise in the field to guide your journey.

The Case for CCUS

Reality dictates it will prove difficult for industry to do its part to reach climate targets – in the near term, at least – by choosing only to avoid, remove or reduce CO_2 emissions.

According to McKinsey & Company (Decarbonization of industrial sectors: The next frontier), industrial CO_2 emissions are hard to abate for many reasons, including:[13]

45%

Forty-five percent of CO_2 emissions from feedstocks cannot be abated by a change in fuels, only by changes to processes.

35%

Thirty-five percent of emissions come from burning fossil fuels to generate high-temperature heat. Switching to alternative fuels such as zero-carbon electricity would require significant changes to the furnace design.

1+N

Industrial processes are highly integrated, so changing one component can require changes to other parts of a process.

During your analysis, consider a multi-pronged effort that features CCUS. It provides one of the most mature and cost-effective options for reducing emissions from industrial processes and high-temperature heat.

Lars-Erik Gärtner, Linde Engineering's Associate Director Sales & Business Development, noted that IPCC and IEA analyses have consistently demonstrated that CCUS is an essential part of the lowest cost path towards meeting climate targets.[14] The IPCC's Fifth Annual Assessment Report (AR5) showed that excluding CCUS from the portfolio of technologies used to reduce emissions would lead to a doubling in cost – the most significant cost increase from excluding any technology.

The multifaceted benefits offered by CCUS technologies

CCUS reduces your environmental impact

CCUS technologies offer a way for companies to demonstrate commitment to offsetting greenhouse gas emissions produced through their processes.

A new generation of investors, consumers, and employees expect companies to incorporate social and environmental goals and values into their mission, vision, and operations.

CCUS opens up commercial opportunities

In addition to the strong environmental case for reducing your company's carbon footprint, other noteworthy factors make a compelling business case for capturing carbon and selling it downstream for use in other industries.

Pressurized CO_2 is used for enhanced oil recovery (EOR) and enhanced gas recovery (EGR). Also, CO_2 purification and liquefaction plants can be engineered to produce gaseous or liquid CO_2 in purity levels required for various applications, including desalination, cryogenic cleaning, welding, cutting, food and beverage production, and healthcare. CO_2 can also be put to chemical use in methanol production and urea synthesis.

Regulatory and financial incentives to mitigate CO_2

Emissions cap and trade systems and carbon taxation are the most widely implemented programs for carbon reduction. These market-based approaches work by creating incentives for emitters to conserve energy, improve energy efficiency, and adopt clean-energy technologies — without prescribing the precise actions they should take.

The Paris Agreement served as a catalyst for local, state, provincial, and federal governments across the world to further consider policy-based incentives to demonstrate commitment to making carbon reduction goals a reality.

Governments have developed – and will further develop – other financial incentives, such as tax credits and appropriate funding to encourage companies to invest in new low-carbon technology projects and retrofits. However, these initiatives are still rare.

For example, the US Department of Energy's investment in five Carbon Storage Assurance Facility Enterprise (CarbonSAFE) initiative projects, which focus on the development of geologic storage sites for 50+ million metric tons (MMT) of CO_2 from industrial sources, will help accelerate the widescale deployment of CCUS technologies.

In addition, the value of the US's 45Q tax credit enacted by the Energy Improvement and Extension Act of 2008 was significantly increased in value by the 2018 Future Act. It provides a credit up to \$50 per metric ton of carbon captured and placed in geological storage and up to \$35 per metric ton of carbon injected into oil or natural gas wells for EOR/EGR. Furthermore, an increase to these 45Q tax credits is currently under discussion.

“We now have the opportunity to kick-start the next important phase of global CO_2 emission reduction through the support of the developing CCUS and Clean Hydrogen Economy. Many of these clean technologies have been proven at industrial scale, and implementation has started. Still, commercial projects will continue to need financial incentives for broad deployment that will enable accelerated technology advancement and reductions in project risk and cost.”

Lars-Erik Gärtner
Linde Engineering’s Associate Director Sales & Business Development

Partner with a leader

Linde

Tackling climate change is a shared and global responsibility. Linde has the technologies, resources and capability to contribute across all aspects of managing climate change and reducing GHG emissions. With our technologies, we want to contribute to eliminating CO_2 emissions and supporting the transition toward a more sustainable economy.

> "For decades, Linde has been innovating technologies for carbon management, and we will need even more solutions as we transition towards a more sustainable future. By 2028, our company will invest more than one billion dollars in decarbonization initiatives. Furthermore, we will dedicate at least 30 percent of our R&D budget to sustainability innovations."
>
> **Juergen Nowicki**
> Executive Vice President Linde plc
> and CEO Linde Engineering

Count on our expertise

Linde has extensive, proven expertise in the treatment of CO_2, including its separation, purification, compression, liquefaction, and storage processes. We provide start-to-finish services for carbon capture, utilization, and storage (CCUS) projects to meet your requirements.

Services include

- Consulting
- Project development
- Economical and technical feasibility studies
- Support and documentation for authority engineering
- Engineering and design
- Procurement
- Construction
- Commissioning and start-up
- Training of operational and maintenance personnel
- Project management
- Licensing arrangements
- Financing
- After-sales support

For more information, please visit Linde Engineering at linde-engineering.com

Get started with Linde

With our technologies and extensive experience and expertise, we will help you achieve your project goals in a fair, transparent, environmentally sustainable, and cost-conscious manner. Let's start with a discussion about your project. Contact us to set up a consultation.

About Linde

Linde is a leading global industrial gases and engineering company. We live our mission of making our world more productive every day by providing high-quality solutions, technologies and services which are making our customers more successful and helping to sustain and protect our planet.

The company serves a variety of end markets including chemicals and refining, food and beverage, electronics, healthcare, manufacturing and primary metals. Linde's industrial gases are used in countless applications, from life-saving oxygen for hospitals to high-purity and specialty gases for electronics manufacturing, hydrogen for clean fuels and much more. Linde also delivers state-of-the-art gas processing solutions to support customer expansion, efficiency improvements and emissions reductions.

Having received several accolades for its work in sustainability, Linde is in the business of resource transformation in a world that is dealing with climate change. We believe that issues over long-term energy availability and climate change will only continue to intensify. At Linde, sustainable development is rooted in our mission, values and policies and extends into all areas of our business.

Linde helps customers worldwide improve their environmental performance and reduce their carbon footprint. At the same time, we are committed to minimizing our own environmental resource intensity, including for energy, water and waste.

To learn more about sustainability at Linde, please visit linde.com/sustainable-development

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