carbon clean

TECHNOLOGY TO ACHIEVE 'NET ZERO'

Achieving Net Zero in the Industrial Sector:

How Carbon Capture Technology Brings Real Solutions to Industry

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Introduction:

Maintaining Priorities with Advanced Technologies

Climate change remains a defining issue for the 21st century. When it comes to meeting the targets set out in the Paris Agreement, time is not on our side. The objective — limiting the increase in global average temperature to below 1.5°C over pre-industrial levels — is as pressing as ever.

Prior to the COVID-19 pandemic, awareness of the issue's urgency was gaining momentum throughout some segments of industry, with an ever-growing list of enterprises outlining plans to achieve carbon net zero.

While there have been concerns that the commitment would wane as focus shifted to the challenges posed by COVID-19, that does not appear to be the case. A recent Ipsos Mori poll found that 71 percent of people worldwide agree that in the long-term, climate change is as serious a threat as the pandemic. Rather than derailing the battle against climate change, the current global health, and economic crisis has created an opportunity to accelerate it, by giving us the chance to examine the lifestyles and social systems that have brought us to the current moment. Governments around the world are seizing the opportunity to advance a "green recovery" from the current crisis that allows us to "build back better."

One significant long-term solution towards decarbonisation and a sustainable economy is a shift towards renewable energy sources. But renewable energy alone will not be enough to help transition the world away from fossil fuels, particularly when it comes to heavy industry.

Carbon Capture, Utilisation, and Storage: A Key Opportunity for Hard to Abate Industries

Critical industries such as cement, steel, refineries, and energy from waste (EfW) are major contributors to global carbon emissions.

In the past, complex production processes and energy demands have made decarbonisation difficult. These hard to abate sectors have also received relatively little attention compared with the focus on energy efficiency, renewables, and consumer behaviours. Heavy industry is here to stay, and provides an immense opportunity for making significant progress towards net zero worldwide.

This is where carbon capture, utilisation, and storage (CCUS) technologies can play a crucial role in moving industry towards net zero. These technologies capture carbon dioxide (CO_2) from industrial plants prior to it reaching the earth's atmosphere, and allow the CO_2 to be converted to useful commercial products or stored underground.

Analysis by the Intergovernmental Panel on Climate Change (IPCC) and International Energy Agency (IEA) has consistently shown that widespread deployment of CCUS is an essential component of meeting climate targets and reaching net zero. CCUS significantly reduces costs and minimises societal disruption in meeting climate targets by enabling hard to abate industries to significantly decarbonise — without more significant overhauls of their current processes.

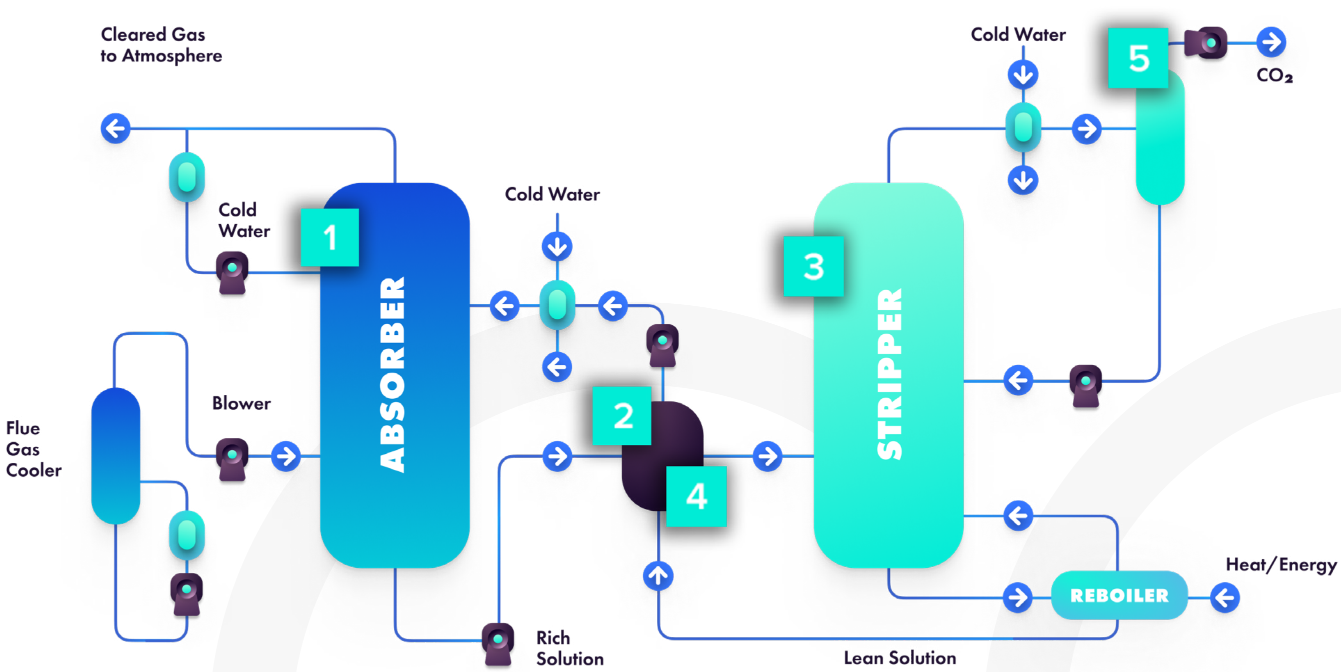
A Proven Solution for Carbon Capture

CCUS is a proven process dating back to the 1970s, but so far, widespread adoption has been limited due to cost and scalability. Our technology fills the need to bring down the cost and make it commercially viable on a large scale. This carbon capture technology offers a scalable method to decarbonise hard to abate industries, including cement, steel, refineries, and EfW. It's intended and tailored for the needs and realities of these industries.

Carbon Clean has developed CDRMax™ technology, a commercially available carbon capture process for industrial flue gases or off-gases with CO_2 concentrations ranging from 3 to 25 vol.%. The CDRMax™ process uses a proprietary solvent and heat integration to provide the energy-efficient capture and/or recovery of CO_2. The process can achieve capture rates of more than 90 percent, and delivers industrial quality CO_2 for re-use or sequestration. The process can be applied to everything from mid-scale (100s of metric tonnes per day) to large-scale (1,000s of metric tonnes per day) capacities for industrial carbon capture and utilisation (ICCU) applications.

CDRMax: How It Works

Process flow diagram of CDMax™



Chapter 1:

The Goal of Net Zero

What is Net Zero?

Climate science demonstrates that the eventual extent of global warming is approximately proportional to the total amount of carbon dioxide that human activity adds to the atmosphere. Since the Earth reacts strongly to small changes in the amount of CO_2, methane, and other greenhouse gases released into the atmosphere, emissions of these gases must be reduced.

In order to rebalance and stabilise the Earth's climate system, CO_2 emissions must fall to zero. Net zero refers to this goal of minimising total carbon (or sometimes, greenhouse gas in general) emissions from humans into the Earth's atmosphere, with any emissions offset by carbon removal to reach a net output of zero. This is also referred to as carbon neutrality.

The 2018 Intergovernmental Panel on Climate Change (IPCC) report concluded that global emissions need to reach net zero around 2050 in order to meet the 1.5°C global warming target set forth in the Paris Agreement. If the world reaches net zero emissions one decade sooner, by 2040, the chance of limiting warming to 1.5°C is considerably higher. But the longer it takes, the greater the impact on the climate.

> *Net zero is not necessarily just a set of technologies or a set of policy or financing options. It's much bigger than that. It has to do with a collective set of actions that humanity needs to take as a whole to be able to get to that space where we're not emitting any excess CO_2 into the atmosphere."*

Aniruddha Sharma
CEO, Carbon Clean

Aniruddha Sharma, CEO, Carbon Clean, says that achieving net zero involves three levels. At the ground level, there needs to be a shift in popular awareness and consumer demand that drives behavioral changes when it comes to individual decisions and product choices. Beyond that, there needs to be planning around the implications of technology on all walks of life, such as transport, travel, and industry. That leads to the third level, which contains tremendous untapped potential: industry-specific options to reducing carbon emissions for hard to abate industries.

The Role of Industry

Industry accounts for 40 percent of global energy demand and one-quarter of global CO_2 emissions — a very significant portion. However, rather than being a hurdle to meeting long-term climate targets, industry is poised to be a major contributor to avert climate change. Transformative decarbonisation of heavy industry is one of the single most important methods to rapidly move society towards net zero.

The largest sources for industrial emissions are vital industries such as cement, iron and steel, EfW, and petrochemicals. Again, these are not industries that are easily replaced. The cement and steel sectors provide the foundational materials for global construction and infrastructure, while petrochemicals produce a range of valuable products such as fuels, gasoline, plastics, and more. A rapidly growing global population and economy are expected to raise demand for these essential commodities, which underlie key aspects of modern infrastructure and economic life.

But these industries are also among the hardest to abate. In part this is due to the emissions that result from chemical reactions inherent to production processes. It's also due to their high-temperature heat requirements. For example, 65 percent of cement emissions result from the calcination of limestone, a process crucial to cement production. This process cannot be avoided by switching to alternative fuels.

Increasing Cost Effectiveness

CCUS provides the only mature and cost-effective option for reducing emissions both from production processes and energy usage from heat demand. And CCUS technology can be harnessed by hard to abate industries to decarbonise without needing to make significant changes to existing processes. The technology can capture carbon directly from point sources on industrial sites, making it a practical and feasible option for industries to begin decarbonisation in the short-term.

Reports such as those by the Energy Transition Commission and the International Energy Agency have concluded that achieving net zero in hard to abate industries without CCUS may be impossible, and at best substantially more expensive. The IPCC's Fifth Assessment Report (AR5) found that excluding CCUS would lead to a doubling of the cost of reducing emissions, the largest cost increase due to the exclusion of any single technology.

Even with today's relatively modest prices on CO_2 emissions, CCUS is being utilised in cost-effective applications. As the cost of carbon capture goes down and the cost of carbon emissions goes up, and as we see tightening climate targets, these applications will become even more cost-effective.

Chapter 2:

The Costs of Capturing Carbon

Industrial installations have a range of options when it comes to decarbonisation measures, from switching lighting to LED bulbs, to buying renewable energy, to installing CCUS technology. Each of these measures has a payoff commensurate with the investment. With CCUS, the investment is measured by the metric cost of capture, which is the dollar cost per tonne of CO_2 that is captured (and then stored or sold), rather than emitted into the atmosphere. Cost of capture allows companies to best prioritise technologies and spending for decarbonisation measures.

This cost includes both capital expenses and operating expenses. The capital cost is a one-time investment in installing CCUS equipment, while the operating costs include the cost of energy needed to power the equipment. While capital costs for CCUS installation have traditionally been expensive, advances in CCUS technology have reduced the cost of capture to new low levels, making CCUS, on balance, a pragmatic and cost-effective option for industry.

Carbon Clean is continuing to invest in the production of their containerised solution to achieve $30 tonne cost of CO_2 capture not including carbon credits by 2021. Consequently, large emitters could potentially offset the cost of carbon capture with their carbon tax from as early as next year.

Calculating the Cost of Capture

The easiest way of calculating the cost of capture is looking at your total investment in getting the measures implemented. Then, divide that by the total amount of CO_2 avoided over the lifetime of that specific measure."

"For example, imagine that you install CCUS technology that captures 100,000 tonnes of CO_2 and it costs $10 million dollars. You operate it for 5 years. Take that as a benchmark: divide the total amount of tonnes by the cost over time. You come to the cost of total CO_2 captured per tonne."

Prateek Bumb
Co-Founder and CTO, Carbon Clean

Since October 2016, Carbon Clean in partnership with Tuticorin Alkali Chemicals and Fertilisers Limited has been operating the world's first low-cost industrial scale carbon capture and utilisation (CCU) plant in India. Installed on a coal fired boiler, the project is located near Chennai and is designed to capture 60,000 tonnes CO_2 per year. Not only does the plant meet cost and performance expectations, but the CO_2 is also converted into a commercial product soda ash (an ingredient found in household products).

Understanding the True Cost of Capture

The truth is, it takes carbon to run the technology to capture carbon. And there are complexities in how CO_2 reductions are determined. But to put it simply, the total cost of using CCUS measures will be impacted by a variety of factors, including:

- Specific technology used (development of technology in this area is lowering costs)
- Site-specific characteristics of the industrial facility
- Purity of the CO_2 in the flue gas waste stream
- Storage (how the carbon is stored, utilised, or sold)
- Transport (the distance and method for the stored carbon to be transported)
- Fuel prices
- Cost of capital
- Regulatory environment
- Operating and maintenance costs

The ROI of Doing the Right Thing

As with many new technologies, the companies that choose to embrace the possibilities offered by affordable CCUS at scale will be those that reap the most reward. First movers shape the path of industry, and have the greatest advantage of positioning their organisations for a new, sustainable way of doing business.

Further, as carbon pricing continues to take off across jurisdictions over the next decades, those companies caught unprepared may quickly find themselves at a major financial disadvantage that will be difficult to recover from.

Carbon price support and subsidies are likely to go down over time as carbon pricing becomes more widespread, giving first movers the greatest benefit from CCUS, as they began avoiding emissions while the price was at its highest.

These first movers will also be the best positioned to create new, valuable product offerings for environmentally-sensitive consumers, helping to future-proof their business models against shifts in both government regulations and consumer demands that aim to support sustainable and green enterprises.

The Value of Job Creation

One important differentiator for CCUS compared to other decarbonisation measures is its ability to create and sustain jobs. Renewable energy sources such as wind and solar farms are important, but can also have a net-negative impact on employment, as they have lower labour requirements than the industries they replace.

CCUS creates and protects jobs in two main ways. First, CCUS has the potential to create thousands of jobs in the construction and operation of CCUS facilities and supply chains, as well as with ancillary service providers. To reach the deployment levels outlined in the IEA's Sustainable Development Scenario, more than 2,000 facilities will be needed by 2050, which would create at least 10,000 new jobs.

Reaching the IEA Sustainable Development Scenario

Timeline
2050

Facilities Created
2,000+
CCUS Facilities

Jobs Created
10,000+
New Jobs (Construction, Operation, Supply Chain, Support Services)

Secondly, CCUS allows hard to abate industries — such as cement, steel, refineries, and EfW — to continue to operate and thrive in a sustainable, net zero economy, protecting the millions who are employed in these industries globally. These industries often co-locate in regions with good access to transport infrastructure and necessary inputs (such as energy demands, feedstocks, and skilled workers), often making the local communities they are based in dependent on them for employment.

These are industries that also typically provide high-paid jobs: in the US, for instance, workers in the refining, cement, and steel sectors are paid significantly more than the average wage in the state in which they live. By converting hard to abate industries to lower emissions, CCUS serves to avoid the kind of local economic and social dislocation that might otherwise result from meeting important climate targets such as net zero.

Chapter 3:

The Four Key Industries — Cement, Steel, Refineries and Energy from Waste

Of the hard to abate industries, four key sectors stand out as ideal candidates for carbon capture: cement, steel, refineries, and energy from waste (EfW) facilities. These sectors encompass the entire lifecycle of modern economic activity, from infrastructure and construction, to consumer products and transportation, to waste. Their centralised facilities provide high-value opportunities to make significant reductions in industrial carbon emissions, while enabling these sectors to continue fueling economic growth.

The Cement Sector: A Key Industry Heading for Change

Cement is the world's leading construction material — but it's also one of the leading sources of greenhouse gas emissions. Carbon is released during the production process by cement kilns, which cook ground limestone with sand and clay at high heat. During this process, CO_2 is emitted by the burning coal to heat the kilns, as well as from gases released from the limestone during heating (known as calcination).

As a result of the more than 4 billion tonnes of cement produced globally each year, the industry generates approximately 8 percent of global CO_2 emissions. If the cement industry were a nation, it would be the third-highest CO_2 emitter after China and the United States.

Going Net Zero:
How Net Zero Impacts the Cement Industry

When it comes to reducing the carbon output of the cement sector, there's good news: the CO_2 concentration in exhaust from cement plants is very high, which makes it easier to capture the carbon. Around 90 percent of the CO_2 can be captured and stored using CCUS with an optimised engineering design.

Net zero has massive implications for the cement sector. Cement is the main ingredient used to create concrete, the most widely used material in the world. Concrete usage worldwide, tonne for tonne, is twice that of steel, wood, plastics, and aluminum combined. Cement and concrete are absolutely essential for construction and homebuilding, and thus essential to global economic progress. Yet cement's current production process is a major source of carbon emissions. Decarbonising it would allow us to harness this amazing material — while also moving towards net zero. There are key business advantages as well. As more jurisdictions adopt carbon taxes, these taxes immediately translate into the price of cement. As cement is a commodity, this can make construction very expensive. Cement producers who harness technology such as CCUS are better positioned to keep their prices low, while also benefiting from new revenue streams through the utilisation of captured carbon. This turns their carbon output from a costly liability to a valuable asset.

Dalmia: A First Mover in the Cement Industry

In partnership with Carbon Clean, Dalmia Cement (Bharat) Limited, a leading Indian cement manufacturer, is building a large-scale, 500,000 tonne per year carbon capture facility at its cement plant at Tamil Nadu, India. Carbon Clean will provide technology and operational services for the plant based on its patented CDRMax™ technology.

While small-scale carbon capture plants have been commissioned at a small number of cement plants in China and Europe, a large-scale demonstration plant of this capacity has never been announced before in the cement industry. Dalmia Cement and Carbon Clean will explore multiple utilisation streams for the CO_2 that is captured from this sizable plant, including direct sale for use in other industries and manufacture of chemicals.

> *At Dalmia Cement, we are committed to becoming a carbon negative cement group by 2040. Capturing process emissions from cement manufacturing will be critical towards reaching net zero. Therefore, our approach is to set up a large scalable demonstration project on carbon capture with multiple utilisation streams."*

Mr. Mahendra Singhi,
Managing Director and CEO, Dalmia Cement (Bharat) Limited

The Steel Sector: Complexity and Carbon

Cement may be the largest source of industrial CO_2 emissions, but steel isn't far behind. If we counted the emissions of the steel industry as if it were a nation, it would rank the 5th largest in the world.

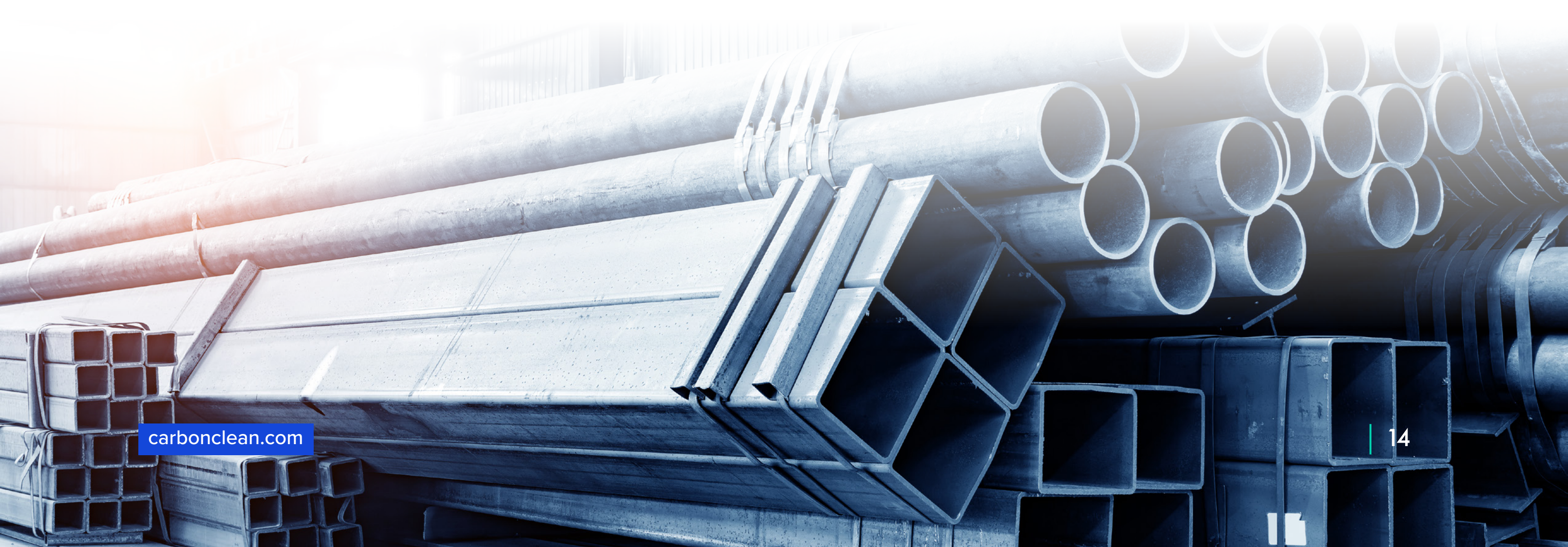
However, carbon emissions in steel is a little more complicated than in the cement sector. Steel and iron production is reliant on coal, both as a feedstock and a fuel. Unlike cement, emissions arise at different points in the steel production process. Steel mills have a number of furnaces and subunits involved in the production process that emit carbon. The largest of these are the blast furnaces (where iron is reduced to make steel) and the on-site power plant.

Going Net Zero: How Net Zero Impacts the Steel Industry

The complexity of the steel production process provides a different set of technical challenges and opportunities. The main question for steel works is choosing exactly where to most effectively install capture technology, as there are multiple emissions sources on-site. A number of solutions are possible to bring steel to net zero.

In the long run, technological changes to the steelmaking process can reduce emissions by producing clean steel, by using electricity instead of charcoal, cutting out the carbon emissions created by coal. However, this technology is still a way off from being commercialised, and will require large modifications to existing steelmaking infrastructure.

The best way to decarbonise existing steel plants is to use CCUS on the blast furnace to capture the majority of emissions, and store the carbon. In some cases, this carbon can be mixed with water and a plant waste known as slag, resulting in a construction material that can then be used for building roads. Utilising captured carbon in this way can provide an additional revenue stream for steelmakers.



Energy from Waste:
Connecting Industry and Municipalities

EfW is the process of generating energy in the form of electricity or heat by processing waste as a fuel source. This process takes place at large plants, typically run by municipalities and local authorities, which intake household waste from municipal waste collections and burn it in a large boiler to produce energy. This serves the double purpose of disposing of waste that would have otherwise gone to a landfill and avoiding millions of tonnes of landfilled waste, while also producing electricity and heat consumers can use.

Going Net Zero:
How Net Zero Impacts the Energy from Waste Industry

> *Energy from waste is starting to become quite a big piece of the puzzle now, especially from the European perspective. There are some 450 energy from waste plants across Europe. So there is a massive impact on emissions, as this waste contains gases such as methane. You're basically reducing the carbon footprint of individuals in cities."*

Aniruddha Sharma
CEO, Carbon Clean

There are three major emission sources from urban areas: transportation, construction, and waste management. By utilising CCUS at EfW plants, municipal authorities can further decarbonise the waste chain by decarbonising households and individuals served by municipal waste authorities. This allows for huge reduction in the carbon footprint of individuals in cities. Further, as packaging becomes increasingly plant-based, we are able to leverage this process into a negative carbon cycle, which is an extremely powerful way to move towards net zero or even negative carbon emissions.

Achieving a Negative Carbon Cycle with EfW and CCUS

Plants absorb CO_2, which is turned into consumables

Which are burned at an EfW plant, and then captured by CCUS technology

Refineries: Revamping Old Technologies

Oil refineries transform crude oil into various usable petroleum products such as diesel, gasoline, kerosene, jet fuel, liquified natural gas (LNG), heating oils, and more. These sprawling industrial complexes separate the hundreds of different hydrocarbon molecules in crude oil into components that are then sold to a variety of different customer segments, who use them as fuels, lubricants, and feedstocks in petrochemical manufacturing processes.

Refineries have several units that emit CO_2, including steam methane reformers that produce hydrogen, catalytic crackers, and Combined Heat and Power (CHP) units. The emissions of an individual refinery depend on a number of factors, such as refinery configuration, types of fuel used, and crudes processed (heavy, sour crudes require more energy to process than light, sweet crudes).

Going Net Zero:
How Net Zero Impacts the Refinery Sector

Refineries play a key role in the petroleum industry, connecting crude oil extraction to its downstream segments. While processing by refineries only contributes around 5 to 10 percent of the total emissions resulting from oil products, the opportunities for reducing these are significant due to the nature of the processes used, and the fact that these are large-scale fixed locations. This makes CCUS more practical than it would be in downstream applications such as individual homes, vehicles, and businesses.

> *Using our technology, you can capture more than 90 percent of carbon dioxide from the smokestacks of refineries. And that's a universal number you can apply to all sectors."*

Aniruddha Sharma
CEO, Carbon Clean

Major players in the petroleum industry have already begun the shift towards carbon neutrality. BP, Shell, and Total have all pledged to be net zero by 2050, while both Chevron and ExxonMobil have announced their own emissions-reduction targets.

By integrating CCUS with other practices such as energy efficiency, using low-carbon oil, and tapping into renewable power generation, refineries can move towards net zero quickly, easily, and practically. These measures can also become a key competitive differentiator for refineries, as their consumers have greater incentives to use low-carbon fuel. This is already happening in the aviation industry.

The Competitive Edge of Low-Carbon Fuel

The net zero journey creates a direct line from the refinery all the way to consumers. From the beginning of 2020, British Airways has begun offsetting all carbon emissions on domestic flights, as part of its transition towards achieving net zero by 2050. For international flights, customers can opt to pay a small fee to offset their carbon emissions from the flight. And British Airways isn't alone: through the UN's adoption of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) in 2016, the global aviation industry is looking to shift the entire industry towards net zero.

If passengers prefer flying on a low-carbon flight, the only current and foreseeable option is low-carbon aviation fuel from low-carbon refineries. This allows net zero refineries to position themselves as providers of a valuable product — low-carbon fuel — which airlines can sell to their customers as a premium product, just as British Airways has begun to do.

Combining proven technology to achieve this is happening right now. Carbon Clean is pleased to be a part of the expert consortium assembled by Liquid Wind to establish commercial-scale eMethanol facilities, in partnership with Axpo, Haldor Topsoe, Nel Hydrogen, and Siemens.

Combining proven technology to achieve this is happening now. We're delighted to be a part of the expert consortium assembled by Liquid Wind to establish commercial-scale eMethanol facilities. Axpo, Haldor Topsoe, Nel Hydrogen, Siemens along with ourselves will collaborate to efficiently integrate their technologies and create cost-competitive, carbon neutral fuel.

Conclusion:

Green Recovery and Decarbonising Heavy Industry with CCUS

During the lockdowns resulting from the COVID-19 pandemic, carbon emissions have dropped between 10 to 30 percent globally, with some areas witnessing clear skies for the first time in decades. The current global health and economic crisis that has appeared in the wake of the pandemic may be an opportunity to make significant advances towards net zero, as governments use economic recovery plans to boost low-carbon industries and bring a "green recovery."

Europe in particular has taken major steps towards supporting a transition to net zero, including the proposal of the European Green Deal program, an ambitious package of initiatives to cut emissions and invest in green technology. One proposal under review includes the European Climate Law, which would enshrine the 2050 carbon net zero objective into EU law. As the public demand for solutions to the climate issue grows, measures like these will undoubtedly become more prevalent across the globe.

While renewable energy, new business models, and consumer choices get the most attention when it comes to "going green," CCUS has the greatest potential to quickly make pragmatic and powerful reductions to CO_2 emissions levels with minimal social and economic disruption.

> *"CCUS is the only way you can decarbonise heavy industry. So if you don't want the industry to go back to business as usual, you must incentivise them."*

Aniruddha Sharma
CEO, Carbon Clean

As governments take greater action to incentivise the transition to a sustainable economy, they have recognised the vital role CCUS has to play. In 2018, the US government expanded the 45Q Tax Credit for CO_2 sequestration, while California's Low Carbon Fuel Standard CCS protocol provides $200/t CO_2 for CCUS facilities that reduce transportation fuel emissions. More recently in 2020, the European Development Fund has launched a €1 billion CCUS funding program for European industry. Governments increasingly understand the need to support and incentivise industry adoption of technologies such as CCUS.

For industry, there has never been a better time to prioritise the reduction of carbon emissions.

Advanced CCUS technology provides a scalable and increasingly cost-effective means to do so. By optimising the new opportunities this technology presents, hard to abate industries can begin to rapidly move towards net zero, transforming their businesses to successive levels of sustainability for the future.

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