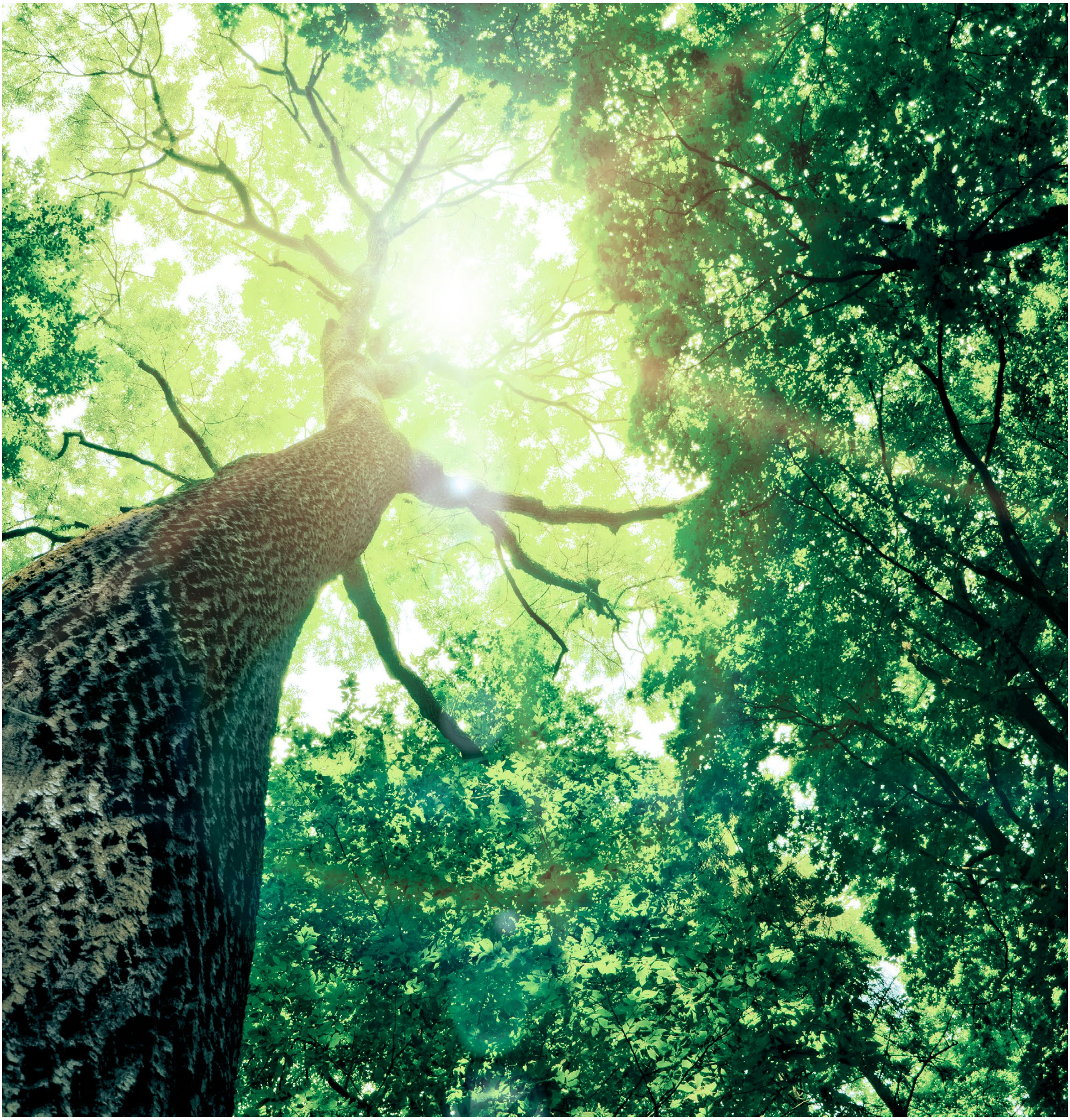
MOVE THE WORLD FORWARD MITSUBISHI HEAVY INDUSTRIES GROUP



CAPTURING THE VALUE OF CO_2

TRANSFORMING A LIABILITY INTO AN ASSET

MITSUBISHI HEAVY INDUSTRIES

EXECUTIVE SUMMARY

Technologies for capturing carbon dioxide (CO_2) sit at the heart of efforts to reach net zero emissions by 2050. But worldwide CO_2 capture capacity needs to increase exponentially to keep global temperatures within the Paris Agreement's 1.5°c target.

Much of the technology exists to capture CO_2 and convert it for re-use, but major challenges remain to scale up projects and initiatives and bring down costs.

Capture systems include:

1. CO_2 Capture and Storage (CCS) and CO_2 Capture, Utilization and Storage (CCUS) - CO_2 emissions are captured directly from the flue gases of power plants and industrial facilities, and then either securely stored deep below ground or transported to end users for applications like cement manufacturing and other industrial processes.

2. Direct Air Capture (DAC) – A capture system that removes CO_2 straight from the atmosphere rather than an emission source. Captured CO_2 can be stored or put to use in a range of industrial applications, resulting in negative emissions.

These systems depend on physical integration with transportation pipeline networks and storage sites, and digital connections to track carbon dioxide supplies and make connections to facilitate end-to-end transactions.

Developing a positive CCUS value chain – where captured carbon is re-used in industrial, agricultural and other applications – could turn CO_2 from a liability into an asset.

As little legacy energy infrastructure can be used for CO_2, investment is needed in pipeline networks, storage facilities and carbon-ready vehicles like ships to transport captured CO_2 to storage sites or for onward transport to end-users.

This investment and the development of an end-to-end CCUS value chain will only happen if there is:

1. A supportive policy framework to encourage CCUS projects and CO_2 utilization;

2. Development of carbon dioxide trading platforms to support an interconnected CCUS value chain;

3. Scaling up of technologies and markets that can utilize CO_2, such as synthetic fuels, chemicals manufacturing and sustainable cement production;

4. Collaboration between scientists, industry, investors, policymakers and other stakeholders to create a framework that accelerates growth and reduces costs.

All of these are vital if we are to turn CO_2 into a tradable commodity and develop a CCUS value chain capable of aiding efforts to reach net zero.

INTRODUCTION

Technologies for capturing carbon dioxide (CO_2) have a vital role to play in supporting global efforts to reach net zero emissions by 2050.

The International Energy Agency (IEA) has recognized CO_2 Capture, Utilization and Storage (CCUS) as a key pillar in the clean energy transition[1], noting this unique solution can both reduce and remove emissions. This includes direct capture from power generation and heavy industry and supporting technologies like synthetic fuels to reduce emissions from hard-to-abate sectors, such as aviation, shipping and road haulage.

Currently, the global annual CO_2 capture capacity sits at 0.04 Gigatonnes (Gt). But this needs to increase exponentially to reach a projected capacity of 7.6 Gt required to reach carbon neutrality by 2050, according to the IEA 2050 Roadmap report[2] – an almost 200-fold increase within two decades. Although this is a significant challenge, scaling up the global CCUS network will add momentum for further technological development and bring down costs, while accelerating long-term progress across a broad range of

To facilitate such growth, near-term policy action will need to establish a framework that encourages investment along the CCUS value chain[4] – where captured CO_2 is utilized in industrial, agricultural and other applications.

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[1] IEA: The world has vast capacity to store CO_2

[2] IEA: Net Zero by 2050: A Roadmap for the Global Energy Sector

[3] IEA: CCUS in Clean Energy Transitions

[4] IEA: CCUS in Clean Energy Transitions

While much of the technology exists to capture and store carbon dioxide, many technologies linked to scaling up the CCUS value chain are still at the laboratory or demonstration stage. Major challenges must be overcome to increase the number and scale of CCUS projects and create a viable market for CO_2.

Developing a positive CCUS value chain that operates at scale could turn sequestered carbon dioxide from a liability into an asset.

Mitsubishi Heavy Industries (MHI) Group has been an early pioneer of several technologies aimed at capturing, transporting and storing carbon dioxide. As well as developing a proprietary CO_2 capture process to prevent flue gas emissions from reaching the atmosphere, MHI group companies are involved in designing the world's first liquid CO_2 carrier for CCS, which will unlock a large amount of global CO_2 transportation, perhaps as much as a billion tonnes annually. Alongside this, MHI has a series of working groups to visualize an end-to-end software platform to monitor, track and trade used CO_2.

This whitepaper will explore some of the initiatives and technologies being developed to turn carbon dioxide into a tradable commodity. It will also demonstrate how the environmental and business cases of developing a CCUS value chain align, and why this is critical for reaching net zero emissions. And it will do so under the umbrella of the three key Cs of the CCUS value chain: Contain, Connect and Convert.

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[5] The Energy Transitions Commission, Reaching Net Zero Carbon Emissions: Mission Possible, 2018

Testing of MHIENG's unique KS-21 solvent is underway at the Technology Centre Mongstad in Norway

SECTION 1: CONTAIN

SECTION 1.1: CARBON DIOXIDE CAPTURE TECHNOLOGIES

CCS technologies can extract more than 90% of CO_2 flue gas emissions from fossil fuel power stations and industrial facilities. Once removed, carbon dioxide is transported and securely stored deep below ground. Projects described as CCUS differ slightly. Here, some of the captured gas is stored and transported to end-users for use in applications like Enhanced Oil Recovery (EOR) - pumping CO_2 into oil wells to force hard-to-reach oil to the surface - cement manufacture, and other industrial processes.

These capture systems depend on physical integration with pipeline networks and storage sites, and digital connections to track CO_2 supplies and make connections to facilitate end-to-end transactions.

Today, there are 65 commercial-scale CO_2 capture facilities around the world at varying stages of development, Global CCS Institute[5] figures show. Twenty-eight sites have been commissioned and three more are under construction. Following a decade of gradual decline, project numbers have been increasing in recent years, with a rich stream of new initiatives in the pipeline: 13 projects are currently in the advanced stages of development and a further 21 in early development.

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[5] Global CCS Institute: Global status of CCS report 2020

One of the major barriers preventing greater adoption is cost. Technological development will be a key part of driving future cost reductions to make CCUS viable for more hard-to-abate sectors.

“The road ahead is challenging but CCS is increasingly well-placed to make its significant and necessary contribution to achieving net-zero emissions around mid-century,” says Brad Page, CEO of the Global CCS Institute[6].

The US has more capture facilities than any other country. It is home to 12 of the 17 new projects initiated in 2020, with the others in the UK, Australia and New Zealand.

Advanced post-combustion capture solutions like MHI Group’s KM CDR Process™ (see box below) are at work at coal-fired plants like Petra Nova in Texas – the world’s largest CO_2 capture facility. Meanwhile, MHI Group is also planning to develop the Rio Grande LNG project in Brownsville, Texas, which is expected to capture and permanently store more than 5 million tonnes of CO_2 annually[7].

This same technology is helping the development of a Bioenergy with Carbon Dioxide Capture, Use and Storage (BECCS) facility at Drax Power Station[8] in the UK, which aims to become carbon negative by 2030 with the capacity to capture and store over 8 million tonnes of CO_2 annually by that date[9].

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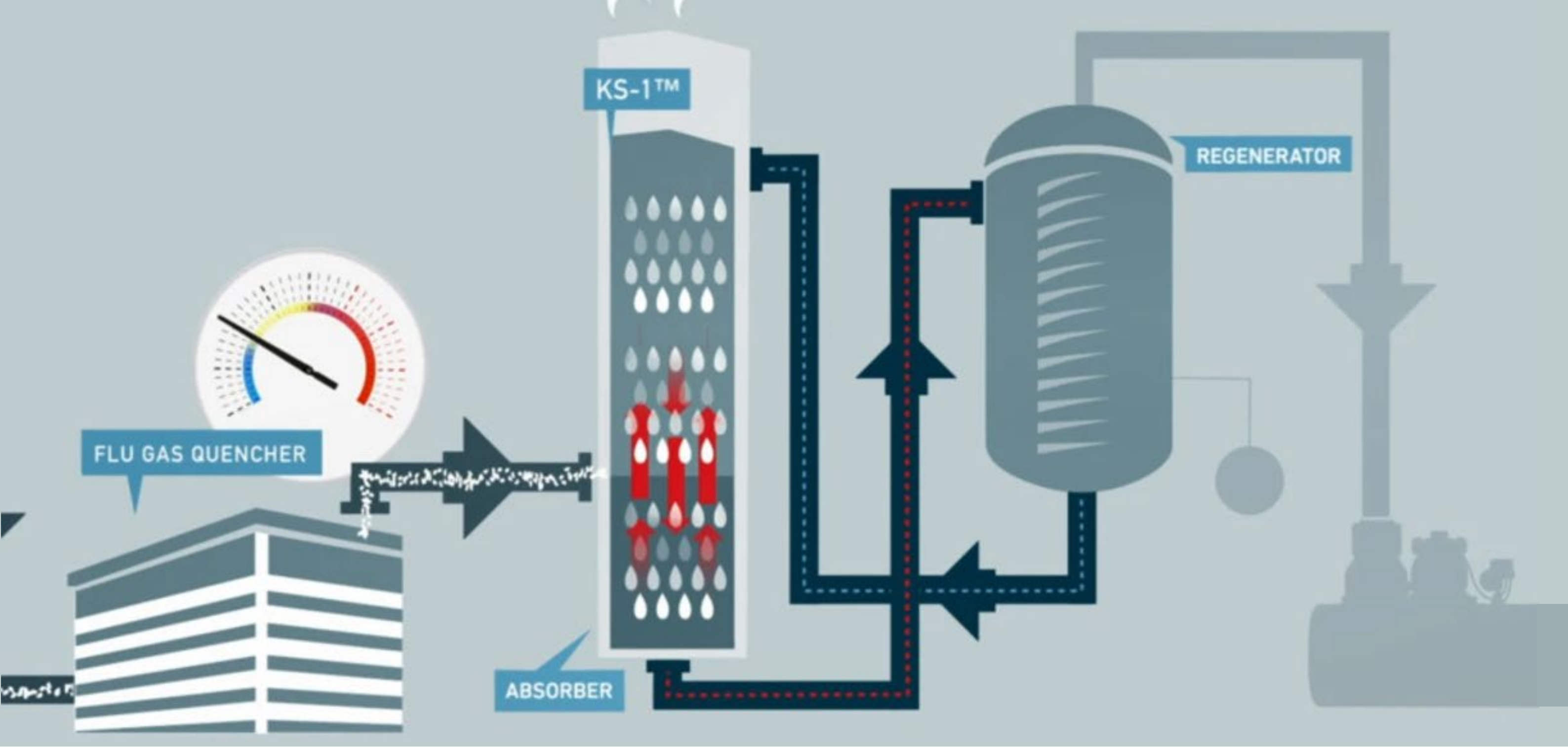
[6] Global CCS Institute: Global status of CCS report 2020

[7] MHI: Rio Grande LNG

[8] MHI: Drax

[9] Drax: Value of Bioenergy with Carbon Dioxide Capture, Use and Storage (BECCS) to the UK Decarbonisation Pathway



THE MHI SOLUTION

Mitsubishi Heavy Industries Engineering (MHIENG) has successfully completed testing a new proprietary solvent for capturing CO_2 at the Technology Centre Mongstad[10] in Norway.

The new KS-21™ solvent is an amine-based absorbent that demonstrates lower volatility, greater stability against degradation, less environmental impact, reduced operating costs and other economic benefits compared to previous versions.

KS-21 increases the efficiency of the company's original CO_2 capture technology, known as the Kansai Mitsubishi Carbon Dioxide Recovery Process (KM CDR Process™, KS-1[11]), which was developed jointly with Kansai Electric Power.

In both versions, the specially developed solvent absorbs CO_2 from the flue gas, cleaning the plant's emissions. The CO_2 -rich solvent is then moved to a regenerator, where steam separates the carbon dioxide from the solvent. This 99% pure CO_2 is sent to a compressor from where it is transported via pipelines to either be stored or used in applications such as EOR. The CO2-free solvent, meanwhile, is recycled and used in the process all over again.

KS-1 has so far supported 13 commercial capture plants globally, with a total yield equivalent to three million tonnes each year. This includes the giant CCUS facility at Petra Nova in Texas.

The successful KS-21 test program is now helping to drive an expansion of MHIENG's CO_2 capture operations in Europe, including development of a Bioenergy with Carbon Dioxide Capture, Use and Storage (BECCS) facility at the Drax power plant in northern England

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[10] MHI: KS-21

[11] MHI: KM CDR process

SECTION 1.2:
DIRECT AIR CAPTURE

While CCUS technologies capture emissions at point-source, Direct Air Capture (DAC) is an open-source system. This means it removes CO_2 directly from the atmosphere rather than a specific emissions source. As with CCUS, captured carbon dioxide can be stored underground or re-used in industrial applications, resulting in negative emissions.

Open-source systems like DAC move CO_2 capture solutions beyond power generation and heavy industry, which is critical for keeping within climate targets. DAC could, for example, play a key role in offsetting emissions from hard-to-abate sectors like aviation. However, capital expenditure and operating costs for DAC projects remain prohibitively high.

There are currently 15 DAC facilities in operation globally, with the capacity to remove more than 9,000 tonnes of CO_2 annually. To achieve the IEA Roadmap's Sustainable Development Scenario target, this would need to be scaled up massively to capture 10 million tonnes annually[12] by 2030 – more than an 1,100-fold increase.

Two approaches are in use:

- Liquid DAC systems pass air through a chemical solution, removing the CO_2 before expelling clean air back into the atmosphere.
- Solid systems use solid sorbent filters that chemically bind CO_2 particles from the air. Stimulating the sorbent by heating, change of pressure or microwaves releases concentrated CO_2, which is then captured and stored.

Although DAC is not a mature technology yet, the world's biggest DAC machine has started operations in Iceland, powered by geothermal energy.

The Orca plant[13] will have the capacity to collect around 4,000 tonnes annually, which is almost half of the current DAC capture capacity. That's the equivalent of removing 870 cars from the road for one year, according to the Environmental Protection Agency (EPA) calculator[14]. Plans are in place by Orca's developer, Climeworks, to design a facility 10 times larger to come online in the next five years.

In Southern Texas, Carbon Engineering and Occidental Petroleum are developing a DAC project that aims to extract 1 million tonnes of CO_2.

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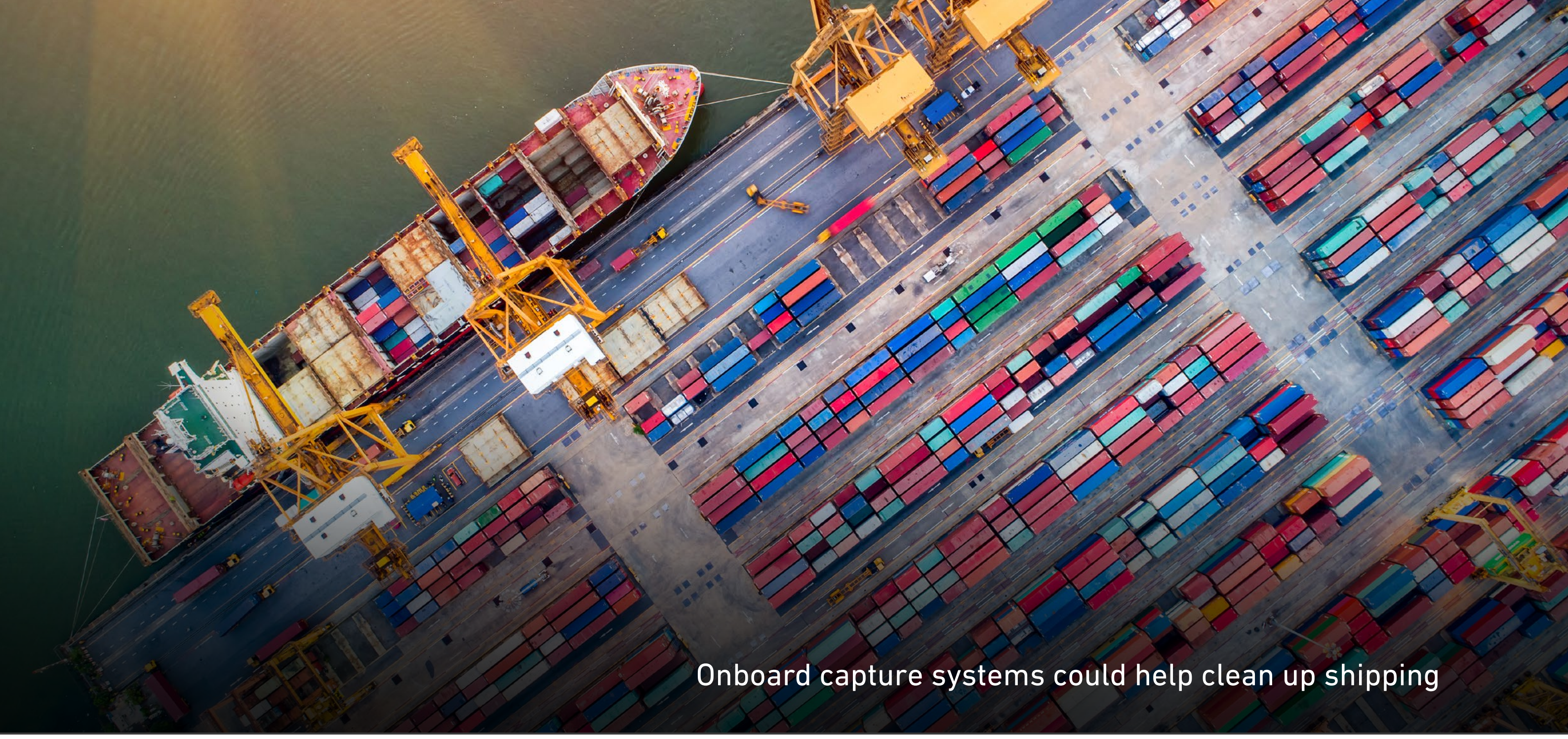
[12] IEA: Direct Air Capture report
[13] Financial Times
[14] EPA: calculator


Onboard capture systems could help clean up shipping

SECTION 1.3: ONBOARD CAPTURE SYSTEMS

As technologies for capturing carbon dioxide evolve, new opportunities are emerging to reduce emissions in sectors like shipping. Maritime transport carries 80% of global trade and generates around 2.5% of global greenhouse gas emissions[15].

Stricter emission targets set by the International Maritime Organization (IMO) aim to cut current shipping emissions by at least half by 2050[16]. This could be partly achieved by maritime fleet owners switching to low-carbon fuels like biofuel, hydrogen and ammonia.

But efforts to clean up maritime fleets could also be helped by on-board capture solutions that remove emissions from a ship's exhaust system, much in the same way land-based capture systems work.

Engineers at Mitsubishi Shipbuilding are designing a system (see box below) to remove CO_2 from ships' exhaust gases, which is then liquified and stored on-board in tanks. Once in port, it can be unloaded and converted into synthetic fuels like methane or methanol, for example.

Onboard capture systems could help decarbonize shipping by up to 90%, depending on technological advancements, according to a study by Japan Ship Technology Research Association[17]. However, liquefied CO_2 is much heavier than shipping fuel, so more energy would be needed to propel marine vessels to their destinations.

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[15] Bloomberg BusinessWeek

[16] IMO: Initial IMO GHG strategy

[17] JSTRA: Roadmap to Zero Emissions from International Shipping

THE MHI SOLUTION

Mitsubishi Shipbuilding is developing the world's first CO_2 capture unit for maritime use, where CO_2 will be removed from ships' exhaust gases.

Working in partnership with Kawasaki Kisen Kaisha ("K" Line) and Nippon Kaiji Kyokai (ClassNK), tests are being conducted to install a CO_2 capture system onboard a working ship.

The project, called Carbon Capture on the Ocean (CC-Ocean)[18], involves adapting an existing land-based CO_2 capture system used for onshore power plants, to marine use.

Knowledge gained from the project's test phase will be used to develop the concept further, making the capture system, liquefaction and storage processes more compact and boosting efficiency.

If successful, the CC-Ocean project would provide shipowners and fleet operators with an incentive to retrofit maritime vessels to meet ever-stricter IMO emission rules aimed at cleaning up global shipping.

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[18] MHI: CC-Ocean

SECTION 1.4: POLICY FRAMEWORK

Today's nascent CCUS sector could grow to potentially capture a third of all industrial emissions by 2040[19]. But scaling up both the number and size of CCUS projects to achieve this depends on policymakers, investors and the energy sector developing a framework that supports a sustainable and viable market for CCUS.

The IEA's CCUS in Clean Energy Transitions[20] report identifies four high-level priorities for governments and industry to accelerate CO_2 capture projects in the coming decade:

1. Create the conditions to stimulate private investment
2. Target the development of industrial hubs with shared CO_2 infrastructure
3. Identify and encourage the development of CO_2 storage
4. Boost innovation to reduce costs and ensure that critical technologies and applications are available, including for hard-to-abate sectors.

Policy has an important role to play in developing a commercial CCUS value chain that operates at scale and incorporates revenue generation from captured carbon dioxide.

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[19] Spectra: In the race to net zero, carbon capture could prove a game changer
[20] IEA: CCUS in Clean Energy Transitions

The US section 45Q tax credit scheme has proved effective in incentivizing companies to capture and reuse their carbon dioxide emissions, the IEA notes[21]. Tax credits were used extensively to support the development of renewable energy technology. The 45Q scheme has already helped raise awareness of CCUS among utilities and energy companies.

This approach differs from the policy framework adopted by countries like Japan – which levies taxes on energy prices – and Canada and other countries that apply a tax to carbon emissions.

Rather than taxing emissions, the UK government is investing up to £1 billion[22] ($1.38 billion) to support the creation of a CCUS value chain in industrial clusters across England, Scotland and Wales. This includes an £800 million ($1.1 billion) UK CCS Infrastructure Fund[23] offering grants and subsidy support for the BECCS pilot facility at the Drax Power Station, part of the Zero Carbon Humber project.

“We will ultimately need to capture 200 times today’s volumes and that requires government subsidies, such as the 45Q tax credit in the US, a sufficiently robust worldwide carbon price and – ultimately – willingness by consumers to pay a ‘green premium’ for products produced with clean technology,” explains Makoto Susaki, Senior Vice President and CTO at MHIENG and Head of CCUS Business Taskforce at MHI[24].

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[21] IEA: CCUS in Clean Energy Transitions

[22] UK Government

[23] IEA: CCUS in Clean Energy Transitions

[24] MHI: Spectra

SECTION 2: CONNECT

SECTION 2.1: INFRASTRUCTURE

Capturing CO_2 is only part of the story. To develop a commercial-scale CCUS value chain, new infrastructure is needed to track, transport and store the captured gas.

This poses a dilemma for investors: scaling up CCUS projects and technologies requires heavy investment in infrastructure to promote demand, but first demand is needed to encourage investment in CCUS projects and infrastructure.

Apart from using depleted oil or gas wells for storage, little existing energy infrastructure can be utilized to store and transport captured CO_2. As such, creating a CCUS value chain will require new pipelines, transport vessels and other infrastructure to be built from scratch.

Trucks can be used for overland transport, but investment in pipelines to connect capture facilities with storage sites, ports and industrial end-users will also be vital.

The means used to transport CO_2 will largely depend on the distance involved and the available storage sites. While countries like the UK have a rich seam of storage sites beneath the North Sea, for example, this is not the case for earthquake-prone countries like Japan where storage near the coastline presents a challenge.

Specially adapted carriers will be required to transport CO_2 over long distances into secure storage sites at low cost; as the CCUS value chain scales up, the volume of CO_2 that needs to be bulk-transported internationally will also increase.

MHI Group is developing CO2L-Blue[2], a LCO2 carrier designed to cost-effectively transport liquified CO_2 over long distances to storage sites, or for onward transport for utilization. The initiative leverages Mitsubishi Shipbuilding's accumulated gas handling technologies and knowledge of designing and building ships for liquified petroleum carriers and liquefied natural gas carriers. The vessel is expected to play a vital role in establishing a CCUS value chain.

MHI Group is also conducting feasibility studies with TotalEnergies to realize this project, which is expected to make a significant contribution to the establishment of a CO_2 ecosystem in the transport sector – and which, in turn, will be an essential component of the CCUS value chain.

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[25] MHI: Feasibility Study of LCO2 Carrier

The Zero Carbon Humber industrial cluster has been set up to capture CO_2

SECTION 2.2: INDUSTRIAL CLUSTERS

CCUS hubs or clusters with shared transport and storage infrastructure overcome many of the challenges associated with transporting captured CO_2. By exploiting economies of scale, these industrial hubs could help accelerate the CCUS value chain by enabling CO_2 emissions to be captured at smaller industrial facilities where dedicated infrastructure would prove impractical and too expensive.

Industrial clusters like the Hamburg Green Hydrogen Hub[26] and Zero Carbon Humber (ZCH)[27], each provide a single location for multiple heavy industries to operate side by side, offering a way for energy-intensive industries like power and steel to continue operating while reducing their emissions. Such hubs could also act as a magnet for new investment, particularly for high-emitting industries with green ambitions.

Occupying multiple sites along the Humber estuary in the UK's northeast, the Zero Carbon Humber cluster has been set up to capture CO_2 from three different sources: natural gas, biomass-fired power generation and hydrogen production. The project aims to create a wave of new "green" jobs and contribute to the UK's efforts to achieve its net zero ambitions.

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[26] MHI Spectra: How industry collaboration can kickstart green hydrogen
[27] Mitsubishi Power

THE MHI SOLUTION

As part of Zero Carbon Humber, MHI Engineering is conducting testing at Drax Power Station in North Yorkshire, a Bioenergy with Carbon dioxide Capture, Use and Storage (BECCS) pilot facility. MHIENG is partnering with Drax to deploy MHI's CO_2 capture technology at the site.

Drax has converted the once coal-fired power station to generate reliable baseload power and heat from renewable biomass. It is one of the largest decarbonization projects in Europe – reducing emissions by 85%. Applying BECCS technologies using MHI's KS-[21] solvent, the site is set to become carbon negative by 2030.

The first BECCS unit at Drax could be operational as soon as 2027, capturing and storing up to 8 million tonnes[28] of CO_2 each year by the end of the decade.

If BECCS were used across the whole Drax site, it would result in the largest volume of negative emissions in power generation anywhere in the world. An estimated 16 million tonnes[29] of CO_2 could be captured and stored annually by 2050. This represents a significant proportion of the annual 55 million tonnes the UK is estimated to need to capture using BECCS by the middle of the century[30].

"MHI aims to continue reducing greenhouse gases globally by providing reliable and economically feasible CO_2 capture technology, supported by research and development activity over 30 years and commercial records around the world," said Kenji Terasawa, President & CEO, Mitsubishi Heavy Industries Engineering[31].

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[28] MHI: Drax and MHI Pioneering Deal
[29] MHI
[30] Energy Technologies Institute
[31] MHI

SECTION 2.3: CARBON TRADING

In addition to the physical infrastructure needed to move and store carbon around the world, building a CCUS value chain requires digital solutions to facilitate how captured CO_2 is tracked, transported and traded. Turning CO_2 into a tradable commodity involves placing a value on reducing emissions.

“Once the physical connection and the digital connections are there, then the CCUS value chain will be there,” says Shuji Hori, Deputy Head of CCUS Business Taskforce at MHI.

Currently, carbon tax schemes like California’s Cap-and-trade scheme[32] or the EU’s Emissions Trading System (ETS)[33] place a cap on emissions from large sources to limit total emissions. Emitters are required to purchase emissions trading certificates or reduce emissions to avoid financial penalties, with the schemes’ proceeds used to support low-carbon initiatives. In essence, these schemes see carbon as a cost rather than a commodity.

However, creating an end-to-end CCUS value chain could turn captured CO_2 into a tradable commodity, potentially transforming costly waste into a valuable asset. The opportunity this presents is giving rise to a new type of carbon trading platform capable of creating a secure and transparent CO_2 supply chain. MHI is developing a unique platform to support a globally interconnected CCUS value chain, called CO2NNEX™[34] (see box below). The platform will visualize, trace and verify the entire ecosystem and expand the scope of CO_2 utilization by matching emitters with companies able to use it.

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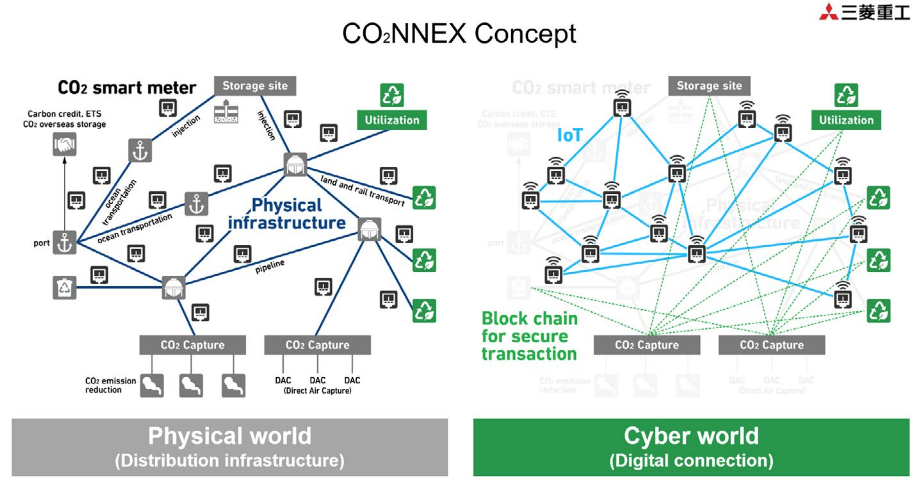
[32] C^2ES

[33] IEA: CCUS in Clean Energy Transitions



Turning carbon into a tradable commodity

THE MHI SOLUTION

At the moment, CO$_2$ is only visible in isolated steps: the total amount captured, the amount transported, traded and stored. Linking this data will allow greater traceability of CO$_2$ across the supply chain and help provide greater pricing certainty for investors.

Working in partnership with IBM Japan, MHI is developing the CO2NNEX™ digital platform to support a CCUS value chain where emissions are turned into industrial feedstock. Taking advantage of blockchain technology and Internet of Things connectivity, the cloud-based solution will analyze, record and verify the volumes of captured, stored, transported, utilized and traded CO$_2$ across the entire global supply chain.

The platform will provide a real-time holistic picture of the global CO$_2$ ecosystem, connecting carbon emitters with off-takers to accelerate the CCUS value chain and provide supply for new applications in sectors like industry, agriculture and synthetic fuels.

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[34] MHI: CO^{2}NNEX

SECTION 3: CONVERT

SECTION 3.1: END-USER DEVELOPMENT

Growing awareness of the energy transition has focused attention on converting CO_2 into usable commodities.

Carbon dioxide has a wide range of uses. It has an important role in the production of much of the meat and poultry we eat, adds sparkle to beer and fizzy drinks, and it's an ingredient in the dry ice used to deliver frozen foods. Its importance to the food and drink industry was highlighted by the disruption[35] in the UK caused by a CO_2supply shortage in September 2021.

The UK food and drink industry uses CO_2 captured from ammonia production, while globally the biggest application is Enhanced Oil Recovery (EOR).

However, more applications are needed to stimulate demand for recycled CO_2 and help grow the whole CO_2 ecosystem.

"There is so much potential for start-ups, academics and existing companies and investors to play a central role in developing the CCUS value chain. This new industry has so much potential to add value to the CO_2 we capture." says Shuji Hori, Deputy Head of MHI's CCUS Business Taskforce.

Key sectors with the potential to expand the CCUS value chain include agriculture, where CO_2 can be used by farmers to help boost plant growth, industrial applications like cement and steel making, and the chemicals and pharmaceuticals industries. Many dangerous or toxic materials currently used to manufacture chemicals could be substituted with CO_2, for example.

Developing the CCUS value chain could create opportunities to produce green solutions, such as sustainable concrete and electrofuels.

Cement is the most widely used construction material in the world. The chemical and thermal combustion processes involved in producing more than 4 billion tonnes each year, contribute around 8% of annual global carbon dioxide emissions[36]. But new low-carbon or 'novel', types of cement are injected with captured CO_2, potentially turning buildings into long-term carbon repositories. Novel types of cement alone could reduce building sector carbon dioxide emissions by up to 90%, according to the Chatham House[37] think tank.

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[35] BBC: Why is there a CO_2 shortage?
[36] Chatham House
[37] Chatham House

Electrofuels use CO_2 to create synthetic drop-in replacement fuels to oil and diesel from three different sources

SECTION 3.2: SYNTHETIC FUELS

While electrofuels are not yet market-ready, they could soon provide cleaner drop-in replacements for diesel and gasoline-fueled vehicles, particularly in hard-to-electrify transport sectors like aviation, shipping and road haulage.

“Electrofuels use recycled CO_2, turning it from an unwanted exhaust gas into a useful feedstock,” explains Steffen Schemme, an MHI-EMEA’s electrofuels engineer based in Germany.

Captured CO_2 is combined with hydrogen produced using renewable energy sources like wind and solar, to create electrofuels. These clean fuels provide a valuable tool to help organizations and policymakers realize carbon reduction targets and accelerate the switch away from fossil fuels.

As with many nascent technologies, cost remains a significant challenge, as electrofuels are currently more expensive to produce than other fossil fuel alternatives like hydrogen, but scaling up the technology could make them more affordable.

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[31] IEA, Renewables 2018
[32] MHI, Hydrogen - The Next Step In Energy Evolution, June 2019
[33] H^{21}, About H^{21}, N/A
[34] Hydeploy, UK’s first grid-injected hydrogen pilot gets underway, January 2020
[35] IEA, The Future of Hydrogen - Seizing today’s opportunities, June 2019

Even with a green premium attached, electrofuels could work in harmony with other fuels. While electric powertrains provide a clean alternative for small vehicles, the power to weight ratio makes battery power impractical for large-scale air or ocean transport, for example. Electrofuels could provide a safer alternative to hydrogen to power hard-to-abate sectors like aviation.

THE MHI SOLUTION

As one avenue of research, MHI America has recently invested in California-based electrofuels provider Infinium[38], as part of a consortium of global organizations that includes Amazon's Climate Pledge Fund.

Infinium's proprietary electrofuel technology – which is still at an early stage of development - uses clean electricity from renewable energy to power electrolyzers, which break down water molecules and produce green hydrogen. The hydrogen is combined with captured CO_2 to produce net-zero carbon fuels that could help decarbonize hard-to-electrify transport sectors like shipping, road haulage and aviation, without requiring a major overhaul of existing infrastructure.

Clean electrofuels are one way for organizations to meet CO_2 reduction goals faster and accelerate their move away from fossil fuels. For companies like Amazon, switching a vast global fleet of petrol and diesel delivery trucks to clean drop-in electrofuels makes both environmental and business sense.

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[38] MHI: Infinium

Policymakers play a critical role in developing the market for captured CO₂

SECTION 3.3: REGULATORY FRAMEWORK

Large-scale transformative change doesn't come easily, but it needs to come quickly.

Once fully matured, technologies for capturing carbon dioxide could potentially sequester about a third of all industrial CO_2 emissions by 2040[39]. But to maximize this opportunity, policymakers, investors and the energy sector need to create a framework that supports efforts to contain, connect and convert CO_2 so the technology can scale up and take off.

Scaling up a commercial market for CCUS requires a holistic approach to encourage innovation, spread investment risk and raise awareness of the need to accelerate change.

Currently, the biggest policy drivers for the CCUS value chain from the EU and other policymakers are broad initiatives like carbon trading schemes[40] to reduce emissions. Bodies like the EPA[41] have issued guidelines for industry to cut Scope 2 (indirect emissions generated by the electricity an organization purchases) and Scope 3 (indirect emissions generated upstream or downstream of an organization's activities) emissions from supply chains.

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[39] Spectra: In the race to net zero, carbon capture could prove a game changer
[40] IEA: CCUS in Clean Energy Transitions
[41] EPA: Scope 3 inventory guidance
[42] IEA: CCUS in Clean Energy Transitions

However, the policies that have had the most tangible impact to date on growing the CCUS value chain have been targeted interventions. Whether that be government support in the form of tax credits for new CCUS projects, such as the US 45Q initiative[42], or subsidies to help support new technologies and encourage investment in CCUS infrastructure.

Cost remains a key barrier to new technologies and solutions, and many of the innovations discussed in this paper are at the early stages of development with their business case yet to be proven. But there is growing acceptance by consumers of the need to pay a “green premium” for environmentally friendly products and services.

This attitude change, combined with technological advances and economies of scale as transition technologies step up, could help reduce the cost burden of CCUS value chain technologies like CCUS and synthetic fuels. Look no further than renewable energies and green hydrogen as very recent examples of how scale economics can reduce costs.

Growing public awareness of climate issues could also increase pressure on governments to put legislation in place to encourage CO_2 capture projects and collaborate with other stakeholders to increase the use of the sequestered gas.

CONCLUSION

Scaling up the number of operational CCUS facilities and developing a market for captured CO_2 is vital if we are to realize a carbon-neutral world. New projects, technical capabilities and policy measures to turn captured carbon dioxide into a tradable commodity are evolving fast and demonstrate how the environmental and business cases of developing a CCUS value chain align to promote efforts to reach net zero. But the question remains: are they evolving fast enough?

A coordinated effort is needed from scientists, industry, investors, policymakers and the public to create a framework that accelerates growth and reduces costs to meet the Paris climate target of limiting global warming to below 1.5°C.