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THE VALUE OF CARBON CAPTURE AND STORAGE (CCS)

ALEX TOWNSEND
Senior Consultant - Economics

NABEELA RAJI
Research Analyst

ALEX ZAPANTIS
General Manager - Commercial

GLOBAL CCS
INSTITUTE

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EXECUTIVE SUMMARY

The Intergovernmental Panel on Climate Change (IPCC) and numerous other credible institutions, studies, and governments have highlighted the essential role of carbon capture and storage (CCS) to economically achieving a net-zero emissions global economy. CCS technologies are particularly important because they both avoid CO_2 emissions at point sources, as well as decrease at scale the stock of CO_2 emissions already in the atmosphere through carbon dioxide removal (CDR) technologies.

The value of CCS is analysed and discussed under two overarching themes in this report:

CCS is an essential climate mitigation technology.

At the **global level**, studies such as the IPCC 1.5°C report and by the International Energy Agency (IEA) consistently show CCS being deployed at significant scale to economically **meet long-term climate targets.** For example, in the IEA Sustainable Development Scenario, which is consistent with meeting the goals of the Paris Agreement, CO_2 sequestration globally using CCS reaches 2.8 gigatonnes per annum by 2050. This would require a one-hundred fold increase in the number of CCS facilities in operation relative to today. Studies also demonstrate that excluding CCS from the suite of technologies used to meet emission reduction targets will lead to increased costs. Furthermore, the versatility of CCS and its ability to reduce both the flow and stock of CO_2 makes it a strategic **risk management tool** for climate mitigation.

At the **sectoral level** there are four areas where CCS has a critical role to play in least-cost net-zero emissions pathways. These include:

- **Achieving deep decarbonisation in hard-to-abate industry:** The cement, iron and steel, and chemical sectors are amongst the hardest to abate due to their inherent process emissions and high-temperature heat requirements. CCS provides one of the most mature and cost-effective options for reducing emissions from these sectors. Several reports, including from the Energy Transition Commission and the IEA, have concluded that achieving net-zero emissions in hard-to-abate industry without CCS may be impossible and at best more expensive.
- **Enabling the production of low-carbon hydrogen at scale:** Hydrogen is likely to play a major role in the decarbonisation of hard-to-abate sectors and may also be an important source of energy for residential heat demand and flexible power generation. To reach net-zero emissions, global hydrogen production will need to grow significantly, from 70 million tonnes per annum today to 425-650 million tonnes per annum by mid-century. Hydrogen produced using coal or natural gas with CCS is currently the lowest cost option for producing low-carbon hydrogen, and will remain the most cost-effective solution in regions where fossil fuel prices are low and large resources of low-cost renewable electricity for electrolysis are not available.
- **Providing low-carbon dispatchable power:** The rapid decarbonisation of power generation is crucial to achieving net-zero emissions. CCS equipped power plants play an important role as they help ensure that the low-carbon grid of the future is resilient and reliable. Flexible power plants with CCS supply dispatchable and low-carbon electricity as well as grid-stabilising services, such as inertia, frequency control and voltage control. These cannot be provided by renewable generation, therefore CCS complements the increased deployment of renewables.

- **Delivering negative emissions:** The deployment of negative emissions technologies will be needed to compensate for residual emissions in hard-to-abate sectors if net-zero emissions targets are to be met. CCS provides the foundation for technology-based carbon dioxide removal (CDR) solutions including bioenergy with CCS (BECCS) and direct air capture (DAC). While CDR is not a silver bullet, with every year that passes without significant reductions in CO_2 emissions, the need to use negative emissions technologies increases.

CCS is a driver of economic growth and employment.

CCS can provide clean growth opportunities, create and retain jobs, and help ensure a just and sustainable transition for communities. Its benefits include:

- **Creating and sustaining jobs:** CCS creates new jobs during the construction and the operation of new facilities, as well as in the supply chain. To reach the levels of deployment outlined in IEA's Sustainable Development Scenario, more than 2,000 facilities will be needed by 2050, requiring at least 100,000 employees in 2050. There will also be jobs associated with the supply of new materials, equipment and professional services. In addition to creating new jobs, CCS enables high-emission industries and the jobs they support to continue, thereby avoiding local economic and social dislocation that could otherwise occur whilst meeting climate targets.
- **Supporting economic growth through new net-zero industries and innovation spillovers:** The widespread deployment of CCS will create new opportunities in the supply of infrastructure and technology, the provision of services and finance, and the production of low-carbon products. Emerging evidence suggests CCS could also be a source of high-value innovation spillovers and therefore play a role in supporting innovation-led economic growth alongside other technologies.
- **Enabling infrastructure re-use and deferral of decommissioning costs:** Where oil or gas production fields are at the end of their lives, there may be opportunities to re-use existing oil and gas infrastructure by repurposing it for CO_2 transport and storage. This could provide a range of benefits, including reducing the cost of building transport and storage infrastructure and potentially reducing permitting time. The re-use of infrastructure could also defer the costs and the environmental impact of decommissioning, freeing-up resources that can be invested in other value generating activities.
- **Facilitating a just transition by alleviating geographic and timing mismatches:** One of the key challenges of achieving a just transition is the disconnect between the geographic spread of job losses and gains, and the timing of these changes. Jobs created in low-carbon industries may not occur at the same time as job losses in high-emission industries. This will reduce the long-term employment prospects of workers in declining industries over time. CCS facilitates a just transition by enabling existing industries to make a sustained contribution to local economies while transitioning to a net-zero economy.

1.0 INTRODUCTION

Several high-profile reports and experts have emphasised the need to better understand and communicate the benefits of CCS. Reports by the Zero Emissions Platform in Europe, the CCUS Cost Challenge Taskforce in the UK, and the National Petroleum Council in the US, all highlight the importance of further exploring and redefining the value of CCS [1][2][3].

This report aims to inform the discussion on the value of CCS by providing an overview of recent analyses published on the topic and completed by the Global CCS Institute.

The report is structured under two overarching themes. Section 2 of the report explores the role of CCS as an essential climate mitigation technology, focussing on how its deployment reduces the costs and risks of meeting climate targets. Section 3 of the report describes the broader benefits CCS provides to the economy, by providing clean growth opportunities, creating and retaining jobs, and helping to ensure a just and sustainable transition for communities. Section 4 concludes, with suggestions for future research.

The report focusses on the main sources of value from the deployment of CCS. It excludes other, smaller scale benefits. For example, the potential benefit of improved air quality from the deployment of CCS at fossil fuel power plants is not included in the report. The omission of these benefits does not prejudice the inclusion of them in other studies, but reflects that these tend to be smaller in scale and more dependent on the context in which CCS is applied.

Throughout the report, country-specific case studies are provided to shed light on the value of CCS in practice. The case studies primarily focus on Europe and North America as these are the regions for which analysis of the societal benefits of CCS is most mature and where data are readily available. However, many of the conclusions of the report will be relevant to other jurisdictions.

STUDIES SUCH AS THE IPCC 1.5 REPORT AND IEA'S SUSTAINABLE DEVELOPMENT SCENARIO CONSISTENTLY SHOW CCS BEING DEPLOYED AT SIGNIFICANT SCALE TO ECONOMICALLY MEET LONG TERM CLIMATE TARGETS.

2.0 CCS IS AN ESSENTIAL CLIMATE MITIGATION TECHNOLOGY

The primary reason for investing in CCS is to reduce CO_2 emissions and mitigate the associated environmental and economic impacts of climate change. This can be viewed from different perspectives, including from a global-level and sector-level persepctive.

A global-level perspective

At a global level, Integrated Assessment Models (IAMs) and scenario models provide valuable insights into the role CCS can play in the transition to a net-zero emissions economy. These models explore the interactions and trade-offs between climate and socio-economic systems, and present possible emissions pathways to meet a given climate goal. IAMs vary in their complexity, coverage, focus and methodology, and in doing so strike different balances between lowering energy and resource intensity, the rate of decarbonisation, and the reliance on negative emissions technologies. Given this variability, technologies that feature heavily across models and scenarios are seen as critical to meeting long-term climate targets [4].

Analysis by the Intergovernmental Panel on Climate Change (IPCC) and International Energy Agency (IEA) consistently show CCS being deployed at significant scale to meet long-term climate targets. For example, in the IEA Sustainable Development Scenario (SDS), which is consistent with meeting the goals of the Paris Agreement, CO_2 sequestration globally using CCS reaches 2.8 gigatonnes per annum by 2050 [5]. This would require a one-hundred fold increase in the number of CCS facilities in operation relative to today [6].

In the IPCC Special Report on Global Warming of 1.5°C, nearly all of the 90 scenarios reviewed include CCS in some form. The average mass of CO_2 sequestered across all scenarios in 2050 is 10 gigatonnes per year, with higher levels of deployment linked to greater use of negative emissions technologies using CCS [7].

Excluding CCS from the suite of technologies used to meet emissions reduction targets will increase costs. There are several low-cost applications of CCS, such as in gas processing, and ethanol and fertiliser production, that are cost-effective to deploy today even under relatively modest prices on CO_2 emissions [8]. As the value on reducing CO_2 emissions rises over time with tightening climate targets, other applications will become cost-effective. In the IPCC's Fifth Assessment Report (AR5), excluding CCS from the portfolio of technologies was found to lead to a doubling in the cost of reducing emissions required to limit global warming to 2°C, the largest cost increase from the exclusion of any technology [9].

In addition to being part of the lowest cost pathway, investing in CCS today will reduce the risks associated with meeting climate targets. Developing and deploying a portfolio of climate mitigation measures, including CCS, reduces the risk to achieving emission reduction targets due to any single technology not meeting expectations. By diversifying the technologies available, the exposure of a given mitigation strategy to the success or failure of one specific technology will be reduced.

The versatility of CCS and its ability to reduce both the flow and stock of CO_2 makes it a strategic risk management tool for climate mitigation. Deploying CCS at scale in low-cost, low-regret applications today, along with investment in pioneering CCS projects in harder-to-abate sectors, provides the foundation to deploy it in other applications in the future.

The value of this versatility has been demonstrated across numerous studies, including for example the Committee on Climate Change's (CCC) advice to the UK Government on options required to achieve its net-zero emissions target (Box 1).

BOX 1:
THE ROLE OF CCS IN ACHIEVING THE UK'S NET-ZERO TARGET

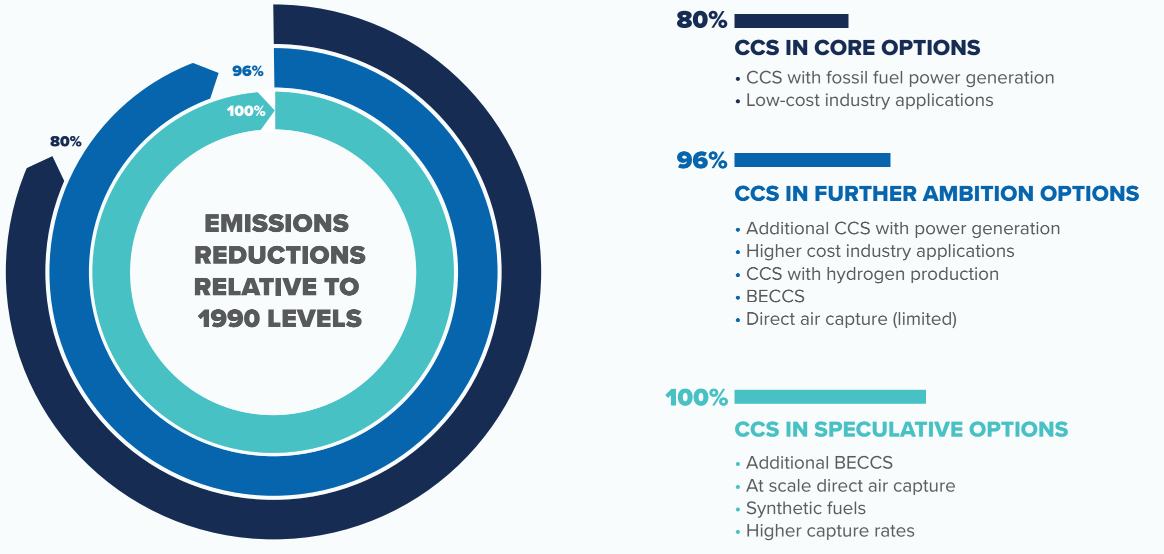
In June 2019, the UK became the first major economy in the world to pass laws to reach net-zero emissions by 2050. To support this decision, the UK Government requested advice from the independent Committee on Climate Change (CCC) on the date for achieving net-zero emissions, how emissions reductions might be achieved, and the cost and benefits of pursuing a net-zero target. The response provided by the CCC was published in May 2019 in its Net-Zero: The UK's Contribution to Stopping Global Warming report [10].

The CCC separated the mitigation options required to meet net-zero emissions into Core options, Further Ambition options and Speculative options. Core options include low-cost, low-regret measures that make sense under most strategies to reduce emissions by at least 80 per cent by 2050 relative to 1990 levels.

Further Ambition options include more challenging and more expensive options that collectively would get the UK close to the net-zero target. Speculative options were also considered, to bridge the gap between the emissions reductions in the Core and Further Ambition options and those required to reach net-zero. Each option was assessed based on its feasibility, cost, impact on affordability, energy security and competitiveness, and consistency with existing policies.

CCS features in all of the options presented by the CCC and across multiple sectors, demonstrating the value it provides in the UK as a versatile emissions reduction technology (Figure 1). In the report, 75 to 175 million tonnes of CO_2 per annum is estimated to be captured and stored in 2050 in the Core and Further Ambition options. This includes CCS on power plants to provide firm low-carbon power, in industry to reduce process emissions, with the production of hydrogen for heat, power and fuel, and with bioenergy to provide negative emissions through bioenergy with carbon capture and storage (BECCS).

Figure 1: CCS in the CCC's advice to the UK Government on reaching net-zero



A sector-level perspective

Looking at the challenges from a sector perspective can provide further compelling evidence of the value CCS offers as a climate mitigation tool. There are four areas where CCS has a critical and valuable role to play in the least-cost net-zero emissions pathways. These are explored in more detail below, and include:

- achieving deep decarbonisation in industry;
- enabling the production of low-carbon hydrogen at scale;
- providing low-carbon dispatchable power; and
- delivering negative emissions.

Achieving deep decarbonisation in industry

To meet long-term climate targets, industrial production will need to be transformed. Industry accounts for 40 per cent of global energy demand and a quarter of global CO_2 emissions (Figure 2).

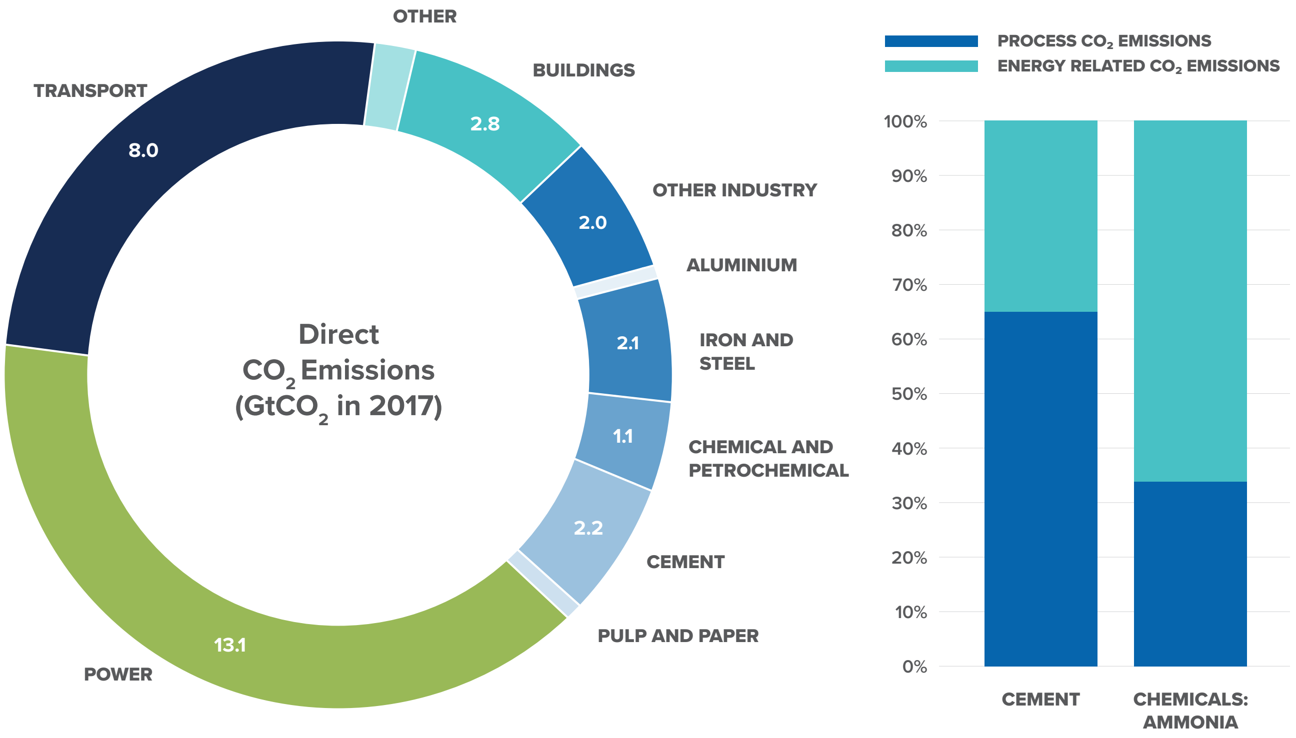
The cement, iron and steel, and chemical sectors are the largest source of industrial emissions. These industries provide a range of products that are vital to everyday life. The iron and steel and cement sectors provide the foundation materials for the construction sector and infrastructure which supports economic growth. The chemicals industry produces a range of high-value products, including plastics, rubbers, fibres, fertilisers, soaps, pharmaceuticals and glass. Demand for the goods produced by industry is expected to grow in the future, driven by a growing population, increased living standards and economic growth.

The cement, iron and steel, and chemical sectors are also amongst the hardest to abate:

- One-quarter of industry emissions are process emissions that result from chemical reactions inherent to production processes. For example, in cement production, 65 per cent of emissions come from the calcination of limestone, a chemical process underlying cement production [11]. These emissions cannot be avoided by switching to alternative fuels.
- One-third of energy demand by industry is used to provide high-temperature heat. Switching from fossil to low-carbon fuels to generate this heat would require significant modifications to facilities [11]. Further energy efficiency improvements in these facilities are also likely to be limited as high energy costs have already incentivised monitoring and reductions in energy use [12].

CCS provides one of the most mature and cost-effective options for reducing emissions from processes and high-temperature heat demand. Several reports, including from the Energy Transition Commission and the IEA, have concluded that achieving net-zero emissions in industry without CCS may be impossible and at best more expensive [12][11].

Figure 2: CO_2 emissions by industry and proportion that are process emissions



Enabling the production of low-carbon hydrogen at scale

Hydrogen is likely to play a major role in the decarbonisation of hard-to-abate sectors and may also be an important source of energy for residential heat demand and flexible power generation. To reach net-zero emissions, global hydrogen production will need to grow significantly, from 70 million tonnes per annum today to 425-650 million tonnes per annum by mid-century [13][12][14].

The three main technologies used to produce low-carbon hydrogen today are gas reforming with CCS, coal gasification with CCS, and electrolysis powered by renewables. Each technology offers its own benefits and will play a role in the global energy transition.

The advantages of low-carbon hydrogen production through gas reforming and coal gasification with CCS centre around the maturity of technologies, scale and commercial viability:

- Low-carbon hydrogen has been produced through gas reforming and coal gasification with CCS for almost two decades. The first CCS facility with hydrogen production, the Great Plains Synfuel Plant in North Dakota in the United States, commenced operation in 2000 [15].
- Scaling up low-carbon hydrogen production with CCS is currently far less challenging than scaling up the use of electrolysis. Commercial scale hydrogen production facilities with CCS are already operating, with five low-carbon hydrogen production facilities with CCS operating globally and three under construction. These facilities have a total production capacity of 1.5 million tonnes of hydrogen per annum. The largest facility produces over 1,000 tonnes of low-carbon hydrogen per day [6].
- Hydrogen produced using coal or methane with CCS is currently the lowest cost option for producing low-carbon hydrogen, with costs of US$1.50-2.40 per kilogram compared to US$4.00-7.45 for hydrogen produced using electrolysis [13][16][17].

While the costs of hydrogen produced via electrolysis are expected to fall, low-carbon hydrogen produced using CCS is and will remain the most commercially viable option in the near-term. Even under ambitious assumptions on electrolysis, producing hydrogen with CCS will continue to be a cost-effective solution, particularly in regions where large resources of low-cost renewable electricity are not available.

Providing low-carbon, dispatchable power generation

The rapid decarbonisation of power generation is crucial to achieving net-zero emissions. Electricity generation accounts for around a third of global CO_2 emissions, making it the largest source of CO_2 emissions globally [5]. Demand for electricity is also forecast to increase significantly due to rising living standards and the electrification of transport and heat, for example with the deployment of electric vehicles.

The rapid deployment and reduction in costs of renewable technologies has spearheaded the transition to a low-carbon electricity grid. In turn, this has reduced the amount of dispatchable power required from fossil fuel sources. However, the intermittent nature of wind and solar generation creates many challenges for electricity systems that must immediately deliver electricity in response to changes in demand [18]. This reality means that a combination of renewables and dispatchable power generation will be required to deliver reliable, affordable and low-carbon electricity in the future.

CCS equipped power plants provide several services to the grid and electricity consumers that cannot be provided by renewables. Flexible power plants with CCS can ramp power up and down, as-needed, to meet demand. They also provide essential grid-stabilising services such as inertia, frequency control and voltage control. The inertia of huge spinning physical components, such as generators, motors and turbines in conventional fossil fuel powered plants, slow down the rate of change in system frequency and provide sufficient time for the system to respond to changes in demand. In doing so, they ensure system voltage and frequency remain within very tight tolerances [18][19].

The importance of these wider grid services for reliable electricity supply means that a holistic assessment of various power generation technologies is necessary. Historically, decisions relating to the optimal technology mix for the future electricity system have been structured around the levelised cost of each technology. While useful for comparing generation costs for technologies of a similar type, the levelised cost of generation is not fit for purpose when determining the optimum technology mix for a low-emissions electricity system. This is because the costs of electricity supply not only encompasses the costs of generation, but also costs of grid services and transmission and distrubution of electricity. These total system costs, which vary according to the technology mix in the grid, yield a different picture about the costs of a power technology in comparison to the levelised cost of generation [21].

Decisions relating to the optimal technology mix for the future electricity system can benefit from holistic valuation metrics which provide new insights. For example, studies utilising the Systems Value metric, which takes a whole systems perspective when calculating the value of a technology, demonstrate how the value of CCS to the system increases as the penetration of renewables increases [18][19][21]. Such findings demonstrate how the ability to provide ancillary services while supplying dispatchable, low-emissions electricity make CCS equipped power plants a highly valuable and economically competitive option which complements the deployment of other low-carbon sources of electricity.

Delivering negative emissions

The deployment of negative emissions technologies will be needed to compensate for residual emissions in hard-to-abate sectors if net-zero emissions targets are to be met.

CCS provides the foundation for BECCS, one of the few negative emissions technologies that can be deployed at sufficient scale to deliver the goals of the Paris Agreement and achieve net-zero emissions by mid-century. There are a number of commercially successful BECCS facilities in operation today. The largest, the Illinois Industrial CCS facility, captures one million tonnes of CO_2 a year from the production of ethanol from corn [15].

CCS also provides the basis for direct air capture (DAC), a suite of negative emissions technologies that use chemicals to directly capture CO_2 from the atmosphere. The CO_2 captured can be permanently stored underground, using the same technology as other CCS facilities. DAC is at an earlier stage of maturity than BECCS, but there are notable examples of DAC projects in operation today using technologies developed by Climeworks, Carbon Engineering and Global Thermostat, for example.

BECCS and DAC, like other negative emissions technologies, are not without their challenges and trade-offs.[1] For example, DAC is highly energy-intensive owing to the low concentration of CO_2 in the air, with costs of between $600-$1,000 per tonne of CO_2 for first-of-a-kind projects. The cost of DAC is expected to fall over time, but most studies suggest costs will remain between $100-$300 per tonne of CO_2 when deployed at scale [23]. Scaling up BECCS will require the development of supply chains for sustainable biomass from the waste products of agriculture and forestry, and potentially significant areas of land for the cultivation of energy crops.

While it is theoretically possible to reach net-zero emissions without BECCS, and without CCS, it will be extremely challenging. One of the four illustrative pathways in the IPCC Special Report on Global Warming of 1.5°C demonstrated how temperature rises could be limited to 1.5°C without CCS [24]. This would require a rapid reduction in energy intensity of around 5 per cent per year between now and 2040. In contrast, energy intensity has been falling at a rate of only 1.6 per cent since 1990 [5]. Even in the IEA Sustainable Development Scenario, which assumes all economically viable energy efficiency opportunities are pursued, energy intensity improves only by 3.6 per cent year-on-year from 2018 to 2040 [5]. Achieving net-zero emissions without BECCS therefore looks infeasible.

Negative emissions technologies are not a silver bullet, but with every year that passes without significant reductions in CO_2 emissions, the need to rely on negative emissions technologies in reaching the goals of the Paris Agreement increases. The development and deployment of CCS, which provides the foundation for scalable negative emissions technologies, will be critical for achieving net-zero emissions.

CCS HAS A CRITICAL ROLE TO PLAY IN ACHIEVING DEEP DECARBONISATION IN HARD-TO-ABATE INDUSTRY, ENABLING THE PRODUCTION OF CLEAN HYDROGEN AT SCALE, PROVIDING LOW-CARBON DISPATCHABLE POWER AND DELIVERING NEGATIVE EMISSIONS.

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[1] Other negative emission technologies that do not require CCS include afforestation, reforestation, soil sequestration, enhanced weathering and ocean alkinisation.

3.0 CCS IS A DRIVER OF EMPLOYMENT AND ECONOMIC GROWTH

CCS can provide clean growth opportunities, create and retain jobs, and help ensure a just and sustainable transition for communities. The broader benefits of CCS deployment are discussed in this section of the report.

Creating and sustaining jobs

The deployment of CCS creates jobs in the construction, operation and maintenance of CCS facilities. It also supports employment at the industrial plant at which CCS is applied and in the associated supply chain.

As large infrastructure projects, the construction of large-scale CCS facilities requires a substantial construction workforce. While the numbers vary by facility type and stage of construction, there are generally several hundred and often thousands of people involved in the construction of a CCS facility at any point in time. For example, 1,700 people were employed at peak construction for the Boundary Dam CCS facility in Canada [25].[2] Similarly, around 2,000 people were estimated to be employed at peak construction for the Alberta Carbon Trunk Line [26]. These jobs are temporary, lasting only for the construction phase of the projects development, but provide employment opportunities for a mix of low and high skilled workers.

The operation of a CCS facility on the other hand requires a relatively small number of workers, but these jobs are long-lived, lasting for the duration of the capture plants operation. For example, data collected from carbon capture facilities currently operating suggests around 20 people are employed in the operation of a capture plant. The individuals typically work shift patterns and include a combination of managers, operators, maintenance personnel and lab technicians.

The number of people employed in the construction and operation of CCS facilities will need to increase significantly if long-term climate targets are met. For example, to reach the levels of deployment outlined in the IEA Sustainable Development Scenario (SDS), over 2,000 CCS facilities would need to be in operation by 2050, requiring a build rate of 70-100 facilities per year. This would require around 70,000 to 100,000 construction workers and 30,000 to 40,000 capture facility operators globally. The operation of the transport and storage network would require additional workers. In Europe alone, an additional 10,000 could be employed in a centralised transport and storage industry in the North Sea.[3]

The deployment of CCS also enables high-value industries to continue to make a sustained contribution to economies by enabling them to make the transition to a net-zero economy [27]. The iron and steel, chemicals, refinery, cement and other industrial sectors employ millions of people globally, are large, local employers, and provide a range of products that are essential to everyday life (Figure 3). These industries often co-locate in regions with good access to infrastructure such as port and rail, and the necessary inputs to production such as energy resources, feedstocks and skilled

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[2] Some construction workers will have been involved in other upgrades to the power station undertaken at the same time as the installation of capture equipment.

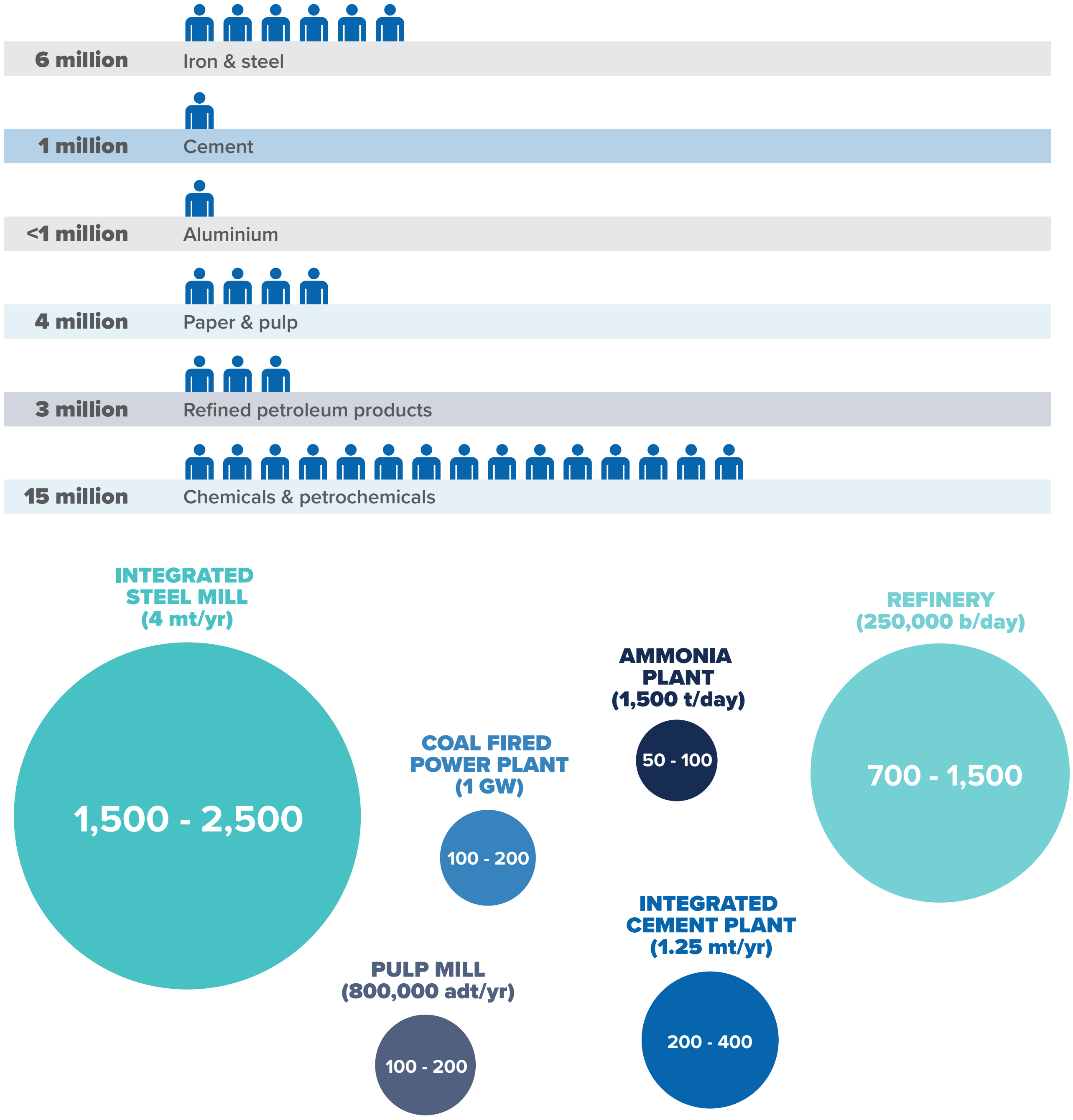
[3] Based on analysis published by SINTEF [39]. For consistency, the job estimate presented is based on the low scenario in the SINTEF report in which CCS deployment globally reaches 1.8 gigatonnes of CO_2 per year in 2050. This is slightly below the estimated deployment of CCS in the IEA SDS.

workers. This results in the local communities in which they are based being particularly dependent on them for employment.

In the absence of CCS, high-emissions industries will become incompatible with net-zero emission commitments causing those industries, and the communities that rely upon them, to go into decline.

CCS enables those industries and the jobs they support to continue, as well as creating new jobs as is discussed elsewhere in this report. While it is difficult to quantify the impact of CCS on jobs in industrial areas, it is clear that by converting high-emissions industries to low-emissions industries, CCS can play an important role in avoiding local economic and social dislocation that might otherwise result from meeting ambitious climate targets.

Figure 3: Global employment in selected sectors and employment at a typical plant

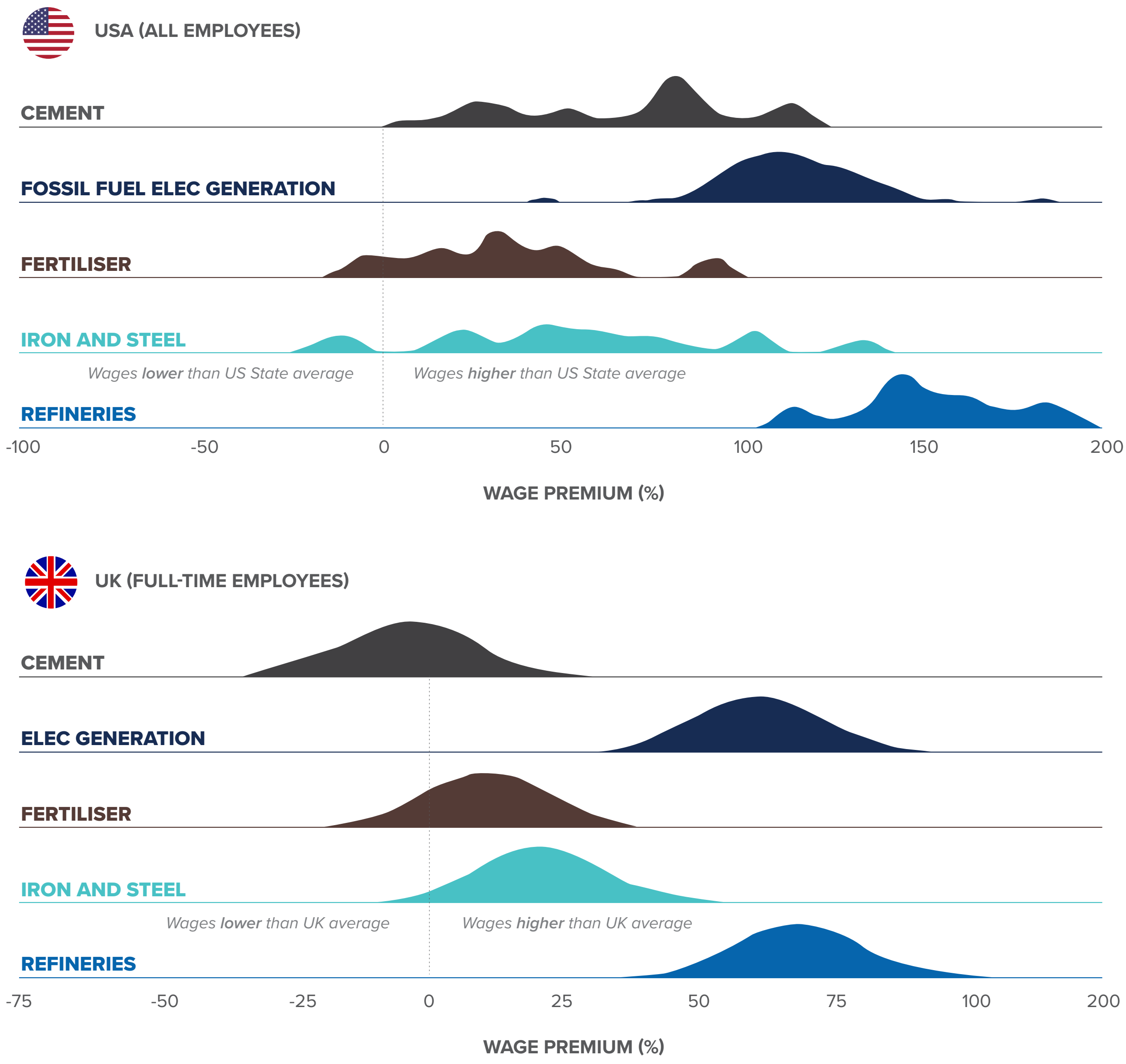


Source: Global CCS Institute analysis of published reports, national statistics and company level reporting.
Size of bubble indicates number of employees at a typical plant [28][29][30][31][32][33][34]

As well as being a source of a large number of jobs to local communities, emissions-intensive industries provide high paid jobs, an important measure of job quality [35]. This is demonstrated by the positive wage premium in these industries, which is equal to the average wage paid by a specific industry minus the average wage in the region or country the industry is located. In the US for example, workers in refining, chemicals, cement, and iron and steel sectors are paid significantly more than the average wage in the state they are located (Figure 4).

The factors contributing to this wage premium are numerous, and could include the capital intensity of the industry, the concentration of profitable firms, and the compensating wage required to reflect the risks of the job.[4] The trends are similar for the UK, except for the cement sector where wages are slightly below the average in the country.

Figure 4: Wage premium in emissions-intensive industries in the UK and US



Source: Global CCS Institute analysis of Quarterly Census of Employment and Wages (US) and Annual Survey of Hours and Earnings (UK) [36][37]

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[4] Differences in the cost of living in which the industries are based could also influence the results, although this is partly controlled for in the US analysis by comparing wages to the state average rather than national average.

In addition to supporting employment directly at the CCS facility and industrial plant where it is located, the deployment of CCS can support jobs indirectly in the supply chain. These multiplier effects can be large. For example, in the UK, the refinery, cement, petrochemicals, iron and steel industries all rank within the top 30 per cent of industries by employment multipliers [38]. The indirect jobs supported in the supply chain are more geographically dispersed and therefore less likely to be additional than the direct employment effects. Nevertheless, they provide a useful indication of the overall contribution of CCS to local and regional employment.

Several studies have estimated employment multipliers for CCS-related industries to calculate the total employment effects of large-scale CCS deployment. For example, SINTEF estimate the deployment of CCS in Europe could provide 150,000 jobs in 2050, of which 60,000 to 70,000 would be indirectly employed in supply chains [39]. A recent study for the UK found higher multipliers, with the large-scale deployment of CCS to capture 75 million tonnes of CO_2 per year estimated to support 68,000 jobs directly and 158,000 jobs indirectly in supply chains [40]. Turner et. al extend this analysis to job quality, demonstrating the deployment of CCS could generate economic value by supporting higher than average wages in supply chains in Scotland [41].

Supporting economic growth through new net-zero industries

The widespread deployment of CCS will create new opportunities in the supply of infrastructure and technology, the provision of professional services and finance, and the production of low-carbon products. The prospect of growth in these markets will stimulate innovation as companies compete for market share, which in turn generates economic growth. Emerging evidence suggests CCS could be a source of high-value innovation spillovers, and therefore a provider of innovation-led growth (Box 2).

There are several examples of industries associated with CCS that are anticipated to grow in the future, providing new employment opportunities:

- The Hydrogen Council estimate the hydrogen economy in 2050 could account for 18 per cent of final energy demand, with annual sales of US$2.5 trillion, providing employment for 30 million people [42]. In Europe, the market could reach EUR 820 billion, providing employment for 5.4 million highly skilled workers [43]. This market would be served by low-carbon hydrogen produced using different types of production processes, including CCS.
- The deployment of negative emissions technologies in line with the rates suggested in Integrated Assessment Models will offer new employment opportunities, particularly in the growing of biomass feedstock, and the supply chains for waste biomass from agriculture and forestry.
- The development of carbon capture and utilisation (CCU) technologies could provide sustainable employment opportunities, where the climate benefits can be demonstrated. Interest in the market has grown in recent years, with over $1 billion of investment in CCU start-ups over the past decade [44].

Some studies extend this analysis to focus on the export potential of these new industries, which could provide an additional source of economic growth. Countries that have a comparative advantage today in the provision of CCS-related products and services, and have a healthy CCS facility pipeline, will be best placed to take advantage of this opportunity.

BOX 2:

UNLOCKING CLEAN GROWTH THROUGH INNOVATION

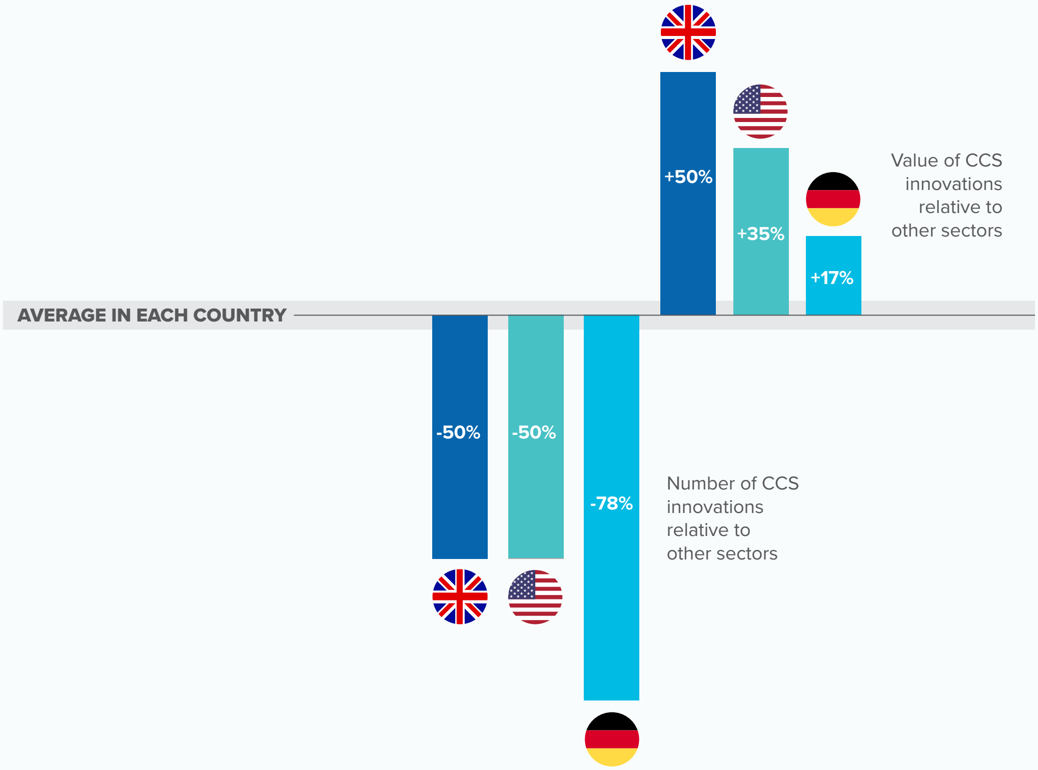
The development and deployment of technologies generates knowledge and innovation which are important drivers of productivity and economic growth. The spillovers generated by the dispersion and diffusion of knowledge created by deployment can be large, with some studies suggesting the social returns from research and innovation can be more than double the returns to the original investor [45]. Given the important role they play in propelling economic change, understanding the spillover effects of different technologies is increasingly the focus of research.

New research by the Grantham Institute attempts to provide this broader perspective for the main technology sectors, including climate mitigation technologies like CCS [46][47]. Using information from over one million patent applications around the world, they estimate the spillover value for major technology sectors for a given country. The metric draws on the approach used by Google to rank the relevance of webpages, ranking innovations based on the number of citations to them in other patent applications. When combined with monetary estimates per citation, this provides a dollar estimate of the value per innovation for each technology.

The results of this analysis suggest CCS is one of the higher value, but lower volume technologies when it comes to spillovers (Figure 5). For Germany, the US and the UK, the value per CCS innovation is 17, 35 and 50 per cent respectively above the average value of innovations in those countries across the sectors assessed. This signals that investment in CCS could provide above average benefits when it comes to innovation, knowledge and associated economic growth. The number of innovations related to CCS are lower than average, but similar to other technologies like geothermal, building efficiency and marine energy technology. The largest source of innovations are artificial intelligence, biotechnology and ICT given their economy-wide applicability.

CCS could, therefore, play a role in supporting innovation-led economic growth alongside other emerging, high-value technologies.

Figure 5: Number and spillover value of CCS innovations relative to other sectors



Extending the lifetime of infrastructure and deferring decommissioning costs

The deployment of CCS will require the construction of infrastructure to transport and permanently store CO_2. This will require large capital investment, particularly for projects storing CO_2 in offshore storage reservoirs.

Where oil or gas production fields are at the end of their lives, there may be opportunities to re-use existing oil and gas infrastructure by repurposing it for CO_2 transport and storage. This could provide a range of benefits, including reducing the cost of building transport and storage infrastructure and potentially reducing permitting time. An example of where this is being put into practice is the Acorn project in Scotland, which plans to re-use both onshore and offshore pipelines, providing an estimated saving of £548 million relative to the cost of building a new pipeline [48].

The re-use of infrastructure could also defer the costs and the environmental impact of decommissioning, freeing-up resources that can be invested in other value generating activities. Over time, the deferral of decommissioning costs combined with learning and innovation could result in lower decommissioning costs overall, assuming other cost drivers remain stable [49].

The costs of decommissioning are projected to reach $85 billion globally between 2019 and 2028 (Figure 6). In the North Sea alone, which accounts for just under a half of the total forecast decommissioning expenditure, 2,624 wells, 1.2 million tonnes of platform topsides and 660,000 tonnes of substructures are due to be decommissioned in the next ten years [50]. Since decommissioning costs are eligible for tax relief in some jurisdictions, the deferral of decommissioning costs would benefit taxpayers as well as the operator [51].

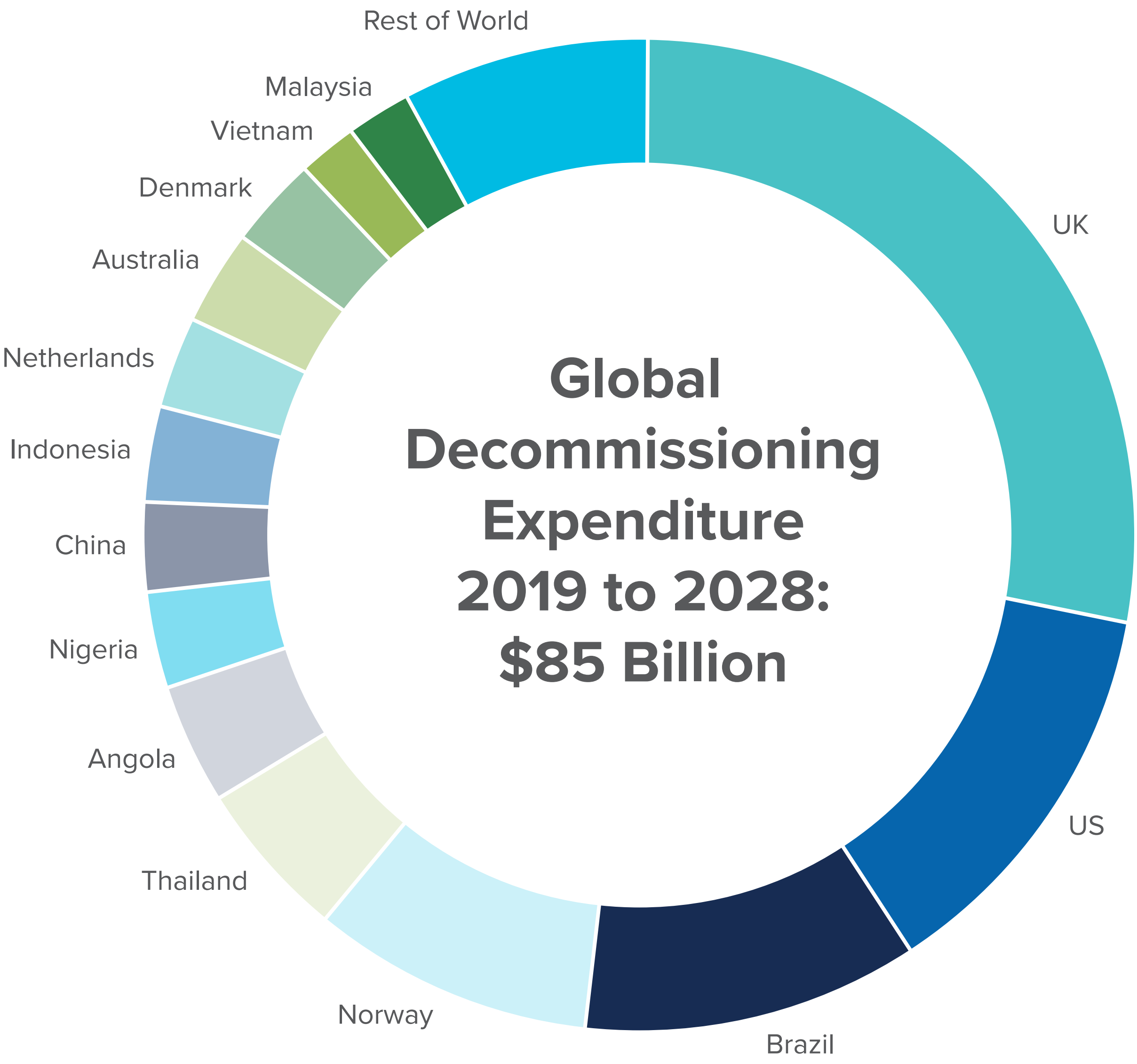
The largest component of decommissioning costs is associated with the decommissioning of wells. In the UK, which has been the focus of most decommissioning activity in recent years, around a half of the total costs of decommissioning are associated with wells [50]. The remainder is split between removing platform topsides and jacket structures (18 per cent), decommissioning subsea infrastructure, including pipelines (9 per cent), and the costs of project management and operating platforms after production has ceased (17 per cent) (Box 3).

While the opportunity to defer decommissioning costs is significant, not all oil and gas infrastructure will be suitable for repurposing for CO_2 transport and storage [49]. There are a range of commercial, technical, operational and regulatory risks that could discourage the re-use of particular aspects of infrastructure. The business case for re-using infrastructure ultimately rests on whether the cost savings of re-purposing assets outweigh the potential risks and costs of remedial work associated with using older infrastructure.

The opportunity to re-use infrastructure will ultimately vary on a case-by-case basis, with some infrastructure asset types being more suitable for re-use than others:

- Pipelines provide the most promising prospect for re-use and deferring decommissioning costs, although they account for a relatively small proportion of total decommissioning costs. To determine whether a pipeline is suitable for re-use, a full integrity and lifetime extension study will be required. These studies will identify whether there are any issues with corrosion or other integrity concerns that would make the pipeline unsuitable for re-use. In general, pipelines that are relatively new, are appropriately located, and are of a sufficient size and pressure rating, would be suitable for re-use [53].
- Oil and gas wells may be suitable for CO_2 injection. Design standards and operational criteria for oil and gas production wells differ to those of CO_2 injection wells, meaning remedial action will be required to modify the well equipment [54]. Operators would need to weigh up the additional costs of remedial work and any other risks associated with using existing wells against the time and potential cost savings of drilling a new well. The re-use of wells is being considered for the Porthos project in Rotterdam [55].
- Platforms could technically be used for CO_2 injection, but it may not be economic to do so. The more complex process and safety systems required for oil and gas production are unnecessary and unsuitable for CO_2 injection, and would need to be removed if the platform were to be re-used. These modifications are expensive as they require modification work to be undertaken offshore. Several reports have suggested that CO_2 injection operations could be easily housed on smaller, unmanned installations [55].

Figure 6: Global forecast decommissioning expenditure from 2019 to 2028 [52]



There may be other commercial considerations that operators will factor into their decisions on whether to repurpose infrastructure, and which assets to re-use. For example, there may be an opportunity for cost savings in the near-term as a result of the coordination of decommissioning activity with nearby fields reaching the end of their lifetime at similar points in time. Changes to long-term decommissioning plans may also result in penalties being incurred by the operator, dampening the case for re-use. An operator may also not want to enter the CO_2 transport and storage market as a result of the fragmented value chain and different risk profile associated with CO_2 infrastructure relative to hydrocarbons.

In summary, the re-use of infrastructure can provide cost savings and defer decommissioning costs. This activity is likely to be reserved for specific circumstances, mainly with the re-use of pipelines. While this accounts for a relatively small proportion of the total decommissioning costs, it could still provide material cost savings that benefit both operators and, in some jurisdictions, taxpayers.

BOX 3:

THE BREAKDOWN OF DECOMMISSIONING COSTS BASED ON UK DATA

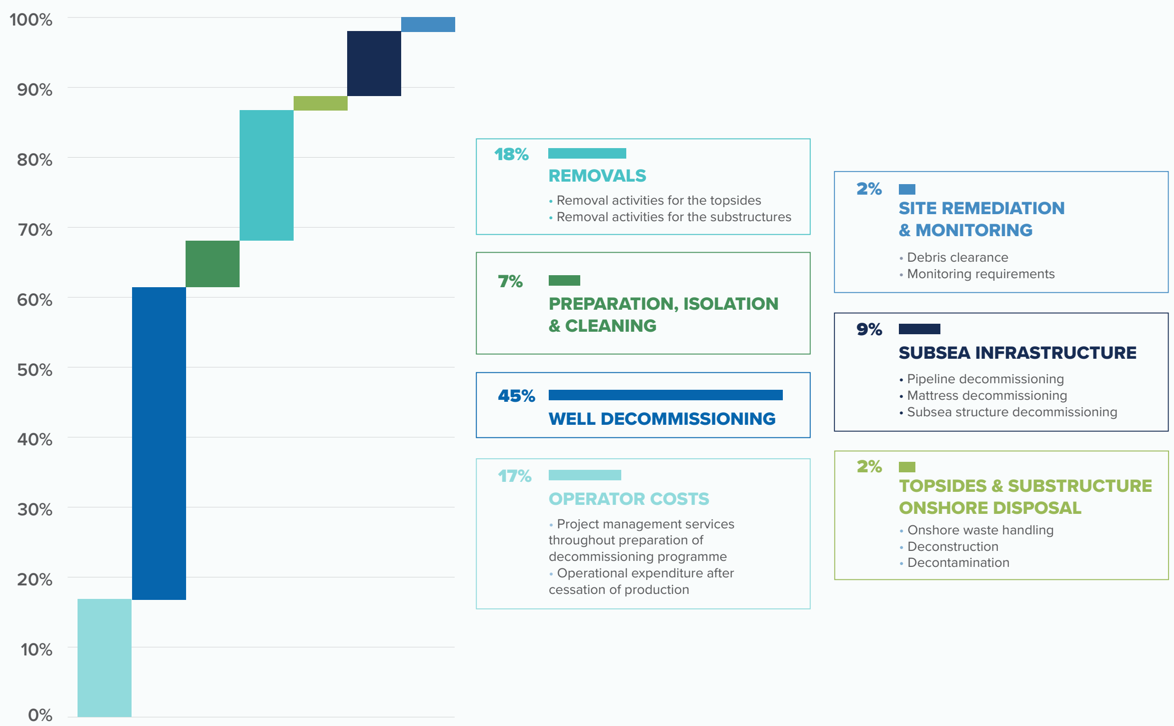
The UK is forecast to be the largest decommissioning market over the next decade, owing to a large portion of the North Sea basin, rather than individual fields, maturing at similar times. While every decommissioning project will be different, evidence of the breakdown of decommissioning costs in the UK can provide insight into where the greatest opportunity to defer decommissioning costs may lie.

Oil and Gas UK compile estimates of the breakdown in decommissioning costs in their annual Decommissioning Insight report [50]. The latest report, published in 2019, shows well decommissioning accounts for almost half of the total cost of decommissioning. The next largest component is the removal of platform topsides and jackets, followed by operator costs related to the project management of the decommissioning project. The decommissioning of pipelines and other subsea infrastructure make up a relatively small proportion of decommissioning costs, at around 9 per cent.

At a regional level, the breakdown of decommissioning costs differs due to the different nature of decommissioning projects. For example, the proportion of costs attributed to project management is much higher in the Central and Northern North Sea regions compared to the Southern North Sea, as projects tend to be larger and more complex. As a result, operator costs in these regions account for 17 to 20 per cent of the total cost of decommissioning, compared to 9 per cent in the Southern North Sea. Similarly, there are material differences in the costs of removals across regions, partly due to some fields already having incurred well decommissioning costs.

However, the overall picture remains the same across all regions, with well decommissioning costs accounting for the largest proportion of decommissioning costs, followed by removals of topsides and jacket structures, and the decommissioning of subsea infrastructure.

Figure 7: Breakdown of decommissioning costs in the UK



Facilitating a just transition

CCS has a vital role to play in the just transition to a net-zero economy, by enabling the growth of low-carbon industries and supporting employment in existing industries.

The transition to a net-zero carbon economy will boost prosperity, but there will be winners and losers. For example, the International Labour Organisation estimates that action to meet the goals of the Paris Agreement will create 24 million jobs but will also lead to job losses of around 6 million [56]. Managed well, the transition to a net-zero economy will prevent the immense human and economic costs of climate change, increase growth and jobs, and reduce inequality. Done poorly, and it could result not only in stranded assets, but also stranded workers and communities in those regions most at risk of job losses.

One of the challenges of achieving a just transition is the disconnect between the geographic spread of job losses and gains, and the timing of these changes. Jobs created in low-carbon industries may not occur at the same time as job losses in emission-intensive industries. This will reduce the long-term employment prospects of workers in declining industries over time.

One of the advantages of CCS in this context is that it provides employment opportunities at the time and place where they are most likely to be needed to support the just transition to a net-zero economy. CCS enables existing industries to continue to make a sustained contribution to local economies while transitioning to a net-zero economy. Inefficient and uncompetitive industrial plants will still close, but supporting the longevity of the most innovative firms will help achieve a fair transition.

No single organisation can deliver the just transition alone. Governments have a leading role to play, by linking climate, macroeconomic, industrial, labour and regional policies under a whole-government approach. Governments can also act as a central point for convening industry and community groups to identify the best options for managing the transition for each region. There are several different examples of government-led initiatives underway to support a just transition:

- Earlier this year, the EU launched the Just Transition Mechanism to ensure the transition towards a climate-neutral economy happens in a fair way. The mechanism provides targeted support to the regions most affected by the transition and aims to mobilise at least EUR 100 billion over the period 2021-27 [57].
- In Canada, the government launched a Task Force on the Just Transition for Canadian Coal Power Workers and Communities, formed of experts from unions, environmental groups, industry and the community. The Task Force consulted with Canadian coal communities and has provided recommendations to government on managing the just phase out of coal in those communities [58].
- In Scotland, the Scottish Government established the Just Transition Commission to advise on its transition to a net-zero economy by 2045. Within the next year, the Commission is required to report to Scottish Ministers, providing practical, realistic and affordable recommendations for action [59].
- In Australia, the Latrobe Valley Worker Transfer Scheme was agreed in 2018, involving the state government, unions and businesses to manage the closure of several coal-fired power plants in the region. The scheme helps workers at coal-fired power plants find work in other organisations in the area [60].

Most effort to date related to the just transition has focussed on managing the near-term challenges associated with the phase-out of coal. In the future, the commissions, task forces and funding mechanisms established to manage the just transition will need to expand their focus to consider a broader range of sectors, which some are already doing. These sectors will include natural gas production, iron and steel, cement, fertiliser and petrochemicals. CCS must be considered within these initiatives, given the advantages it provides by supporting communities that are highly dependent on emission-intensive industries.

4.0 CONCLUSION

The deployment of CCS is essential to meeting climate targets at the lowest possible cost. However, as demonstrated in this report, the benefits of CCS go far beyond just reducing emissions. CCS can provide clean growth opportunities, create and retain jobs, and help ensure a just and sustainable transition for communities.

For policymakers, the report highlights the need to take into account the broader benefits of CCS to ensure its important role is appropriately reflected in country-level strategies to meet the goals of the Paris Agreement. This will require a mix of quantitative and qualitative metrics, rather than focussing on a single metric.

The report also identifies several areas where analysis could be built upon to improve the evidence base on the value of CCS. For example, extending the analysis completed for the IPCC Fifth Assessment Report to include 1.5°C scenarios could provide further compelling evidence of the criticality of CCS in meeting long-term climate targets at the lowest possible cost. In addition, a greater focus on the additionality of jobs created and supported by investment in CCS, drawing on the advantages of CCS identified in this report, could enhance its value in the context of a just transition.

> **THE BENEFITS OF CCS GO FAR BEYOND JUST REDUCING EMISSIONS. CCS CAN PROVIDE CLEAN GROWTH OPPORTUNITIES, CREATE AND RETAIN JOBS, AND HELP ENSURE A JUST AND SUSTAINABLE TRANSITION FOR COMMUNITIES.**

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AMERICAS

Washington DC, United States

americasoffice@globalccsinstitute.com

EUROPE & MIDDLE EAST

Brussels, Belgium

europeoffice@globalccsinstitute.com

AUSTRALIA

Melbourne, Australia

info@globalccsinstitute.com

UNITED KINGDOM

London, United Kingdom

ukoffice@globalccsinstitute.com

CHINA

Beijing, China

chinaoffice@globalccsinstitute.com

JAPAN

Tokyo, Japan

japanoffice@globalccsinstitute.com

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