CARBON CAPTURE AND STORAGE

Balancing the Carbon Cycle

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Carbon Capture and Storage (CCS) has a unique role to play in decarbonising global industrial processes and power generation. There is increasing focus on the necessity to utilise CCS and the International Energy Agency (IEA) has stated that 'the deployment of Carbon Capture and Storage is critical to global efforts to mitigate climate change and keep global warming below 2°C to pre-industrial levels'.

Delivering a low carbon world

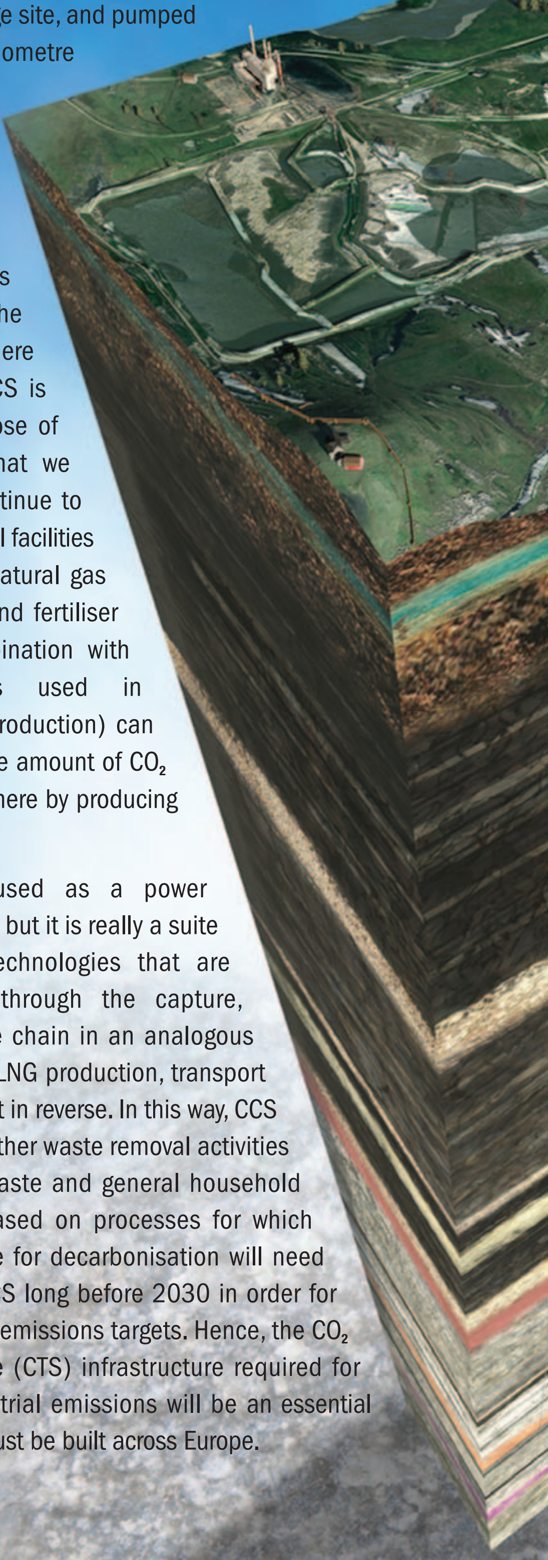
The EU and its member states have recognised that CCS will be one of a number of different technological solutions required to deliver decarbonisation targets, particularly for industrial emissions, but efforts to date to move full scale CCS projects forward have been less than successful. In order for CCS to fulfil its potential and necessary role in decarbonising European industry, large scale infrastructure for transport and permanent storage of CO_2 will need to be deployed. For this to take place a number of separate market, investment and co-ordination issues will have to be overcome.

New metrics are required that effectively value CCS within our socioeconomic system and which enable governments to rigorously allocate public funds for decarbonisation options that minimise downside loss (or increased cost) to the economy. Such metrics can also help the community relate to and understand the reasons why investments in CCS infrastructure are essential to achieving a viable low carbon Europe and the world beyond.

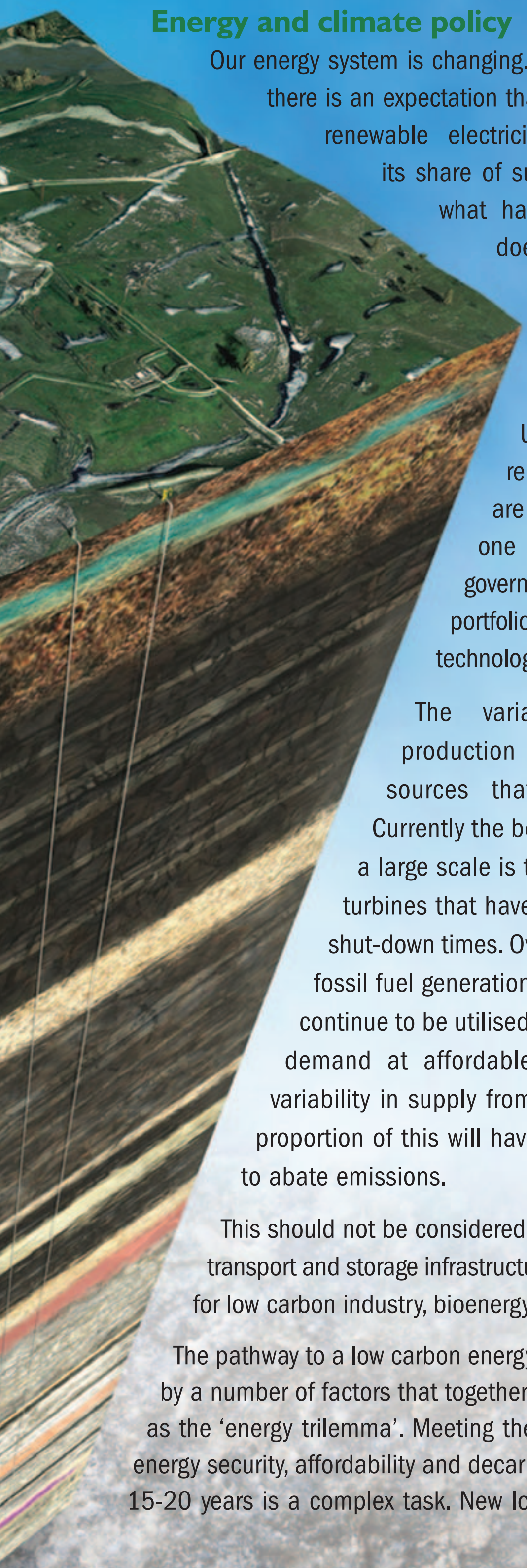
What is Carbon Capture and Storage?

When fossil fuels are burnt or used in some industrial processes CO_2 is produced. Because CO_2 is considered a major contributor to global warming, part of the solution to climate change is preventing that CO_2 from entering the atmosphere. But we cannot simply turn off the global use of fossil fuels overnight. Transitioning to a sustainable low carbon world will take many, many decades, and our advanced lifestyle will still depend on industrial activities that produce CO_2.

CCS is a way to address this – CO_2 can be removed from the exhaust gases of power stations and industrial plants, transported to a storage site, and pumped more than one kilometre underground into stable geological formations that will keep it there permanently, like the oil and natural gas accumulations of the North Sea and elsewhere in Europe. In fact, CCS is the only way to dispose of the unwanted CO_2 that we produce, and will continue to produce, from industrial facilities such as steelworks, natural gas processing, cement and fertiliser plants. CCS in combination with bioenergy (biomass used in electricity and heat production) can also help to reduce the amount of CO_2 already in the atmosphere by producing 'negative emissions'.



CCS is often confused as a power generation technology, but it is really a suite of many different technologies that are combined together through the capture, transport and storage chain in an analogous way to natural gas or LNG production, transport and utilisation – except in reverse. In this way, CCS can be compared to other waste removal activities (such as industrial waste and general household refuse). Industries based on processes for which there is no alternative for decarbonisation will need to begin deploying CCS long before 2030 in order for Europe to meet 2050 emissions targets. Hence, the CO_2 transport and storage (CTS) infrastructure required for removing these industrial emissions will be an essential minimum scale that must be built across Europe.



Energy and climate policy

Our energy system is changing. Over the next 15 years there is an expectation that the cost of producing renewable electricity will decrease and its share of supply will increase. But what happens when the wind doesn't blow and the sun doesn't shine? And what about other energy forms used for heating and transport? Unfortunately, many renewable energy sources are variable, and that is one of the reasons why governments talk in terms of a portfolio of electricity generation technologies.

The variability in electricity production has to be matched by sources that can fill the gap. Currently the best way of doing this on a large scale is to use natural gas-fired turbines that have very fast start-up and shut-down times. Over the coming decades fossil fuel generation capacity will therefore continue to be utilised in order to meet power demand at affordable prices and balance variability in supply from renewable sources. A proportion of this will have to be fitted with CCS to abate emissions.

This should not be considered problematic if common transport and storage infrastructure is seen as synergistic for low carbon industry, bioenergy and power.

The pathway to a low carbon energy system is complicated by a number of factors that together are regularly described as the 'energy trilemma'. Meeting the three requirements of energy security, affordability and decarbonisation over the next 15-20 years is a complex task. New low carbon technologies, industrial processes and power plants cost more than conventional ones based on fossil fuels. Across Europe the power station fleet is ageing, and there is a pressing need to build new base-load capacity to ensure the total portfolio delivers affordable and secure electricity. At the same time, however, CO_2 emissions from the whole economy need to be reduced. Energy policy therefore has to satisfy the short term needs while avoiding the creation of new emissions for which there is no mitigation solution.

> "Currently, a lack of targeted deployment policies to bridge demonstration efforts with longer term emission reductions initiatives represents the most critical gap in government policy support for CCS globally. The United Kingdom is the only country to date to commence implementing such support."
>
> International Energy Agency, 2014

Minimising 'carbon lock-in'

European governments have taken a 'middle ground' on new fossil fuel power stations with a 'Carbon Capture Ready' (CCR) policy that essentially requires power stations greater than 300MW generation capacity consented after April 2009 to be capable of retrofitting CCS in the future. A downside to this is the risk that CO_2 transport and storage infrastructure is not built in time to enable retrofitting of these unabated power stations so that carbon budgets and climate targets can be met. Because power stations have long operating lives this will lead to carbon-lock in.

The effectiveness of a CCR policy is therefore critically dependent on how realistic the future transport and storage options are. If this infrastructure is not deployed, new-build power stations will eventually lead to residual emissions in the future that will not be abated without prohibitive costs.

A key objective of governments' energy and climate policies should be ensuring carbon lock-in is reduced to the lowest possible level. To effectively manage this risk, governments clearly need to be mindful of the negative impact of slow progress in deployment of CTS infrastructure at scale.

Policy drives investment behaviour and benefits

Because carbon (CO_2) pollution and the cost of effects of climate change are not yet priced into all the activities and products of our economy, we have what economists call an 'externality' with the effect that free markets, including all energy forms, do not drive us towards decarbonisation. The UK Government is taking a global lead with its policies to address this externality. In particular, its electricity market reform (EMR) framework is designed to create the transitional conditions that will result in a properly functioning market for low carbon electricity in the future.

However, the electricity sector is only one part of our energy system (Fig. 1, below), with interactions between it and many other energy-related activities. Policies operating to decarbonise only one part of the system will have spillovers and unintended consequences in other parts. Hence decarbonisation of the energy system should be managed holistically to avoid market failures and distortions. Furthermore, the private sector does not operate with a system perspective of emissions reduction in focus, so its business models/cases can only ever be as effective as the system-level policies of government.

New policy thinking is urgently required to create the pathway for deployment of CO_2 transport and storage infrastructure that can be used for decarbonisation across northern and eastern Europe, and the western Mediterranean.

Developers, investors and financial institutions all need a degree of certainty to take forward new projects to a final investment decision (FID) within a low carbon system context. To turn conceptual power or industrial capture projects into reality, offshore storage sites have to be 'characterised' and ready to be developed – in other words financeable or 'bankable'. If European and member state policies are left to focus solely on low carbon or renewable electricity generation, then the all-important development of CTS infrastructure at scale for use with abating industrial emissions may not be forthcoming.

Under current regulatory and policy frameworks across Europe, significant market barriers and market failures exist that discourage and prevent investment in common CO_2 transport infrastructure and storage hubs (Fig. 2). Policies at member state and pan-European levels are not enabling a virtuous cycle of storage appraisal, CTS infrastructure development, lowering of CCS cost, and construction of capture plants on power and industry that will deliver a sufficient scale of emissions abatement in the required timeframe. This outcome also runs the risk that industrial decarbonisation and production of low carbon transport fuels in the future will be more expensive, and the projected savings to the economy of including CCS in the energy system will not be achieved.

Unless addressed, these barriers and market failures are likely to severely restrict the development of CCS in the coming decade, with a net increase in the cost of decarbonisation across the European economy. In the UK the Energy Technologies Institute (ETI) has demonstrated that meeting emissions targets with CCS optimally deployed will be cheaper by 1% of GDP (about £30 billion (~€41.8bn)) *per annum* by 2050 than if CCS is not utilised. This lower cost includes the benefit of CCS in industry, flexible low

Modern economies are complex 'ecosystems' of energy-related activities and holistic policies are required to manage decarbonisation without creating new market failures and distortions.

Fig. 1

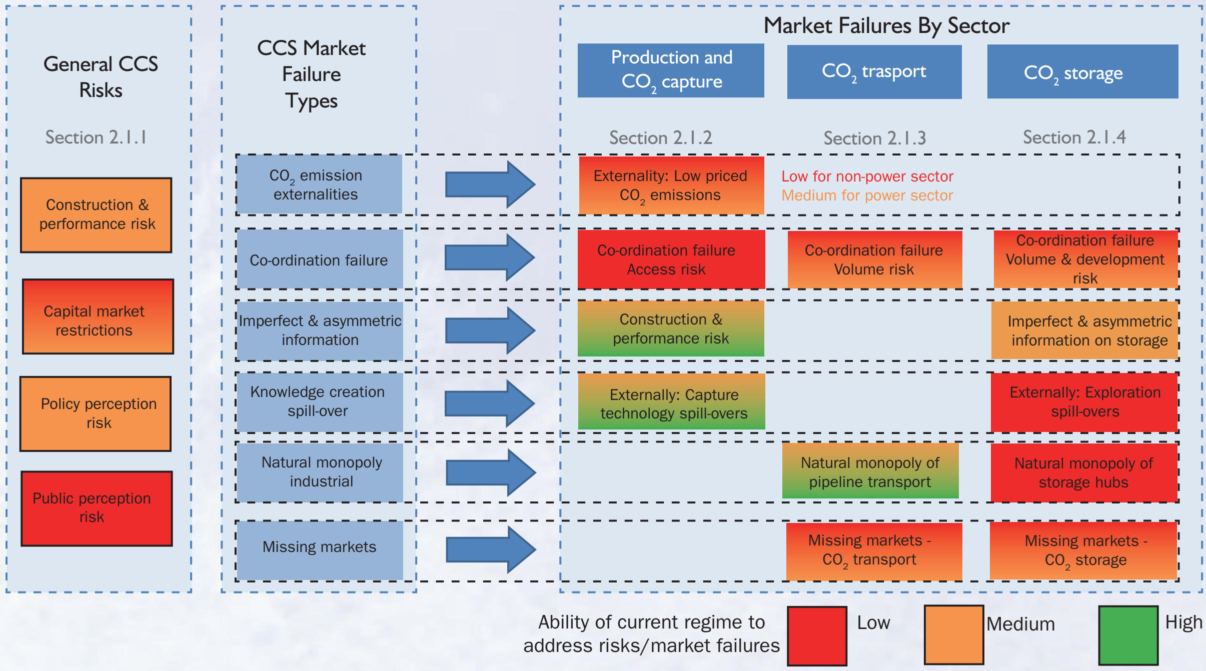


Fig. 2

carbon fuels (for transport and heating), power generation and 'negative emissions' using biomass. IEA analysis has shown analogous benefits at a pan-European level. A new socioeconomic paradigm, new metrics and new policy measures are required if infrastructure development is to be encouraged, these benefits realised and climate targets met.

Market failures

Contemporary energy policy is attempting to minimise energy costs for consumers over the long term while meeting emissions targets over various time periods (carbon budgets). Underpinning this objective is an implied use of CCS on industry, and the critical prerequisite for this to eventuate is availability of proven financeable storage sites for capture projects to take FIDs. Given the long lead times for such projects, the consequence of this is that investment in storage appraisal and de-risking has to occur ahead of market demand, but currently there is no market for the disposal of CO_2. This is a classic case of a market failure known as a **missing market**. Typically the private sector cannot overcome such a failure, which is often associated with a 'public good' need.

In theory, properly functioning, technology-neutral, market-enabling frameworks such as the European Trading Scheme or the UK Government's EMR (with a subsidy mechanism known as a Contract for Difference Feed in Tariffs, or CfD FiTs) should provide fossil fuel power generators with reasons for utilising transport and storage infrastructure. However, such infrastructure does not yet exist, so the first CCS power projects have to be built as 'full chain' projects.

Subsequent expansion of the transport and/or storage infrastructure will then need either further complex full chain contractual/ commercial arrangements between different businesses or independent transport and storage 'part chain' projects to be built decoupled from capture projects. But the substantially different investment risks, lead times and access to finance/remuneration required to achieve FIDs create a barrier to this happening in practice. We call this market failure a **co-ordination failure.**

Investment risk is too high

Given time horizons stretching over many decades and the political sensitivity of energy policy, potential storage investors perceive significant risk. The EU CCS Directive (Directive on the geological storage of carbon dioxide, 2009) effectively requires storage operators to carry liabilities for a long time, with potential impacts to company balance sheets and credit ratings, without clarity about future income or support mechanisms. This makes overall expected returns difficult to assess.

It is virtually impossible for transport and storage developers to make an investment case with uncertainty in future demand requirements and uncertain value to investors at the final stage of a value chain disposing of carbon emissions that are currently not fully priced through the EU carbon market. No developer can create a business case outside a full chain government-backed project.

The absence of direct public funding support such as capital grants or capacity payments for transport and storage developers makes any investment highly speculative and therefore untenable. Hence, without targeted financial incentives for transport and storage projects, which are essential public good infrastructure to future-proof the economy, the pre-FID funding needs for independent storage appraisal will not materialise.

Failure of the market to value the public benefits of CCS

A key characteristic of CCS is that it can create benefits to the economy, consumers and business in the form of 'avoided costs'. This is a practical and realistic solution to the so-called problem of fossil fuel 'subsidies'. However, under current policy frameworks there

Intervention type	Intervention options
Financial incentives	■ Direct revenues under carbon penalty frameworks ■ Direct payments under low carbon subsidy frameworks ■ Centralised funding models for transport & storage ■ Capital grants for storage characterisation ■ Purchase guarantee by government ■ Capacity payment by government
Tax breaks	■ Cross-sector tax breaks ■ Sector-specific tax breaks (targeting hubs)
Market creation	■ CO_2 storage liability aggregation ■ Options contracts for transport & storage ■ Leasing rounds for options over storage sites ■ Long term storage capacity auctions
Knowledge generation	■ Public engagement programme ■ R&D on CO_2 storage and monitoring

is no clarity, as to how investors in CCS can share in a portion of this value, or even how governments can capture the savings to society for wider, longer term decarbonisation that deployment of CCS can deliver. Clearly, to entice investors, the CCS business model needs to be an equally attractive investment with other opportunities.

New metrics need to be found that effectively value CCS. The current approach of valuing CCS simply on the cost of delivering low carbon electricity on a £/MWh basis, or on marginal abatement cost, which is then compared to other power generation technologies, is neither sufficient nor helpful for driving forward policies or action on infrastructure deployment.

Overcoming the market failures in CCS infrastructure investment

A long term strategic vision for the development of essential CTS infrastructure based on rational and transparent criteria within an holistic energy system context is currently absent from policy manifestos across Europe. This has the effect of exposing CCS to important policy risks and decision making biases that damage investment prospects. A change in how to initiate, decide and implement policy in a much more reasoned and holistic way is essential if the significant investment by the private sector needed to deploy CCS is to materialise in time to lower total decarbonisation costs on the pathway to 2050 emissions targets.

Historically, attempts to overcome market failures in infrastructure investment have led to a mixture of public and private participation. Such an approach for CCS transport and storage developers would help to direct funding that creates the right risk-reward profile, and enables the development of coherent long term enduring infrastructure frameworks in which individual projects play a role, but which require national and supranational or regional strategic leadership and decisions, and ensure value for money for the public purse.

The table provides some examples of interventions that could comprise a long term infrastructure framework. Some can work at national level and some at supranational level.

As discussed, transport and storage stages suffer from being at the 'downstream' end of the CCS chain, so mechanisms that provide revenue streams directly to them can greatly improve their development prospects and help to overcome co-ordination failures. Two key components of an effective support framework are fiscal incentives and market creation mechanisms.

The problem of high risk investment in storage appraisal ahead of market demand can be resolved by capital grants and public funding contributions to 'market maker' organisations. Operational support to provide greater certainty on income streams in an emerging market can be achieved through CO_2 purchase guarantees or storage capacity payments by government. Funding for such payments can come from re-directing government subsidy or carbon-related revenue flows rather than relying on the 'trickle-down' effect where only the power generation/capture plant is remunerated or penalised and the transport and storage operators must await payment from utilisation of their facilities.

Lack of a market in the provision of transport and storage services means it is harder for new entrants to value their projects and leads to high barriers to market entry. An intervention that is particularly relevant to this early stage of CCS development is that of creating a market for leakage liability insurance (possibly by a similar pooling arrangement to the nuclear industry) to lower the risks and insurance costs for storage owners.

CCS requires commercial innovation and new business structures

There is limited experience in commercially structuring integrated CCS projects and infrastructure with different developers and operators, and sector development will involve complex new value chains with novel business structures, risk allocation and counterparty arrangements that can take many years to negotiate. One key barrier for CCS development is that there is currently no risk allocation template which can be readily adapted, so we are starting with a blank canvas on which we need to build a new risk matrix and associated commercial structure.

CCS comprises three very different businesses, leading to individual risk profiles that result in dissimilar investment business cases and development timelines – storage has long lead times compared to capture, which are much shorter, and transport is sandwiched between the two.

Key questions for infrastructure developers are:

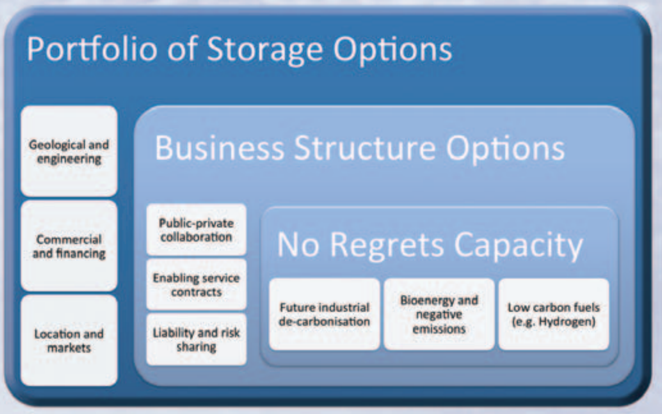
- If I develop a storage site will the capture capacity be built?;
- Will storage sites be available if I build the pipeline?; and
- Will the CO_2 turn up even after I have built my storage site?

The interdependency of capture and storage means that confidence to invest in CO_2 storage depends on clarity around the approach to rewarding investment in capture, and at the same time creates access risk for the power plant developer, as they will not build a capture plant without assurances of access to a transport network that can take the CO_2 from the power station and deliver it to a storage site. The co-ordination failure for transport and storage leads to volume risk, the result of which is to discourage any speculative oversizing of pipes or speculative appraisal of larger storage sites to allow sharing with future projects.

The option value of CCS

Early CCS projects are strategic enablers of lower cost decarbonisation, along with further economic value through job retention and creation, and the reduction of 'subsidy' spillovers such as environmental degradation, reduced air quality and human health issues. As such these projects have an option value over the future benefits they create.

There is a level of CCS infrastructure capacity that will be unequivocally needed within 15-20 years in order to meet emissions targets and climate goals by the middle of the century. This is not a long time for infrastructure deployment requiring public and private partnerships and commercial, financial and business model innovation. Hence, the sooner we undertake no or low regrets investment in CCS infrastructure that creates the high value options for economy-wide decarbonisation, the more likely we are to lock-in the benefits in a much more cost effective way.



The way forward

Delivering Europe's aspirations for energy security, decarbonisation and retention of its industries in a low carbon world means that complementary national and pan-European policies should support a clear development pathway for CO_2 transport and storage infrastructure.

A key to the success of delivering CCS as an essential component of the future low carbon system will be avoiding unco-ordinated deployment of full chain 'demonstration' power projects over the next decade that do little to promote a common transport infrastructure or the development of storage hubs that can contribute to economies of scale. Such 'point to point' CCS projects will suffer economically and will not set up the lower cost options for future use of CCS in industrial processes, negative emissions applications and low carbon transport fuels.

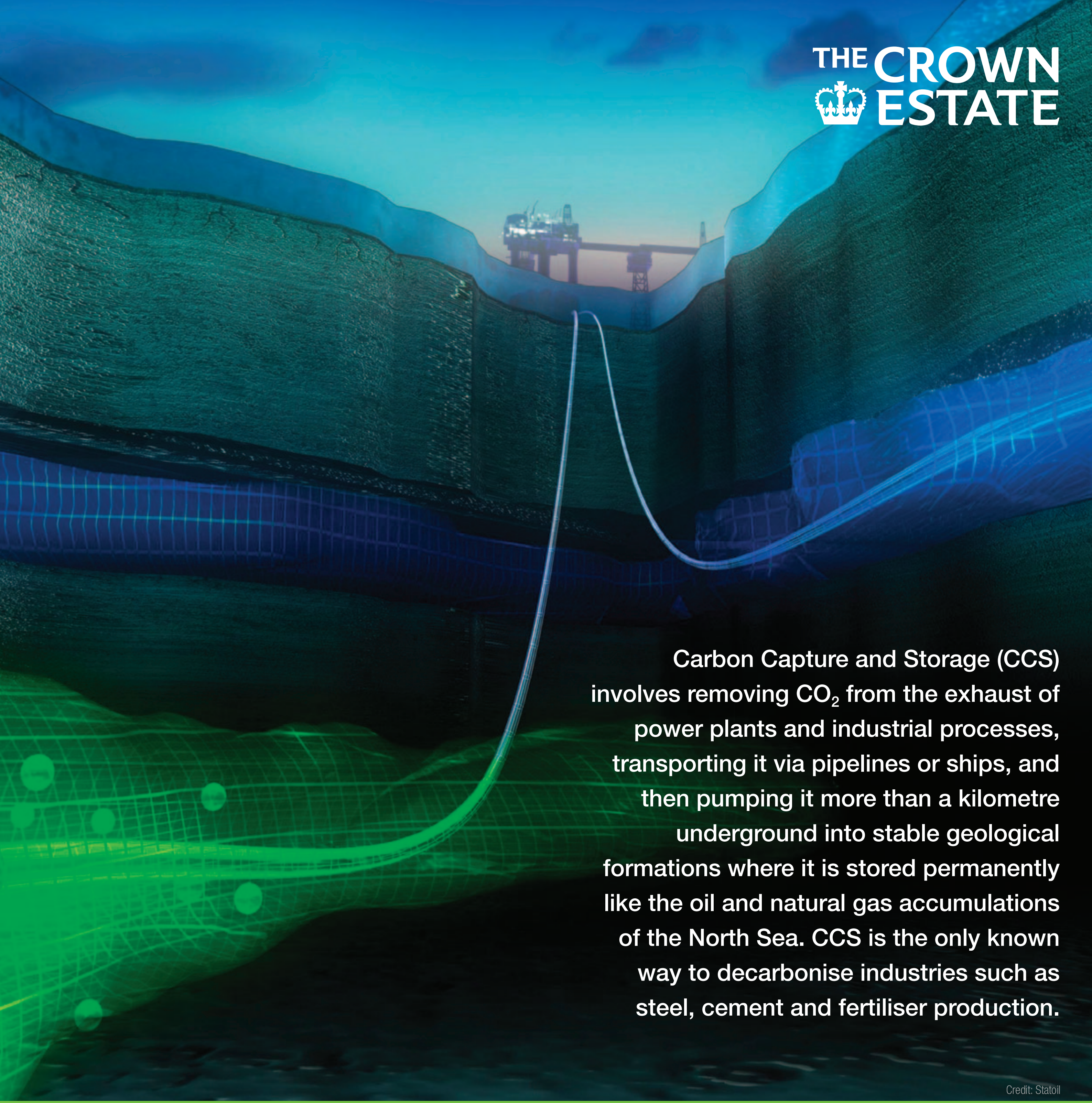
Therefore, additional government interventions are required that address the structural problem of CO_2 transport and storage infrastructure needing a development pathway in parallel to policies that support low carbon power generation or industrial processes. Critically, a distinction needs to be made with renewable power generation projects when formulating policy because, unlike power transmission infrastructure, there is no existing CO_2 pipeline network for carbon capture projects to connect to.

While individual countries around the North Sea Basin such as the UK, the Netherlands and Norway could create the early to middle stage CO_2 transport and storage infrastructure for their own use, it is highly likely that at least some of the CO_2 emissions from the major industrial regions of northern and eastern Europe will eventually need to be transported to safe storage sites in the North Sea. Future costs will be minimised if pan-European policies support an emergent smart design that can leverage scale and the legacy pathway for infrastructure deployment followed over the next 10-15 years.

CO_2 storage represents a realistic option for emissions abatement in low carbon industrial economies. In order to create infrastructure development options with inherent minimal or no regret for investors, the options must be 'purchased' by spending money ahead of market demand to generate sufficient understanding of the bankable storage resource and the risks associated with project delivery. At a European scale, existing funding mechanisms such as Horizon 2020 and the Connecting Europe Facility, along with the Strategic Energy Technology Plan, as they relate to CCS, are not currently designed with the intent of creating storage options or to optimise the value of expenditure to 'buy' such options within the context of a low carbon system.

A portfolio of storage projects with different characteristics and risk profiles is less risky than each project separately. Furthermore, whilst storage potential can be optimised to geological attributes, lowest risk and lowest cost development will require managing a portfolio of storage appraisal options that may change with time.

Bespoke, early targeted government investment in CO_2 storage appraisal combined with mechanisms to provide income support in the face of an uncertain emerging market are critical prerequisites for generating future option value and delivery of choices for private sector investment in industrial decarbonisation, low carbon fuels, and power generation.



THE CROWN ESTATE

Carbon Capture and Storage (CCS) involves removing CO_2 from the exhaust of power plants and industrial processes, transporting it via pipelines or ships, and then pumping it more than a kilometre underground into stable geological formations where it is stored permanently like the oil and natural gas accumulations of the North Sea. CCS is the only known way to decarbonise industries such as steel, cement and fertiliser production.

Credit: Statoil

At the Crown Estate, we focus on the second and third stages of the process, providing leases for the transportation and storage of CO_2 in areas of the 12-mile nautical seabed and continental shelf that we manage.

Our work includes collaborating with industry and other stakeholders to understand the policies and mechanisms required to create a functioning market for CO_2 storage over the next 15 years, how to ensure value for money options are created for deployment of infrastructure, and how to de-risk technical, commercial and legal aspects of permanent CO_2 storage.

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