element energy

: vivid economics

Policy Mechanisms to support the large-scale deployment of Carbon Capture and Storage (CCS)

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Element Energy is a leading low carbon energy consultancy working in a range of sectors including carbon capture and storage, low carbon transport, low carbon buildings, renewable power generation, energy networks, and energy storage. Element Energy works with a broad range of private and public-sector clients to address challenges across the low carbon energy sector, and provides insight and analysis across all parts of the CCUS chain.

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Vivid is a specialist consultancy working globally at the nexus of business strategy and public policy, providing clients with robust evidence-based analysis communicated effectively to clients and their target audiences. It has a wealth of experience across major sectors, especially energy, natural resources, industry, transport, cities and urban infrastructure; as well as public and private finance in these sectors.

1 Executive summary

The brief

Element Energy and Vivid Economics have assessed policy mechanisms that could accelerate the deployment of Carbon Capture and Storage (CCS) to the scale required to meet climate change targets. The report begins by considering why, despite the central role that CCS plays in many deep decarbonisation trajectories, CCS has failed to build momentum. Having identified the problems, the work lays out policy and market mechanisms that could stimulate investment across the stages of deployment, acknowledges regional circumstances, and suggests principles that could help governments and firms to collaborate. Note that in this report CCS includes CCUS (carbon capture, utilisation and storage) in those cases where storage is permanent.

The situation

For the most part, CCS has not progressed beyond the demonstration stage, with stakeholders hesitant to commit the resources necessary to scale-up and roll-out deployment of the technology. This hesitant progress reflects several characteristics: the large financial magnitude of individual investments, the creation of new networks, the relatively high level of perceived technology and real commercial and policy risks, together with the often tentative commitments of governments to deep decarbonisation investments. Furthermore, the deployment so far has not yet established a learning curve of cost reduction. By recognising that CCS deployment is a shared beneficial endeavour, public and private sectors can collaborate to achieve deployment. There is experience in other low carbon technologies where such joint commitments have supported the deployment of technologies at scale, using commercial business models.

Carbon pricing appears insufficient to deliver CCS commercially. This is due to a number of reasons. First, CCS is not the lowest cost abatement option available *today* in a number of sectors, but it is expected to be needed as part of the least cost deep decarbonisation programme in those sectors in the future. For example, in the power sector some renewables are lower cost than CCS today. Second, carbon prices *today* are not high enough to incentivise CCS. A high carbon price *in the future* is too distant and uncertain to incentivise the near term CCS development that is necessary to prepare the way for widespread deployment in the future. Last, a carbon price only addresses the externality of CO_2 emissions, whereas there are a number of other market failures, such as counterparty risk and natural monopolies, which also merit intervention.

Deployment of CCS will reduce the cost of achieving climate targets. The precise scale of contribution that CCS will make to addressing climate change remains uncertain, but a common finding across technical and modelling studies such as IPCC AR5 and the IEA CCS scenarios is that CCS is vital to reducing emissions at lowest cost. In industry, CCS is the only way to decarbonise some sectors.

In order for CCS to be contributing at scale in the period 2030-2035, immediate action is needed. Unfortunately, momentum in CCS deployment is currently low. **A principal cause is that the dialogue between stakeholders has articulated the costs of CCS, without sufficiently articulating its value.** There is need to demonstrate CCS across a range of applications, and though there have been notable project successes, the abandonment of some CCS support initiatives together with some high profile project cost and delivery over-runs has made investment in CCS appear high risk in some jurisdictions. Support of CCS now carries reputational risk for both politicians and for managers within the private sector, principally where offers of public support have failed to reach contractual close in the past. Meanwhile, governments can meet near term policy targets, contribute to longer term decarbonisation goals, and enjoy unit cost reductions from renewable energy, at low risk.

The choice of policy instruments

The work began with a comprehensive set of policies that were assessed against three criteria:

- *Feasibility*, that the policy passes a minimum standard of acceptability to private and public investors.
- *Efficiency*, minimising cost or making maximum use of efficient pore space; and
- *Effectiveness*, ability to deliver a fleet of operating CCS projects.

Four policies were shortlisted. They are: CCS obligation with certificates; emissions performance standard (EPS) with certificates; public procurement and tax credits.

An assessment of the four policy instruments examined their potential strengths and weaknesses. The assessment considered their performance on both a stand-alone basis and in a regional context and found some to be *flexible,* spanning the needs of the scale-up and roll-out phases, and working in several regions; *equitable*, in that both public and private sectors could gain; and *feasible*, in that there are precedents which confer confidence.

The timing of action

A scale-up phase of deployment is required to counter a prevailing view that CCS initiatives are risky and the technology is not available in the near term. It is not enough for the technology to be technically available. Market participants must become familiar with a new technology and the contractual arrangements supporting its deployment. The scale-up phase proposed here comprises a limited number of full-scale projects, focussed on improving cost certainty and proving deliverability globally in key application sectors, such as flexible gas-fired power (in regions with high and increasing renewable energy penetration), coal-fired power in baseload applications, iron and steel, cement, and chemicals. A successful track record in the scale-up phase builds trust and reduces risk. Scale-up projects are templates for generic CCS applications with significant cost elements typical of subsequent projects. The roll-out phase which follows has a focus on standardisation and cost effectiveness. The different purposes of these two phases, *risk reduction* followed by *efficiency*, demand distinct policy treatments.

The viable policy instruments to deliver CCS in the scale-up and roll-out phases

The viable policy instruments to deliver CCS in the roll-out phase include an obligation, public procurement and tax credits; the choice will be region-specific. It is worth considering the roll-out phase first, because it is much larger in scale, and whatever policy instruments are chosen for the roll-out phase will inform the choice of instruments for the scale-up phase. First, a CCS obligation could deliver CCS efficiently and be gradually implemented from scale-up to roll-out, but requires complementary measures to unlock finance. Second, government can directly procure CCS projects using a competitive bidding process, but this can impose a fiscal burden on the public purse. Third, tax credits could provide an incentive, and are used with some success in the US, though they carry a policy risk due to the fiscal burden on government and the relative political ease with which they can be changed. An EPS cannot be a primary mechanism, because it does not specifically incentivise CCS within the most important sector: the power market. The example of the US Clean Power Plan regulations shows that standards can require new coal-fired plant to fit CCS, but in this example investors may choose to build other low carbon power generation without CCS. An EPS could be a complementary instrument, for example to tax credits.

A CCS obligation could be a policy instrument for delivering efficiency in the roll-out phase for specific regions and market structures. The assessment of the CCS obligation shows that the obligation ensures a target for CO_2 stored can be met and the market element creates efficiency by allowing obligated parties with high CCS costs to fund lower cost CCS opportunities at other sites. However, these strengths do not imply a CCS obligation is the appropriate policy solution in all regions as the weaknesses of the obligation scheme, such as its administrative complexity, may outweigh its strengths in some locations. Public procurement is another leading option. The two can also work together at the scale-up phase, to build trust, using the obligation as a means of tuning the allocation of the costs of procurement. Indeed, market mechanisms cannot work alone in the scale-up phase, because they depend on sufficient market scale. Nevertheless, from the start it is valuable to have a clear future, sustained policy commitment, pathway and set of instruments.

Public procurement could offer strong incentives for CCS projects in the scale-up phase. The inefficiency that may be expected from public procurement, that might be acceptable in the early stages of CCS deployment, could be addressed during the roll-out phase through transition away from public procurement to a market based mechanism. Not all jurisdictions will wish to make this transition and some may not possess the scale or capabilities to do it.

Tax credits show promise in mitigating first-of-a-kind costs and could have wider use. An example is their use in conjunction with a tradeable obligation scheme, when CCS costs are expected to fall over time. Tax credits for initial capital expenditure can make the initial capital outlay more manageable, with the obligation and certificate revenue covering operating costs. Without tax credits that begin generously and taper down over time, the certificate price might fall steeply over time, making financing difficult. Tax credits could have a wider, longer-term role to play in enhancing the commercial returns to investment along the CCS chain even after the first generation of plant have been built.

Care has to be taken in the design of policy instruments to avoid unintended consequences. A poorly-designed instrument could encourage carbon-intensive emitters to increase their share of production, to the detriment of the total quantity of emissions released, when a well-designed scheme would not. This problem is easily avoided by paying only for the CO_2 that is stored below the emissions of a benchmark carbon-efficient production technology.

Design features such as price floors and ceilings as well as complementary instruments such as advance market commitments may mitigate policy risk and provide initial liquidity. Following the well-established economic principle of using one policy per market failure, a package of measures emerges in which several instruments each addresses one aspect in which the market or another policy might fail.

There is no one-size-fits-all package. Jurisdictions may choose policy mixes based on several considerations. Jurisdictions will have their own preferences, considering: policy culture; market size; market structure; endowment of institutional capability, technical skills and pore (storage) space. These regional circumstances are illustrated in four places. In India, public procurement suits the state-owned enterprises and absence of market mechanisms. The same is true in China, although China is actively testing carbon pricing market mechanisms. Saudi Arabia's high market concentration and state ownership makes public procurement seem most feasible. In contrast, the culture and practice of

North America and Europe suit market mechanisms, suggesting a CCS obligation with tradeable certificates, supplemented by tax credits.

Government can support investment by taking on long term CO_2 storage liabilities which are highly challenging to privately adopt or insure. Certainly the long-term post-closure liabilities could be transferred to government, and the geological leakage risks during the filling of the store could perhaps be managed through a limited liability mechanism. It may be more equitable for CO_2 storage post-closure costs to be covered by an independently managed fund into which storage site operators and government pay over time, rather than accumulating costs for future taxpayers.

The conditions for collaboration

Successful cooperation relies on the expectation of a future agreement. The conditions for a future collaboration are mutual self-interest, urgency, experience of past successful arrangements of a similar nature, and a mechanism to encourage compliance over time. The next steps for parties are to determine the key terms of such collaborations.

The debate around the value gained by developing CCS remains immature but appropriate decision making tools are available. The question is whether there is greater value from backing CCS or from not backing it. Recognising this, governments can compare future costs and policy arrangements to deliver a 2°C goal using CCS with scenarios in the absence of CCS. They can then apply an appropriate decision making analytical framework, for example, the minimum regret or maxi-min rules, which suit a cautious decision-maker by avoiding the worst outcomes. In doing so, they might have more success in informing decisions.

The cost of CCS deployment will have to be shared, and here too, agreement over principles could lay the foundation for subsequent discussion of details. The principles of distribution of costs are to seek the widest funding base (affordability), make the polluter pay, place the incentive closest to the mitigation decision, ask for contributions from beneficiaries and assign risks to those who have most control of the risks and the appetite to bear them. Applying these principles, all parties must contribute to costs, but the burden shifts over time onto consumers. Industry and government pay more at the outset, reflecting that business is developing an option that maintains the value of its underground and over-ground assets and that government is acting to create an option for future consumers. Those future consumers will benefit and they will pay the majority of future costs. In practice, cost can be shifted to the private sector via a levy or, in the case of an obligation, a declining level of government certificates purchase.

Government has an important role in reducing or adopting risks from the private sector and coordinating delivery as CCS scales up, although effort can shift towards the private sector over time, achieving more efficient outcomes. By signalling the transfer of these roles to the private sector in advance, alongside overall policy direction and timelines, governments help to build confidence and strengthen the pool of projects under development.

Glossary

Term	Definition
Carbon capture and storage (CCS)	The process of capturing CO_2 and transporting and storing it so that it is not released into the atmosphere.
CCS certificates	Tradeable certificates representing a certified t/CO_2 stored.
Consumers	Consumers of final goods and services in the economy.
Emissions performance standards (EPS)	A policy instrument which sets maximum emission standards for specified emitters.
Obligations	A policy instrument which obliges a party, for the purposes of this report, to surrender a number of CCS certificates each year.
Policy instruments	Interventions by the government in the economy to achieve certain objectives.
Private sector	The for-profit sector of the economy not part of state control.
Public procurement	The purchasing of goods or services by the government. Note that this refers to the government performing the act of purchase; it may levy the private sector for the necessary financial resources.
Public sector	The sector of the economy controlled by the state
Roll-out phase	Roll-out succeeds the scale-up phase. The technology builds sufficient track record to access capital at reasonable market rates. Furthermore, a sustained CCS industry supply chain capable of delivering sufficient installation rates is built up.
Scale-up phase	During the scale-up phase of technology development, a technology moves from demonstration to commercial scale projects. For CCS, the scale-up phase consists of around 15 to 20 CCS projects with an indicative capital investment of $30 billion.
Storage liability	The liability for any environmental or other damages arising from storing CO_2.
Tax credits	A policy instrument which provides reductions in the tax liability of a tax payer for fulfilling defined criteria.

2 Introduction

2.1 Objectives

CCS has strategic value in contributing to a low carbon energy supply though progress towards its acceptance to date has been slow. In the last 15 years, the annual global CO_2 storage rate doubled to a 2017 value of around 37Mt/year. However, most policy-driven greenhouse gas emissions trajectories require CCS to deliver 1,000-2,000Mt/year by 2030, a hundred-fold increase over the next 15 years[1].

A shortlist of policies has been evaluated which might be effective in supporting CCS deployment at this scale. This report, examining key CCS policies which might be effective from both a government and an industry perspective, supports the accelerated deployment of CCS technology and make a meaningful contribution to climate stability.

2.2 Scope of work

There is a substantial existing literature on CCS policy which this report acknowledges and builds upon. The premise of the work is that the policies currently in place across the world have not supported deployment at a rate sufficient to contribute to climate stability, for example, the ETS in Europe has been in place for over a decade without incentivising meaningful CCS deployment. Historically, carbon prices have fallen well short of levels required to cover the additional costs of CCS and so have not supported deployment of the technology. For example, over 10 years the EU ETS price has decreased from around 25 to 5 €/tCO_2, whereas CCS power applications require around \$80/tCO_2 for commercial viability[2]. So the challenge taken up in this work is to find ways to strengthen policies. Since CCS may be deployed globally and in a number of sectors, the scope of analysis is international, multi-sectoral and multi-fuel.

2.3 Approach to the work

Government and the private sector already recognise that CCS deployment is a shared endeavour. Yet the distribution of responsibilities between them has not yet been resolved. It is critical to understanding the slow progress of CCS. Therefore, this work deliberately examines the policy constraints and opportunities from both public and private perspectives, exploring which options and processes might lead to agreement. The work gains insights from analogies with renewable energy supply (RES) technologies, in particular the rationale for and performance of policies in that sector.

2.4 What is new and how this work builds on previous work

While there is an extensive literature on CCS policy mechanisms, the policies which deliver accelerated deployment of CCS have yet to emerge. It would be an error to think that all private and public parties believe that the case for large scale CCS deployment is clear. Although there is strong evidence in favour of the case for CCS, its current relatively high unit costs and perceived novelty have discouraged commitment. To date, policies have focussed on individual CCS projects and associated infrastructure. These individual projects have tended to be large and complex and hence challenging to deliver.

This report explains that the vital case for CCS has yet to be made, and concludes that the technology is in a post-demonstration, pre-commercial state with stakeholders unwilling to commit resources to increase its scale. Taking public and

[1]' Energy Technology Perspectives 2017, 2DS and BSDS scenarios. www.iea.org.
[2] CCS Cost trends, Rubin et al. 2016

private stakeholder perspectives, this work identifies core issues behind the slow development of the technology, and focuses on policy instruments and processes which address these issues.

Even during early deployment, it is critical to identify a path towards full and large scale deployment. Clarity of direction helps players coordinate and reduces risk when making commitments. The stages along this path have distinct characteristics. This work examines the effectiveness of market mechanisms during the earlier scale-up phase and later roll-out phase of the technology.

Previous work has been limited to a high level comparative analysis of CCS policies. This study undertakes a more detailed analysis of a short list of policies, incorporating regional suitability, the question of who pays, and the issue of value and risk. It also identifies the conditions for collaboration between public and private stakeholders, allowing their combined resources to support the deployment of CCS in an equitable and sustained manner. Table 1 provides an overview of the contributions this study adds to the evolving debate on CCS.

Recent studies of CCS policy highlight a difference from renewable energy. Renewable power generation technologies are often deployed solely using incentives for individual projects, such as feed-in tariffs. However, CCS involves building systems of capture, networks and storage, so an approach based on rewarding individual projects is not sufficient. Previous work notes the chain of inter-dependent investment from capture to storage lumpiness of CCS investments (PÖYRY 2013). The UK Government's statutory advisors recommended a part-chain approach whereby the support for capture is separated from the support for transport and storage (CCC 2015). The CCC's intention was for developers at each stage to manage their own risks, thinking that this would promote shared infrastructure.

In 2016 paper, a parliamentary advisory group to the UK Government recommended the establishment of a public company (Parliamentary Advisory Group on Carbon Capture and Storage, 2016)**.** This group suggested that the CCS Development Company (CCDC) should manage risk across the CCS chain and develop of transport and storage infrastructure. The CCDC would sequence deployment such that multiple projects could connect to network hubs.

The Norwegian based Zero emissions resource platform argued for a CCS certificate system (ZERO 2013)**.** In this model, this market based mechanism would be combined with an environmental performance standard which prohibits emissions intensive technologies. A simpler form of the certificates proposal has also been suggested, in which certificates link the extraction of carbon to an obligation to store a proportion of emissions (Stuart Haszeldine 2016).

Table 1 Key contributions of the study

Section	New evidence	Supporting studies
S3. Overcoming the causes of inaction of CCS	CCS pre-commercial loop Conditions for collaboration	
S4.CCS deployment roadmap	CCS policy pathways and phases	(PÖYRY, 2016) for policy timeline (IEA, 2012) for policy gateways
S5.-5.3 and 6 Assessment of policy instruments	Shortlisting of viable policies and deep dive assessment Suggestion and analysis of innovative policies (e.g. tax credits with broadened tax base; EPS with tradeable credits)	Existing high-level policy assessments include (Parliamentary Advisory Group on Carbon Capture and Storage (CCS), 2016) and (ZERO, 2013)
S5.4 Recognition of value	Decision-making under uncertainty	
S5.5 and 6 Distribution of costs	Assessment of costs	(Haszeldine, 2016)
5.6 and 6 Risks and financeability	Measures to unlock investment	Liabilities and risks are analysed by (PÖYRY, 2013)
5.7 Infrastructure	Options for public and private infrastructure delivery	(ZERO, 2013) make the distinction between full and part chain projects and necessary complementary measures
6. Regional case studies	Applicability of different policies in different regional contexts	(ZERO, 2013) analyses the difference between CCS in developed and developing countries
7. In depth analysis	New insights on the details of policy instrument design	

2.5 Structure of the report

Section 3 explores the root causes of inaction on CCS, identifying four distinct challenges from which emerge the preconditions for effective CCS policy. Section 4 describes a phased approach, with a tightly focussed scale-up phase followed by a roll-out phase. Policies that are effective during the roll-out stage may also have a role to play during the scale-up phase. Section 5 notes the process of reviewing a broad suite of policies and selecting four. Section 5 assesses these shortlisted policies in detail, covering aspects of costs and value, risk and financeability, and infrastructure. In Section 6, a series of regional illustrations shows how policy preferences may reflect political, market and natural resource contexts.

3 Overcoming the causes of inaction on CCS

3.1 The failure to achieve concerted action on CCS

CCS deployment needs to accelerate significantly if it is to play a role in combatting climate change. A number of global energy models indicate that to achieve a 2°C climate scenario requires storage of approximately 1,000-2,000 MT CO_2 per annum in 2030[3]. This is the equivalent of fitting approximately 30GW of power capacity with CCS each year, comparable to the peak annual coal or nuclear construction rate following the 1970s oil crisis. The CO_2 capture and storage rate in 2016 is estimated at 37 $MtCO_2$ per annum[4].

The growth rate in CCS languishes far below the required level, having only doubled from a miniscule base in 15 years. The sector suffers from a high rate of attrition in moving from project initiatives to deployment. The sector is highly exposed to policy risk; notable examples including the UK CCS competition and the European NER300 initiatives, neither of which delivered any projects. While a number of operational large scale CCS projects have been realised successfully, such as Sleipner, Quest, Port Arthur, and Petra Nova, it is unfortunate that first of a kind coal power CCS projects such as at the Kemper county facility and Boundary Dam have seen significant cost and/or time over-runs, affecting stakeholder confidence that projects can be delivered on time, to budget and to specification.

CCS technology is proven and in use around the world (GCCSI, 2017). Seventeen large-scale projects are in operation and four due to become operational by the end of 2018. There are a further 16 projects in advanced planning. The world's first large-scale CCS project in the power sector, at SaskPower's Boundary Dam facility in Saskatchewan, Canada, has been in operation since 2015. The world's first steel plant with large-scale CCS was launched in Abu Dhabi in 2016. The Petra Nova coal power CCS plant started up in 2017.

Urgency of action on CCS cannot be overstated. Integrated assessment models show that, to achieve a 2°C scenario, decarbonisation of the power sector must begin immediately, resulting in approximately 75 per cent reduction in power sector emissions by 2040[5]. CCS is expected to contribute 15-20 per cent of those reductions. To achieve this, the IEA estimates a near 100-fold increase in CCS capacity is required by 2030.

Economic models suggest that CCS is crucial to meeting global climate targets. The IEA's Energy Technology Perspectives has repeatedly found that CCS is an essential part of meeting internationally agreed climate targets (IEA, 2014; IEA, 2016, IEA 2017). In the IEA's 2°C scenarios, around 14 per cent of global electricity is provided by CCS in 2050. The IPCC's Fifth Assessment Report (2014), which considered over 900 mitigation scenarios, found that most climate models could not meet emissions reduction targets without CCS. These global findings have been replicated at the regional and national level for the UK (UKERC, 2013; CCC, 2010). A substantial number of the model runs are unable to produce a 2°C scenario if CCS is not available (Krey et al., 2013).

Thousands of CCS installations are needed to achieve climate target but only tens are in operation or currently planned. A recent study in Nature Climate Change (2017) assesses the technology deployment requirements in order to meet the 2°C target. The study suggests that the absence of CCS is one of the biggest challenges to meeting the

[3]'Energy Technology Perspectives 2017, 2DS and BSDS scenarios; www.iea.org
[4]'The Global Status of CCS: 2016, Summary Report'; www.globalccsinstitute.com
[5] IEA technology perspectives, 2016

target. This study is important as it takes into account the latest information on the rapid cost reduction and deployment of wind and solar. Even given these advances, CCS remains vital.

The IPCC (2015) suggests that without CCS, the cost of meeting climate targets would increase by between 30 and 300 per cent. This is supported by the IEA (2012) which estimates that cost of meeting 2°C inflates by at least 40 per cent in a no CCS scenario. The absence of CCS increases costs for three reasons:

- Other sectors would have to pursue more expensive mitigation options. For example, in the power sector, very high rates of renewable deployment are required, and in the industrial sector moving to electricity for high temperature heat in production processes.
- If used in combination with bioenergy, CCS generates negative emissions thereby avoiding higher cost mitigation options.
- Models assume that CCS allows for protracted use of fossil fuels, continuing access to this source of low cost energy.

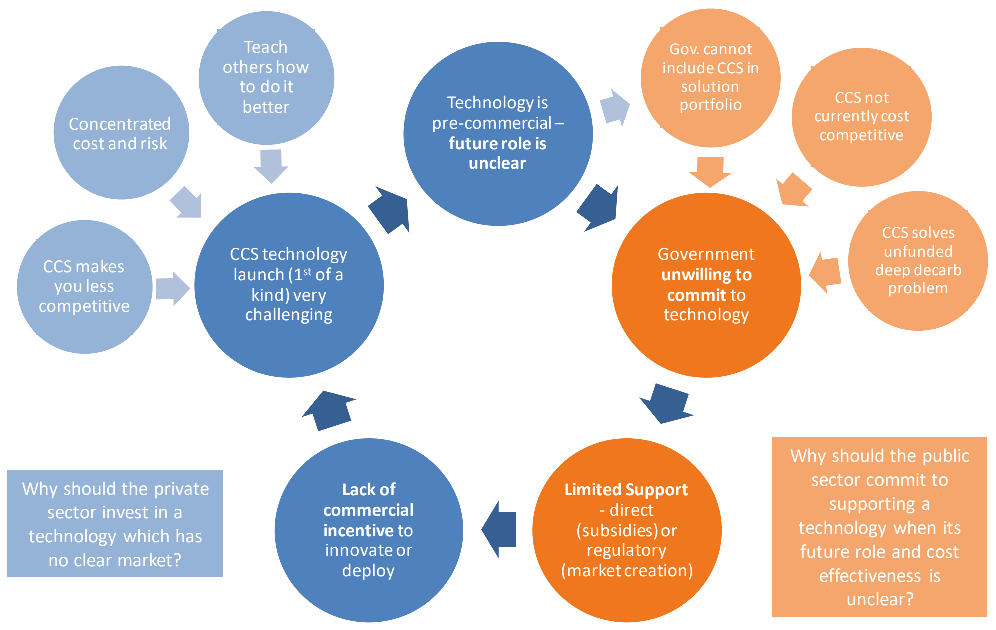
While the value-based argument favours CCS, it appears high cost relative to *some* other technologies. A meta-analysis of CCS cost estimates presented costs in terms of both the levelised cost of energy (LCOE) and the cost of avoided carbon (Bassi, et al, 2013) found that:

- LCOEs, used in studies of the use of CCS in the power system, average 100 Euros/MWh for gas, and average around 115 Euros/MWh for coal. Higher costs for coal are a result of higher volumes of CO_2 to be stored.
- The cost of avoided carbon in studies examining emissions reductions across the economy, was estimated for gas at between 65-125 Euros/tCO_2, and for coal at 35-91 Euros/tCO_2.
- In industry, the cost of avoided carbon varies widely by sector, with low costs for industries that have a pure stream of CO_2, for example, around 7-15 euros/tCO_2 for LNG production, and much higher costs for sectors where emissions sources are dispersed or the stream of CO_2 is less pure, for example, in refineries 38-58 euros/tCO_2.
- CCS cost estimates have been increasing over time, based on a meta-analysis of around 50 studies conducted globally (Gross et al., 2013).

The widely-held view of developers of CCS demonstration projects is that CCS technology has been demonstrated and projects can be delivered. CCS developers agree that CCS has moved beyond the technical demonstration stage, as is evidenced by the operational status of an increasing number of large scale facilities. CCS projects, including fully integrated ones, lie within the scale and complexity of integrated oil and gas projects which are routinely delivered to time, budget and specification.

The stalling of CCS deployment is a consequence of the unresolved tension between public and private stakeholder positions; current policies are insufficient for CCS to play any role of significance in combatting climate change. The public sector prefers to wait and see how cost effective CCS will be. Commercial stakeholders hold back investment in a technology with no committed market support and vulnerability to policy risk. This is the state today.

Figure 1 CCS is stuck in a pre-commercial state, no stakeholder believes there is enough to gain through action, nor enough to lose through inaction



3.2 The conditions for collaboration

Major investment in CCS involves commitment from both governments and energy intensive industries. Substantial up-front investment and ongoing operating commitments are foreseen. These commitments rely on trust, urgency, understanding of future intent, and a strong bond of mutual endeavour. They allow parties to embark on the process of translating interests into a set of enforceable public institutional arrangements and private assets. Yet, none of these foundations will be in place unless two conditions are satisfied.

The two conditions for collaboration between governments and industry are mutual interest and urgency. Furthermore, precedent, although not necessary, is a useful third element.

Mutual interest is necessary because without it there is no potential for collaboration. Citizens, through governments acting on their behalf, and firms have to perceive clear gains in order to invest effort in pursuing a collaboration. Neither party can act alone, but they can act together. Private firms cannot act alone because the benefits are public in nature, not private. The government cannot act alone because the emitting assets and technical know-how is private. Given the limited resources of governments, it is inevitable that the majority of the resources for CCS will have to come from consumers and from firms' shareholders.

Mutual interest may not be a sufficient condition for collaboration. If one of the parties feels that the other side is unwilling to make a reasonable offer, they may withdraw from the negotiating process. So, sometimes it is easier to begin by agreeing the process of dialogue rather than the outcome itself. In some of the most difficult and critical situations, arbitration is used to define the outcome and establish helpful incentives. The parties agree to a process of binding arbitration and in one of the most successful of the arbitration rules, pendulum arbitration, one of their final offers is imposed by an independent arbiter. The point here is that governments and firms may wish to consider not only the scope for mutual interest but also the importance of the choice of process for moving discussion forward.

Urgency is necessary because without it dialogue will be deferred. In order for an outcome to be achieved at one time, the parties have to prefer to conclude a dialogue at that time than at a later time. For governments to make commitments now, the value to the public of a CCS commitment now has to be higher than one that is deferred. For firms, the value, for the firms themselves, of a commitment now must be higher than the value of one made later. For each side to commence dialogue, it has to be clear that the incentive for the other side is also to progress collaboration at this time. Hence, there is some preliminary work for both sides to understand their own situation and the interests of the other party.

Although not strictly necessary for collaboration, the existence of a suitable precedent can significantly smooth the path. A precedent means some previous or similar collaboration which both sides might interpret as establishing a principle or expected outcome. Precedents are helpful because they show what third parties have, in the past, found to be a reasonable division of value. It is easier to defend an outcome which others have previously accepted than to be open to criticism for error. In addition, by identifying precedents, time may be saved in the dialogue.

3.2.1 The value of CCS

Among stakeholders there is active debate on the costs of CCS, but the debate around the value of CCS remains immature. Unlike wind or solar power, which also produce electricity, CCS for decarbonisation is solely employed for its CO_2 removal. In the process, costs increase and production efficiency decreases, but the value of decarbonisation, particularly the deep levels of decarbonisation that CCS offers, is not widely understood.

Recognition of the value case is a precondition to supporting investment and identifying an equitable agreement between government, consumers and firms. It is difficult to imagine CCS developing at the scale required until there is recognition of the value of its deployment. Integrated energy system models agree that, under a 450ppm climate scenario, CCS allows fossil fuel use to be maintained at current levels (approximately 400 EJ/year[6]) out to 2050. Without CCS, annual oil use may drop by one third, from 120 to 80 EJ/year, and gas use by two thirds, from 135 to 52 EJ/year, by 2050[7]. Coal use has already seen a dramatic decline, and in the above scenarios, without CCS, its contribution to the energy system in 2050 is small[8]. If the large emitting industries accept that they will face some of the same pressures facing the coal industry now, then CCS may have significant value in maintaining asset values as well as offering society value in access to large low-carbon energy resources. With CCS, a 2°C scenario can be achieved, while maintaining access to hydrocarbons would contribute security, diversification and economic stability during a transition to decarbonised energy.

In order for the public sector to support CCS, it will have to understand the value proposition. A challenge for the public sector in committing to strong decarbonisation policy is the cost, in the short term, it imposes either on its own budgets or on the private sector. This includes the effects on tax receipts from key sectors such as oil and gas. Governments will hope to understand the value to society in return for the commitments they make. Furthermore, they expect their own contributions to leverage much greater contributions from the private sector. In particular, governments may wish to determine the future role of

[6]Imperial College, Can Technology Unlock Unburnable Carbon, 2016, Figure ES1
[7]Imperial College, Can Technology Unlock Unburnable Carbon, 2016.
[8] This also aligns with WEO predictions of a 30 per cent decrease in coal use by 2030.

CCS within their own decarbonisation trajectories and explore how investments now might avoid larger decarbonisation costs later (associated with deployment of less cost-effective technologies). The role of CCS in avoiding large decarbonisation costs in the long term is a key aspect of the value of CCS, particularly from the point of view of consumers. CCS enables access to large amounts of low carbon energy, reducing prices of a large amount of consumer goods compared to a decarbonisation scenario with no CCS.

3.2.2 The role of CCS in power and industrial processes

It would be unwise to assume that the future role of CCS is secure. The energy system is dynamic and its future is uncertain. The recent delays in CCS deployment took place while the costs of RES fell rapidly. Recent integrated assessment modelling predicts a smaller role for CCS[9] than similar modelling a few years ago. Some model predictions are that CCS provides approximately 12 per cent of decarbonisation by 2050; if its predicted role falls further it may not be seen as a core decarbonisation technology.

The comparison of CCS and alternatives will change as the power sector evolves. For many regions, decarbonisation means high levels of renewable energy deployment. Increasingly, thermal plant runs in a flexible way as it balances renewable output. However, many current operational and financial models of CCS do not recognise the erosion of baseload run hours. It is no longer appropriate to compare costs on a simple levelised \$/MWh basis, but in addition it is correct to include the value of low carbon balancing and capacity services. Increasing RES deployment will rely more heavily on balancing and firming technologies, and the costs of these should be included when considering relative viability. Rather than competing with RES on a \$/MWh basis, in many regions CCS will complement renewables, and potentially compete with technologies such as batteries or demand side response. At times of low RES generation, electricity prices may increase, and generators may choose to run without CCS and pay the CO_2 costs. Regions where RES availability is highly seasonal will need more CCS. In contrast, in equatorial regions, with abundant solar and stable diurnal patterns, PV and electricity storage will be more competitive and will demand a smaller contribution from CCS. Regions with high penetration of seasonally variable RES may require flexible gas CCS. Regions where coal use is increasing, such as India, are likely to require continued thermal baseload for some time and coal CCS may have a baseload role there.

In industry, CCS is vital but there are significant unsolved barriers. CCS is the only deep decarbonisation solution available to industrial sectors such as iron and steel and cement production. However, process heterogeneity limits the scope to standardise CCS, and erosion of international competitiveness remains a politically unsolved barrier. Furthermore, modelling suggests that industry will decarbonise more slowly than power. This, combined with decarbonisation achieved through fuel substitution, including electrification, may allow industrial firms to delay investment decisions on CCS.

CCS suffers from the lack of a unified voice to argue its case. Other sectors, such as nuclear power, have been more successful at arguing their case, probably in part because they have a unified industry voice. Also, CCS, in common with many new technologies will be rejected by a sizeable fraction of the population, and a clear articulation of its benefits may balance this. Although CCS embraces a spectrum of process types at capture, as well as the distinct processes of transport and storage, the sector could unite around a limited number of clear issues and thus increase its influence.

[9] IEA technology modelling between 2008 and 2016 decreased the share of CCS in decarbonisation in 2050 from 19 per cent to 12 per cent and increased the share of RES from 21 per cent to 32 per cent.

3.2.3 CCS availability to firms as an abatement option

CCS is technically proven and has passed through the demonstration stage. Stakeholders agreed at interview that CCS technology had matured, so that it now sits beyond the demonstration stage and all its elements have been proven technically. Learning from related sectors shows that stable market demand can accelerate cost reduction, research and development[10] and drive cost reductions and performance improvements.

Support for CCS initiatives carries political and reputational risk. Though technically proven, CCS carries political and reputational risk[11]. Examples of recent failures include:

- UK CCS competition (under tight budget constraints, UK Treasury made a determination that this was not 'value for money')[12];
- NER300 (where a focus on lowest Euro/tonne drove selection to large, complex coal projects which could not be delivered);
- Projects where budgets and delivery timelines have been significantly exceeded, such as in Kemper county[13].

As a result, there is prevalent view that CCS projects are complex and vulnerable to cost over-runs. This is unfortunate given there are successful case studies available (Petra Nova, Quest, Port Arthur).

The public sector believes it has options other than CCS. The government can meet near term climate policy targets, contribute to longer term decarbonisation goals and to impressive cost reduction trajectories by supporting RES deployment, and do so with low reputational risk. For example, in Germany, a feed-in tariff law (EEG) means RES have dispatch priority, and coal-fired power displaces power from gas-fired power stations. It has not been shown that this is a robust strategy for long term decarbonisation. Yet no government has committed to policies that deliver deep decarbonisation, consistent with a 2°C scenario, within which a technology such as CCS may be viable and necessary.

There is an acute need for CCS track record in power and industry. Having emerged from the demonstration phase, the CCS industry can focus on deliverability, achieving reliable cost estimation and minimising operational risk. One way to do this is to focus early efforts on a limited set of archetype projects, where core elements can be repeated, improving confidence in deliverability and costs. These should reflect the expected roll-out of CCS application to ensure they are relevant. The chemical, pipeline, and oil and gas industries have the skillsets to complete this initial step quickly.

[10]Patent activity on No_x emission control technology peaked in the 15 years after best available legislation was introduced. 'Technology Innovations and Experience Curves for Nitrogen Oxides Control Technologies', Yeh et al. J. Air and Waste management Association 55:1827 – 1838.
[11] 'European politicians are also now wary of advocating a technology that appears to have failed to deliver on its promises' CCS Institute.
[12] This decision has since been heavily criticised, with the UK increasing the risk of not meeting its climate targets.
[13] The facility started operation in 2017, 3 years late, and three times over budget and operations were suspended in Q3 2017.

3.2.4 Making the case for immediate action

Short-termism or myopia means that investors, managers and politicians place less weight on the future than society would wish them to. For many reasons, institutions often under-invest in assets which offer long term benefits. This is reflected in the behaviour of elected governments, shareholders and firm managers.

A clearly articulated value case can overcome short-termism or myopia. One protection against myopia is a clear exposition of future scenarios. For example, showing the role of CCS in enabling consumers to rely on coal, oil and gas as sources of energy while meeting climate change targets. Without CCS, models of vigorous policy effort suggest oil and gas consumption might drop by 30 per cent over the next 20 years. In the power sector, models indicate emissions falling by 80 per cent in 20 years.

4 CCS deployment roadmap

4.1 The need for scale-up and roll-out phases of deployment

An analysis of low carbon technology deployment identifies four distinct phases. Using the development of offshore wind in the UK as an example, technologies move towards commercial financeability through several distinct phases. Early stage demonstration focuses on proving that a novel technology works in practice. Scale-up develops archetypal projects near or at full-scale, proving viability and deliverability. The number of projects at this stage is still relatively few. At roll-out, the objectives are to establish a sustainable industry and to build capacity, via a pipeline of projects, multiple developers, and a mature understanding of risks and contracting structures. Once this is established, a mature and stable industry can attract commercial finance on reasonable terms.

Figure 2 Stages of development of offshore wind energy

Offshore wind stages			
1. Demonstration Government funding for turbine demonstration projects e.g. UK Offshore Catapult supporting novel offshore foundations	**2. Scaling up** Increase in physical scale: turbine and farm size, projects in deeper water and further offshore	**3. Roll-out** Establish a project pipeline. Multiple mature project developers (i.e. capable of incurring development costs and risks)	**4. Commercially financeable** Projects receive commercial terms for finance

CCS has progressed through the demonstration phase but has stalled at scale-up. Only the USA has established projects beyond a demonstration phase. All stakeholders consulted, the wider CCS community, and the public sector, agreed that the sector had completed the demonstration phase. Key elements such as large-scale capture and storage have been proven to work, and there are no areas of fundamental technical uncertainty. The sector is in the scale-up phase but has stalled because there are too many initiatives abandoned (UK competition) or projects over budget (Kemper County). There are regional variations in terms of progress but as a whole CCS development is far slower than projected. The sector has yet to prove its ability to manage the risks associated with delivery of projects. Much of the public sector is struggling with the rationale behind the significant funding required for scale-up, evidenced by the failure of so many current initiatives to proceed.

Figure 3 CCS has passed through the technical demonstration stage, but has yet to become established at the scale-up phase (model is conceptual; some regions will lead others)

CCS Stages			
1. Demonstration Objective: Technically prove CCS, technical risk is high	**2. Scaling up** Objective: Batch of full scale projects proving viability deliverability globally	**3. Roll-out** Objective: Sufficient track record to access capital, capacity building	**4. Commercially financeable** Objective: Competes for capital on same terms as established investments

Distinguishing the scale-up phase from the roll-out phase helps to highlight the role of market mechanisms. During scale-up, there is no demand for CCS, because the scale-up stage is needed to prove to stakeholders that the technology can supply to a future market. In roll-out, market mechanisms can come into play, supporting the transition towards a commercial level of deployment.

4.2 Scale-up: definition and objectives

The scale-up phase consists of a batch of full-scale projects improving cost certainty and proving deliverability globally in key application sectors in power and industry. They should generate confidence that the technology is a realistic, low risk decarbonisation option and through applications demonstrate the vital role of CCS in meeting climate objectives. The projects maybe templates for key CCS applications with core cost elements transferrable to subsequent projects. To avoid concerns about first mover disadvantage, suitable projects could be sited in any region globally, and maximum learning across regions could be a key objective.

The scale-up phase consists of around 15 to 20 projects with an indicative value of $30B. The International Energy Agency CCS Roadmap from 2013 was built upon the set of CCS initiatives from that time, and as a result, its scope was broad, incorporating all technologies, sectors and applications. The limited progress since then indicates the strategy was not appropriate. The scale-up and roll-out phases in this report are similar in duration and objectives to the 'Demonstration' and 'Early Deployment' phases described by the IEA in its publications. However, scale-up has a greater focus on controlling and proving costs and lasts a shorter time.

Scale-up projects address all four of the challenges identified in Section 3. By focussing efforts on a limited number of key applications, scale-up projects help all stakeholders determine the value of CCS in these vital applications. By delivering on time and to cost, these projects increase stakeholder confidence, reduce risk, and mature the technology to the point of being a realistic option for policymakers to back. By limiting the number of facilities to a focused set, a rapid deployment can be achieved. Existing facilities which demonstrate on-time on-budget delivery, and successful operation are potential reference plants (for example the $1B Petra Nova project which was delivered on time and budget).

During scale-up, deliverability is more important that choosing lowest unit cost. As with other low carbon technologies, once confidence and cost certainty improves, successive generations of technologies can be expected to deliver cost and performance improvements. At an early stage, selecting the right projects that deliver confidence is more important than a project that promises least cost CO_2 storage, but at elevated risk of cost and programme over-runs. Even at this early stage however, it is vital to identify a feasible technology pathway towards these technology performance improvements.

A coalition of the willing could contribute the support necessary at scale-up. Before market mechanisms can support CCS, the scale-up stage will require support from enlightened stakeholders, public and private. The fleet of scale-up plants may need to be deployed in jurisdictions worldwide where such support exists. Scale-up could trial voluntary versions of the market mechanisms that would operate subsequently at roll-out.

The chemical, pipeline, and oil and gas sectors have the skills and experience to implement rapid scale-up. From the consultation exercise, there was broad agreement that the chemical, pipeline**,** oil and gas sectors have the skills and experience to deliver scale-up projects rapidly. These industries have a good track record of managing large complex projects at scale and at rapid replication. Though scale-up is indicated to extend out to 10 years, projects could be delivered in less time if they are given priority.

A signal of policy intent is required at scale-up. Though a market mechanism may not support scale-up, because it is too early in deployment to expect to see an operational market, nevertheless a signal of policy intent is required at scale-up, to support the initial investment. This mirrors the need to identify a feasible technology improvement pathway from the start.

4.3 Roll-out: definition and objectives

Roll-out phase: this phase has the objective of building sufficient track record to access capital at reasonable market rates and it creates a sustained CCS industry supply chain capable of delivering sufficient installation rates.

Commitment increases over the period to $50 to 100 billion p.a. With roll-out expected to last 15 to 20 years, the end of roll-out would occur in the 2040s. Model estimates suggest hundreds of full-scale projects being built annually by the end of this period.

In roll-out, the focus increasingly turns towards cost effectiveness. While scale-up is focussed on establishing the CCS industry, roll-out establishes the technology as a competitive decarbonisation option. Although forward looking projects can be setup with clustering in mind during scale-up, focus during scale-up is on delivery and not cost effectiveness. In contrast, roll-out includes a shift in focus towards cost effectiveness and demonstrates economies of scale that come from clustering of projects, and realising value through oversized pipeline infrastructure and sharing of sinks.

5 Assessment of policy instruments

This section presents the assessment of four shortlisted policy instruments designed to encourage CCS deployment during the roll-out phase. Section 5.1 reviews the rationale for policy intervention and the procedure for policy instrument selection. It also provides an overview of the selected policy instruments. The focus of the policy assessment is on policy instruments for the roll-out phase; Section 5.2 presents a discussion of the phasing of policy implementation and argues why roll-out policy instruments are critical to consider now, and how they influence policy choice for the scale-up phase. Section 5.3 then proceeds with a brief overview of all policy instruments, before assessing each instrument individually.

5.1 Selection and function of policy instruments

Policymakers typically justify economic policy interventions as attempts to correct market failures; the primary market failure in the case of CCS is the carbon externality. However, addressing the carbon externality alone is not sufficient to drive emissions down to target levels because of a range of further market failures and barriers to investment. For example, there are market failures in transport and storage infrastructure which have to be corrected. These include natural monopolies, and incomplete contracts in the form of counterparty risk (Pöyry, 2013).Table 2 provides an overview of market failures associated with CCS and potential policies to address these.

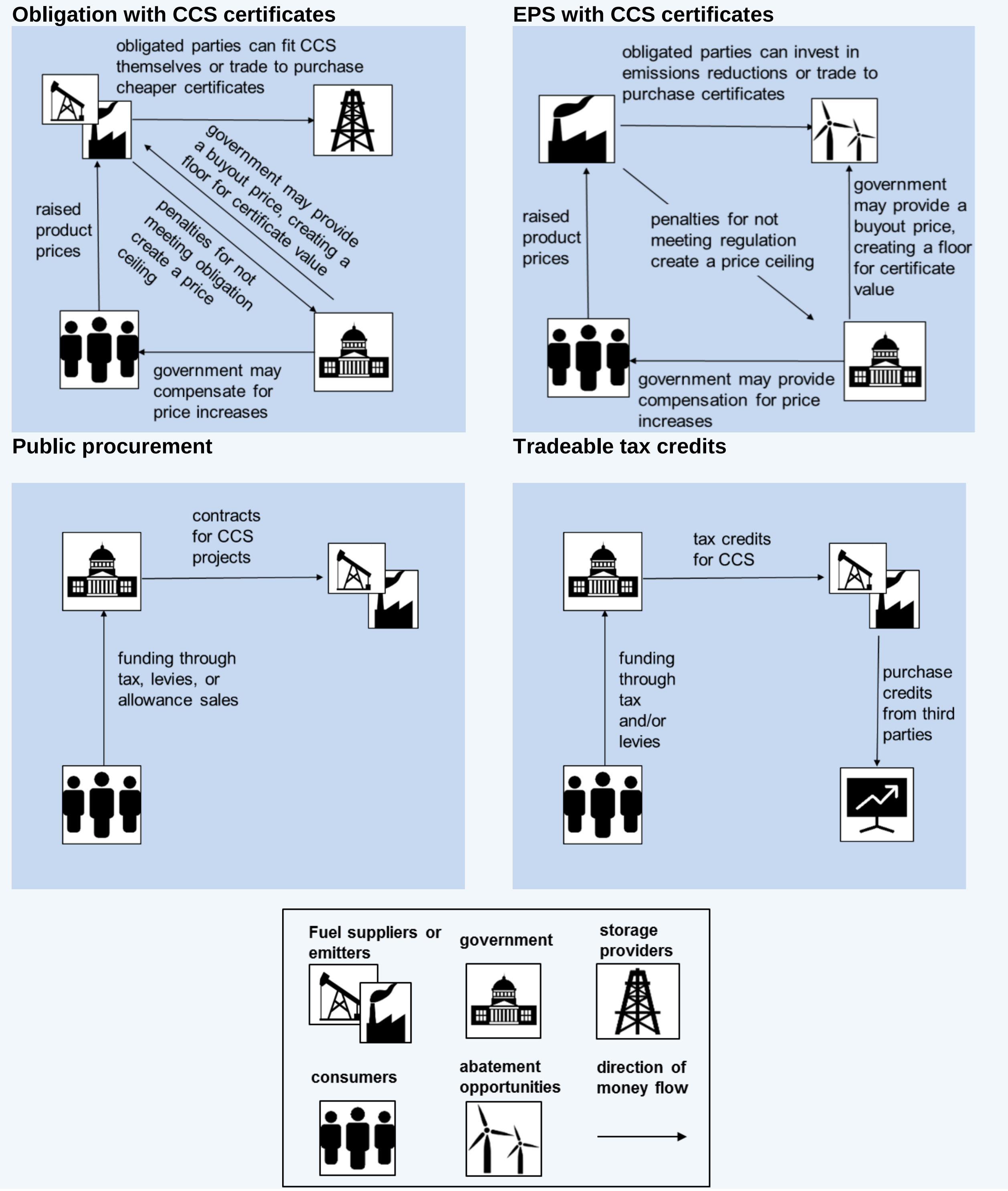
Table 2 Overview of policy types and objectives

Market failure or barrier to investment	Policy instruments
Carbon externality	• Emissions trading scheme (ETS) • CCS obligation • Tax credits or subsidies • Sector-specific carbon tax • Public procurement • Emissions performance standard
Barriers to infrastructure investment	*Ownership structure* • Government-owned company • Public body • Private *Natural monopoly regulation* • Price regulation • Quantity guarantees
Complementary measures	*Storage liabilities* • Liabilities underwritten by government • Collective insurance arrangements *Storage preparation and maintenance* • Storage appraisal • Taxpayer-funded post-operation maintenance • Independent fund for post-operation maintenance *Financial support* • Credit guarantees • Co-investment equity • Debt provision • Insurance products *Planning consents* • Siting arrangements for pipelines • Access arrangements

The four policy instruments analysed here were selected for their relative effectiveness, efficiency and feasibility in supporting the build of CCS. The four selected policy instruments, from a long list of candidate instruments, are graphically summarised in Figure 4, and discussed in detail in Section 5.3. As a preamble, the following provides a headline summary for each policy:

- **Obligation with CCS certificates:** Emitters or fuel suppliers are obligated by law to ensure a certain amount of CO_2 is captured and stored. Certificates are awarded for storage and can be used to meet the obligation and traded freely.
- **Emission performance standards with CCS certificates.** An EPS sets minimum emission standards by which emitters must abide. The tradeable certificates function similarly to the obligation scheme and can be used to meet the standard.
- **Public procurement** entails the government directly procuring CCS. It does not imply the government necessarily funds CCS.
- **Tax credits** are reductions in the tax liability of firms if they perform CCS. Credits can be provided for stored carbon but also for capital investment.

Figure 4 Overview of four policies chosen for further analysis



5.2 Phasing of policy instruments

Phasing is needed because market based mechanisms may not be effective during scale-up. Without a sufficient number and scale of suppliers of CO_2, transport and storage services, a market mechanism will not function well because of the large uncertainty surrounding price and volume. The risk premium demanded by suppliers of first-of-a-kind installations is likely to be higher than any offer, incentivised by obligations or other market instruments, and the market might fail. There are two reasons behind this. First, there are few projects and so there are few transactions. With a thin and illiquid market, in other words with low trade volumes, price formation is inefficient and prices volatile. It is difficult for both buyers and sellers to ascertain what the fair market price is. Second, first-of-a-kind costs are usually significantly higher than the costs of subsequent projects, which means that certificate prices fall over time, making it possible that first-of-a-kind assets will become stranded.

During scale-up, the private sector cannot efficiently bear the risks associated with CCS and hence government may absorb the majority of these risks to encourage CCS deployment. Although technical risk can be further reduced during the scale-up phase, the scale-up phase is necessary to establish and demonstrate the financing, commercial and administrative arrangements surrounding CCS and create the capacity, coordination and trust between emitters, transport and storage providers. So long as these practices are immature, private actors will perceive unacceptable levels of risk.

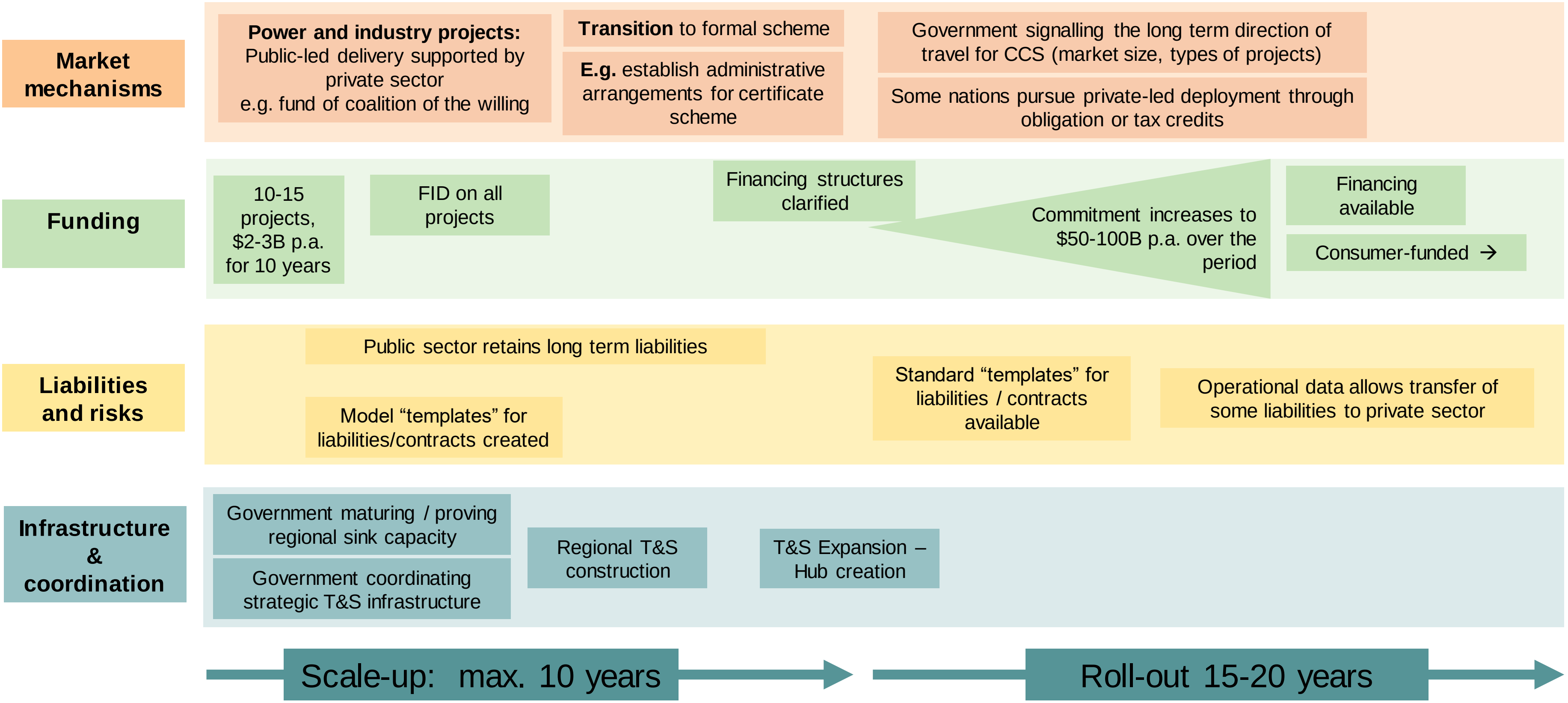
It is necessary to prepare the roll-out policies during the scale-up phase, in order to plan a smooth transition to a long term CCS market. A clear, early picture of a future CCS market is critical for financing reasons as it allows:

- Private actors to anticipate market conditions and hence investment needs, which is crucial for investor confidence and also a practical necessity given the long lead times of investment in the power and industrial sectors.
- Government to potentially justify public investment during the scale-up phase, some of which may be recouped through the sale of CCS assets during the roll-out phase.

In addition, with a clear future policy design, the scale-up phase can be used to lay and test the foundations of a future market based policy, such as a certification system for stored CO_2. In practical terms, the implementation of a market policy may take five years from inception.

Scale-up and roll-out have distinct objectives and policy needs: Policy support in the early scale-up phase should be focussed on primary objectives of derisking the application of the technology in key markets. To do this, there should be a focus on delivering a limited set of successful archetype projects in a short time. To avoid unnecessary delays, a 10-year time-frame is indicated for scale-up; a focus on deliverability, and leveraging skills of the chemical, pipeline, and oil and gas sectors, would allow this period to be reduced. The transition into roll-out is given by a number of elements such as cost and developed storage capacity, which in combination provide sufficient certainty for private investment. Towards the end of this period, successful confidence building is indicated by the public sector structuring its longer term commitment, by a standardised framework for contracts and liabilities, a pipeline of projects and by the build-up of industrial capacity necessary to deliver these. An indicative timeline for scale-up and roll-out is given below.

Figure 5 Timeline for CCS delivery



5.3 Policy assessment

The following policy assessment focuses on roll-out phase policies. This is partly since market mechanisms are unlikely to function well during scale-up. The focus on the roll-out phase provides a medium and long term direction for CCS development. The transition to a roll-out policy can already be set in motion during the scale-up phase, so the future roll-out policy in part determines policy during the scale-up phase. Hence, alongside each roll-out policy assessment sits a brief comment on the transition between scale-up and roll-out. To complete the picture, the assessment considers the important role public procurement may play.

The policies are assessed along six dimensions, capturing practical elements around the efficiency, effectiveness and feasibility of a policy. The criteria are defined in Table 3.

Table 3 Rating criteria for policy assessment

Dimension	Definition
Strength of incentive	The revenue available for delivering carbon storage and its certainty. Price and volume risk are considered in this category, as well as technology risk if the policy encompasses technologies other than CCS.
Financeability and risk	The level of risk the private sector bears. The risks include: • Development; • Construction; • Market; and • Counterparty. Policy risk is critical to financeability, but is assessed separately.
Policy risk	The risk of government reneging on future commitments. Key aspects include whether the policy imposes a significant cost on government, whether total cost can be controlled, and the legislative ease with which the policy can be changed.
Track record	Whether similar policies have spurred capital investment in other sectors.
Efficiency	Efficiency is high if key performance metrics (such as the $/t$CO_2$ cost of delivering CCS) is low.[1]
Competitiveness and affordability concerns	Competitiveness concerns arise if high costs are borne by carbon-intensive trade-exposed sectors. Affordability concerns arise if CCS costs raise prices of goods consumed by poor consumers. The distribution of costs is assessed assuming there are no mitigating instruments available to make the distribution of costs less regressive.

Note: 1 Economic arguments suggest that, because of the uncertain costs of CCS, it is efficient for the policy instruments to become more price based as scale builds (Hepburn, 2006).

Each policy is analysed in turn in sections 5.3.1 to 5.3.4, with a description of:

- key strengths and weaknesses of the scheme;
- a transition path from scale-up to roll-out;
- design details;
- policy implementation risks.

5.3.1 Obligation with tradeable CCS certificates

The obligation scheme is rated favourably compared to the other policies, with particular strengths in policy track record and efficiency. The following paragraphs highlight key strengths and weaknesses along criteria described in Table 3, with the assessment presented in Table 4 and Figure 6. A more detailed discussion is laid out in Section 7.2.

A tradeable obligation scheme allows price discovery and can be effective and efficient in a large market. By allowing trading of CCS certificates, CCS investment is channelled to where it is most productive. That is, obligated parties who face relatively high costs per tonne of CO_2 can elect to purchase certificates from operators who can perform CCS at lower cost, improving the efficiency of CCS deployment. In addition, past and current obligation schemes have proven effective in spurring significant renewable energy investment in a number of countries, including the US and UK. However, the proposed market mechanism will function well only if the certificate market enjoys a degree of liquidity, which it would lack during the scale-up phase.

Table 4 Assessment of obligation with CCS certificates

	Key features
1	The incentive acts through an uncertain certificate price, although elements such as a price floor and ceiling can reduce uncertainty. In part chain projects, storage providers face volume risk as they are dependent on CO_2 flow from emitters. This risk also exists for projects where operators capture, transport and storage, but is internalised within the firm.
2	Government does not absorb any risks through this mechanism.
3	Tradeable obligations have track record in securing high capex renewable energy investment in a number of countries including the US and UK.
4	Obligations involve the creation of markets and long term legal requirements, which makes reneging on the policy more difficult and costly for government. Instead of abandoning the whole scheme, the main policy risks arise around • The level of the obligation, which drives the certificate price and hence return on investment. Government may be tempted, usually in the face of industrial lobbying, to weaken the price by loosening the obligation. One solution is to introduce a price floor. • The level of financial support from the government, through for instance buying up certificates. Unless contractually obliged, government may be tempted to wind down a certificate buying program more quickly than initially indicated.
5	For large volumes, the market mechanism is likely to allocate resources more efficiently than government. However, a pure quantity instrument may perform less well than a price instrument.
6	An obligation on emitters may raise affordability concerns relating to power consumers and competitively-exposed industrials. These concerns may be smaller for an obligation on fuel suppliers.

Without further policy support, the obligation scheme places significant risk on the private sector. The scheme rates poorly on financeability. This is because investment revenues depend upon the certificate price, which is uncertain. There are two primary ways for government to reduce this uncertainty:

- Government can act as an intermediary for contracts between certificate buyers and sellers, in order to provide volume certainty, see Section 5.6. A further benefit is that this may reduce counterparty risk.
- Government can implement a price floor and ceiling for certificates to reduce price uncertainty, see Section 5.6.

An obligation scheme might be phased in gradually during the scale-up phase. During scale-up, certification procedures for CO_2 stored could be implemented. The government may then start to write payments per certificate into its scale-up procurement contracts, and gradually taper its own demand for certificates as it increases demand from suppliers or emitters by raising the obligation on them.

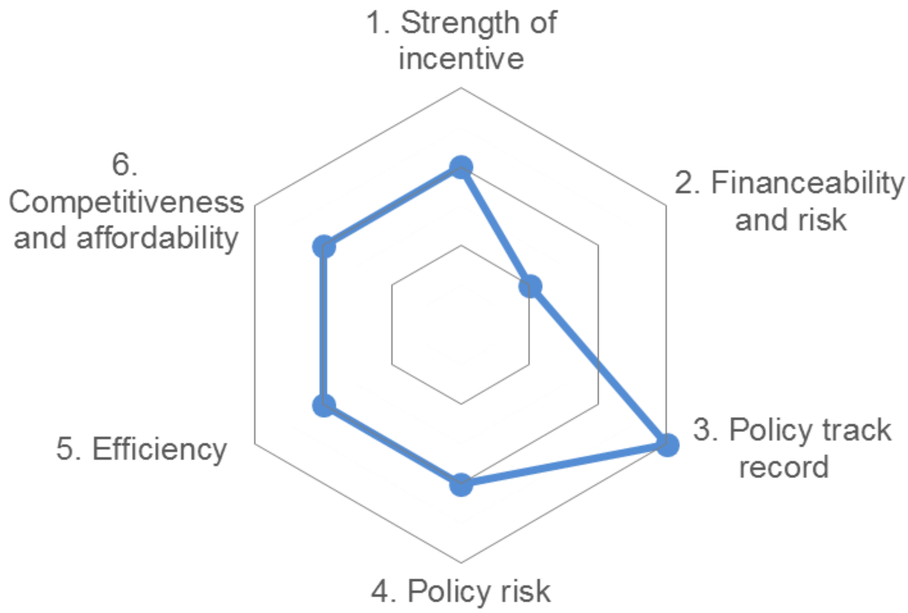
There is also an opportunity for government to act as a supplier of certificates, using the CCS infrastructure it procured in scale-up to recoup some of its initial investment. If the government procures a number of projects during scale-up, it can sell the certificates generated by the stored CO_2 to an obligated party, which may be, for example, a power station or fuel supplier. The prospect of these revenues defrays the final cost to government of initial funding during the scale-up phase.

The placement of the obligation is a key design consideration for an obligation scheme. Either emitters, such as power generators and industrial facilities, can be obligated, or the obligation can be placed on fuel suppliers. A third option, placement on storers, is less favoured, see Section 7.2.4. In both the emitter and supplier obligations, the obligation might be defined in terms of a percentage of CO_2 associated with the fuel. Placing the obligation on fuel suppliers could have three benefits over an obligation on emitters:

- A number of fuel suppliers, particularly some O&G companies, have the technical capability to build and operate full chain CCS projects, performing the capture, transport and storage aspects of CCS, but not all fuel suppliers have this capability.
- If the obligation is placed on *all fuel supplied,* instead of fuel supplied to emitters who can install CCS, the costs of the obligation would fall on a larger base and the burden of CCS would be spread more thinly.
- It may be administratively simpler since there are far fewer suppliers than emitters. However, in some jurisdictions, such as those where an ETS has been implemented, existing administrative processes for emitters would make the additional administrative burden slight.

On the other hand, placing the obligation on the emitters has an advantage over placing the obligation on fuel suppliers. The CCS capture plant is associated with the previously emitting plant. For this reason, it is contractually simpler to apply the obligation to the emitter: it reduces counterparty risk. For example, in the situation where the obligation is placed on the fuel suppliers, a fuel supplier may contract a particular steel plant for a supply of CO_2. However, if that steel plant reduces production as a result of a decline in the price of steel, and hence its supply of CO_2, the fuel supplier remains obligated for the same amount of CO_2 but now cannot fulfil its obligation. In contrast, if the obligation is on emitters, the steel plant's obligation would have been less because it burned less fuel when it decreased production.

Figure 6 Assessment scores of obligation with CCS certificates



5.3.2 EPS with tradeable CCS certificates

The proposed emissions performance standard (EPS) scheme rates relatively poorly on strength of incentive, financeability and policy track record. The paragraphs below discuss these relative weaknesses along criteria described in Table 3, with Figure 7 and Table 5 presenting the full assessment.

An EPS is technology neutral and therefore unlikely to incentivise CCS to the same degree as the other proposed schemes. As shown in Figure 7, the EPS rates poorly on the strength of incentive as the scheme not only involves price and volume uncertainty in the certificate market, similar to the CCS obligation, but also incentivises other technologies, such as renewable power, rather than CCS. This scheme thus sits in between an economy wide emission reduction scheme such as an ETS, without the full efficiency benefits of a broad scope ETS, and the other CCS specific policies, without the benefit of effectively developing CCS by focussing efforts on one policy, discussed in this report.

Table 5 Assessment of EPS with CCS certificates

	Key features
1	Price and volume uncertainty in the certificate market reduce the incentive to abate, in similar fashion to the obligation scheme. In addition, alternative technologies to meet the EPS can lead to less CCS being deployed.
2	Government does not socialise any risks through this mechanism.
3	An EPS for CO_2has been implemented in a number of jurisdictions. It has not been combined with CCS certificates anywhere. While it has successfully deterred investment in unabated coal-fired power plants, it has not encouraged CCS investment. For other gasses such as NOx and SOx an EPS has been effective in reducing emissions from thermal generation; however, SO_x and NO_x abatement is arguable easier and these standards did not need to encourage significantly different technologies such as CCS.
4	Although government can renege, it has no strong reason to do so since its financial burden is light.
5	In a large market, the mechanism is likely to allocate resources more efficiently than government. This is a quantity mechanism, which may be less efficient than a price mechanism.
6	An EPS imposes costs on emitters, potentially creating affordability issues in power and competitiveness issues in industry.

The EPS can be defined in terms of average gCO_2/kWh for the power grid, whereas for the industrial sector the standard may be industry specific, such as $kgCO_2$/tonne product, similar to the ETS benchmarks.

- For the power sector, the power producers can perform CCS or purchase CCS certificates to bring the average gCO_2/kWh of their generating portfolio below the emissions standard. This requirement can be met through use of CCS or fuel switching or through deployment of renewable energy. The standard is placed on the portfolio level instead of on the facility level to avoid creating excessive costs for individual installations.

- In industry, the defined standards might be modelled on the emissions trading scheme benchmarks and be product based. For example, the allowable CO_2 intensity for steel production could be defined as tCO_2/t crude steel produced. The definition of benchmarks is a significant administrative undertaking.

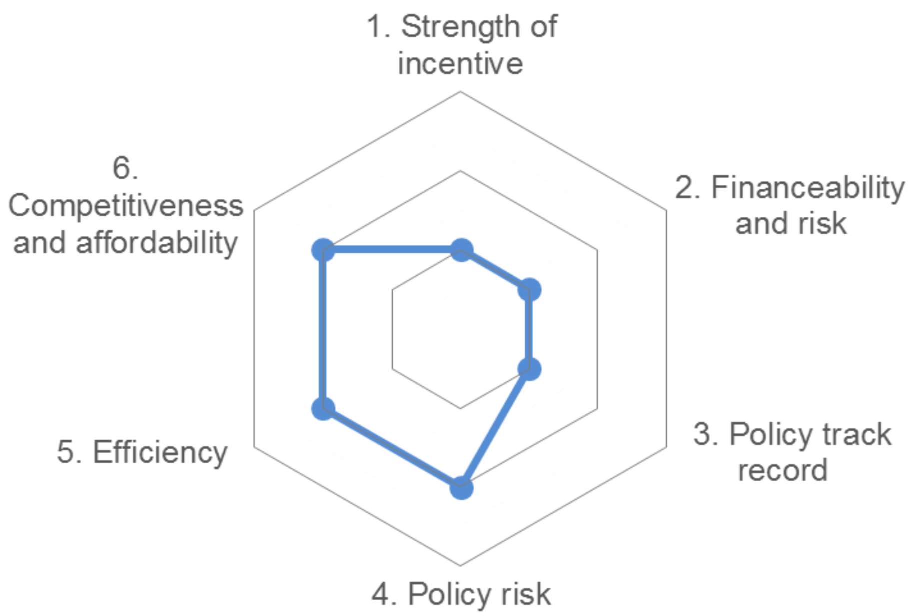
There is an alternative definition of EPS which only applies to fossil power generators. In this version, new or both new and existing fossil fuelled power plant have to comply with an emissions intensity standard. The portfolio over which the standard operates is over all fossil plant rather than all power plant. It can only be met by making fossil plant more efficient, switching fuels and fitting CCS. Thus, if the standard is tight enough it demands the use of CCS.

Both definitions of EPS can involve a market element. Like the obligation with tradeable CCS certificates, the market aspect yields efficiency benefits, together with potential drawbacks for financeability. The market would function in the same way as proposed for the obligation scheme, with demand created by the ability of generators to use CCS certificates to meet their EPS. However, because the EPS creates demand for a wider range of emissions abatement options, making it more efficient in securing abatement, it may create less demand for CCS certificates.

Although EPS schemes have been implemented in a number of jurisdictions, they have not been used to encourage investment in low emissions technologies. The EPS scores poorly on policy track record for this purpose, as shown in Figure 7. Instead of spurring investment in, for example renewable energy, EPS schemes have to date mainly functioned as a deterrent from building new unabated coal-fired power plants.

Similar to an obligation scheme, an EPS can be ramped up by gradually increasing the stringency of the EPS to increase certificate demand. This would increase the demand for CCS certificates over time. Initially the demand could be met by CCS installations built during the scale-up phase, providing an opportunity to recoup some investment. With an increasingly stringent EPS, demand for certificates would incentivise additional CCS to be deployed.

Figure 7 Assessment scores of EPS with CCS certificates



5.3.3 Public procurement

Public procurement offers strong incentives for CCS deployment and lends itself well to the socialisation of risks. These strengths, together with concerns about the risk of government reneging and the financing burden for government, are discussed below along criteria described in Table 3. Figure 8 and Table 6 summarise the full assessment.

The incentive for CCS deployment is strong insofar as the government designs contracts which minimise or eliminate volume and price risk for CCS developers. For example, government can offer contracts in terms of a set \$/tCO_2payments to eliminate price risk and can offer availability payments to transport and storage providers, reducing volume risk. Government is a reliable counterparty (in most countries) and can offer contracting structures to reduce development risk, as described in more detail in Table 6.

Table 6 Assessment of public procurement

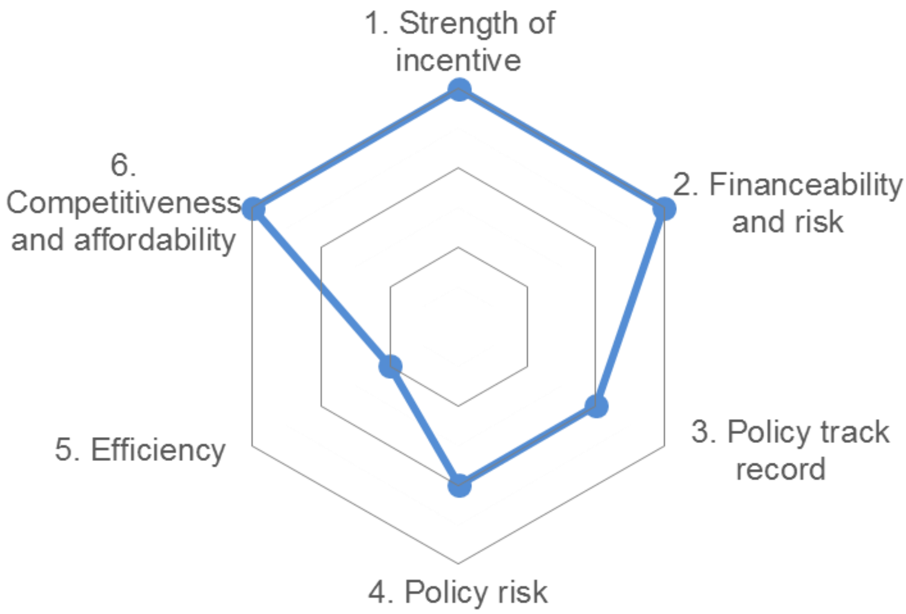
	Key features
1	Contracts provide a strong revenue incentive with minimal revenue uncertainty as government can build in guaranteed payments for availability and a set price per t/CO_2.
2	Government can socialise development and construction risk by offering payment upon delivery of CCS infrastructure. By acting as a counterparty itself, it minimises counterparty risk.
3	Public procurement is a common tool for large infrastructure developments and has successfully spurred investment. However, there have also been examples of failed or cancelled projects, including in CCS.
4	Once committed to contracts, government has no opportunity to renege. However, the potentially high cost to government, depending on funding structure, may lead it to abandon or scale back at programme level.
5	In a large market, government is unlikely to be sufficiently informed to allocate resources to the most cost effective projects, though this might be mitigated through the use of auctions.
6	The degree of competitiveness and affordability issues depend on how government funds its procurement, for which it has a number of options.

Although public procurement provides strong incentives for CCS deployment, it is likely to be inefficient, especially at scale. While there are potential economies of scale, particularly in transport, which can be achieved with government-led coordination, a market mechanism is likely to deliver greater efficiency than government procurement. This is because, particularly as the market for CCS grows, government will likely hold insufficient information to find the least cost options.

Even though the government directly procures CCS, it may not fund it. The government could fund contracts through general taxation but it also has options to levy, for example, fuel consumers (emitters) or suppliers. For more detail on funding options and the general distribution of costs, see Section 5.4.

The method of procurement can significantly affect the efficiency of this policy instrument, and may be varied from scale-up to roll-out. During scale-up, government procurement is likely to involve bespoke, project specific contracts which socialise a high degree of risk. These could target individual opportunities for CCS, for example establishing a CCS hub around an industrial cluster. As the number of CCS projects grows, government might establish an auction system for contracts, ranked in terms of \$/tCO_2stored, which would return risk back to the private sector. Specifically, government may withdraw from shouldering development and construction risk as the CCS industry matures during scale-up. Auctions may encourage competition and through them, governments may find the lowest cost CCS opportunities, so long as there is no manipulation through strategic bidding. Even if government uses auctions, it would miss out on other aspects of efficiency, such as innovation in contracting that a dynamic market might deliver.

Figure 8 Assessment scores of public procurement overview



5.3.4 Tradeable tax credits

Tax credits perform well on efficiency, competitiveness and affordability, but the tradeable element remains unproven and government has an incentive to renege. The text below discusses these key strengths and weaknesses along criteria described in Table 3 are discussed below, with Figure 9 and Table 7 presenting the assessment.

Tax credits might provide a strong incentive for CCS take-up, so long as developers are able to sell on the credits. The key benefit of a tax credit, for the private sector, is the certainty of the price signal. Given the individual size of CCS projects, it might be that only large firms would be able to deduct the full value of tax credits off their own tax liability. Consequently, tax credits may be made tradeable, allowing CCS operators of any size to take advantage of the full incentive on offer. Such tax credit trading is not common practice; the foremost example of transferable tax credits is a number of US states. For example, the MGM Grand Casino in Las Vegas recently purchased, for close to face value, $20 million of tax credits Tesla had accrued from the State of Nevada for building its battery factory in the State (Jones, 2016). The volume of typical tax credit trades seen to date is smaller than would be required in a functioning CCS tax credit trading scheme.

Table 7- Assessment of tradeable tax credits

	Key features
1	Tax credits provide a strong incentive, if set at a sufficient rate, and price certainty. Volume risk is left with the CCS operator.
2	Tax credits per t/CO_2 do not socialise any specific risks (except for price risk). Tax credits on capital investment may reduce construction and development risk as the net upfront costs to the developer are reduced.
3	Tax credits are widely used, but are typically intended to add to an existing revenue stream and marginally increase investment, instead of in the proposed context, where they would be the main revenue source and investment incentive. For the scheme to work effectively, tax credit trading would have to work effectively at large scale. This is currently not commonplace.
4	Government can easily change the tax code, and may be tempted to do so if the credits reach a level of significant cost. Unless guaranteed by contracts, any change in tax treatment can affect all current operating projects.
5	This is a price mechanism, which may be more efficient than a quantity mechanism. It could scale to a large market.
6	Competitiveness and affordability issues are dependent on how government funds the tax credits. Without additional instruments government funded procurement would not create affordability or competitiveness concerns for consumers and competitively-exposed firms.

The tax credits scheme could be a combination of operational credits provided per t/CO_2 and initial tax credits for capital investment. The combination could mitigate some of the initial construction and development risk for CCS developers. Tax credits for capital investment have been provided in a number of countries including Australia, Canada and the US totalling multiple billion USD (Price, 2014). The provision of tax credits per t/CO_2 stored has been at a smaller scale to date. For example, the US federal 45Q tax credit, which provides \$20/tCO_2 for non-enhanced oil recovery storage and \$10/tCO_2 for enhanced oil recovery storage, is predicted to have a total outlay of \$700 million in the period between 2014 and 2018 (Banks & Boersma, 2015; Legal Information Institute, 2014); however, the US is currently considering raising the tax credit to \$50/tCO_2 (Global CCS Institute, 2016c).

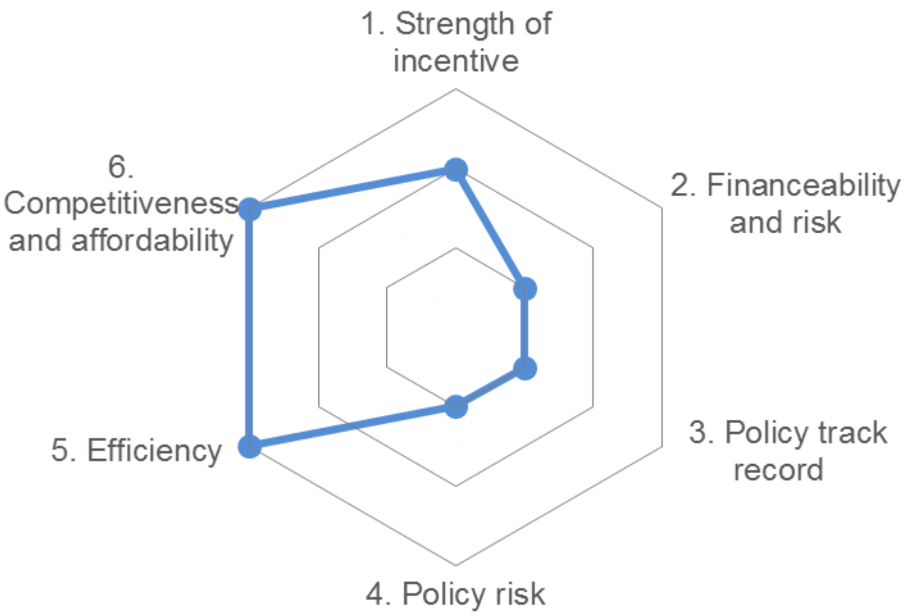
Tax credits are likely to be a relatively efficient instrument, but can be prohibitively costly for government. Tax credits are a price based instrument which, as mentioned in Table 3, economic theory suggests would be efficient in the delivery of CCS. The downside of tax credits is that government commits to a large amount of funding passing through its books. It could potentially recoup the cost of tax credits through specific levies on, for example, fuel consumers or suppliers. These costs to government, combined with the relative ease of changing tax codes, create a significant policy risk, as indicated in Figure 9, because governments are always under pressure to find expenditure savings.

Tax credits can be offered in the scale-up phase. The tax credit could serve as an element of the incentive for CCS deployment in the scale-up phase, and could also continue through the roll-out phase.

Uniform tax credits could perversely incentivise high emission projects. A tax credit is an abatement subsidy. High carbon intensity sources, such as coal-fired power stations, would command larger quantities of tax credits, relatively speaking, than lower carbon intensity sources, such as gas-fired power stations. Where both types of source compete in the same market, a tax credit could have the perverse effect of encouraging a shift towards

CCS-abated carbon-intensive sources, if the tax credit rate is sufficient to cover the full costs of CCS. In order to prevent this, the level of the tax credit could be made dependent on the source of the CO_2 emissions.

Figure 9 Assessment scores of tradeable tax credits



5.4 Decision making rules and CCS policy

CCS contributes to decarbonisation in virtually all decarbonisation projections. CCS plays a role across the global, deep carbonisation projections of many authors. Nevertheless, the scale of its deployment remains quite uncertain.

The 'with without' test shows the value of CCS. Like any cost benefit analysis, the value of CCS is given by comparing the costs of scenarios in which CCS is deployed and scenarios in which it is not deployed; the 'with without' test. For example, global integrated assessment models agree that CCS is an important component of the lowest cost decarbonisation pathway[14]. The aspect which makes this analysis unfamiliar to many governments and firms is uncertainty. This presents an obstacle. Uncertainty is a challenge for decision-makers, who have a standard set of assessment tools for dealing with certain, that is sure, events, and can also compute the costs and benefits of action where risks, that is probabilities, are known.

Decision science shows how to handle value under uncertainty. When the future value of CCS is poorly understood, the appropriate decision-making framework is less clear. In this context of ignorance, standard decision theory tends to propose two simple rules, which differ in the degree of caution they imply. 'Maximin' chooses the policy option that results in the least worst case. 'Minimax regret' chooses the policy that minimises regret, in terms of the difference between the best and worst cases. These two rules might be put to use to good effect in explaining the value of CCS[15].

Maximin and minimax regret decision rules operate without reference to probabilities, instead they operate on a set of outcome values. Maximin selects the option that offers the least-bad worst case, so that if the worst case occurs, at least it is not as bad as it could have been. This is equivalent to having an infinite level of risk aversion in a context where probabilities are known, which shows why it is not generally recommended for decisions under risk. The mitigation cost of such extreme caution may well be high, as the choice with the best worst case may not be the best choice with other cases. Furthermore, the probability of the worst case occurring may be small.

Minimax regret selects the option that minimises the maximum regret. Regret is the difference between the best case and the worst case. If regret is minimised then the best opportunity our choices present is not ignored. In contrast to maximin, minimax regret is less cautious, because it trades off the severity of the worst case with the benefit of the best case. However, minimax regret still ignores the value of intermediate cases and the probabilities of the best and worst cases occurring. These decision rules apply caution in situations where probability information is lacking altogether. Decision rules under ambiguity are a work in progress in decision theory. As yet, there is no consensus on their application. However, the minimax regret rule offers a practical solution to the problem of valuing CCS policy action without embedding excessive caution in the analysis. It is feasible to prepare the regret tables and carry out the analysis using these decision rules, and to do so from the perspective of both government and firms.

[14] IPCC, Fifth assessment report, Mitigation of climate change, 2014
https://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_full.pdf

[15] Vivid Economics (2011), 'Aggregating, presenting and valuing climate change impacts'.

5.5 Distribution of costs

There may be political economy limits to the burden of costs which any group or party can bear. There are three groups on whom the costs of CCS can fall: taxpayers (through government), consumers and shareholders. There may be limits to the willingness of each of these parties to accept costs, driven by the trade-offs each group has to make. In particular, these limits concern the amount of expenditure government can divert from public services; the amount consumer energy prices can increase before political opposition becomes too great (impacting government's willingness to impose more costs on energy consumers); and the amount of cost firms can absorb before significant swings in investment occur across jurisdictional or policy scheme borders. Some groups of firms, in some sectors, will be more susceptible to investment swings than other firms and sectors, because of the nature of their carbon intensity, profitability, customer price sensitivity and the competition that they face.

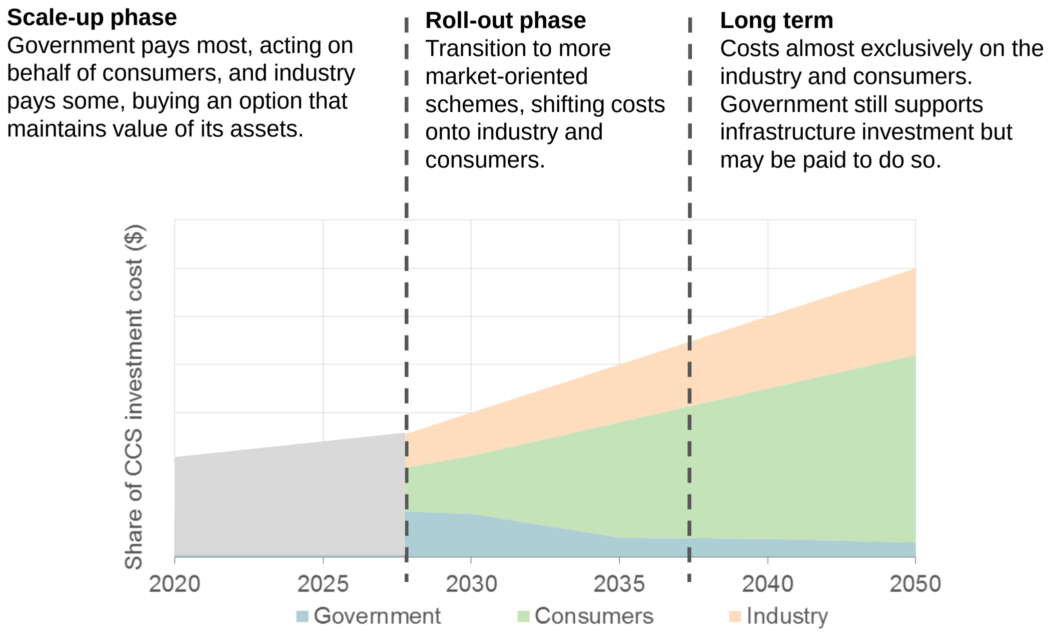
The polluter pays principle is well established in many jurisdictions. In Europe and North America in particular, legislators claim to apply the polluter pays principle, requiring the burden of the costs of mitigating pollution to fall on the polluters themselves. The principle is championed by environmental NGOs but is rarely implemented in full by governments. For example, many polluting sectors in Europe have been granted so many EU Emissions Trading Scheme allowances in the past, that rather than bear costs from the scheme, they have enjoyed windfall profits at consumers' expense. Even so, an offer which appears to conflict with the polluter pays principle may not be politically acceptable.

The policy options encompass a range of ways in which the burden of costs can be allocated between the three parties. They fall broadly into three approaches: a levy on consumers, emitters or suppliers; taxpayer funding; and obligations on emitters or suppliers. A *levy* on consumers can be imposed on final consumers of goods, or final consumers of fuels. It can also contain exemptions for specific types of consumer such as small consumers and households. A levy can be raised instead or in addition on emitters of carbon dioxide and/or suppliers of fuels. Some of these levies will involve new administrative arrangements in some jurisdictions and others will not. There is political capital involved in introducing new levies, especially on consumers. A levy can be used to pay for public procurement or to fund an obligation taken on by government. *Treasury funding*, in which the costs are paid for by general taxation, or are hypothecated from direct taxes on energy or carbon, can be used to cover the costs of tax credits, public procurement or an obligation taken on by government. In the case of both levies and Treasury funding, where the government takes on an obligation, it can cast that as an Advance Market Commitment, where the government promises to purchase a specific or minimum volume of carbon storage at a specific price. Models for advance market commitments have been developed for pharmaceuticals supply in less developed economies. Finally, *obligations placed on firms* assign the initial incidence of costs to them, as in the obligation and the emissions performance standard options. Any combination of these cost application options can be employed together, allowing a very flexible allocation of the costs, to achieve whatever initial cost incidence is desired.

All parties will have to contribute to costs. It is difficult to imagine an agreement where one party picks up the entire bill for CCS. Experience from renewable electricity is diverse. In Europe, the consumer has picked up most of the bill through first an obligation on suppliers and then a levy. As the bill has risen, energy-intensive trade-exposed firms in some jurisdictions have been relieved of their burden. In the US, the government has picked up much of the bill through tax credits.

It is likely that the distribution of burden will shift over time, away from government and towards consumers. There are several reasons for this. First, the public good aspects of research, development and deployment, which are heavily supported by government, become less important as the technology becomes more mature and the cost reduction rate over time declines. Second, as the rate of carbon capture increases through the adoption of the technology, a larger base is needed to fund it. Third, a possibility is that specific policies supporting CCS will, in the very long term, be replaced by general policies such as taxes and trading systems that operate through a carbon price. Except through the allocation of allowances for free, there is little scope for tailoring the incidence of these policies and their incidence falls mostly on consumers, except where there are competitiveness effects across borders. The changing pattern of incidence is shown in Figure 10.

Figure 10 All parties will have to contribute to costs, but the balance shifts over time towards consumers



5.6 Risks and financeability

CCS investments carry all the usual risks of asset construction projects plus several sector-specific risks. The usual risks such as construction risk, technology risk, changes in market prices of energy or manufactures, and operational risk all apply to CCS. In addition, CCS faces specific risks around the future value of policy support, the volume of demand for carbon dioxide transport and storage on individual pieces of infrastructure, and store leakage risk. The market can absorb some risks efficiently and not others. The market is certainly able to absorb the commercial and market risks. The commercial risks are common across these and many other types of investment. The market will learn to absorb technology risk as it gains experience with the assets. The market will be able to absorb policy risk, but at a price, so that it may not be efficient for government to transfer that risk to market participants. The price is high because, in principle, it is preferable for the party which can manage the risk to absorb it, which in this case is the government; and second, because if the market takes the risk, government faces no direct incentive to honour its policy commitment. Lastly, the market will fail to bear leakage risk. Although contracts might be written to transfer the risk, they will be incomplete because firms may not survive in the long-term to stand behind them. Thus, the public interest may be better served to place the leakage risk with the government in the long term.

A package of measures can cover difficult-to-transfer risks. Since most investment during scale-up is public, these measures are mostly applicable in the roll-out phase to support private investment, although they would be required to support private investment during scale-up as well. The candidates for mitigating policy risk are price floors and caps, together with minimum revenue or market size guarantees. Price caps and floors give greater certainty to asset owners of the value of carbon dioxide capture and storage. These price limits can enhance the functioning of a tradeable obligation or EPS, where the future price otherwise depends entirely on future policy demand and costs of supply and can be highly uncertain. Minimum revenue or market size guarantees also reduce policy risk and could potentially reduce counterparty risk and make contracting easier. For a storage or network operator who depends on the adoption of CCS by various customers, a specific market size or revenue guarantee would reduce the risk of asset stranding. For the market as a whole, a market level guarantee ensures that there will be a minimum aggregate level of market demand to contract with the supply that firms may develop. Contracting may be made easier if the government enters the market to write contracts and allows third parties to co-contract with it, reducing search and legal costs and giving greater reassurance that the contract will be honoured or enforced.

The socialisation of storage liabilities may make CCS easier to finance. There is no market for insurance of seepage or leakage risks because the conditions for insurance markets to function are absent. First, there is no established record of long term leakage rates and those rates are expected to be very low, making them hard to measure accurately. Second, though storage sites may be independent of each other and not linked, the mechanism for leakage at one site could apply to others. This prevents the risks from being pooled. Third, the risks are extremely long term and insurers may not persist long enough to honour insurance contracts.

Governments will have to adopt storage liabilities. Like coal and nuclear liabilities, there is no substitute for government taking on long-term storage liabilities. There are two options for how they are funded. One is for the taxpayer to fund them outright and the other is for a fund to be set up, managed by government, into which storage site operators pay over time. Following previous precedent, the government is likely to collect contributions from operators and either establish a ring-fenced account or a fund, or receive the monies into its general purse.

Governments may offer risk transfer instruments for novel markets. It may be difficult for developers to secure finance to build carbon dioxide networks and stores, because of the novelty of the market, or because of a mixture of the novelty of market, technology and business model. One scenario is that only large existing companies with the balance sheet strength to absorb these risks enter the market. Another scenario is that government steps in with additional share equity or with credit guarantees, either of which might satisfy the concerns of creditors as to the financial viability of the financial vehicle. In this way, it might encourage independent network and storage operators to enter the market. Such an intervention carries the risk of crowding out other entrants, so it would be worthwhile carrying out some market testing before embarking on such a proposal.

Table 8 Risk allocation and mitigation options

Policy	Risk allocation	Options for risk mitigation
Private-led delivery	*Government* carbon price risk *Private sector* volume of sales construction development	price floor price ceiling buyer of last resort government-backed counterparty advance market commitment credit guarantee equity support
Public-led delivery	*Government* carbon price risk revenue *Private sector* construction development	credit guarantee equity support development compensation

5.7 Infrastructure

A policy instrument solely focussed on providing revenue for stored carbon is likely to result in inefficient infrastructure investment. As with other infrastructure with network benefits, such as railways, electricity grids, or gas grids, the market is likely to inefficiently provide the infrastructure pushing up the overall price of CCS. This provides a rationale for public intervention and investment in transport and storage infrastructure *in addition* to the main CCS policy instruments described in Section 5. The options described below are compatible with any of the main policy instruments.

There are several options for the ownership of CCS transport and storage infrastructure. The ownership of the infrastructure is part of the policy question, because whatever risks are not transferred by ownership could be transferred through policy instruments instead. A consideration in the question of ownership is the effectiveness of risk transfer through policy instruments. The three ownership options are a public agency or government owned company; a public private partnership; and private ownership. Any of these are possible. In the first case, the government owned company may not be contractually protected from risks, but its shareholder, the government can make directions to the Company Board and can choose to accept the impact of those risks on the return on the company's assets. In the second case, a public-private partnership, the return paid to the private party on its investment may be insulated in part or fully from some of the risks through the partnership contract. In the third case, the privately-owned company may be protected through policy instruments which could include specific risk transfer contracts.

Two of the possible risk transfer instruments are availability payments and a minimum revenue guarantee. The availability payments make some of the revenue of the infrastructure asset independent of the volume it carries or stores. The minimum revenue guarantee ensures that the investors are not exposed to volume risk below a minimum threshold, which would presumably be set to deliver a minimum reasonable return on capital, or, less generously, to secure repayment of creditors.

The case for policy intervention either through ownership or risk transfer instruments is strongest for part-chain projects. In part-chain projects, the capture, transport and storage are performed by more than one actor. Then, while the principal CCS instrument might be imposed on one actor, the other actors rely on contracts with the prime actor. This vertical separation in the supply chain could deter investment if it turns out to be difficult to coordinate timing of investment and if the value of the investment to one actor is not felt by the other actors.

Table 9 Ownership remedies

Ownership structure	Example
Public agency or public company	Proposal by UK CCS Advisory Committee
Public–private partnership	Control could be retained by government via a special share
Private ownership	Full-chain enhanced oil recovery projects

Table 10 Policy contract remedies

Revenue certainty	Example
Availability payments	Analogous to capacity markets in electricity
Minimum level of revenue	Proposal in Norway to guarantee storage revenue

6 Policy case studies: regional assessment

6.1 Introduction

The performance of CCS policies can vary between regions and at the same time jurisdictions have diverse preferences. All of the above policy instruments have their strengths and weaknesses, which can become more or less relevant depending on the national or regional context. Although the instruments can in principle be implemented on a supra-national scale, across multiple administrative areas, national or regional characteristics can influence policy choice. This variation is illustrated for India, Saudi Arabia, the US and China, capturing a diversity of national contexts. Though these illustrations highlight specific opportunities for CCS in particular applications and economies other opportunities will also be relevant.

Four characteristics are particularly relevant to CCS policy:

- **Storage or EOR endowment** reflects both the number of low cost CCS opportunities available and the availability of chemical, pipeline, and oil and gas sector expertise in the region.
- **Government preferences,** reflecting historic choices and track record on renewable energy and CCS support, together with cultural attitudes towards ownership and plan-led or liberalised market organisation.
- **CCS need:** market based policies add most value when allocating resources across a large heterogeneous market. If the cheapest CCS opportunities are focussed in one sector, market instruments may yield few benefits compared to command and control policies.
- **Development level**: The development level reflects the capability of national institutions. Strong institutions are able to implement and run market based instruments.

Figure 11 summarises how characteristics lying at the opposite ends of each dimension might affect CCS policy.

Figure 11 Regional policy assessment criteria

High endowment	low financing support required, potential for full chain approach
Low endowment	role for government in financing, part chain approach to insulate companies from commercial risk
Public	public infrastructure ownership
Private	privately owned and market based mechanisms
Power only	homogenous sources suggest regulatory instruments could perform well
Multiple sectors	heterogeneous sources suggest market based instruments
High	industrialised countries with stronger institutions and ability to operate market based mechanisms
Low	difficulty allocating property rights and ensuring compliance for market based mechanisms

6.2 India

Public procurement is a suitable policy for India, potentially in conjunction with an EPS in power. This is because India has a particularly large CCS opportunity in the power sector and a history of public ownership. On the other hand, the Indian government also faces many calls on its limited resources. Figure 12 summarises India's key characteristics, followed by a brief discussion of unique features for India relevant to the development of CCS.

Figure 12 India country overview

No EOR opportunities	Focus on power projects
Preference for public ownership	Lower-middle-income country

The main opportunity for CCS deployment in India lies in new build coal-fired power plants. Electricity demand in India is forecast to more than triple by 2040, and to meet this need, India is expected to increase its coal fleet by around 250 GW (IEA, 2015)[16]. In comparison, Germany's total generating capacity is 200 GW (Federal Ministry for Economic Affairs and Energy, 2016). The growth in coal burn provides an opportunity for relatively low cost implementation of carbon capture. India's overall energy mix is coal heavy, and there are similar CCS opportunities in industries where coal is used; however, deployment may

[16] This projection has been revised downwards recently in the new Draft national Electricity Plan (Dec 2016). See http://www.cea.nic.in/reports/committee/nep/nep_dec.pdf

be more difficult in industry as, amongst other things, it involves retrofitting bespoke systems.

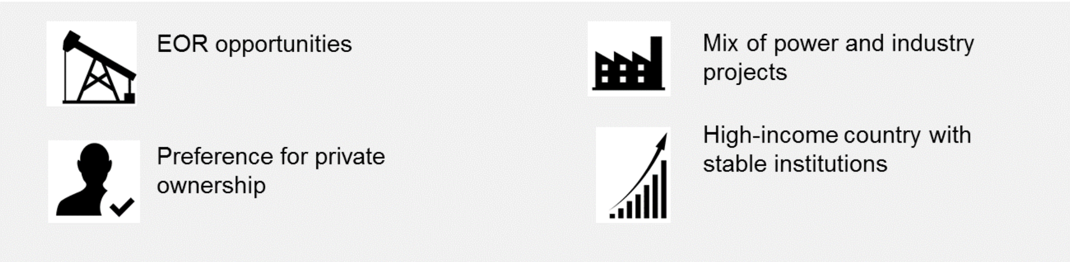
Government has traditionally been heavily involved in procurement of generating capacity in India, and can choose to procure additional coal capacity with CCS. The fast growth of demand is consistent with continued heavy state involvement in capacity procurement. In addition, the government might implement an emissions performance standard, in terms of gCO_2/kWh, for new build generating plants, to signal its intent, similar to some of the standards it has introduced to govern local air quality.

To date, India has done little to progress CCS deployment. Given the costs involved, India is likely to prioritise cheaper abatement opportunities in the short and medium term. The clean development mechanism and various other international climate funds might make a funding contribution in the future.

6.3 USA

The USA is a market oriented economy with a strong CCS track record and could support a market based scheme such as a CCS obligation with tradeable certificates. As summarised in Figure 13, the USA has access to significant EOR opportunities and a broad range of carbon capture opportunities in both power and industry. The heterogeneous nature of CCS opportunities implies gains from trade in CCS certificates. The possible size of USA certificate demand suggests the potential for market liquidity. In this environment, an obligation scheme with tradeable certificates could function well and deliver CCS efficiently. The following text briefly discusses the implementation of an obligation scheme in the context of the current CCS support arrangements in the USA.

Figure 13 USA country overview



The USA has supported CCS deployment to a greater degree than any other nation and as a result possesses significant experience in implementing the necessary policy and contracting arrangements to support CCS. The Department of Energy (DOE) has a number of distinct CCS programs through which it has spent 7 billion USD (Folger, 2016) to support CCS. There are a variety of programs for R&D support, but support has also come through direct grants to specific CCS projects, such as grants of over $200 million to the soon to be operational $1MtCO_2/y$ industrial CCS project in Illinois (Global CCS Institute, 2016a), and the 45Q tax credit (Legal Information Institute, 2014). To date, the existing policy package has encouraged EOR, but it is generally acknowledged that a strong market incentive to deploy CCS is missing (Banks & Boersma, 2015). The current tax credit at USD 20 tCO_2 has stimulated little investment outside EOR. Various legislative proposals have been tabled to increase the value of tax credits available and to remove the cap on their issuance, for example the proposed Heitkamp-Whitehouse CCUS Act (DOE 2016).

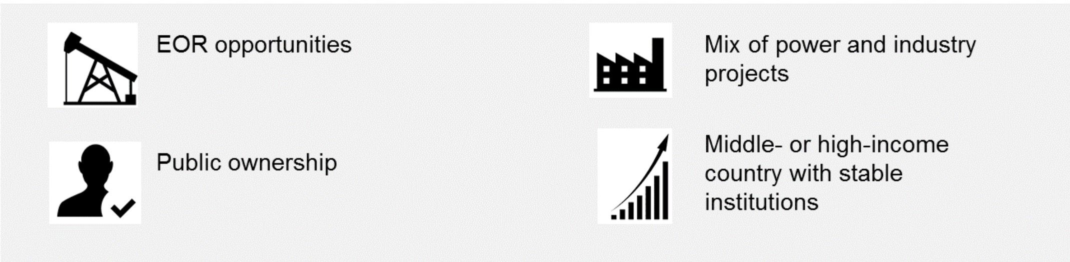
A gradually increasing CCS obligation can be integrated with the existing policy package to form the core incentive for CCS deployment. One option is to implement the

CCS obligation at the state level to complement the existing federal programs with support through the tax code. This is similar to the current USA arrangement for renewable power deployment (Banks & Boersma, 2015).

6.4 Saudi Arabia

Saudi Arabia possesses technically capable state owned companies with control over resources in their respective markets, and would be a natural fit for public procurement of CCS. Although, as summarised in Figure 14, Saudi Arabia has the necessary institutional capabilities and sufficiently heterogeneous opportunities for CCS to consider a market based mechanism, the economic structure of the country is such that public procurement may be a natural option. Saudi Aramco (100 per cent state owned) the Saudi Electricity Company (80 per cent state owned), which has a monopoly on electricity generation, and Saudi Arabia Basic Industries Corporation (70 per cent state owned), the largest publicly listed company in Saudi Arabia, are all majority state owned. The state's controlling stake in all these companies, and the monopolistic nature of the economy, suggest little opportunity for a market scheme. Public procurement of CCS appears the natural fit with the government potentially coordinating capture from power or industrial facilities and transport and storage through Saudi Aramco.

Figure 14 Saudi Arabia country overview

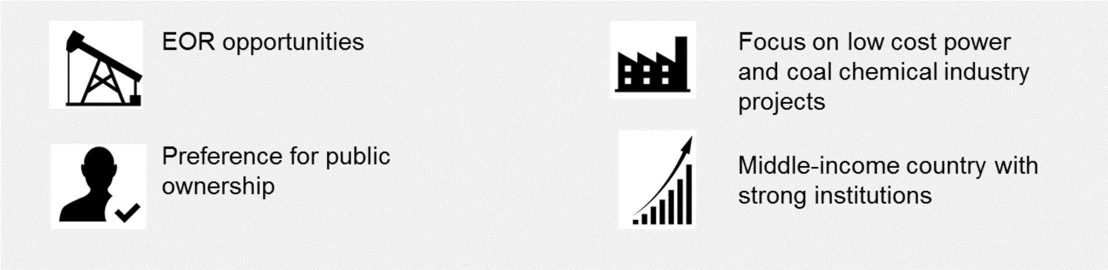


Future projects are likely to be similar in nature to the existing EOR project in Uthmaniyah, Saudi Arabia. Given the revenue obtained from EOR, most CCS projects in Saudi Arabia are likely to sequester their CO_2 through EOR. For example, the Uthmaniyah project injects 0.8 $MtCO_2$/a captured from a natural gas liquids recovery plant into the Uthmaniyah oil field, of which around 40 per cent is expected to be permanently sequestered (Aramco, 2015). The state, through Saudi Aramco, directly procured the contracts for the necessary capture technology from a number of international corporations and provided the transport and storage itself (Kable Intelligence, 2016).

6.5 China

Given the high degree of government involvement in sectors with CCS/CCUS opportunities, public procurement and tax credits may be suitable policies for CCS deployment in China. As summarised in Figure 15, China has a multitude of opportunities for CCS and CCUS in both industry and power; furthermore, it has the institutional capacity to implement complex market mechanisms as evidenced by the regional implementation of a number of ETS schemes (World Bank, Ecofys, & Vivid Economics, 2016). However, the significant presence of state owned enterprises in both the power and industrial sectors makes public procurement and tax credits accessible approaches; indeed, a pipeline of publicly procured projects is emerging in China (Global CCS Institute, 2016b). The following describes two large public procurement opportunities in China, exemplifying how China can utilise its state owned enterprises.

Figure 15- China country overview



In power, a large near term opportunity for CCS deployment lies in large coal power stations. Similar to India, Chinese electricity demand will grow significantly over the coming decades. Despite large scale renewable energy and gas-fired power deployment, significant coal generating capacity will still be required, providing opportunities for low cost, large scale, CCS deployment (ADB, 2015). As nearly all electricity in China is generated by five state owned utilities with regional monopolies (Sioshansi, 2013), public procurement of CCS is a possible approach.

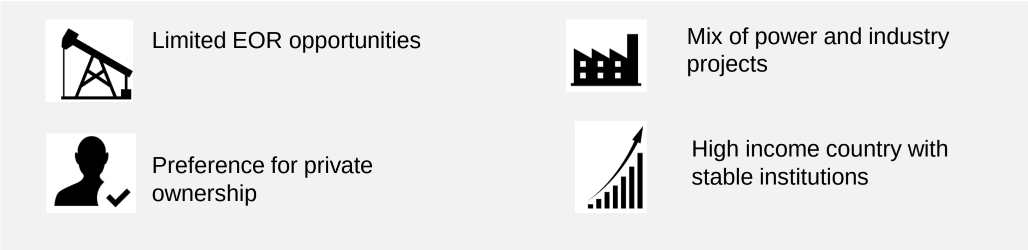
In industry, implementing CCS in the coal feedstock chemical industry is a large scale, low cost opportunity for CCS deployment. The coal chemical industry is significant both in terms of revenue and emissions in China, with annual emissions projected to grow to 1GtCO_2 per year by 2020 (ADB, 2015). CCUS applications (including using CO_2 as a chemicals feedstock or for producing oil) may come first, and once large scale CCUS projects reach commercially sustainability (indicating that all technology barriers have been overcome), policies to support CCS in other applications may follow.

In addition to the scale of the industry, public procurement is an attractive policy to deploy CCS in coal-chemicals as in some coal chemical plants separate CO_2 as part of the production process, creating a high purity and high pressure CO_2 gas stream, making carbon capture low cost compared to other industries, operating within state owned enterprises (KPMG, 2013).

6.6 Europe

Europe is a market oriented region with a strong carbon policy ambition and the world's first large-scale greenhouse gas emissions trading scheme. The EU could support any of the policy instruments. As summarised in Figure 13, the EU has access to CO_2 storage and a broad range of carbon capture opportunities in both power and industry. The heterogeneous nature of CCS opportunities implies gains from trade in CCS certificates. There is also the technical and financial capacity to build and operate CCS systems in Europe. The possible size of EU certificate demand suggests the potential for market liquidity. In this environment, an obligation scheme with tradeable certificates could function well and deliver CCS efficiently. There is wide experience across industry with emissions trading. On the other hand, public procurement has been widely used in the EU renewables sector and latterly nuclear power, especially in the form of feed in tariffs. Tax credits are available for R&D and emissions performance standards have been employed for other pollutants and by some Member States, for carbon emissions from power. In summary, there is experience and potential across all four policy instruments in Europe.

Figure 16 EU region overview



The European Union passed a Directive on CCS in 2009 (2009/31/EC) which established a legal framework for storage of carbon dioxide. It also has a small number of operating CCS projects. Since the Directive came into force, a small number of applications have been made to explore for storage or to store carbon dioxide. Meanwhile, new fossil power stations, as required by law, have been setting aside land for capture plant and assessing their technical and economic feasibility. In the UK, new fossil power stations must go further and demonstrate the economic feasibility of CCS within the lifetime of the new plant. There is also intra-regional cooperation taking place, supported by governments, exploring locations for possible storage and network development, and many EU governments are supporting research and development. However, the original intention to use EU ETS receipts to fund large-scale demonstration projects, through the New Entrant Reserve 300 fund, has been a disappointment, failing to deliver any projects.

The European Union possesses the institutions to drive a scale-up and subsequent roll-out programme across the region. However, it lacks the political will to do so at present. This is in part due to a combination of fiscal austerity, in part public opposition in some countries, and in part because its immediate emissions targets can be met through renewable energy. In some areas of Germany, public concern has already been translated into laws passed to prohibit the storage of carbon dioxide underground.

7 Detailed Discussion

7.1 Introduction

To supplement the summary assessment presented in Section 5, this section offers further discussion of some of the more important detailed design elements of the four short-listed instruments. The CCS obligation, EPS and public procurement each deserve some further exploration as they present a number of implementation options. Tax credits are somewhat more straightforward and are already in use, so receive little additional elaboration here.

In addition, this section also shows how the incidence of the costs of a scale-up or roll-out programme might fall, under each of the instruments and some of their main design options. The analysis of the distribution of the burden divides the encumbered parties into fuel suppliers, energy intensive manufacturers and final consumers.

7.2 CCS obligation

7.2.1 Structure

The structure of the discussion follows the more important of the design elements laid out in Section 5. Of these elements, the *placement* of the obligation along the hydrocarbon supply chain and the breadth of the *base* of obligated parties influence the distributional outcome to the greatest degree. The mechanism's efficiency – the extent to which it is able to drive investment – is affected by a set of *market arrangements* as well as by its *flexibility* and *transparency*. And finally, there is the *geographic* scope, which is relevant to its political feasibility. These are discussed in turn below.

Table 11 Design Elements of a CCS Obligation

Design elements	Options	Effect on
Target	market value, tonnes stored	level of ambition, certainty in demand for storage, certainty in total cost
Geography	national, regional, global	political and legal feasibility
Base	all emissions (process and fuel), all hydrocarbons, all industrial and power use, non-trade exposed industrials and power, power only	distribution of cost
Placement	fuel suppliers, emitters (manufacturers, final consumers), CCS-capable installations	distribution of cost
Party	installation, site, person, minimum size threshold	administrative cost (consistency with other obligations)
Enforcement	penalty level	control of total cost, storage price uncertainty
Flexibility	certificates fungible over time (banking), certificates not fungible	end of year volatility, risk of supply-demand mismatch
Price floor	price floor, no price floor	control of total cost, storage price uncertainty
Market arrangements	exchange, government intermediary	market liquidity, depth of forward pricing
Guarantees	counterparty risk mitigation, no risk mitigation	buyer and seller risk
Transparency	no reporting, contract price reporting, storage capacity reporting	forward price uncertainty

Source: *Vivid Economics*

7.2.2 Target

The target for quantity of carbon dioxide stored could be set as an absolute physical amount per annum (or over a period), or as a relative amount. A relative amount would be a fraction of total relevant gross emissions, where the relevant emissions may be defined as a sector or collection of sectors and gross means emissions before storage. One difference between these two formulations of a target is that the absolute amount is known with certainty in advance and the relative amount is not known with certainty until after the target date has passed. This results in greater market size (demand) risk for the CCS supply chain in the latter case. Similarly, the cost or burden of the obligation will vary with carbon dioxide emissions in the relative target case and not with the absolute target.

In its technology pathways scenarios, the International Energy Agency imagines a contribution from CCS of 5.4 per cent in 2030 and 14 per cent of global emissions by 2050, see Table.

Table 12: Illustrative CCS target from the IEA

Year	Emissions baseline for all sectors & regions (Gt)	Emissions captured for all sectors & regions (Gt)	Proportion of emissions captured (%)
2020	38	0.2	0.6
2025	40	1.1	2.6
2030	43	2.3	5.4
2035	46	4.1	8.8
2040	49	5.6	11.5
2045	52	6.8	13.1
2050	56	7.8	14.0

Source: *Element Energy based on OECD Environmental Outlook 2011 and IEA Technology Roadmap 2013. Note that these capture emission volumes are around ten times that of the scale-up phase.*

The target illustration above is used to estimate costs faced by obligated parties in Table 13 below.

The target level can be announced in advance and may increase over time. It takes time for investment to respond to incentives, especially when investment has to be coordinated along a supply chain and regulatory permissions are needed. In these circumstances, one can make the incentive work for the widest possible set of investments by announcing the arrangements well in advance of the time they come into force. Having been announced in advance, there also comes the question of how quickly the target can be increased, to suit the growing capability of the sector to invest in new capacity. If the target increases too quickly, unit costs could rise steeply, if it increases too slowly, investors may be discouraged by the modest scale of market opportunities and having to wait longer to achieve larger scale and thus increase their efficiency and competitiveness.

A combined ETS and CCS scheme offers price differentiation between CCS and other general emissions reductions. In the same way that emissions reductions from renewables have been achieved using separate schemes, the Obligation offers price discrimination and certainty of pricing. It is no accident that to date, renewable energy, which is capital intensive, has benefited from its own incentive schemes, while general emissions trading schemes have driven fuel switching and greater energy efficiency, both of which are less capital intensive. This differentiation of incentives could evolve in the future into a single, harmonised arrangement with a single carbon price, at least for those low carbon technologies whose costs fall sufficiently to be stimulated by a modest carbon price. An alternative scenario sees the general carbon price rise to a level sufficient to stimulate CCS. This increase in price would have to be achieved over some time. As the general carbon price rises, the CCS obligation price falls (by the same amount). The CCS obligation price could eventually collapse to zero, at which point the scheme could be withdrawn. Analogously, the feed-in tariffs supporting renewable energy have been reduced over time as technology costs have fallen and some renewable energy scheme developers expect the combination of fossil fuel prices and carbon prices to be sufficient to stimulate demand, allowing specific renewable energy support measures to be retired.

As discussed below in sub-Section 7.2.7, there can be unintended consequences from rewarding the storage of carbon dioxide without accounting for the efficiency of the process to which CCS is applied. It may be that only a proportion of the tonnes of gas stored count towards the target.

7.2.3 Geographical scope

The principal issue for political and legal consideration is the geographical scope. The obstacle here is the challenge of reaching agreement on the design elements across political jurisdictions. National level schemes are possible, but if the cost of the scheme rises to a high level, national level schemes can become increasingly difficult to sustain unilaterally, in open trading economies. Informal coordination of schemes is a possible solution, in which the rate of storage is comparable, the base and placement are alike, and the administrative arrangements are similar. The alternatives are to keep the cost of the scheme relatively low, to narrow the base of the scheme to avoid trade-exposed sectors, to compensate exposed sectors, or to enact border adjustments on trade-exposed goods. Of these options, emissions trading schemes have employed the first, second and third options, but not yet the last. All of these options are technically feasible, but so far there has been the threat of trade retaliation from some governments for the introduction of border adjustments, and no governments have been prepared to test the resolve of other governments to carry out their retaliatory threats.

A regional level scheme is feasible in some locations. A regional level scheme is feasible and might even be necessary where supra-national legislative structures already exist, such as in the European Union, where joint legislative structures exist, or between the USA and Canada, where trade agreements take the place of joint legislative structures. In other locations, without these administrative structures, it seems unlikely that it would be possible to reach supra-national political agreement in a reasonable timescale and especially difficult to implement arrangements for the periodic revision of the obligation, which would be needed in order to build the scale of obligation over time. Thus the scope for regional schemes seems limited to the places where the administrative mechanisms for tight economic cooperation already exist.

A global scheme suffers from even greater difficulties than regional schemes. A global scheme lacks any existing institutional structure to operate it or any precedent on which to model it. The nearest arrangements can be seen in the attempts to control emissions from aviation, shipping and refrigeration systems. They have succeeded in addressing environmental issues where the consequences are high and quite immediate, such as atmospheric ozone depletion and oil tanker spills, but they have had little success so far in curbing greenhouse gas emissions, because of differences in views across participating nations. The negotiations under the governing conventions are difficult and slow, taking many years, and CCS would be harder, given that it lacks any obvious United Nations or similar administrative apparatus under which negotiations could take place. The one existing international vehicle available, the Clean Development Mechanism, is not suitable because it has near-zero prices for the rights issued under it, which are known as Certified Emissions Reductions.

7.2.4 Placement of the obligation

The obligation can only be placed on emitters, suppliers or government, while certificates can only be issued to storage providers. The basic mechanics of how the obligation would operate if placed on the various parties are as follows. First, if it were placed on storers, each storer would be required to store a certain volume of CO_2. They would be issued with certificates on proof of storage and would be required to surrender these certificates to honour their obligation. The fatal flaw in this option is that these storers do not currently exist. There are no companies engaged in storage who could be obligated, and no companies will enter the market because in the process they would place themselves under an onerous obligation. Second, if the obligation were placed on emitters, then each would face an obligation in proportion either to their emissions or their production of goods, almost certainly the former. They would surrender certificates showing proof of carbon dioxide stored, in satisfaction of their obligation. They would obtain these certificates from storage providers, in return for a payment. The storage providers would be issued certificates for free, or at least only at the cost of regulatory supervision and leasing of the pore space, by a regulatory authority, upon proof of having stored carbon dioxide. Third, a similar arrangement would exist if the obligation were placed on suppliers. They too would purchase certificates from storage providers. There are no options in which the certificates are issued directly to emitters or suppliers because proof of storage is needed; proof of capture is insufficient.

There are primary and secondary determinants of distributional impact. The primary determinant of impact is the level of ambition and the base. *The level of ambition* directly affects the cost imposed. A low level of ambition will not impose a high cost even if it falls quite narrowly across a small group of firms or individuals. The target, together with price stability mechanisms such as penalty rates and price floors reflect the level of ambition. A *wider base* results in costs being spread more thinly, over more participants.

The incidence of the obligation is neutral to the placement of the obligation upstream or downstream in the supply chain. Economic theory shows that the way the costs fall between energy suppliers, manufacturers and final consumers is neutral to the placement of the obligation, in the long run. This result is well known in the economic literature of taxation of perfectly competitive markets where the choice is between taxing producers or consumers. The result generalises to other sorts of obligation other than taxation, to market structures which are oligopolistic, and to supply chains with more layers. Proof of this generalisation has been known for a while but was first published in the literature in 2013 for oligopolistic markets, and Vivid Economics has proven it for oligopolistic supply chains in parallel to this work. The reader wishing to understand this further may refer to Weyl and Fabinger (2013) and note that the identity ‘cost pass-through rate plus demand pass-through rate equals unity’ leads to the neutrality principle. This neutrality of placement is an important result. It implies indifference to the placement of the obligation. There is a caveat that in the short run, in the order of a couple of years, prices may be sticky, and in the time it takes for prices to adjust a higher share of the burden may fall on the parts of the supply chain where the obligation is placed.

Wherever the obligation is placed, suppliers, downstream manufacturers and final consumers will each bear a fraction of the cost. The proportion of the cost they bear depends on the structure of the market (the number and size of rivals) and the behaviour of other firms (how aggressive or passive they are as competitors). It also depends on the downstream market structures and consumer price sensitivity. In general, upstream firms will be able to pass on a proportion of the costs of the obligation, and they will often pass on more than half of the direct cost. The circumstances in which they do not are limited to obligated firms who face strong competition from non-obligated firms. The rate of cost pass-through will vary by sector and the final product market. This is well established both in theory and empirical evidence which supports the theory.

Even when the obligation is placed on emitters (manufacturers and consumers) and upstream suppliers bear no direct costs, they still experience the same total costs as if they themselves had been obligated. The suppliers still face an indirect cost from a reduction in sales as demand shrinks and their margins will suffer as they adjust their pricing to fulfil their objectives, be they profit or sales maximisation or some compromise between the two.

The obligation can be placed on both suppliers and emitters. There is no reason why the obligation could not be split and placed partly on suppliers and partly on emitters. It could even be placed partly on suppliers, partly on non-trade exposed, energy intensive emitters, and partly on all other emitters. While these tuned options would involve higher administrative costs, administrative costs are usually a small fraction of total costs, so they could still be attractive. In the past, governments have not participated in obligations, so while in theory governments could impose obligations upon themselves, and this should not be ruled out, they appear unlikely to do so.

The distributional impacts vary by sector, but in general it seems likely that the majority of the costs will be borne by consumers. Using Vivid Economics' industrial market models it is possible to estimate cost pass-through rates for manufacturing sectors, a parameter that is needed for the distributional analysis. The results show that for most sectors the share paid by consumers is between 40 and 80 per cent, the share absorbed by the downstream manufacturer is between zero and 40 per cent and the share absorbed by the upstream supplier is probably around 20 per cent. Hence upstream suppliers should not be overly anxious about the costs falling on themselves of taking on a CCS obligation. The shares are influenced by exposure to competition through trade with jurisdictions not facing similar costs, market structure, firm behaviour and customer price sensitivity. Even in trade exposed sectors, consumers bear a substantial fraction of the cost.

A downstream obligation may carry a higher administrative burden where there is no existing administrative infrastructure. The administrative burden is higher downstream principally because there are a greater number of emitters than there are hydrocarbon suppliers. However, in many jurisdictions which would consider a CCS obligation, there are administrative systems already in place, for example, to support an Emissions Trading Scheme, and these would be sufficient to operate a CCS obligation. In this situation the additional administrative burden of a CCS obligation would be very low. The administrative burden of an upstream obligation should be low in all circumstances and might be reduced still further by making use of existing arrangements for collecting fuel taxes, where these are applied upstream.

The geographic scope and compensation arrangements are a secondary determinant of distributional impact. The geographic scope matters for the pass through of costs in some manufacturing sectors, in which a narrower geographic scope leads the sector to absorb more of the cost of the obligation in both the circumstances where it bears the obligation directly and in the case where the obligation is placed upstream. The geographic scope does not affect cost incidence on suppliers nor final consumers of fuels, so long as the obligation is placed on all fuels supplied within a jurisdiction, regardless of origin, and that the obligation is not placed on fuels which are exported from the jurisdiction. Of course, if compensation arrangements mitigate these trade effects, then the geographic scope may no longer influence the distribution of costs.

7.2.5 Sectoral coverage

The obligation could be imposed on a wide or a narrow base. The widest base is all hydrocarbons. Narrower bases exclude certain sectors, fuels or uses. There may be an argument for excluding sectors which are carbon intensive and trade exposed (such as steel and aluminium) if two conditions are satisfied. First, the costs falling on the sector are significant relative to sector profits; second, the obligation falls on part of a market only. If both conditions are satisfied, the obligation could distort competition, pushing production into the unobligated part of the market. This is known as leakage. It is not possible to exclude sectors if the obligation is imposed upstream, but equivalent effects can be achieved by issuing compensation in the form of credits to specific sectors. There are precedents in renewable electricity obligations which have been imposed both on wide bases and with exemptions. The base can also be chosen for administrative simplicity. For example, if applied downstream, then the obligation might be limited to large emitters, as has been the case in emissions trading schemes. Even with an upstream obligation, there is precedent for small suppliers to receive exemptions, to reduce administrative costs. There is also the option of excluding installations where CCS is not feasible because of small scale, such as small boilers.

It is possible to begin the obligation with a narrow base before extending coverage as time passes. This also has precedent, for example in the EU ETS. There might be administrative cost savings in this approach if the total obligation is small at the beginning, and it can be politically helpful by reducing the scale of opposition at the introduction of the policy, and by creating a political constituency (those already obligated) who wish to see the base widened over time.

There is another variant, which is to set different levels of obligation by sector or fuel use. There might be reasons to do this on the basis of avoiding carbon leakage but the setting of discretionary levels of obligation by sector will open the policy up to lobbying and to challenge on grounds of discrimination. The creation of opportunity for lobbying means that more political capital is spent on securing agreement, leading to greater risk that the policy will not receive political support. Of these options, a wide base seems preferable and precedent indicates that energy intensive trade exposed sectors can be given some relief where they operate in markets which extend beyond the jurisdiction of the obligation.

The size of the burden on individual sectors or firms is sensitive to the breadth of the obligation across sectors and the regions of the world which participate in delivering the target. Simple arithmetic shows that as the obligation base is expanded from industry only to all carbon dioxide emissions, the obligation rate per tonne of carbon dioxide falls by a factor of four, see Table 13. Similarly, as the base is widened from OECD, Russia and UNFCCC Annex 1 to all countries, the obligation rate per tonne falls by a factor of three. Thus there is a range of about four times three, that is, twelve fold between the broadest obligation base globally and the narrowest base in industry in selected regions only, keeping the global target constant. In the period 2020 to 2030, the IEA's technology pathway for CCS implies an obligation of about USD 9/tCO_2 if applied to all emissions in OECD, Russian and Annex 1 countries. The expected cost impact (e.g. on suppliers) can be determined by taking the appropriate fraction (from the distributional impact assessment) of the cost figures in table 13. Note that the 2013 IEA pathway initially requires a volume of CO_2 storage which is approximately ten times larger than the scale-up phase. Table 13 uses an indicative value of $100/tonne held constant throughout the period. This value could decrease in response to CCS technology improvements, and an increase in carbon prices.

Table 13: Projection of global expenditure on CCS

	Which sector pays for the obligations (all regions)?							
	2020-2030				2031-2050			
	All	Power & Industry	Power only	Industry only	All	Power & Industry	Power only	Industry only
Total cost of CCS obligations	$1,294b	$1,294b	$1,294b	$1,294b	$11,052b	$11,052b	$11,052b	$11,052b
Total CO2 emissions affected by obligation	429 Gt	314 Gt	185 Gt	129 Gt	879 Gt	643 Gt	413 Gt	229 Gt
Average obligation cost per tonne emitted	$3.0	$4.1	$7.0	$10.1	$12.6	$17.2	$26.7	$48.2

	Which region pays for the obligations (all sectors)?					
	2020-2030			2031-2050		
	All	OECD, BRICCS & A1	OECD, Russia & A1	All	OECD, BRICCS & A1	OECD, Russia & A1
Total cost of CCS obligations	$1,294b	$1,294b	$1,294b	$11,052b	$11,052b	$11,052b
Total CO2 emissions affected by obligation	429 Gt	313 Gt	140 Gt	879 Gt	668 Gt	286 Gt
Average obligation cost per tonne emitted	$3.0	$4.1	$9.3	$12.6	$16.6	$38.6

Note: *The projection for the volume of CO_2 emissions stored is taken from [IEA, 2013, Technology Roadmap Carbon Capture and Storage](). The projection for the unabated emissions is taken from [OECD, 2011, Environmental Outlook to 2050](). The regions and sectoral splits are varied according to the breakdown provided by the OECD.A1 countries are part of Annex I of the Kyoto Protocol. BRIICS countries are Brazil, Russia, India, Indonesia, China and South Africa.*

Source: *Element Energy*

We illustrate the impact of a certificate scheme using the US electricity sector as a case study. In the period 2020-2030, the total cost of a CCS obligation upon the US electricity sector is projected as $58B[17]. This represents an average obligation cost of $1.30/MWh, which is an approximately 1-2 per cent increase in the average cost of electricity. In the period 2030-2050, the total cost of a CCS obligation upon the US electricity sector is $389B. This represents an average obligation cost of $4.70/MWh, which is approximately a 5 per cent increase in the average cost of electricity[18].

[17] Global CCS storage levels consistent with IEA 2013 projections. Modelling assumes largest possible 'base' for obligations (all sectors, all regions) and so represents a lower bound on expected on-costs. Certificates held constant over the period at $100/tonne stored.

[18] This simple model excludes two potentially important price dynamics. In future, increasing RES deployment could reduce the load factor of thermal plant, increasing electricity prices from these sources. Secondly, as explored elsewhere in this chapter, the use of a $/tonne abated metric (rather than $/tonne stored) increases the cost of a certificate dramatically when the CO_2 intensity of a CCS plant is similar to the grid-averaged CO_2 intensity. Both of these effects would be expected post 2030 and would increase the on-cost due to CCS.

7.2.6 Price stability and risk transfer

Both buyers of certificates and operators of CCS systems prefer certainty in certificate prices. Buyers like some certainty in future prices: it reduces the possible regret from having misjudged future market prices and overpaying for certificates. Similarly, developers find it easier to invest in CCS with some certainty in the certificate price, because it lowers the risk that their investment will underperform. There are several ways to stabilise certificate prices. Both parties are risk averse.

An effective method of reducing uncertainty in prices is to set price floors and ceilings. The government can set a price floor by promising to buy certificates at the price floor price. It can set a ceiling in one of two ways. It can either offer to sell CCS certificates at the ceiling price or it can allow obligated parties to buy out their obligations at the ceiling price. These measures ensure that the CCS certificate price always trades between the floor and ceiling prices.

End of year flexibility avoids end of year price volatility. Most trading schemes allow some flexibility at the end of each compliance period, allowing banking of a proportion of the obligated amount from one year to the next. This avoids the problem of price spikes and collapses at the end of obligation periods that can otherwise occur when supply and demand are not in balance at the end of the period.

Price transparency and exchange trading can reduce volatility by improving liquidity. When a buyer or seller places a trade on the market and the placement causes the market price to move, the market lacks liquidity. The characteristic of such thin, illiquid markets is volatile prices. Price volatility depresses trading and makes the market less efficient. In order to have a reasonable level of liquidity, there must be a sufficient number of trades passing through the market and this is usually associated with a sufficient number of market participants. It can also help if traded contracts are standardised, concentrating trading volumes in specific products, and if market rules demand that trades are made through an exchange and prices and volumes are published. This transparency helps investors in CCS and investors in certificate purchase contracts to identify the fair market price. Exchange markets exhibit economies of scale, so they may only be feasible once the CCS target reaches a certain level.

The price of a CCS certificate, or an EPS credit (introduced later) will be difficult to predict, especially over the investment appraisal life (typically 15 to 20 years) of a project. Even if they can be predicted, the future markets would not be sufficiently liquid to make the exchange long term contracts reliable or easy to price. Intermediation may be necessary to transform short term market prices into long term fixed contracts. If the risk appetite of the CCS project developers is low, they may need to transfer certificate price risk to a third party. Either a private party such as a trader or bank, or the government or a government agent could play this role, writing long term contracts to CCS developers, allowing them to secure finance to make capital investments, and selling certificates on short term contracts to buyers. The presence of persons in the market providing these services can be critical to the effective functioning of a market. It may take some time for these services to appear.

7.2.7 Unintended consequences

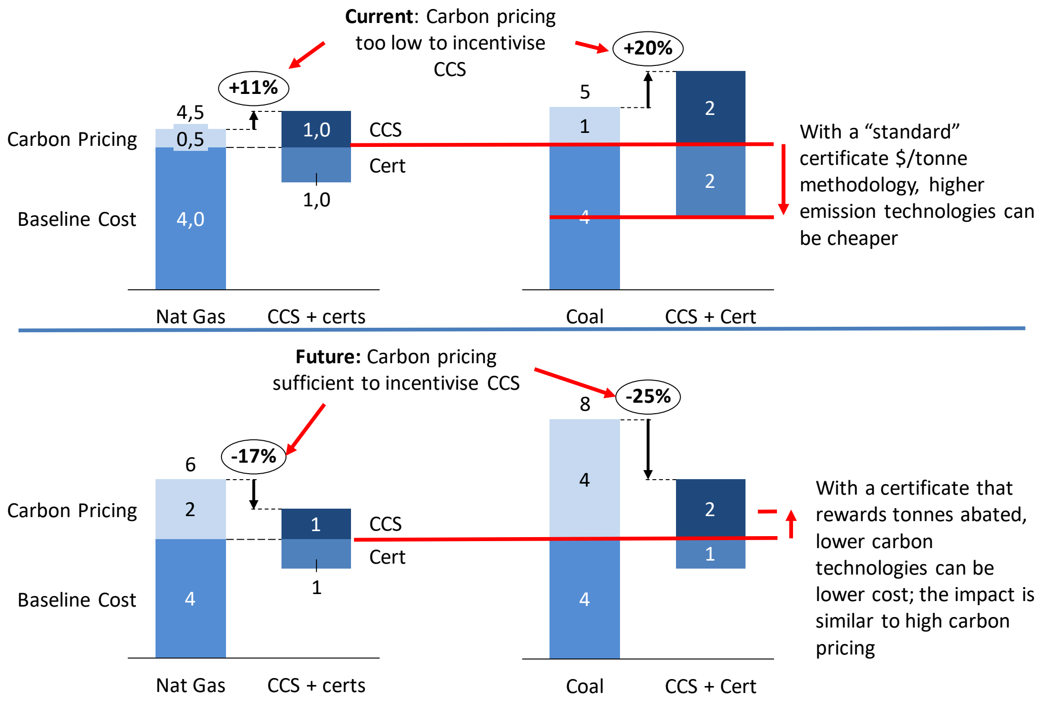
Interaction with general carbon trading and pricing schemes

A CCS obligation will interact with an emissions trading scheme. By avoiding the release of carbon dioxide emissions, a CCS obligation reduces the demand for ETS allowances and so depresses the ETS allowance price. At the same time, the depressed allowance price reduces emission reductions from across ETS installations. Where an ETS and a CCS obligation operate in parallel, the CCS obligation may not cause *additional* carbon dioxide reductions. So, in parts of the world where emissions trading schemes are already established and effective, there might be no environmental benefit from the CCS obligation. The counter argument is that the emissions trading scheme could be tightened upon introduction of the Obligation, so that the ETS creates additional environmental benefit. For this tightening to take place, the administration introducing the CCS has to have political influence over the administration of the ETS.

A poorly designed CCS obligation could, in some circumstances, deliver less emissions reduction than a well-designed scheme. A CCS obligation funds a payment for carbon capture and storage. While one naturally thinks of CCS as taking carbon dioxide that would otherwise have been released and capturing it, when money is paid for CCS that money could also encourage the production of carbon dioxide for capture. For example, this effect could stimulate carbon dioxide production from carbon intensive industry at the expense of less carbon intensive industry. This is a perverse, unintended outcome and there is a remedy that would prevent it, in the form of a benchmark, explained below. But before the remedy is introduced, here are two examples without the remedy.

First, a simple example in the power sector. A coal-fired power station that is able to capture and store carbon at a cost below the market CCS obligation certificate price makes a profit on the CCS activity. Its profit margin consequently increases by fitting CCS. In fact, its profit margin increases by more than its rival, a natural gas plant, when it fits CCS. In response, it increases its power output and consumes more coal, displacing other forms of generation. Overall, the coal-fired plant has become relatively more competitive, its market share increases, and the effect of the CCS obligation has been to increase the amount of coal burned while reducing overall carbon dioxide emissions, see Figure. As shown by Rubin, when comparing the carbon dioxide savings from fitting CCS to CCGT, the costs are \$106/tCO_2 avoided compared to CCGT and \$41/tCO_2 avoided compared to fitting CCS to unabated pulverised coal. By virtue of producing and storing more carbon dioxide per unit of energy, a coal-fired plant can add CCS more cheaply than a gas-fired plant. As a result, certificates valued at a \$/tCO_2stored basis would reward power production from CCS-fitted coal-fired plant more strongly than from CCS-fitted gas-fired plant. Generalising this observation to any power or industrial process, a simple issuance of certificates for tonnes of carbon dioxide stored tends to reward capture from less efficient processes and dirtier fuels. The unintended consequences might be the additional use of lignite for power, high carbon dioxide content natural gas fields increasing production, and greater production from high carbon dioxide emitting plant.

Figure 17: The effect obligation certificates on coal and gas fired power generation with low and high Emissions Trading Scheme carbon prices.

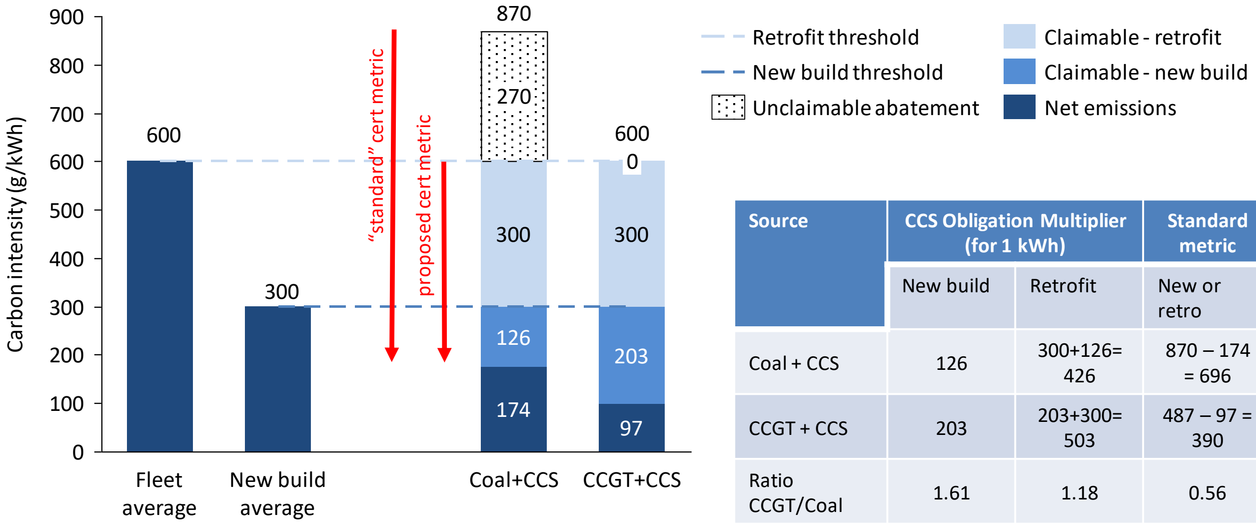


Source: Element Energy. Example is illustrative. Residual emissions after capture are omitted for clarity.

Second, a simple example in gas production. A field producing natural gas with 50 per cent co-produced carbon dioxide and with a low cost of capturing and storing CO_2, makes a profit on each tonne of CO_2 captured. The profitability of the carbon intensive field is increased relative to less carbon intensive fields. As a result, it attracts more investment and expands production, increasing its market share. The CCS obligation has encouraged a production process that has higher unabated carbon intensity.

The preferred remedy for this problem is to reward CCS only for reductions in carbon dioxide intensity below a benchmark. Such benchmarks already exist for most emissions intensive sectors, in the system for allocating free emissions trading scheme allowances. If a benchmark is set at, for example, the top quartile or top decile for the lowest carbon intensity in a sector, then the certificates issued will reflect only carbon dioxide emissions improvements beyond that benchmark. The emissions abatement would be unambiguously additional if the benchmark were to be set at the average emissions intensity of a new power plant, and similar best available technology for new plant in other sectors. To work effectively, the benchmarks have to be chosen carefully. A benchmark covering all fossil power production would avoid the unintended effect, whereas separate benchmarks for coal- and gas-fired generation would not solve the problem. Figure 18 illustrates this arrangement.

Figure 18: Certificates could be issued for net emissions relative to a suitable benchmark (Illustrative data for China)



Source	CCS Obligation Multiplier (for 1 kWh)		Standard metric
	New build	Retrofit	New or retro
Coal + CCS	126	300+126= 426	870 – 174 = 696
CCGT + CCS	203	203+300= 503	487 – 97 = 390
Ratio CCGT/Coal	1.61	1.18	0.56

Note: *The fleet average emissions are estimates; 600gCO_2/kWh illustrative. If China is decarbonising more slowly than the UK, the new build average is estimated as half the fleet average. Ratio illustrates the relative impact of benchmarks on capture from CCGT and coal.*

Source: *Element Energy*

An alternative remedy is to award multiple abatement credits to cleaner plants. Biomass CCS would be rewarded a higher multiple of credits than efficient gas-fired plant and coal would be awarded credits at a rate at or below par.

One note on the Obligation with which to close this discussion. If the obligation is formulated as a share of emissions, then plant equipped with CCS will benefit both from the sale of storage certificates and from not having to buy certificates to cover their emissions.

7.3 Environmental performance standard

7.3.1 Placement

The emissions performance standard (EPS) can only be applied downstream at the point of combustion. It is not possible to apply it upstream, to fuel suppliers, because it uses a measure of carbon dioxide per unit of output and the physical production of output occurs solely downstream. Thus, in contrast to the obligation, there is no need to compare upstream and downstream versions.

7.3.2 Trading

The EPS works by introducing a performance standard for the carbon intensity of production. If it fails to meet the standard, then it faces a penalty. The firm has to achieve the standard for individual plant, but the obligation is tradeable, so it can choose to comply across its portfolio of plant, or can choose to trade and satisfy the obligation by buying certificates from others. If it decides to trade, then in theory, it could either trade tonnes of carbon dioxide alone, or it could trade a block of emissions and output together, assigning both to another party, or it could assign some of its output to another party, without the omissions. In practice, it is advantageous to be assigning carbon dioxide rather than output:

carbon dioxide is fungible across many sectors whereas output is specific to the products made in one sector. There are two options: one is to assign carbon dioxide from carbon intensive firms to less carbon intensive firms, and the other is to allow firms that have low carbon intensity to issue credits which they can sell to high carbon intensity firms. Either is possible. These tradeable credits are specific to the EPS scheme. They are separate from the certificates discussed under the obligation.

If a firm decides to pool its assets, then it combines its assets together for the purposes of compliance with the EPS. This pooling could happen between non-associated firms too, but it seems unlikely to be attractive to choose to pool obligations unless the firms already have a close working relationship. Payments would be made as part of the pooling deal. It would be possible to pool assets either within a sector or across sectors because although the output units will not be fungible across sectors, carbon dioxide would be fungible.

As an aside, the trading of carbon dioxide makes the EPS similar to an emissions carbon trading scheme, with one major difference: when firms produce more output and associated emissions, provided that they do so at the standard, they incur no liability. While an emissions trading scheme imposes a cost on production, an emissions performance standard does not. Hence an EPS fails to discourage consumption of carbon intensive goods in favour of less carbon intensive goods.

7.3.3 Definition of standard

The standard is specific to a sector. It is defined per unit of output and the output metrics are specific to each sector, being units of electricity, steel, cement and so on. The standard could be set on a long term path, starting at the current average intensity and declining over time. As the standard becomes more stringent, it encourages higher cost emissions reductions and at some point may stimulate CCS.

An EPS operating in parallel to an ETS creates a parallel currency of carbon certificates. This stimulates similar mitigation measures such as fuel switching and renewable energy in both schemes, but with different targets. The operation of the EPS in parallel with an ETS makes it harder to identify the future price of ETS allowances and EPS certificates. The interaction between the two schemes makes the pricing of the tradeable instruments in each more uncertain. As with the CCS obligation, the EPS will not deliver a net reduction in carbon dioxide emissions when it is implemented alongside an ETS, so it would have no additionality, that is, no environmental value, unless the number of allowances issued under the ETS is reduced appropriately. In the absence of an ETS, however, it would offer environmental benefit.

An EPS can be effective in stimulating particular technologies, such as CCS, only if it is set tightly, such that it stimulates a raft of carbon reducing measures alongside CCS. This is the particular weakness of the EPS, from a CCS perspective. Unless there are reasons to support these non-CCS measures specifically, they could equally well have been stimulated through a general carbon trading or other carbon pricing scheme, which would be broader and hence more efficient. The EPS neither offers the narrow focus of the CCS Obligation nor the broad compass of the ETS. It is a compromise between the two.

In electricity generation, the scope of the sector could be set as fossil generation only. This would stimulate fuel switching, generation efficiency and CCS. Alternatively, the scope could be set as all generation, which would in addition stimulate renewable energy production. In neither case would there be any guarantee that CCS would be commissioned in response to the standard.

The EPS would encounter the same issues and remedies over geographical scope and price stability as a CCS obligation. It is much less likely to have the unintended consequence of stimulating carbon intensive production because it incorporates a standard which is the remedy for this unintended effect of the obligation.

7.4 Public procurement

Public procurement can be used alongside a CCS Obligation or EPS. Public procurement offers three distinctive features which are complementary to the two market mechanisms described above:

- a credit-worthy counterparty, insofar as the government is of good credit risk;
- a potential greater willingness to absorb long-term and poorly understood risks than markets; and,
- access to a financial contribution from a number of potential tax bases.

There are a number of ways in which public procurement can bring these attributes to bear.

The problem of credit-worthiness is most acute in the writing of contracts between infrastructure providers and emitters with capture plant. If and when CCS networks mature to a point where they have a diversified and atomised customer base, there will be a default rate across the portfolio contracts which infrastructure operators could price in to those contracts. The infrastructure operator's business viability would not be vulnerable to default on individual or small numbers of contracts in the event of individual customer business failures or a recession triggering more widespread writing down of contract values. However, in the potentially lengthy build up to this diversified situation, the infrastructure operator will be exposed to default on individual contracts. Public procurement can provide a separation between the emitter's credit risk and the infrastructure operator, or can underwrite those risks. Government or its agency can interpose between the emitter and infrastructure operator, by acting as a reseller and writing contracts with each. The infrastructure operator then has contracts with a sovereign rather than with multiple emitters. A similar effect can be achieved if the government writes guarantees on the contracts between emitters and the infrastructure operator. The government could take a fee for its services under either arrangement.

Governments are best placed to absorb policy and uncertain risks. Markets have developed the contractual arrangements and experience to handle common, market and technological risks. They struggle to handle policy and novel risks. There are several risks of this nature in CCS. First, there is the risk that the policy support, established by government through a CCS obligation, EPS, tax credits or other means, will be modified or withdrawn in the future. The sovereignty of governments allows them to change policy and statute in ways that can affect returns and recovery of capital by investors. Unlike policy and statute, when governments write contracts in the form of public procurement, the force of contract law applies and, so long as there is effective contract law and an independent judiciary, investors are entitled to seek compensation. Public procurement via contracts is an effective means of eliminating investors' policy risk exposure.

The uncertain risks include development and construction risk and long-term leakage from stores. The capital cost of large scale projects is difficult to estimate precisely, especially where there is limited track record of previous projects. Investments in development of CCS projects and construction of CCS infrastructure are two examples where investors might find it difficult to judge how much a project could cost or, rather, what the potential for cost over-runs could be. At the end of the project, the likelihood of leakage from a store after closure might be estimated from theoretical principles, but may be sufficiently novel to be indigestible to investors. In each of these cases, public procurement might help. In the case of development and construction risk, government can write risk-sharing contracts rather than fixed price contracts and in the case of long-term storage liabilities, government can accept the risk on its balance sheet, in exchange for a payment.

The economics of network businesses is sensitive to the number of participants and volumes using the network. In addition to policy risk, these businesses are sensitive to the recruitment of network subscribers. Many early stage networks receive public support to reduce investors' exposure to this demand risk. This could include fixed payments for completion of accessible network or payments for available capacity. These payments reduce the share of network and storage revenue that depends on volumes of carbon dioxide carried by the network and stored. At the same time, it decreases the incentive to build the appropriate capacity in the best location, so if the government chooses to make payments of this type, it may also take an active interest in and influence over capacity investment plans.

There can also be a limit on aggregate capacity for specific risk exposure, which government can alleviate. In some situations, in particular where novel investments must be made on the balance sheets of existing firms, there can be limits to the total risk exposure that those existing firms can take on. Firms have a variety of claims on their profits, notably to pay dividends to shareholders and make other investments. If CCS were to be a significant drain on a firm's current profits, it might not be able to find the full capital sum to invest in capture equipment or in a new network and storage business. This has been seen in other sectors, such as offshore wind and waste disposal. In these circumstances, government can co-invest, supplying co-equity or subordinated debt to augment the supply of equity available for CCS projects.

All of the above arrangements may be possible for governments to execute bilaterally, by negotiation if the numbers of contracts involved are small. However, within larger numbers of contracts, which may be achieved by the time the roll-out phase begins, competitions could be used to ensure governments receive the best prices for its participation, and government may play a more focussed role, taking on only the most difficult risks.

The government's role opens up a range of new funding bases. The government may choose to fund its participation implicitly, using its balance sheet and tax-raising powers to underwrite its trading activities in the CCS market. Alternatively, it could decide to fund its capital contribution explicitly as a ring-fenced account and it could go further still and raise money explicitly to offer subsidised services to the CCS market. This latter option, of raising funds for subsidy allows governments to adjust the balance of burden between the private sector and general tax payer. Money could be raised by levy from the energy supply sector, or from emitters, for example. If the levy is collected by central government, it is likely to be classed by national accountants as a tax; if it is levied by a statutory licensee set up for that purpose this is less likely to be the case.

7.5 Tax credits

Tax credits have a long history of use to support renewable energy, particularly in the United States of America, where they have mobilised billions of dollars of investment. They are now being used in the USA to promote CCS. The interested reader can look at two published discussions (DoE 2016) and (Sherlock & Folger 2014). Tax credits have been set up to offset the costs of capital expenditure and to reward production of renewable energy or storage of carbon dioxide. Of these two ways of applying the tax credits, the production tax credit appears to have been more effective in driving down costs and raising output than the capital expenditure tax credit. This finding suggests that, while tax credits offer great flexibility in being able to target specific costs, a production basis for payment is more effective.

Outside the energy field, tax credits have been commonly used in two specific ways: to encourage research and development and to encourage location in a particular place. It is probably no accident that these two applications have been common because they share a similarity in that each is addressing an externality, a benefit from the activity which the firm does not accrue itself. Research and development benefits society widely because knowledge is difficult to protect and leaks out to other firms and its benefit to firms is competed away, passing to customers. Knowing this, it makes sense to subsidise research and development to encourage more to take place. Location in particular places can also benefit wider society. For example, location in an economically depressed area can put the unemployed back to work, or co-location with other similar firms in a cluster can bring additional competitive strength to the other firms. CCS tax credits could be used in both these ways, to encourage greater research and development and to encourage the formation of clusters, by making tax credits available only in certain locations or by making them more generous in priority locations, in order to make the infrastructure configuration more efficient and to strengthen the supply chain and make it more competitive.

A further use for tax credits is to help with the issue of declining costs over time. The costs of many new technologies decline over time, in fact most technology costs fall as scale increases, as new techniques are introduced and as large firms move in, specialising in cost reduction and distribution. This creates a time consistency problem for economic support policies. As deployment moves from first of a kind, through next of a kind, to n^{th} of a kind, the contract prices needed to pay for the projects decline. If the projects are all funded by a common instrument, such as a tradable obligation or performance standard, the early high cost projects will soon be competing for the issue of certificates with much lower cost, future projects. Tax credits offer a solution to this problem, by tapering the tax credit level from a high level of support for early projects, to a low level of support for later projects.

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