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The CCS challenge

the practical potential for gas carbon capture and storage in Europe in 2030

Summary

This analysis provides the first assessment of the practical potential for gas power with carbon capture and storage (CCS) in Europe in the medium term. Much of the debate around CCS so far has focused on coal. However, the December 2011 European Commission *Energy Roadmap 2050* identified the need for a significant ramp up of gas power with CCS and indicated it will be of greater importance than coal CCS within two decades.

There are multiple hurdles to CCS deployment, creating risks of 'carbon lock-in' or 'stranded assets' for unabated gas power plant. Chief among these is the absence of a clear business case for investment in gas CCS, given uncertainties around technology, carbon prices and potential load factors. Another hurdle is the absence of robust economic incentives to support the additional high capital and operating costs associated with CCS.

However, additional practical challenges could limit the deployment of gas CCS. In particular, it must be practical to capture CO_2 at individual gas plants, and transport it to storage sites with sufficient capacity.

Europe is likely to experience a 'dash for gas' in its power sector in the next two decades, with currently planned gas plant expected to double EU gas power capacity. This is both an opportunity and a challenge for Europe's decarbonisation mission.

Our analysis suggests that by 2030 over 60 per cent of gas power plants will either not have been assessed for capture readiness or will face difficulties in accessing CO_2 storage. This highlights the risk of fresh investments locking in generating plant to locations unsuitable for CCS and increasing the future costs of decarbonisation.

More positively, our analysis indicates that the practical potential for gas CCS could reach 50 to 100 GW by 2030 under different policy scenarios. However, this will only be delivered with strong facilitation from governments and the European Commission to require meaningful capture readiness actions from plants constructed during the coming dash for gas.

Our study has additionally identified that:

- there is a large gap between the conditions that define minimal and meaningful capture readiness of gas plant;
- the storage readiness for new gas plants is currently not being assessed meaningfully by any country outside Norway;
- integrated CO_2 transport pipelines, which also meet the needs of coal and industrial CCS, can help overcome storage constraints.

Governments can begin to address the challenges of the capture, transport and storage of CO_2 for gas power plants through their implementation of the CCS directive. The European Commission can actively increase industry expectations and create positive momentum in support of gas CCS deployment. This will require fresh proposals for financial and regulatory

incentives that support the business case for gas CCS, as well as attention to the practical barriers to deployment.

Encouragingly, the five biggest economies of the EU have the greatest potential for CCS by 2030. It is, therefore, the actions of a few key countries in western Europe which will largely determine the uptake of gas CCS in the next 20 years and, by implication, the future of gas-fired power generation in the EU.

We identify seven recommendations which would secure significant gas CCS by 2030. The 'Big 5' economies of France, Germany, Italy, Spain and the UK, together with likely early adopters of CCS in The Netherlands and Norway, should lead the way by:

- requiring meaningful capture readiness assessments on all new gas plant permitted from 2012 onwards;
- financing or underwriting the characterisation of geological storage capacity in the period to 2020 to enable deployment to proceed in the following decade;
- developing additional incentive structures that progressively prioritise the operation of gas plant with CCS over unabated plant.

The European Commission should support these member states and continue to set the agenda for CCS at European level to foster the creation of a robust market and stimulate further investment by CCS technology providers. It should do this by:

- restating the essential role of gas CCS in its forthcoming communication;
- announcing the prioritisation of gas CCS demonstration in the second round of the NER300 financing process;
- enabling financial support from the next EU budget period for CO_2 transport infrastructure projects that would unlock future cluster potential;
- developing further financial and regulatory measures to support gas CCS deployment in advance of the scheduled review of the CCS directive in 2015.

These practical steps would inject fresh momentum into the pursuit of gas CCS deployment, and help ease Europe's path to a decarbonised power sector. Conversely, without these actions, Europe risks locking in unabated gas infrastructure that will make decarbonisation more disruptive and costly in the future.

Introduction

The future role of gas-fired power generation in Europe is coming under increasing scrutiny, in the context of ambitious climate stabilisation objectives. Scenarios developed by civil society, industry and the European Commission consistently point to an increasingly important role for gas power to provide flexible generating capacity that can respond to intermittent generation from renewables. But, despite gas possessing a lower carbon content than coal, these studies also indicate that gas plant may need to fit CCS technology in the future.

The European Commission's *Energy Roadmap* 2050[1] sets out the scale of the challenge: "For all fossil fuels, carbon capture and storage will have to be applied from around 2030 onwards in the power sector in order to reach the decarbonisation targets…Without CCS, the long term role of gas may be limited to back-up and balancing renewable energy supplies."

These statements present a fresh perspective for consideration in CCS policy debates, where the overwhelming focus over recent years has been on how CCS could enable the continued use of coal and lignite. Gas CCS has not received the same level of priority, for example in respect to funding CCS demonstration projects.

But, despite this lower level of attention, the *Energy Roadmap* 2050 and other studies identify a significant ramp up of gas power with CCS in decarbonising the power sector to 2050. Table 1 below outlines the levels of generating capacity and percentage of CCS for both gas and coal under the different scenarios developed for the European Commission. It can immediately be seen that the quantity of gas CCS envisaged under the decarbonisation scenarios is significantly higher than for coal CCS.

Table 1 Installed power capacity for gas and coal by 2050[2]

	Gas-fired installed capacity (GW)	Gas CCS capacity (GW)	% of gas capacity equipped with CCS	Coal-fired installed capacity (GW)	Coal CCS capacity (GW)	% of coal capacity equipped with CCS
Reference scenario – Business as usual	226	37	16%	131	64	49%
EC 1bis – Current policies initiatives	366	6	2%	104	33	32%
EC 2 – High energy efficiency	187	121	65%	70	28	40%
EC 3 – Diversified supply technologies	218	142	65%	94	50	53%
EC 4 – High renewables	182	34	19%	62	18	29%
EC 5 – Delayed CCS	210	118	56%	73	30	41%
EC 6 – Low nuclear	255	169	66%	125	79	63%

Similarly, other scenarios developed by industry predict a large role for gas CCS. The European Gas Advocacy Forum (EGAF) estimates that gas CCS capacity will reach between 310 GW and 420 GW by 2050. In its optimised, low gas price scenario, EGAF assumes that 65 per cent of new plants built after 2030 will be equipped with CCS, while gas plants less than ten years old in 2030 will also be retrofitted. The study acknowledges that CCS deployment after 2030 will be subject to technical progress, public acceptance, costs and availability but concludes that this technology "appears to be an unavoidable instrument in achieving the 80 per cent emissions reduction target by 2050."[3]

Figure 1 New investments in gas and gas CCS[4]

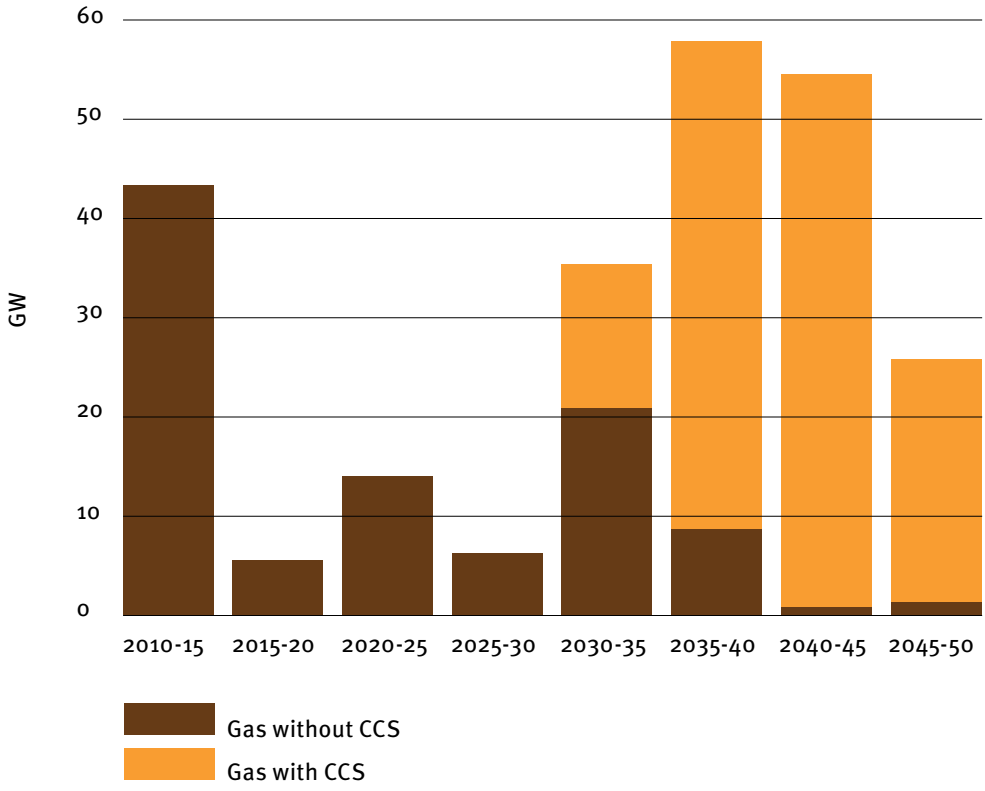


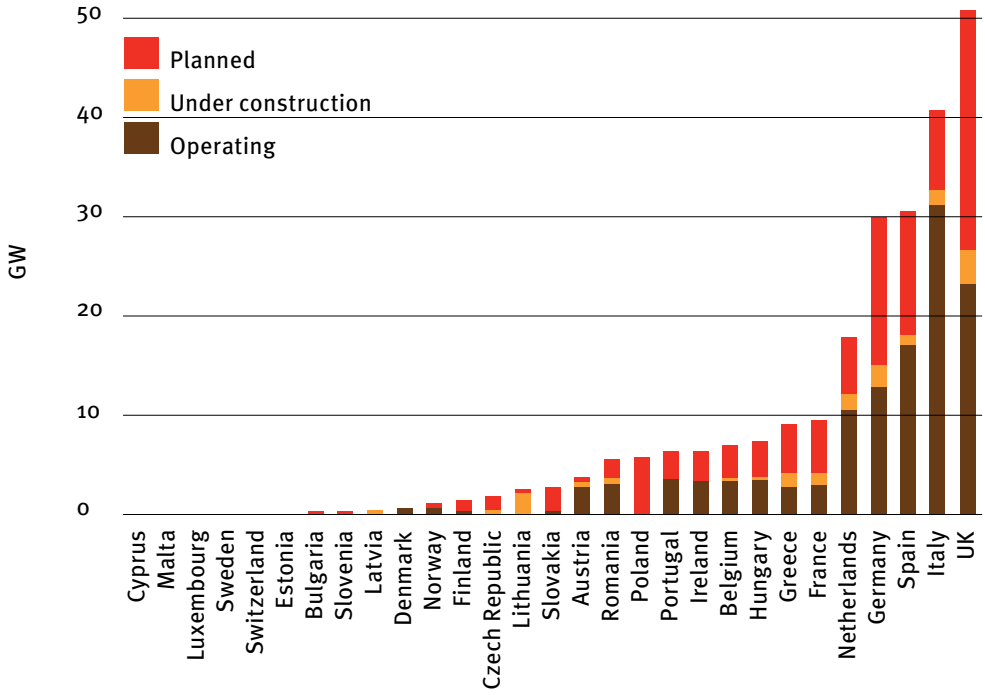
Figure 1 above presents the results of the European Commission's modelling for the diversified supply technologies scenario, showing the potential new build of unabated and gas CCS capacity over the coming decades. This suggests that CCS on gas will be deployed at scale beyond 2030. Varied analytical approaches across roadmap exercises have identified different timeframes for the deployment of gas CCS, with previous analysis carried out for the European Climate Foundation suggesting that this could begin in the period 2020 to 2030.[5]

Figure 1 also highlights that significant new unabated gas capacity is envisaged for the coming decade. The potential distribution of this new build is shown in Figure 2 overleaf, with many EU member states expected to see a doubling of gas capacity. Early clarity on the prospects for gas CCS will be important to avoid risks of carbon lock-in and stranded assets.

This is a challenge that private sector actors are starting to engage in, following a recognition that gas CCS represents a significant opportunity that could enable gas to play a long term bridging role in support of decarbonisation objectives.[6] European technology companies are at the forefront of international efforts to develop commercial solutions for gas CCS, and the availability of a domestic market for CCS would significantly bolster their

ability to maintain this position in the face of growing competition from China and elsewhere. Gas suppliers and utilities are similarly seeking clarity as they take investment decisions in infrastructure and generating plant.

Figure 2 Gas turbine stock across Europe[7]



However, there are currently multiple economic hurdles to CCS deployment, for both coal and gas. Chief among these is the current absence of a clear business case for investment in CCS demonstration projects given uncertainties around political support, carbon prices, potential load factors and the absence of robust economic incentives to support the additional capital and operating costs associated with CCS.

Nevertheless, there are practical barriers that could limit the deployment of gas CCS even if there were a positive business case. In particular, it must be practical to capture CO_2 at individual gas power plants, and to transport it to storage sites with sufficient capacity. These questions have not yet been considered in detail in existing energy sector roadmaps and their associated modelling. Instead, these studies have assumed that gas CCS is technically feasible, and used generic approaches to the costs of CCS. There has yet to be a study of the practical potential for gas CCS that considers the interplay of technical factors around the capture, transport and storage of CO_2.

Our analysis

In December 2011, the European Climate Foundation commissioned Green Alliance and Element Energy to address this gap in the knowledge base. The remit of our study was to analyse the practical potential for CO_2 capture, transport and storage in the European gas power sector in 2030, exploring at a high level the practical issues and policy approaches that could influence the deployment of gas CCS in the EU, Norway and Switzerland.[8]

Our study focuses on the timeline to 2030, as a milestone en route to 2050. This enables consideration of the potential applicability of CCS to the expanding European gas fleet.[9] Full details of the modelling approach and results are provided in the accompanying

report and technical appendix. Here we outline our approach and discuss the policy implications of the main findings.

Assessing the practical potential for gas CCS

The 2009 EU CCS directive[10] requires, as part of permitting, that all new plant in the EU above 300 MW assesses the availability of storage, the technical and economic feasibility of transport, and the feasibility of capture. If these assessments are positive, the plant should set aside space for the future retrofit of CO_2 capture equipment. Such actions will mean it has met current requirements for CCS readiness.

CCS readiness demands that CO_2 capture, transport and storage are all feasible for any given site. Current legal requirements are, however, relatively weak when compared to guidance published by the Global Carbon Capture and Storage Institute.[11] Furthermore, the implementation of the EU directive by many member states is lagging behind schedule,[12] with varying approaches to the strength of CCS readiness required. Some proposed plants have been subject to legal challenge for failing to undertake the required assessments.

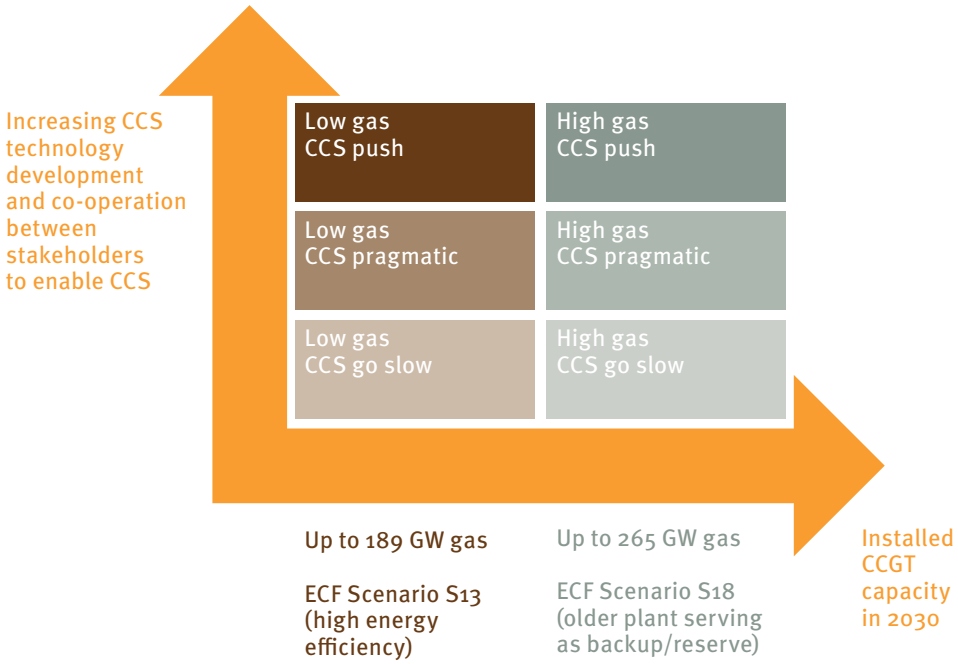
Our study recognises that the existence of the directive and the accompanying guidelines does not guarantee that, by 2030, a sufficient number of Combined Cycle Gas Turbine (CCGT) plants will be capture ready, that CO_2 transport networks will be developed where required, or that societies and individual countries will support the development of storage facilities. We have supposed that member state regulators may, in practice, require CCS assessments over different timescales, and have evaluated how this might impact on the overall practical potential for gas CCS in 2030.

We defined this 'practical potential' for gas CCS to refer to plants that will have met permitting requirements for assessment of capture readiness, and which we score highly for feasibility of CO_2 storage and transport. This plant could either be new build, incorporating CCS from the outset, or CCS ready plant suitable for retrofit. Such decisions will depend on the business case for gas CCS in the period to 2030.

Analytical approach

Following stakeholder review, we designed scenarios to correspond to three levels of CCS technology development and policy support. These were then each considered for 'high' (265 GW) and 'low' (189 GW) levels of installed gas capacity, identified in the ECF's *Power Perspectives* 2030 analysis. These levels of demand for gas in 2030 were selected to provide reference points in line with the analyses undertaken in the different industry roadmaps and the European Commission's *Energy Roadmap* 2050. Figure 3 overleaf sets out how these scenarios relate both to each other and the levels of gas demand considered in the study.

Figure 3 Six scenarios quantifying the practical potential for gas CCS in 2030



In our **CCS go slow** scenarios, there is limited progress with CCS demonstration, technology development or co-operation between stakeholders to enable CCS beyond existing legislation. This represents a further stagnation of current low levels of political engagement across member states.

At the opposite extreme, in our **CCS push** scenarios, CCS demonstration is highly successful, new low cost/high performance capture technologies are developed, and all stakeholders co-operate to ensure large scale CCS roll-out in the 2030s across multiple sectors on a pan-EU basis. This represents the aspirations of the recent past which envisaged multiple demonstration plants entering operation between 2015 and 2020.

Our **CCS pragmatic** scenarios see additional policy efforts taken, but envisage that these build on current member state approaches and priorities. Timescales for action, therefore, differ across EU member states. This represents an approach that might see accelerated action by some member states ahead of pan-EU co-ordinated efforts.

It must be remembered that the results for these scenarios do not constitute forecasts, they are 'what ifs', intended to enable consideration of alternatives for the way the world might develop relevant for gas CCS uptake.

In each scenario we examined the impact of the differing availability of geological storage capacity. We did this by considering that different percentages of the current theoretical capacity might be sufficiently well characterised to be considered bankable by CCS investors. This approach helps to identify the level of investment that might be required to develop sufficient CO_2 storage capacity.

Our study adapted Element Energy's existing peer-reviewed models for gas CCS readiness and source-sink matching to enable Europe-wide geographic coverage with a focus on 2030. A detailed report and appendix, available from Green Alliance, provide full details of the development of the scenarios and the modelling approach, together with sensitivity results for individual variables. Table 2 opposite sets out the different assumptions tested under our scenarios.

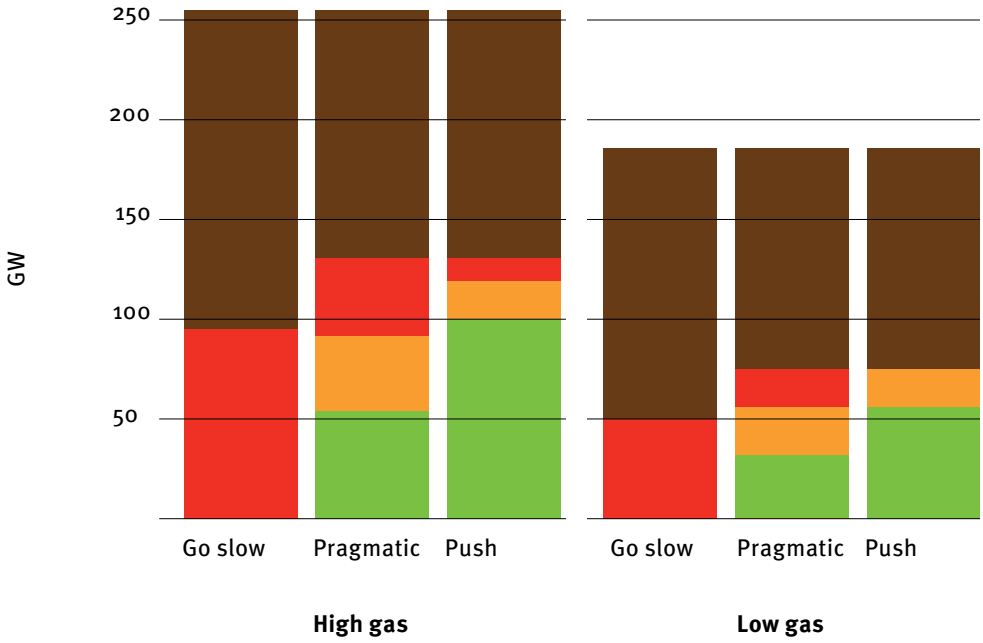
Table 2 Overview of scenarios and assumptions

Scenario	Assumptions
CCS push co-ordinated and proactive approach to CCS deployment and supportive pan-EU policies	- All countries insist on meaningful CCS readiness for all plant planned from 2012 - Onshore storage allowed - Cross-border projects allowed - Storage capacity reserved for coal and industry CCS - Shared transport and storage with coal and industry CCS - Bankable storage capacity = 25% of theoretical storage capacity - Maximise use of storage capacity
CCS pragmatic successful demonstration accompanied by extension of current trajectory for progress on transport and storage	- Pragmatic implementation of meaningful CCS readiness (follows current national enthusiasm) - Onshore storage banned in Germany, Netherlands, Denmark, Austria - Cross-border projects allowed - Storage capacity reserved for coal and industry CCS - No benefit from shared transport with coal and industry CCS - Bankable storage capacity = 10% of theoretical storage capacity - Maximise use of storage capacity
CCS go slow uncertain political support, unsuccessful or delayed demonstration & very cautious storage	- Implementation of meaningful CCS readiness follows demos (only for plant consented after 2016) - Onshore storage banned - No cross-border CCS projects - No coal or industrial CCS transport networks or reserved storage - Bankable storage capacity = 1% of theoretical storage capacity - Storage redundancy required - Gas CCS projects cherry-pick transport and storage

Results

Figure 4 below presents the results from our modelling of the three sets of scenarios against the two levels of gas demand considered for 2030.

Figure 4 Scenario results – levels of potential for gas CCS in 2030

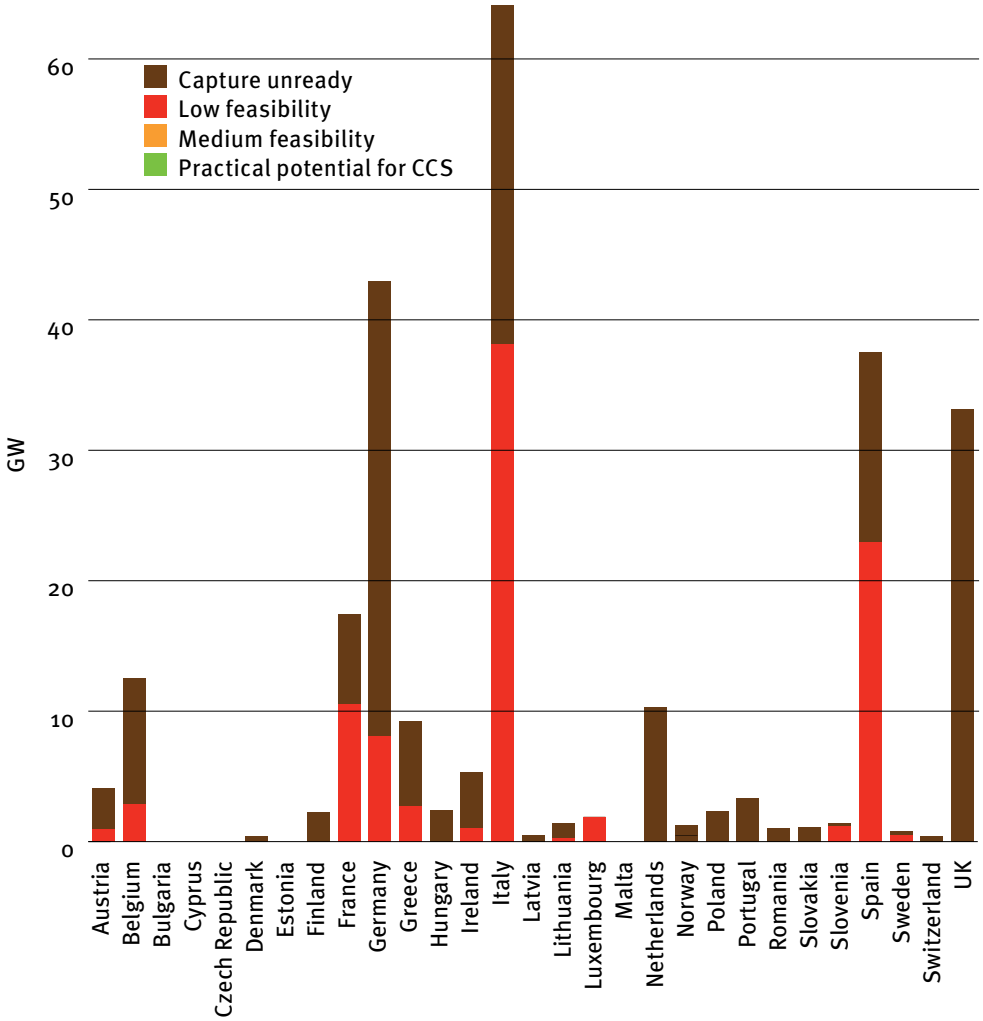


Level of potential	Go slow	Pragmatic	Push	Go slow	Pragmatic	Push
Capture unready	166 GW 64%	127 GW 49%	127 GW 49%	135 GW 73%	112 GW 61%	112 GW 61%
Capture ready, low feasibility for transport and storage	90 GW 35%	41 GW 16%	11 GW 4%	47 GW 26%	17 GW 9%	<1 GW <1%
Capture ready, medium feasibility for transport and storage	1 GW <1%	37 GW 14%	17 GW 6%	0 GW 0%	23 GW 13%	16 GW 8%
Practical potential for CCS	<1 GW <1%	52 GW 20%	103 GW 40%	1 GW <1%	32 GW 17%	56 GW 31%

These results highlight that the deployment of gas CCS cannot be assumed to be straightforward, with the levels of practical potential being highly scenario-dependent. Even if there were a positive business case for gas CCS plant it is evident that there would still be practical barriers to deployment. These barriers affect each of the three areas of capture, transport and storage and will require policy responses that consider their interactions.

The following figures present findings for each of these scenarios under conditions of high gas demand. Similar findings for the low gas demand scenarios are presented in our detailed report and appendix.

Figure 5 Potential for gas CCS in 2030 – High gas, go slow scenario



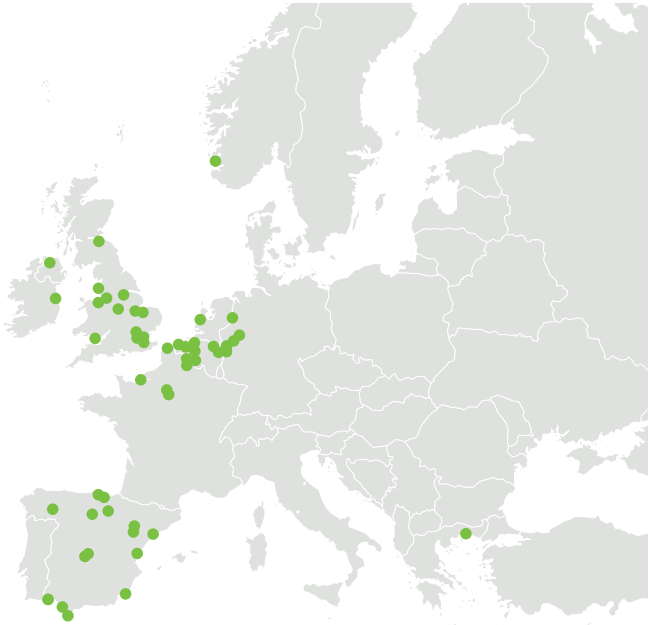
Under this scenario, there is less than 1 GW of practical potential for gas CCS in Europe

The overwhelming picture is one of low feasibility for transport and storage of any plants meeting capture readiness assessment requirements.

Figure 6 Potential for gas CCS in 2030 – High gas, pragmatic scenario

Under this scenario, Spain and the UK would have more than 10 GW of gas plant with practical potential for CCS in 2030.

Transport and storage of CO_2 would be a significant limiting factor for Italy, reducing its practical potential to zero. France and Germany would also see reduced practical capacity as a result.



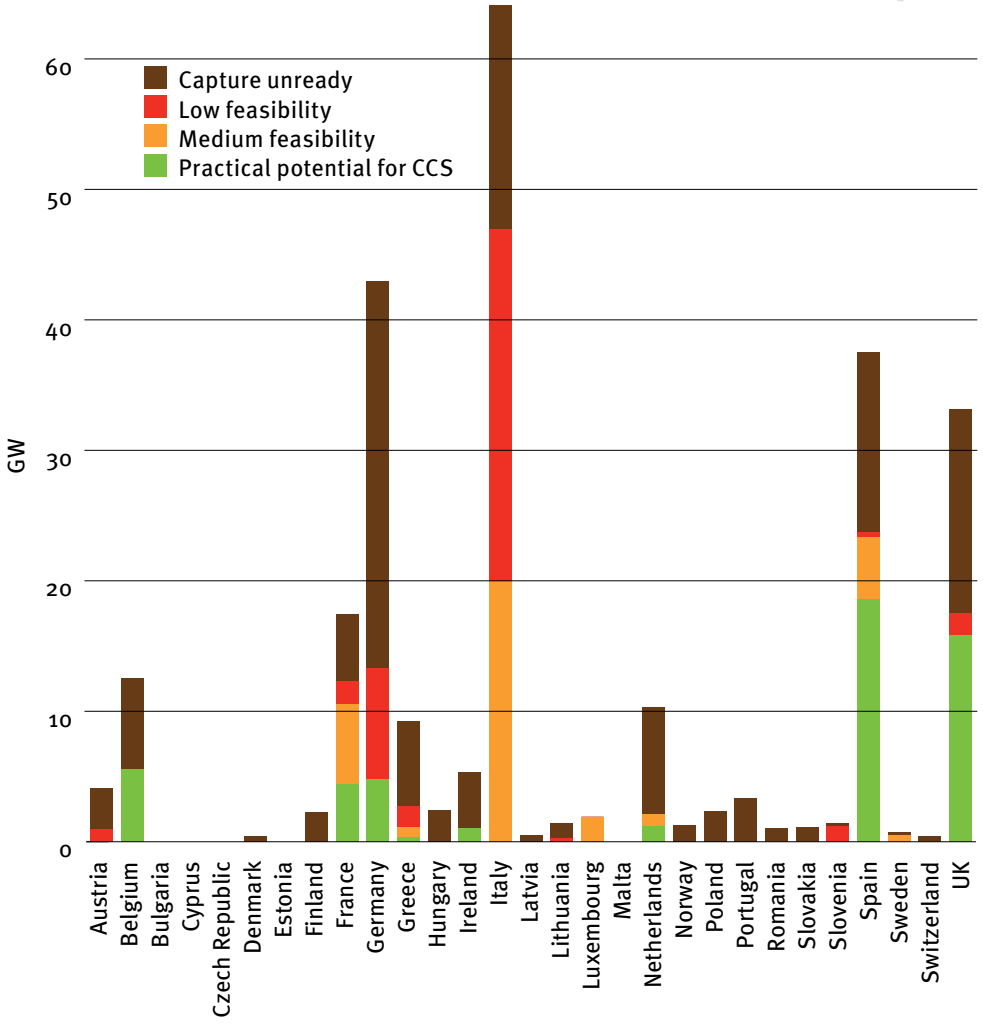
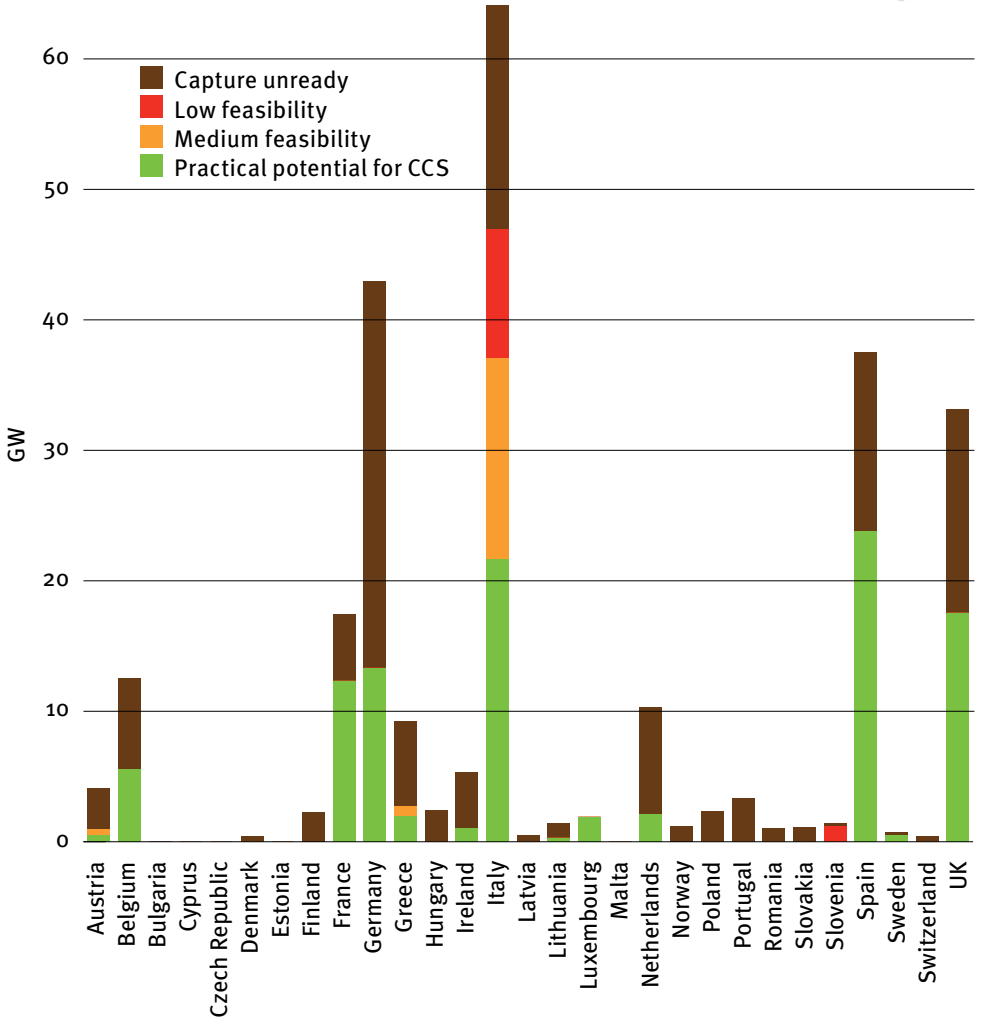


Figure 7 Potential for gas CCS in 2030 – High gas, push scenario

Under this scenario, France, Germany, Italy, Spain and the UK would have more than 10 GW of gas plant with high practical potential for CCS in 2030.

Transport and storage of CO_2 is mainly a limiting factor for Italy.

Most countries continue to have a significant part of the gas fleet failing to meet capture readiness requirements (eg due to plant age).



En route to 2050?

Our results provide an opportunity to assess how progress on gas CCS by 2030 might contribute to the transition to a fully decarbonised European power sector by 2050.[13] Tables 3 and 4 below set out the results from our study and those for the scenarios considered in the European Commission *Energy Roadmap* 2050.

Table 3 Practical potential for gas CCS in 2030

	Scenarios	Total gas capacity (GW)	Practical potential for CCS in GW	% of gas plants potentially CCS ready
	CCS push		103	39%
	CCS pragmatic		52	20%
High gas	CCS go slow	265	0.4	0%
	CCS push		56	30%
	CCS pragmatic		32	17%
Low gas	CCS go slow	189	1.2	1%

Table 4 Installed power capacity for gas by 2050[14]
European Commission decarbonisation pathways

	Gas-fired installed capacity (GW)	Gas CCS capacity (GW)	% of gas capacity equipped with CCS
Reference scenario – Business as usual	226	37	16%
EC 1bis – Current policies initiatives	366	6	2%
EC 2 – High energy efficiency	187	121	65%
EC 3 – Diversified supply technologies	218	142	65%
EC4 – High renewables	182	34	19%
EC 5 – Delayed CCS	210	118	56%
EC 6 – Low nuclear	255	169	66%

'Go slow' is not a viable option

The European Commission scenario titled 1bis represents the continuation of current policies, with a consequent failure to meet decarbonisation goals. Our **go slow** scenarios reflect a continuation of a reluctant approach to CCS with policy actions only following a delayed CCS demonstration programme. The results from these are in line, suggesting a minimal level of deployment of gas CCS. Therefore, it is clear that renewed political engagement and further policy actions will be required to enable the future deployment of gas CCS.

Scenarios with low demand for gas

More positively, the European Commission's high renewables scenario projects that just 34 GW of gas CCS might be required by 2050, representing 19 per cent of the total gas fleet. Our **low gas, pragmatic** scenario similarly projects that 32 GW of gas capacity would have practical potential for CCS in 2030, representing 17 per cent of the total fleet. Both of these scenarios assume a very similar overall capacity of the gas fleet. Given that our scenario is focused on 2030 rather than 2050, this outcome suggests that deployment of gas CCS as a means of balancing increased levels of renewables would be feasible over an accelerated timeframe.

Comparing these results, it must be remembered that we have only considered the practical potential for CCS rather than its operation. Even for this, least stretching, scenario, member states would still need to take additional proactive steps to secure this level of practical potential for gas CCS and further incentivise its deployment.

A greater level of gas CCS deployment is assumed for 2050 under the European Commission's energy efficiency scenario. This has a similar level of gas demand, but projects that 121 GW of gas CCS would be required, representing 65 per cent of the gas fleet. The level of practical potential predicted for 2030 under our **low gas, pragmatic** scenario would be 32 GW, just over a quarter of the way towards this target. Alternatively, our **low gas, push** scenario would indicate that 56 GW of potential could be achieved, suggesting progress half way towards the 2050 level.

Given that our assessment of the practical potential for gas CCS represents an upper boundary for 2030, significant pan-European efforts would be required to enable sufficient CCS capacity to be deployed in the period from 2030 onwards. A pragmatic approach that leaves efforts to a few member states is unlikely to be sufficient in this case.

Scenarios with high demand for gas

A similarly high percentage of gas CCS is envisaged under the other European Commission scenarios, with up to 66 per cent of the gas fleet potentially requiring CCS by 2050. Under the low nuclear scenario, this would correspond to 169 GW of gas CCS by 2050. This reflects a similar level of projected gas demand to our high gas scenarios. The level of practical potential for CCS predicted under our **high gas, pragmatic** scenario would, at 52 GW, be just under a third of the way to meeting this target in 2030, while that of our **high gas, push** scenario would be, at 103 GW, just under two thirds of the way.

These results further reinforce the view that the projected levels of CCS capacity considered in the European Commission scenarios could be practically achievable, but only if accelerated policy decisions can strengthen the business case for gas CCS and address barriers to deployment. Given the long-lived nature of investments in infrastructure and generating plant, a failure to pursue a sufficiently aggressive approach to enabling the deployment of gas CCS would increase the risks of lock-in to unabated generating plant.

Such a situation would pose two risks. The first would be to the EU's ability to meet its climate goals cost-effectively by increasing the costs for future CCS deployment on plants, where continued operation is desired. The second would see the risk of stranded assets increase if plant owners are unable to operate to the level originally envisaged, due to higher

carbon prices or the introduction of regulatory measures. Neither of these outcomes is desirable, supporting the case for early action to secure a pathway to the deployment of gas CCS.

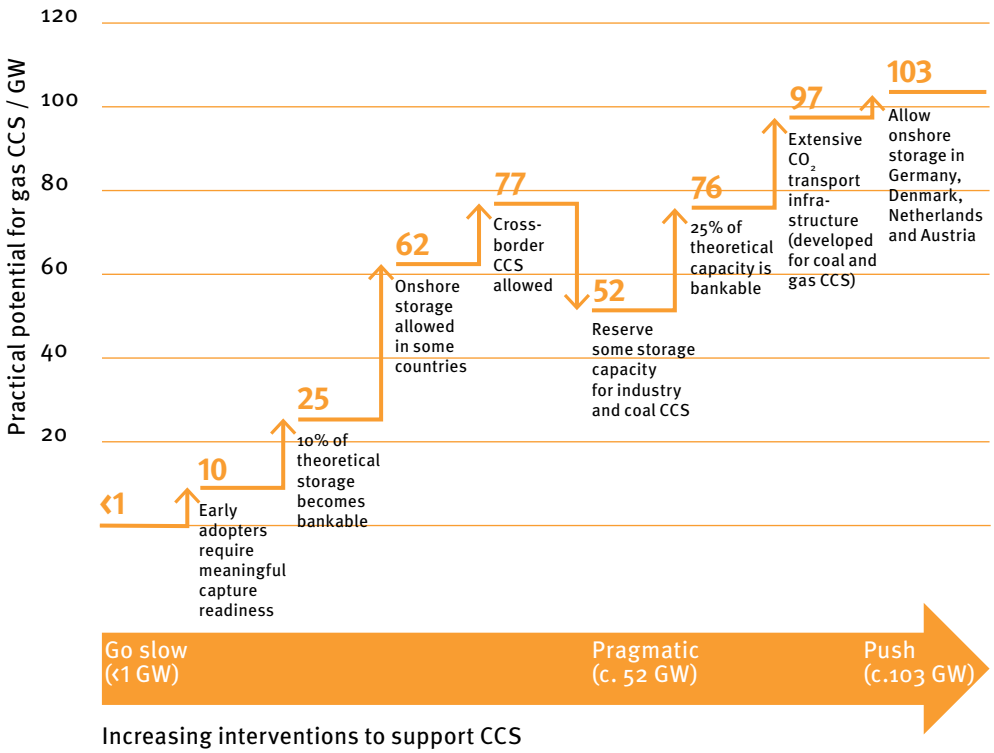
Implications for policy choices

Our results show that policies around capture, transport, and storage can change the practical potential for gas CCS in 2030 from less than 0.1 per cent to over 40 per cent. These positive outcomes are, however, dependent on policy action to avoid barriers to CCS deployment such as:

- late or weak application of capture readiness requirements;
- low levels of bankable storage capacity;
- restrictions on onshore storage;
- the absence of CO_2 integrated transport networks with coal or industrial sources;
- the absence of strong cross-border agreements.

Our model enables consideration of the different factors that could affect the level of CCS deployment. Figure 8 below highlights how different policy interventions identified under each of the scenarios contribute to the overall level of practical potential for CCS. There are, of course, many other alternative combinations of policy choices. The ones selected for our scenarios represent a useful starting point for discussion of the practical barriers and relevant policy approaches. Our analysis also considered the impact of different sensitivities resulting from changes to individual variables. These are given separately in the detailed report and appendix.

Figure 8 Impact of policy choices on the level of practical potential for gas CCS



Our analysis identifies the need for a combination of policies affecting capture, storage and transport readiness, to deliver the highest levels of practical potential in 2030. However, rather than absolute and independent levels for each area, it reveals that the impacts of policies are highly interdependent, ie non-additive. Furthermore, it is apparent that different policy interventions will have varied impacts according to the conditions present in individual member states, which we return to below. There are, however, particular challenges relating to capture readiness and CO_2 storage that apply across Europe.[15]

Capture readiness

Our analysis highlights the primary challenge of whether or not individual gas plants would have undertaken a meaningful assessment of capture readiness. This depends on the interplay between the timing of plant permitting and refurbishment activities and the speed at which member states are likely to require a proactive approach to capture readiness. We categorised countries as early, middle or late adopters of CCS, based on social and political factors. We also assumed that capture readiness assessments would be undertaken for plant scheduled to undertake repowering during the 2020s. This is not yet a requirement in legislation, and is an area ripe for further consideration under the review of the CCS directive.

The results presented in Figure 4 identify that even under the most proactive **push** conditions, 49 per cent of the gas fleet would have failed to undertake such an assessment in the high gas demand scenarios, rising to 61 per cent under the low gas demand scenarios. These plants are categorised in our analysis as having low potential for the capture of CO_2 and, thus, are excluded from contributing to Europe's practical potential for CCS.

Figure 9 below projects the potential distribution of this 'capture unready' plant for the **pragmatic** and **push** scenarios under conditions of high gas demand, showing that this is likely to be a pan-European challenge.

Figure 9 Low potential for capture – High gas, pragmatic and push scenarios

With gas industry projections predicting that in excess of 300 GW of gas CCS capacity could be required by 2050, our results suggest that the deployment of CCS must be proactively considered across the whole of the gas fleet well in advance of 2030. In the absence of such an approach there would be increased risk of lock-in to locations unsuitable for CCS deployment in future. Proactive requirements for meaningful capture readiness assessments will particularly benefit countries that we have classified as middle adopters of gas CCS. This includes Italy, Spain and Germany, where significant new build gas capacity is currently proposed.

CO_2 storage

The second essential cross-cutting issue is ensuring that a sufficient level of bankable storage capacity is in place during the 2020s to underpin multi-billion Euro investments in capture, transport and storage infrastructure. Our results for the **high gas, pragmatic** scenario suggests that around ten per cent of theoretical geological storage capacity would be sufficient to enable 52 GW of gas CCS capacity. For the **high gas, push** scenario, 25 per cent of theoretical storage capacity could enable 103 GW of gas CCS capacity. These levels of storage capacity would provide sufficient CO_2 storage for 20 year plant lifetimes at average member state load factors. They also include the reservation of storage capacity for emissions from coal CCS and industrial sources of CO_2. Our sensitivity analysis shows that, if bankable storage capacities in this range were available, other policies have greater impact in increasing the practical potential for CCS, rather than further increases in storage capacity.

The distribution of this storage capacity across Europe will be an important influence on future policy choices, with some member states such as Italy, Spain and France particularly dependent on onshore storage locations. Growing competition for limited CO_2 storage capacity among sources (other gas plants, or coal and/or industry CCS) means that national and, in some cases, Europe-wide planning of the use of storage would enable greater levels of CCS deployment than an approach which enables individual plants to cherry-pick storage locations. Integrated transport networks and cross-border CCS agreements similarly offer benefits in most countries, but will be particularly relevant where storage capacity is restricted, eg reduced onshore, limited site availability or competition from coal and industrial CCS. This is likely to be the case for Germany.

Improving bankable storage capacity will require a combination of experience from CCS demonstration programmes and a programme of storage characterisation lasting several years across multiple basins. This may cost as little as €1 per tonne of subsequently stored CO_2, but may need to be spent at risk and many years before revenues from CO_2 storage are obtained. The business case for this to be undertaken by the private sector is currently highly uncertain. Member states will have to consider whether they can undertake these assessments themselves or find ways of underwriting the costs of geological investigation.

Member state actions

We considered the potential results that could be achieved by pursuit of alternative **pragmatic** and **push** scenarios. Both will require significant actions to support the deployment of CCS on gas, but differ in the extent to which they seek co-ordinated pan-European action from the outset.

Based on the current slow progress made in many member states to implement the provisions of the CCS directive (agreed in 2009 and required by 2011), it would appear unlikely that a co-ordinated push approach will be forthcoming until further progress can be made on both CCS technology demonstration and the development of a more positive business case for CCS. Actions by individual early mover member states to support CCS, for example under the UK government's proposals for electricity market reform, offer a means of addressing these issues on a faster political timescale. Pragmatic actions appear necessary in the short term as a means of building momentum towards wider deployment.

Short term actions by individual member states will help to advance the prospects for gas CCS. These can start from an active implementation of the existing CCS directive. Given the likely distribution of gas plant across Europe, actions in France, Germany, Italy, Spain and the UK will have the greatest impact on the overall level of practical potential for gas CCS. These countries should be priorities for the introduction of meaningful requirements for capture readiness and the characterisation of bankable CO_2 storage options. As noted above, careful management of public engagement for onshore CO_2 storage is particularly required for Spain, France and Italy to facilitate storage readiness. Table 5 below outlines the key factors and policy implications for the five largest predicted gas users in 2030.

Table 5 Determinants affecting the practical potential for gas CCS

	France	Germany	Italy	Spain	UK
Impact of CCGT demand	**	**	**	**	**
Value of early capture readiness on ready stock in 2030	*	*	*	*	***
Impact of bankability of domestic theoretical storage	**	**	***	***	**
Value of onshore storage	***	**	**	***	No onshore
Impact of reserving storage for coal and industry CCS	***	***	***	*	*
Value of cross-border CCS	** (especially if coal and industry capacity reserved or onshore restricted)	***	**	* (only if onshore restricted)	Not required
Value of integrated CO_2 transport networks with coal and industrial sources	*	**	**	*	*
Most useful policy to increase gas CCS ready capacity	Increase bankable storage & acceptance of onshore storage (& cross-border if storage reserved for coal/industry)	Facilitate cross-border storage eg with Norway if storage reserved for coal/industry	Increase bankable storage, acceptance of onshore storage (& cross-border if storage reserved for coal/industry)	Increase bankable storage & acceptance of onshore storage	Early capture readiness

*** very high ** moderate * limited

Actions in these member states would be further supported if aligned with those of early movers on CCS such as The Netherlands and Norway. This is particularly relevant in respect to access to offshore storage of CO_2. Furthermore, all countries are dependent on positive progress from CCS demonstration programmes and will need to consider how their domestic support regimes for gas CCS relate to shared European mechanisms, such as the emissions trading scheme (ETS).

The role for EU policy

It is clear that the deployment of gas CCS will ultimately have to take place across more member states if the levels envisaged for 2050 are to be achieved. Significant policy levers remain at EU level, presenting an opportunity for member states to seek support for their own efforts and ensure that economies of scale are developed to stimulate cost-effective deployment. The immediate prospects for the use of European policy levers can be considered in respect to the areas of agenda setting, financing, and regulation.

Agenda setting

The European Commission will publish a communication on CCS during 2012. This will seek to advance the analysis set out in its *Energy Roadmap* 2050 and consider the implications for CCS policy. Although the communication will not have direct legislative consequences, it will provide a reference point for future policy development, and can usefully serve to provide coherence across the CCS agenda.

Our analysis suggests that the communication must address both the practicalities of CCS deployment and the business case for action. It should reassert the importance of gas CCS for European decarbonisation efforts and broaden understanding of and interest in the benefits that gas CCS would bring. This should include discussion of the broader environmental and economic benefits.

Alongside this, the European Commission will need to address the question of the avoided cost penalty that gas CCS would face when compared with existing unabated gas plant. While current efforts to strengthen the price signal via the ETS will be of value, it also appears that additional approaches may be required to ensure that CCS is despatched ahead of unabated plant. The Commission should therefore signal that it intends to consider options that further strengthen the business case of gas CCS via the scheduled review of the CCS directive in 2015.

Financing

The effective demonstration of gas CCS is a prerequisite for its subsequent deployment at scale. The European Commission must also signal that it intends to revise the criteria for selecting demonstration projects from the second round of the NER300 financing process for CCS and innovative renewables. The first round of the NER300 prioritised coal CCS projects via use of a metric that considered euros per tonne of CO_2 stored. The second round should equalise the cost comparison by assessing projects on the basis of euros per MWh.

To complement this, negotiations are currently underway to agree the priorities for investment under the next EU budget period. CO_2 transport infrastructures have already been identified as eligible for support under the Connecting Europe facility. Proposals for CO_2 networks that connect multiple new gas CCS plants over the coming decade should be prioritised as a means of accelerating progress towards deployment at scale, even if those networks might initially have a domestic rather than a cross-border focus.

Regulation

As noted above, the CCS directive is currently undergoing implementation by member states. The European Commission has already issued infringement proceedings against those member states which have missed the initial timetable. The directive additionally includes a clause requiring it to be reviewed in 2015.

The Commission should therefore signal its intent to start an early assessment of the implementation of the directive and a consideration of areas for strengthening action. We have identified some immediate practical considerations within the scope of the directive that require attention:

- the extent of member state requirements for meaningful CCS readiness assessments;
- the need for capture readiness provisions to include existing plants contemplating life extensions as well as new plants;
- member state progress to assess available CO_2 storage capacity and enable extensive characterisation of the leading locations.

Furthermore, the directive includes a clause that states: "the review shall examine whether it is needed and practicable to establish a mandatory requirement for emission performance standards for new electricity-generating large combustion installations."[16]

While contemplation of Emissions Performance Standards has proved controversial in previous legislative processes, the review would provide the opportunity to consider how appropriate regulatory measures could help build the business case for CCS. By signalling now that all options will be considered, the Commission will increase the pressure on industry to come forward with its own proactive views on how the deployment of gas CCS can be prioritised in the period to 2030.

Our conclusions and recommendations

Europe is likely to experience a 'dash for gas' in its power sector in the next two decades, with currently planned gas plant expected to double EU gas power capacity. This is both an opportunity and a challenge for Europe's decarbonisation mission. The European Commission's *Energy Roadmap* 2050, published in December 2011, identified the need for a significant ramp up of gas power with CCS and indicated that gas CCS will be of greater importance than coal CCS within two decades.

But practical challenges could yet limit the deployment of gas CCS. In particular, it must be practical to capture CO_2 at individual gas plants, and transport it to storage sites with sufficient capacity for storage. Our analysis has provided the first assessment of the practical potential for gas power with CCS in Europe.

Our findings suggest that by 2030 over 60 per cent of gas power plants will either not have been assessed for capture readiness or will face difficulties in accessing CO_2 storage. This highlights the risk of fresh investments locking in generating plant to locations unsuitable for CCS and increasing the future costs of decarbonisation.

More positively, our analysis indicates that the practical potential for gas CCS could reach 50 to 100 GW by 2030 under different policy scenarios. However, this will only be delivered with strong facilitation from governments and the European Commission to require meaningful capture readiness actions from plants constructed during the coming dash for gas. Such actions would help provide wider impetus for the application of CCS for the power sector and industry worldwide.

Governments can begin to address the challenges of the capture, transport and storage of CO_2 for gas power plants through their implementation of the CCS directive. The European Commission can actively increase industry expectations and create positive

momentum in support of gas CCS deployment. This will require fresh proposals for financial and regulatory incentives that support the business case for gas CCS, as well as attention to the practical barriers to deployment.

Encouragingly, the five biggest economies of the EU have the greatest potential for CCS by 2030. It is, therefore, the actions of a few key countries in western Europe which will largely determine the uptake of gas CCS in the next 20 years and, by implication, the future of gas-fired power generation in the EU.

Policy recommendations

We propose seven recommendations to secure significant gas CCS by 2030. The 'Big 5' economies of France, Germany, Italy, Spain and the UK, together with likely early adopters of CCS in The Netherlands and Norway, should lead the way by:

- requiring meaningful capture readiness assessments on all new gas plant permitted from 2012 onwards;
- financing or underwriting the characterisation of geological storage capacity in the period to 2020 to enable deployment to proceed in the following decade;
- developing additional incentive structures that progressively prioritise the operation of gas plant with CCS over unabated plant.

The European Commission should support these member states and continue to set the agenda for CCS at European level to foster the creation of a robust market and stimulate further investment by CCS technology providers. It should do this by:

- restating the essential role of gas CCS in its forthcoming communication;
- announcing the prioritisation of gas CCS demonstration in the second round of the NER300 financing process;
- enabling financial support from the next EU budget period for CO_2 transport infrastructure projects that would unlock future cluster potential;
- developing further financial and regulatory measures to support gas CCS deployment in advance of the scheduled review of the CCS directive in 2015.

These practical steps would inject fresh momentum into the pursuit of gas CCS deployment, and help ease Europe's path to a decarbonised power sector. Conversely, without these actions, Europe risks locking in unabated gas infrastructure that will make decarbonisation more disruptive and costly in the future.

Endnotes

[1] European Commission, December 2011, *Energy Roadmap* 2050 http://ec.europa.eu/energy/energy2020/roadmap/index_en.htm

[2] European Commission *Energy Roadmap* 2050 *impact assessment –installed power capacity*

[3] European Advocacy Gas Forum, February 2011, *Making the green journey work, optimised pathways to reach* 2050 *abatement targets with lower costs and improved feasibility* http://www.centrica.com/files/pdf/making_the_green_journey_work.pdf

[4] European Commission *Energy Roadmap* 2050, Diversified supply technologies scenario.

[5] European Climate Foundation, November 2011, *Power perspectives* 2030 http://www.roadmap2050.eu/attachments/files/PowerPerspectives2030_FullReport.pdf

[6] Van Foreest F, May 2011, *Does natural gas needs a decarbonisation strategy? The cases of the Netherlands and the UK*, The Oxford Institute for Energy Studies http://www.oxfordenergy.org/wpcms/wp-content/uploads/2011/05/NG-51.pdf

[7] Element Energy analysis based on Platts database

[8] This study has not considered the business case for gas CCS within its modelling, although these issues have been discussed with stakeholders.

[9] Beyond 2030, technology options expand, for example in respect to the use of hydrogen turbines or fuel cells, while the passing of further investment cycles makes the extrapolation of scenarios from the existing gas fleet less robust.

[10] *European Union directive on the geological storage of* CO_2 2009/31/EC, April 2009 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0114:0135:EN:PDF

[11] Global CCS Institute, February 2010, *Defining CCS ready: an approach to an international definition* http://cdn.globalccsinstitute.com/sites/default/files/publications/5711/ccs-ready-full-report-intl-def.pdf

[12] As of March 2012, 19 member states had yet to fully implement the requirements of the CCS directive, which should have been completed by August 2011.

[13] It may be, however, that individual member states move faster on this timescale. The UK, for example, has been advised by its independent Committee on Climate Change that UK power sector average emissions should be reduced to around 50gm/kWh by 2030. As a consequence, the UK adapted its policy on CCS demonstration to include consideration of gas power plants as well as coal.

[14] European Commission *Energy Roadmap* 2050 *impact assessment –installed power capacity*

[15] These are just some of the implications, contact Green Alliance for the full report and appendix for further discussion. Approaches to CO_2 transport also have an important role to play in facilitating the practical potential for CCS in 2030, but there are differences between member states as to what approaches will be most effective.

[16] Chapter 8, Article 38 (3), *European Union directive on the geological storage of* CO_2 2009/31/EC, April 2009

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Element Energy is a dynamic and growing strategic energy consultancy. They specialise in the intelligent impartial analysis of low carbon energy, and help their clients (in the sectors of transport, power generation and buildings) to understand low carbon energy. Over the past eight years they have gathered a team of experts who provide robust technical insights into low carbon energy technologies and markets. Their services include strategy and policy, due diligence, and techno-economic analysis.

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