The Practical Potential for Gas Power with CCS in Europe in 2030

Final Report

For:

The European Climate Foundation

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About Element Energy

- Element Energy is a dynamic and growing strategic energy consultancy. We specialise in the intelligent impartial analysis of low-carbon energy, and help our clients (in the sectors of transport, power generation and buildings) to understand low-carbon energy.
- Over the past eight years we have gathered a team of experts who provide robust technical insights into low-carbon energy technologies and markets.
- Our Services include Strategy and Policy, Due Diligence, and Techno-Economic Analysis.

Relevant CCS projects include:

- Studies on CCS infrastructure in the North Sea (for the North Sea Basin Task Force)
- Due diligence study for a CCS demo candidate (Confidential)
- CCS in the Gas Power Sector (for the UK Committee on Climate Change)
- The UK Storage Appraisal Project (for the UK Energy Technologies Institute)
- The Costs of CCS Demonstration (for the UK Department of Energy and Climate Change)
- The Investment Case for a Tees Valley CCS Network (for the North East Process Industries Cluster)
- Global study of CO_2 pipeline infrastructure (for the IEA GHG)
- Evaluation of the Climit Programme (for Gassnova)

www.element-energy.co.uk

About Green Alliance

- Green Alliance is a charity and independent think tank focused on ambitious leadership for the environment. Founded in 1979 "to inject an environmental perspective into the political life of Britain" we have been inspiring and influencing change for over 30 years.
- Over recent years Green Alliance has played a leading role in influencing CCS policy, primarily in the UK but also at European level.
- Through our convening role we have facilitated cross-sectoral understanding of CCS technology and its key role in decarbonisation pathways.

Relevant projects include:

- '*A last chance for coal: making carbon capture and storage a reality*' – publication prior to 2008 European Parliament votes on NER300 and CO_2 Storage Directive.
- UK CCS dialogue, September 2009 – over 40 stakeholders took part in two days of facilitated discussions on how to accelerate CCS commercialisation in the UK, as an input to UK government policy formation.
- Series of workshops with academia, industry and NGOs on how Emissions Performance Standards could be developed to improve the investment business case for CCS.

Outline

- ❑ Background and Objectives
- ❑ The need for gas CCS for power sector decarbonisation in Europe from 2030
- ❑ A reality check – practical challenges and CCS readiness requirements
- ❑ Modelling approach
- ❑ Results
- ❑ Summary of key findings
- ❑ Policy implications
- ❑ Acknowledgements

Background and Objectives

- The future of gas within the European energy mix is coming under increasing scrutiny, in the context of ambitious climate stabilisation objectives.
- To date much of the debate around CCS has focussed on coal. However, the December 2011 European Commission Energy Roadmap and other studies identify scenarios with a significant ramp up of gas power with CCS in decarbonising the power sector from 2030.
- There are multiple practical hurdles to CCS deployment, creating risks of "carbon lock-in" or "stranded assets". Chief among these is the absence of a clear 'business case' for investment in gas CCS given uncertainties around technology, carbon prices, potential load factors and the absence of robust economic incentives to support the additional high capital and operating costs associated with CCS.
- Additional **practical** challenges could yet limit the deployment of gas CCS even if there were to be a positive business case. In particular, it must be practical to capture CO_2 at individual CCGT plants, and transport the captured CO_2 to storage sites with sufficient capacity for storage. These questions have not been considered to date in existing energy sector roadmaps and associated modelling.
- In December 2011, the European Climate Foundation commissioned Green Alliance and Element Energy 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 these practical issues that could limit the take-up of gas CCS in the EU. The methodology pursued focuses on understanding the practical challenges that will influence the extent to which the European gas fleet could be able to fit or retrofit CCS technology.

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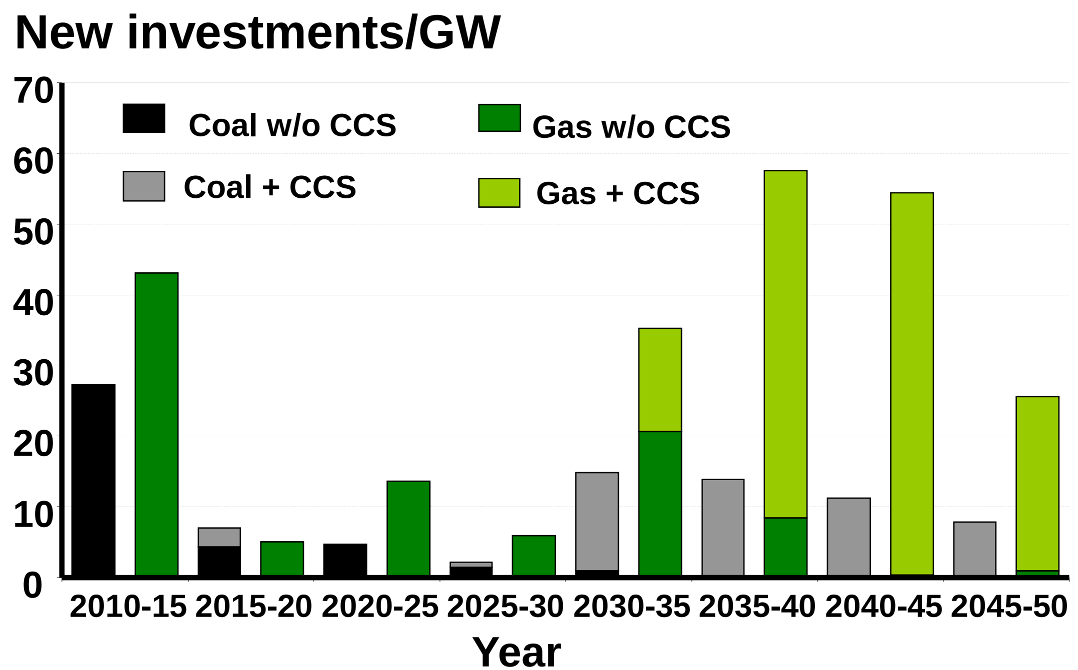
The European Commission's Energy Roadmap 2050 identifies the need for a rapid ramp up in gas CCS capacity in the 2030s.

- The Energy Roadmap clearly sets out scenarios requiring CCS on gas.
- "Without CCS, the long term role of gas may be limited to back-up and balancing renewable energy supplies."
- "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."
- By 2040 there could be a demand for a large fraction of the gas fleet to operate with CCS, implying a massive ramp-up during the 2030s.
- Therefore there is a need to ensure plants built in the 2010s and 2020s are developed CCS ready to reduce the risks from "carbon lock-in" or "stranded assets".
- It may be too late to tackle the capture readiness of investments already consented or currently under construction.

CCGT plant lifetimes are typically at least 20 years. Unless gas plants built in the 2010s and 2020s are CCS ready, these could be locked-in to high emissions or low load factors.

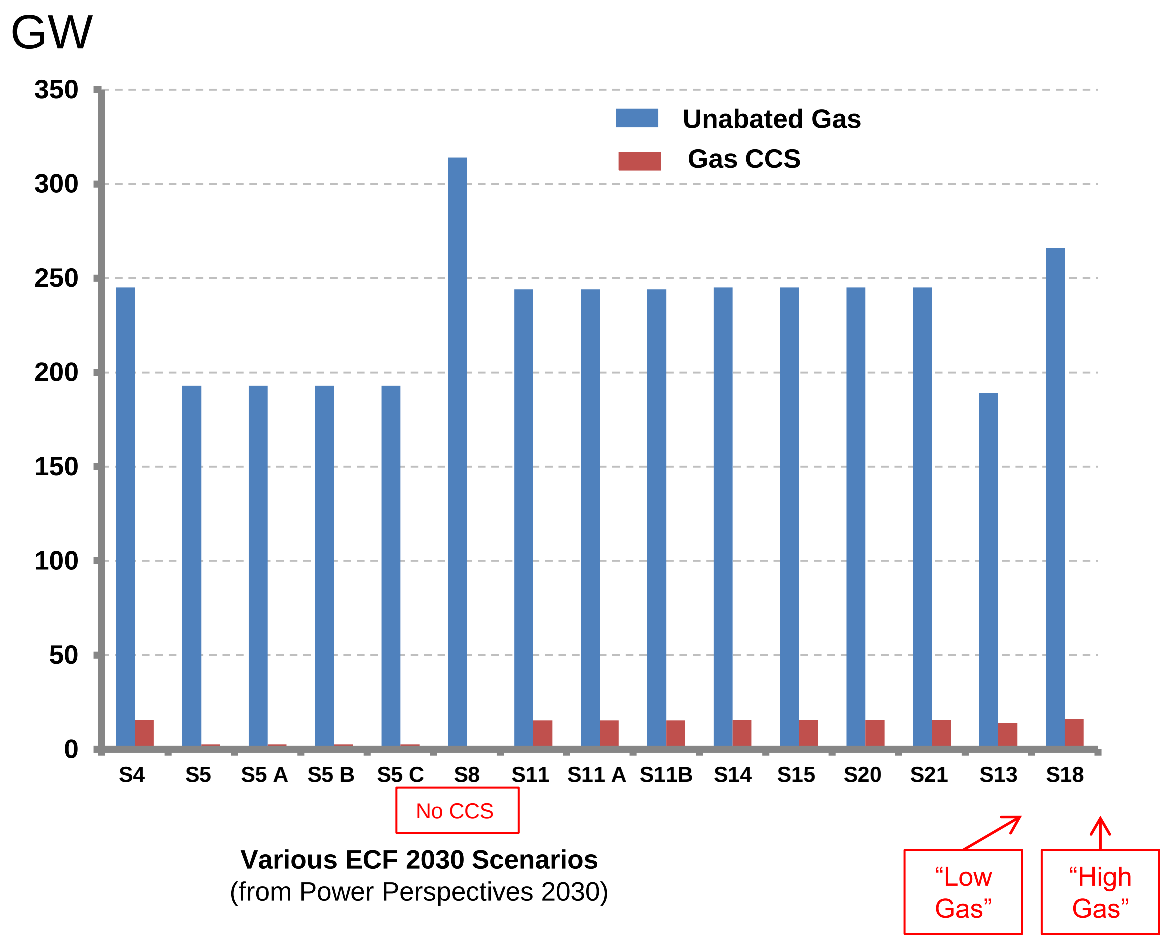


Source: European Commission Energy Roadmap 2050

The ECF Roadmap identifies a small but significant role for gas power with CCS in parts of Europe in 2030 on the path to CO_2 cuts of at least 80% by 2050.

- The role of gas power is predicted to increase in decarbonisation scenarios involving high renewable electricity penetration.
- ECF modelling identifies ranges of installed gas turbine capacity in 2030 between ca.189-310 GW, supplying 960-1300 TWh electricity/yr.
- These and other published scenarios* for Europe identify roles for gas power generation **with CCS** in meeting European decarbonisation objectives in 2030 and beyond.
- ECF scenarios identify up to **16 GW** gas CCS in operation by 2030, delivering up to 105 TWh/yr of low carbon electricity.
- The following analysis uses two of these scenarios to model the implications for high and low levels of gas demand in 2030.

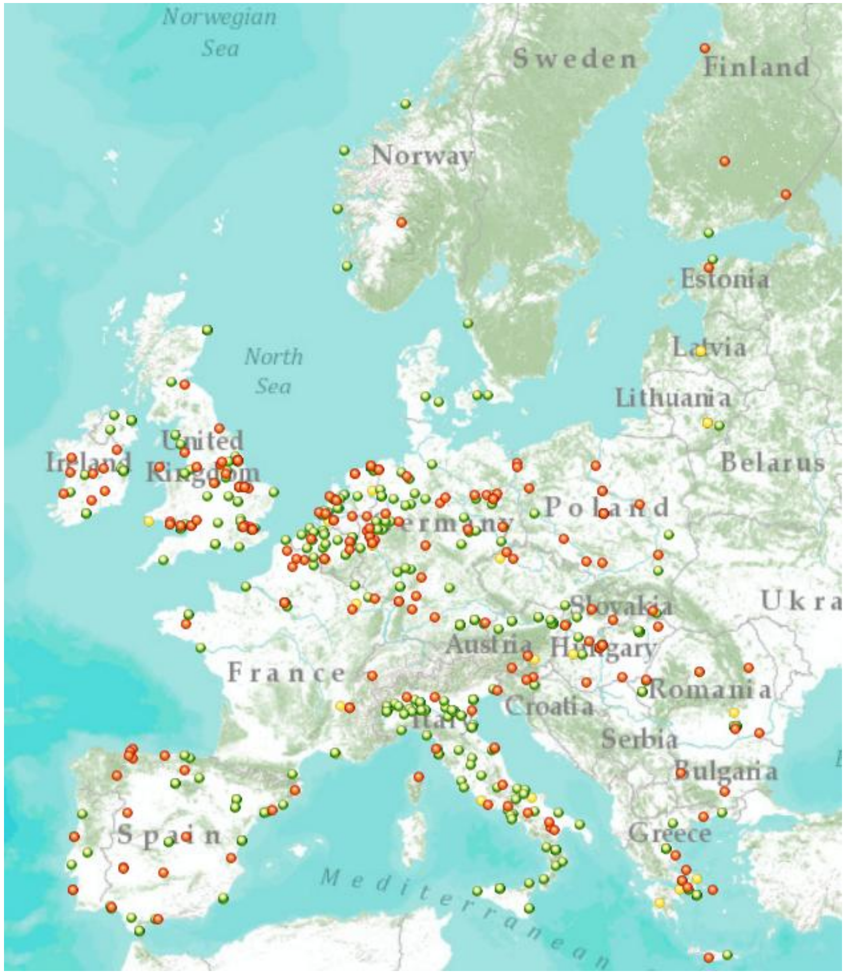
Comparison of ECF scenarios - Gas capacity projections GW - in 2030



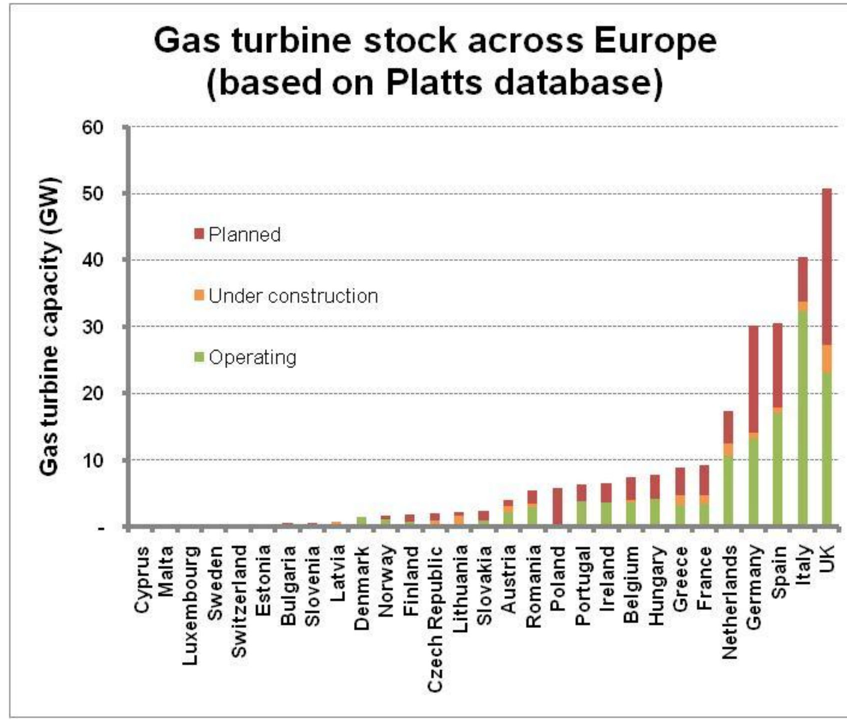
Various ECF 2030 Scenarios
(from Power Perspectives 2030)

* including EGAF, Eurogas, and Eurelectric

Significant new CCGT capacity is already planned across Europe, which could help or hinder the future deployment of CCS on gas.



Operating Under construction Planned



❑ If all were to be built, the current planned CCGTs would double gas capacity in Europe.

❑ The relative capacities installed per country under the ECF 2030 scenarios are similar to those described in the Platts European Power database, although the positions of the Netherlands and France are reversed.

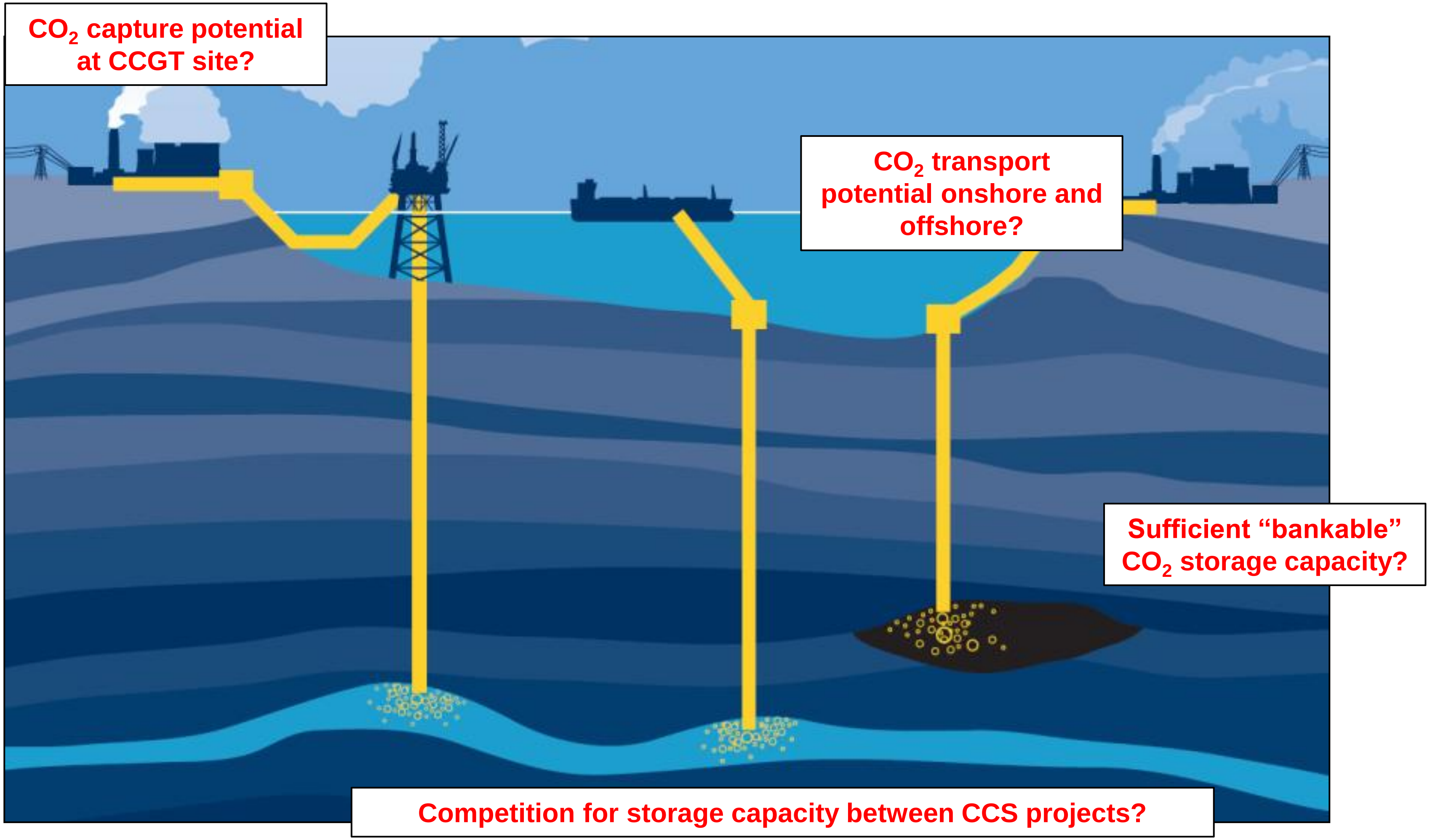
❑ Much of the currently installed fleet will also need to be repowered before 2030.

Outline

The CCS Directive provides the first step to facilitating CCS deployment on the existing and planned gas power fleet.

- The 2009 EU CCS directive requires, as part of consenting, that all new plant in the EU above 300MW assess 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 that the plant will have met current minimal requirements for 'CCS readiness'.
- Meaningful gas CCS readiness demands that CO_2 capture, transport and storage are ALL feasible for any given site. Current legal requirements are however relatively weak, and there are risks that plant approved as CCS ready will not in fact be able to adopt CCS economic or regulations support this.
- This study recognises that the general implementation of the requirements of the directive by many member states is lagging behind schedule, and the existence of the Directive alone, or the accompanying guidelines, does not guarantee that by 2030 a sufficient number of CCGT plants will be sufficiently 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 for captured CO_2 (domestic/cross-border, onshore/offshore).
- Over time, more meaningful requirements might become required by member state regulators (over different timescales).
- In this study, we define the "Practical potential for CCS" as the capacity of the CCGT fleet that combine capture readiness with high feasibility of transport and storage (recognising potential competition for storage). 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 and regulatory case for gas CCS.

Meaningful CCS readiness demands capture readiness, transport readiness and storage readiness. Failure of any of these will limit or eliminate the potential for CCS.



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There is a large gap between the conditions that define minimal and meaningful capture readiness.

Aspects of capture readiness	Minimum capture readiness	Meaningful capture readiness (required to ensure CO_2 capture)
Site Selection	Locate where Transport and Storage is feasible	Locate where transport and storage are planned or in place
Capture Technology Selection	Identify possible technologies	Identify chosen technology with understanding of performance
Design of Capture Facilities	Preliminary generic /benchmark design	Design Basis Memorandum or Front End Engineering Design for capture integration
Space Allowance	Allow sufficient space based on benchmarks	Allow sufficient space based on design
Equipment pre-investment	Limited (e.g. space set aside, access points)	High level of pre-investment appropriate to preferred technical solution
Cost estimation	Benchmark cost calculation	Detailed economic model, understand site-specific sensitivities
Environmental, Safety & other Approvals	Identify requirements	Obtain required approvals
Public/Political Awareness and Engagement	Notify public of potential CCS application	Public and political support for CCS application
Supply of Equipment, Materials & Services	None	Obtain letters of intent to bid from preferred Tier 0/1 suppliers.

Adapted from GCCSI (2010) Defining CCS Ready: An Approach to an International Definition

The storage readiness of new CCGTs is currently not being assessed meaningfully by any Member State*.

Aspects of storage readiness	Minimum storage readiness	Meaningful storage readiness (required to ensure CO_2 storage)
Site selection	Identify required storage capacity and one or more sites with the theoretical capacity to accommodate this	Obtain rights to one or more appropriate storage sites with sufficient capacity
Verify site suitability	High level review of risks, integrity etc. based on regional studies	Conduct initial modelling of long-term reservoir behaviour and prepare storage integrity risk assessment
Design of storage facility	Preliminary design for storage facility (based on benchmarks)	Design Basis Memorandum or FEED for storage facility, including monitoring and verification plan
Competing uses	Identify conflicting surface and subsurface uses, as well as feasibility of access to sites	Resolve conflicts around storage access and use
Cost estimates	Preliminary storage cost analysis (using benchmark estimates)	Rigorous economic modelling based on detailed technical design
Environmental, safety and other approvals	Identify approvals that may be required	Obtain required approvals for use of storage facility
Public awareness and engagement	Notify stakeholders of storage requirements	Public and political support for CO_2 storage
Supply of equipment, materials and services	None	Non-binding letters of intent to bid from Tier 0/1 suppliers.

* Norway has arguably taken the greatest steps to ensure CCS could be fitted to new gas plants.

Transport readiness will need to address consenting risks to desired CO_2 pipeline routes.

Aspects of storage readiness	Minimum transport readiness	Meaningful transport readiness (required to ensure CO_2 transport)
Transport method	Identify possible transport methods	Identify chosen transport strategy
CO_2 transport corridor	Identify one or more feasible pipeline and/or shipping routes	Obtain rights of way for pipelines/shipping routes, or reserve capacity in shared pipelines or port/shipping systems.
Design of transport facilities	Preliminary design options	Design Basis Memorandum or FEED for chosen transport method
Competing uses	Identify any conflicting land use, port access issues	Resolve any conflicts of use
Cost estimates	Preliminary economic analysis, using benchmark data	Detailed costs estimates based on chosen technical design
Environmental, safety and other approvals	Identify approvals needed for transporting CO_2	Prepare documents for obtaining approvals for transportation facilities
Public awareness and engagement	Notify public of chosen transport methods and corridors	Public and political support for chosen CO_2 transport strategy
Supply of equipment, materials and services	None	Non-binding letters of intent to bid from suppliers

Adapted from GCCSI (2010) Defining CCS Ready: An Approach to an International Definition

CCS readiness assessments are already required for new build plants, while major refurbishments also offer significant opportunities to make plants capture ready.

- CO_2 capture technologies relevant for 2030 have major (but differing) site impact requirements.
  - Post-combustion capture - flue gases must pass through a solvent scrubbing tank and the CO_2 is regenerated via heating in a stripper column.
  - Pre-combustion capture – a steam methane reformer and water shift reaction are used to generate H_2 and CO_2. These gases are separated and the H_2 is reacted with air in a gas turbine.
  - Oxyfuel capture – oxygen is prepared from an air separation unit. The natural gas is burnt in an environment of pure oxygen, and the resulting water vapour and CO_2 can be separated (relatively) readily.
  - The technical requirements to manage non-baseload operation may differ substantially between capture technologies.
- In general, retrofitting capture equipment to “unready” plant would likely cause extended downtime (e.g. more than a year) and in some cases may not be feasible.
- However, installation of capture technology on a capture ready plant may take as little as a few months, and is assumed to be feasible to undertake according to the operators’ preferred timing.
- Periods of extensive overhaul (“repowering”), lasting 6-12 months, typically occur after 20 years of CCGT operation. These offer an excellent opportunity to undertake more extensive plant modifications to ensure plant capture readiness at low investment costs. (Note, however, that although we have included this within the modelling exercise, this is not yet explicitly required practice under the terms of the CCS Directive.)
- Beyond 2030, alternative technological solutions to CO_2 capture may become available with their own requirements e.g. chemical looping combustion, use of fuel cells, growth of a hydrogen network.

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The timing of implementation of CCS readiness will likely be linked to political and industry enthusiasm for CCS.

All EU member states have been required to incorporate minimum CCS readiness considerations from 2009 based on the CCS Directive.

The implementation of readiness requirements requires appropriate regulatory capacity, which can be linked to the degree of political and industry enthusiasm for CCS.

For the purposes of this study, countries (EU27 + Norway and Switzerland) were therefore classified according to their likely rate of implementation of meaningful CCS readiness requirements, drawing from their existing approach to:

- ❑ Legislation promoting CO_2 capture readiness / CCS
- ❑ Speed and extent of transposition of EC Directive
- ❑ Existence of dedicated national legislation supportive / forbidding CCS
- ❑ National Government stated support / hostility
- ❑ Other relevant political support / hostility
- ❑ Expressed public hostility to elements of CCS
- ❑ Number of industry proposals to carry out CCS projects
- ❑ Financial support mechanisms in place to support CCS
- ❑ Other relevant published literature

France, Netherlands and UK are early adopters and have predicted high gas power capacities in 2030. Italy, Spain and Germany also have predicted high gas capacities in 2030 but are “middle adopters”.

Early Adopter	Middle Adopter	Late Adopter
France	Belgium	Austria
Netherlands	Denmark	Bulgaria
Norway	Finland	Cyprus
UK	Germany	Czech Republic
	Ireland	Estonia
	Italy	Greece
	Lithuania	Hungary
	Poland	Latvia
	Portugal	Luxembourg
	Romania	Malta
	Spain	Slovakia
	Sweden	Slovenia
		Switzerland

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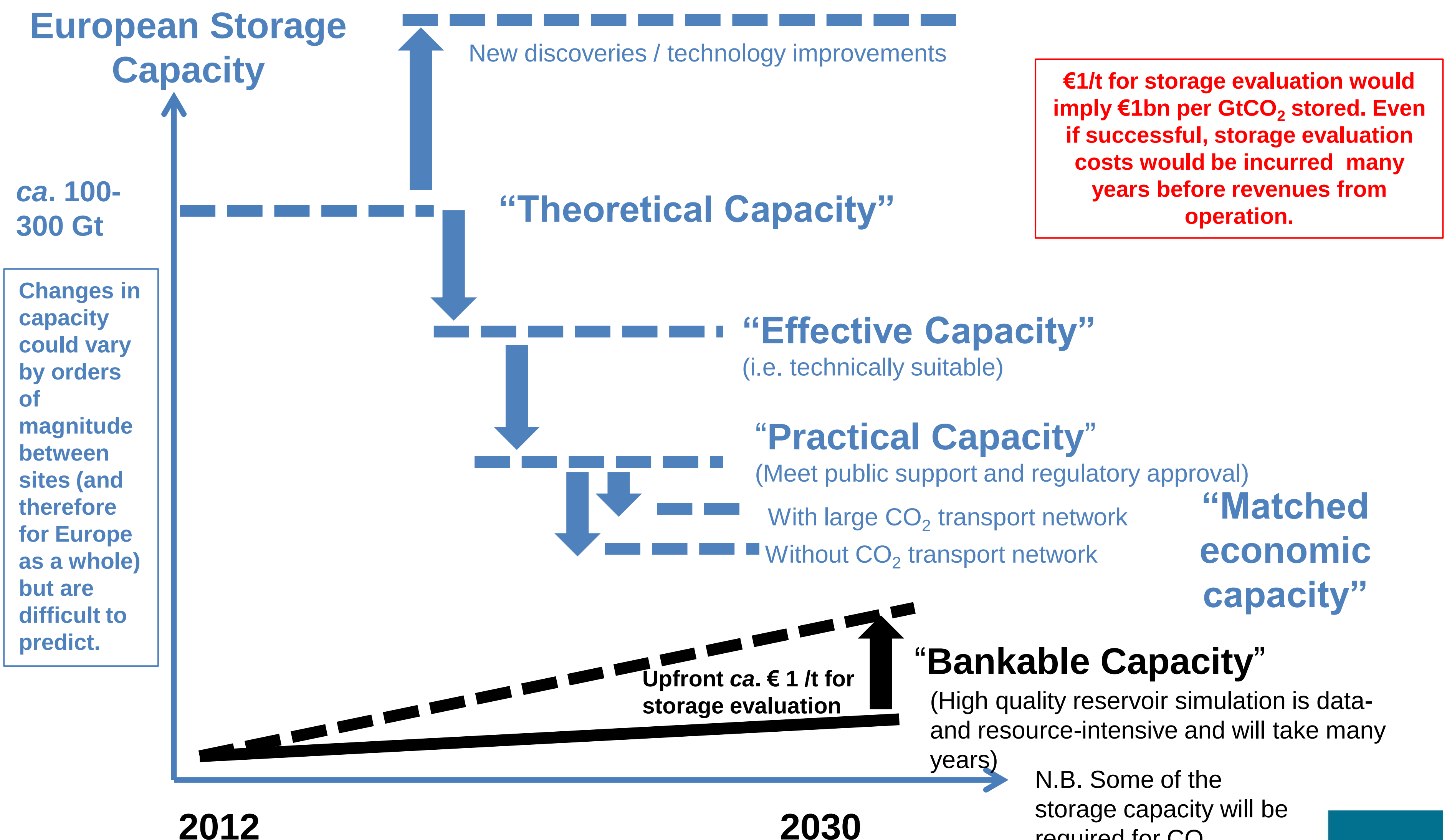
Theoretical CO_2 storage capacity estimates of *ca*. 100-300 Gt have been published, but the "Bankable Capacity" for 2030 is not clear.

- European CO_2 storage capacity is distributed across thousands of discrete sites.
- Each site has unique characteristics – this results in wide variations across the key performance indicators of capacity, containment, injectivity, cost, degree of appraisal work required, and lack of conflict with other land users.
- Published studies give aggregated national theoretical capacity estimates, typically based on pore space and a crude "efficiency factor".
- Information on storage Key Performance Indicators is not widely available in any reliable standardised format, and the likely 'success rate' for storage sites is far from clear.
- Most of the capacity is located in saline aquifers, which will in general require considerable time and resources to be able to guarantee successful operation in 2030.
- Some capacity is also located in depleted hydrocarbon fields. The performance of these may be more predictable but there still remain numerous challenges to their successful deployment in 2030 for CO_2 storage.
- Across Europe there are a few national storage capacity mapping studies, a handful of active pilot CO_2 injection projects, and a few detailed reservoir simulations connected to planned demonstrations, making it hard to generalise or forecast.
- Discussions with geological experts identified that there is no consistent estimate for "bankable" storage capacity, but this is expected to be a small fraction of theoretical European storage capacity (theoretical capacity modelled in this study as 200 Gt – see appendix for details).

Europe may need to assist in unlocking early funding mechanisms to ensure high levels of confidence in CO_2 storage site performance in time to underpin CCS investments.



N.B. Some of the storage capacity will be required for CO_2 captured from heavy industry or coal plant.

Europe's theoretical storage capacity of 100-300 GtCO_2 is distributed unevenly between countries. Some storage is onshore, which is currently unpopular in Germany, the Netherlands and Denmark.

- An individual CCGT plant could capture 1-5 Mt CO_2/yr depending on plant size and load factor.
- The ECF's High gas scenario estimates 105 TWh generation from gas CCS in 2030, i.e. in the region 20-40 Mt CO_2/yr captured (depending on plant and capture efficiencies).
- Plant operating in 2030 would therefore have a 20 yr storage requirement of 0.4-0.8 Gt.
- Therefore if CCGT plants were appropriately located for access to storage, even if only 1% of European storage capacity was developed, this could meet gas CCS need in 2030.
- However, there has been public opposition to onshore storage in the Netherlands, Denmark, Germany and Austria.
- In this study we have modelled that onshore storage accounts for *ca*. 84 Gt storage capacity in Europe.
- Any scenario with high levels of gas CCS in operation is likely to see competition for CO_2 storage from industrial CCS and coal CCS (in operation or in anticipation of eventual need).
- If Europe were to reserve 20 yrs storage capacity for all large European industrial CO_2 emitters, this could exceed *ca.* 9 GtCO_2
- If Europe were to reserve 20 yrs storage capacity for the coal CCS projected in ECF scenarios for 2030, this would amount to *ca*. 4 GtCO_2
- Note that the scope of study in 2030 provides only a snapshot. Over the longer term, bankable storage requirements in the tens of Gt could be required for Europe to meet high CCS scenarios e.g. into the 2050s.

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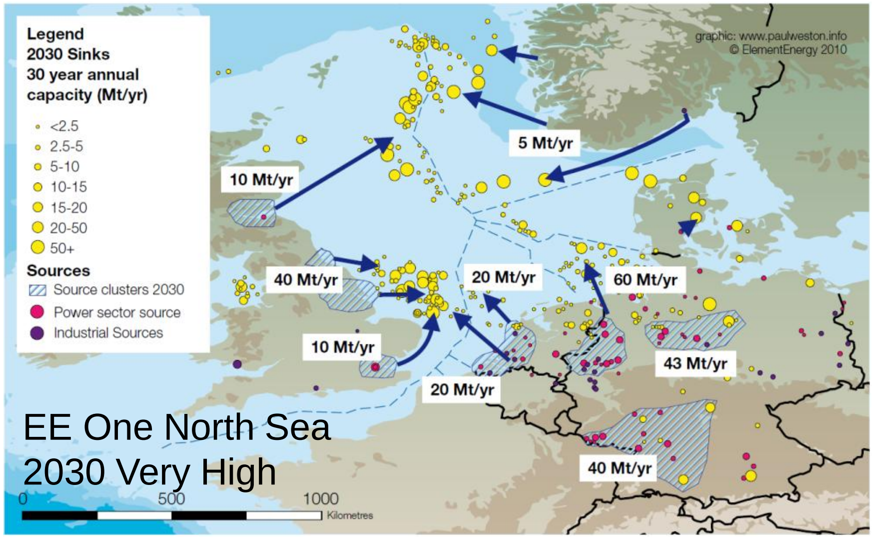
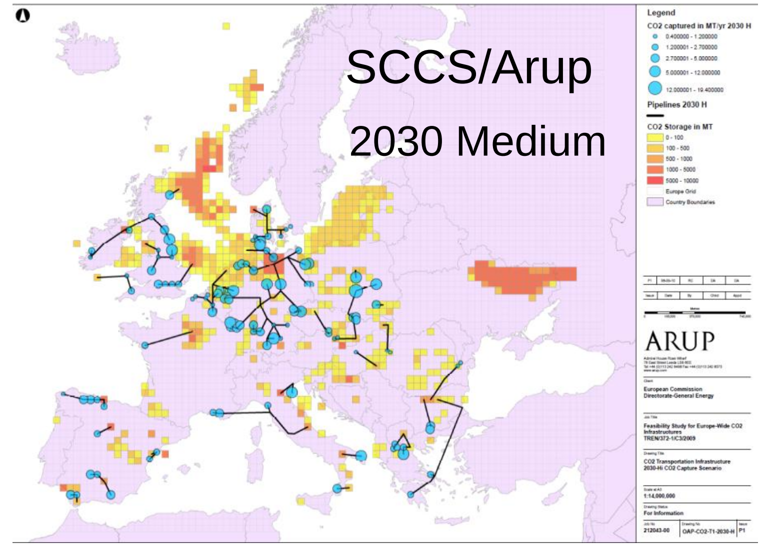
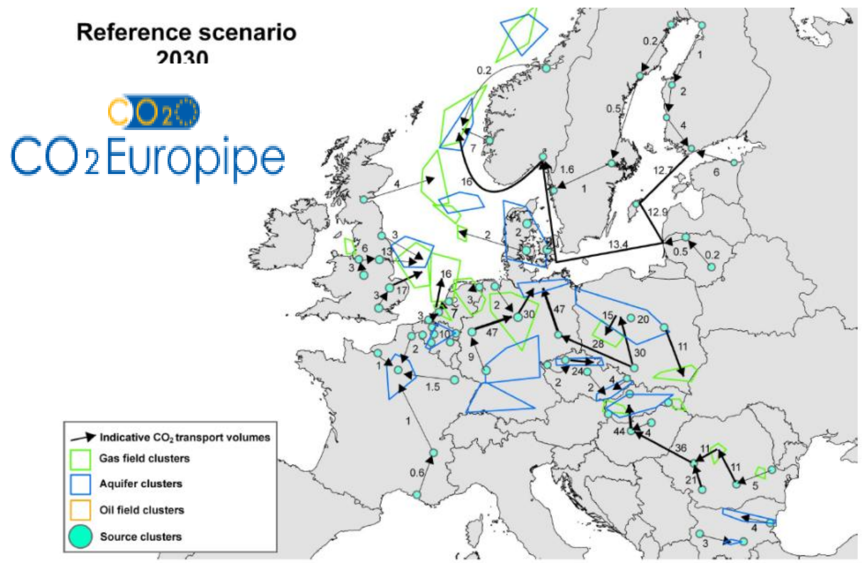
Recent studies have emphasised the potential need for large CO_2 transport networks in 2030 to meet high CCS demand scenarios…







- The implied transport infrastructure capacity for CCS in the highest published scenarios would be comparable to the existing oil and gas pipeline capacity.
- However, this level of investment took several decades to build up and required high confidence in hydrocarbon reservoir properties, a wide range of standards in place, and an excellent business case for investment founded on the existence of robust demand for oil and gas supplies.

…But even with strong market drivers, extensive or cross-border pipeline infrastructure may take more than a decade from techno-economic assessment to commissioning.

*Case study: Nord Stream natural gas pipeline**

In addition, CO_2 transport **<u>onshore</u>** may be heavily limited by the availability of corridors for pipelines and onshore conflicts of land use (i.e. high consenting risk)

Timeline for NordStream Pipeline

1997-99
Techno-economic feasibility

2000
Political backing by EU

2005
Joint Venture company established

2006
Strong EC support
Consultations

2007
Supply contracts signed

2008
Technical design finalised

2009
Transboundary permits
Environmental Impact Assessments

2010
1st line construction begins

2011
Phase II financing
Construction of 2nd line
Commissioning of 1st line

* 9 countries needed to approve the project's environmental and economic impact assessments

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A model was developed to quantify the impacts of practical constraints and policy drivers on the practical potential for CCS on gas power plant in 2030

The approach taken involved adapting 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. Key drivers considered (variables in the model for different scenarios) are :

- Overall CCGT fleet capacity and country distribution in 2030
- Member State social and political enthusiasm for CCS, and the subsequent timetable for regulators to enforce a more meaningful set of requirements for CCS readiness
- Levels of "bankable" storage capacity
  - Onshore/offshore
  - Competition between sources, particularly capacity reserved for coal or industrial CCS
  - Required levels of storage redundancy
- Ability to connect CCGT fleet with storage locations
  - Distance from power station to CO_2 injection site (onshore and offshore)
  - Potential to share CO_2 transport infrastructure with coal power or/industrial emitters that have CCS fitted
- Importantly, the model allows for a range of combinations of these drivers to be explored at a wide range of levels.
- Modelling details and assumptions are provided in the technical appendix.

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Defining scenarios for modelling the practical potential for gas CCS

2030 Gas power stock
- CCGT stock projection (GW)

Capture readiness
- Policy implementation year (early / middle / late adopters)
- Minimum CCS size threshold (MW)
- Repowering frequency (years)

Source-sink allocation
- Theoretical storage available (%)
- Capacity reserved for industry or coal
- Allowance of onshore / cross border
- Storage redundancy needed
- Storage allocation based on score or distance

Transport
- Sharing infrastructure with coal / industrial CCS

Sequence in which the model applies variables to determine overall readiness.

Different variables limit uptake under different scenarios / sensitivities.

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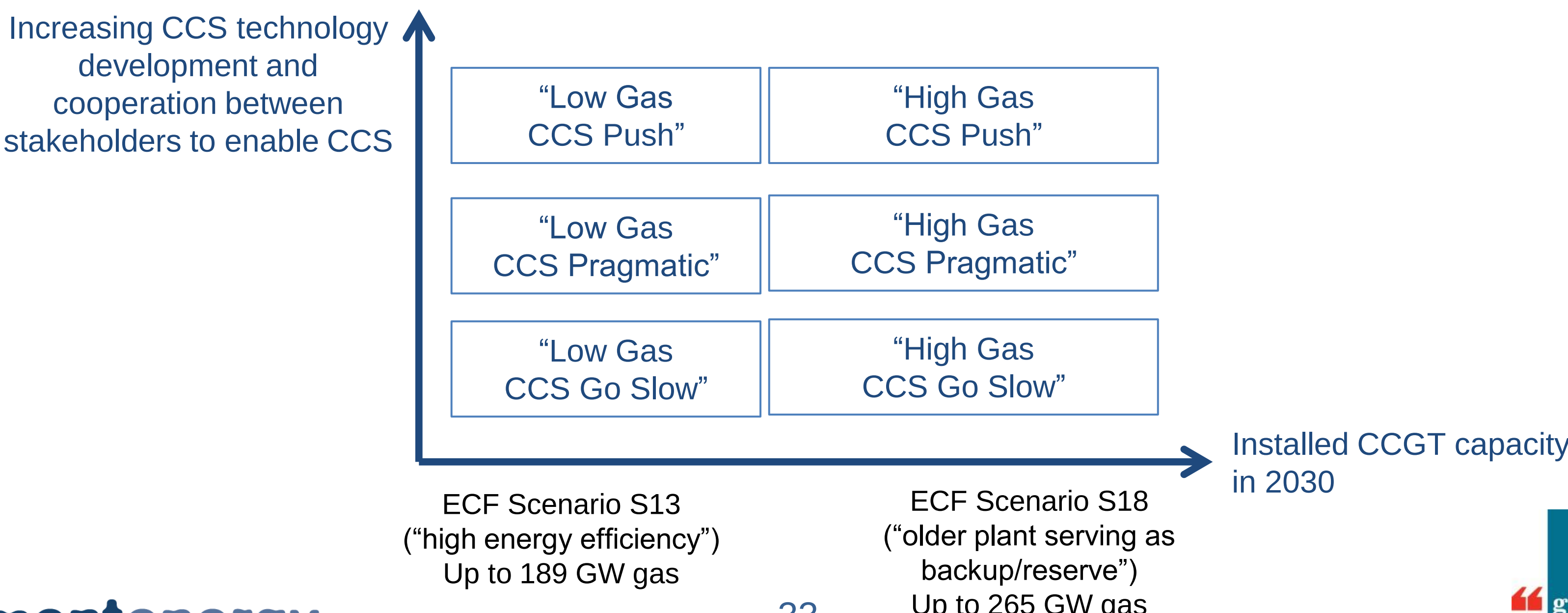
Key drivers were identified to develop scenarios for gas CCS in 2030.

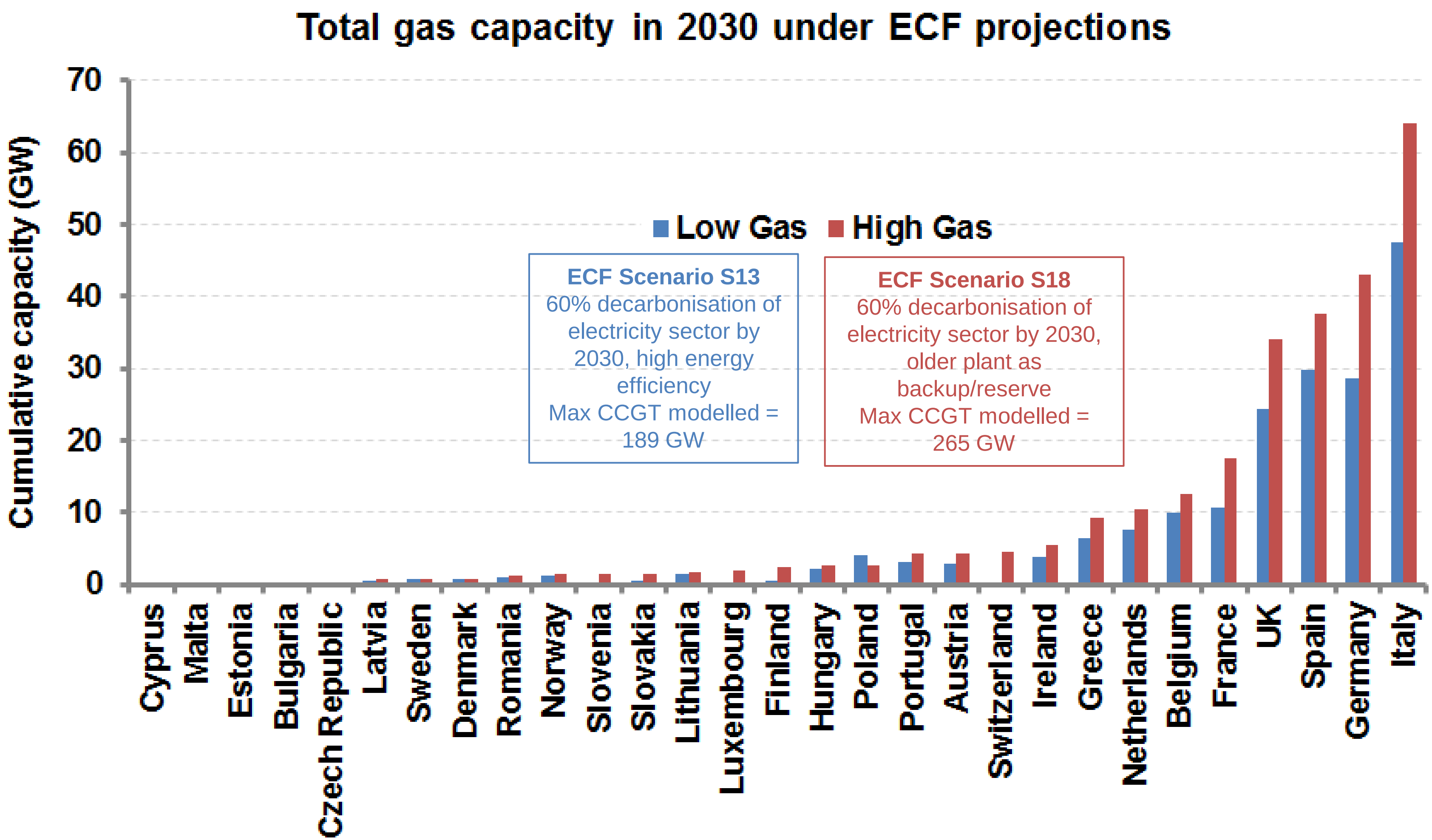
- Scenarios provide the opportunity to examine multi-dimensional systems to understand where additional policies may be required, and to provide quantitative insight into the levels of policy outcomes that may be possible from different measures.
- The scenarios do not constitute forecasts, they are “what ifs”, intended to enable consideration of alternatives for the way the world might develop relevant for gas CCS uptake.
- It is neither feasible nor necessary to model all fundamental drivers and possible outcomes. As an example, scenarios with very low levels of CCGT capacity, power sector decarbonisation, or the (unlikely) outright failure of CCS technology, were excluded. It is unlikely there would be sufficient demand for gas CCS in any of these cases to require policymakers or industry to alter behaviour beyond business as usual.
- Instead, following peer review, the two most useful sets of drivers likely to influence the potential level of gas CCS in 2030 and beyond were identified as:
    1. The total installed capacity of the CCGT fleet and its distribution across Europe. The installed CCGT capacities in this study were identified from the ECF Power Perspectives 2030 modelling (based on a 60% decarbonisation of the electricity sector in 2030) and are consistent with the more recent EC Energy Roadmap.
    2. The progress of CCS technology development and policy support, which in the model is derived from the timing of CCS readiness implementation, the availability of bankable storage, the growth of CCS on coal and industry, the access to CO_2 transport infrastructure, as well as the extent of restrictions on how CO_2 storage can be used.

Six scenarios were developed to quantify the practical potential for CCS on gas in 2030.

- Following stakeholder review, scenarios were designed to correspond to three levels of CCS technology development. These were then considered for 'high' (265 GW) and 'low' (189 GW) scenarios of installed gas capacity identified in the ECF Power Perspectives 2030 scenarios .
- In a "CCS go slow" scenario, there is limited progress with CCS demonstration, technology development or cooperation between stakeholders to enable CCS beyond existing legislation.
- At the opposite extreme, in a "CCS push" scenario, CCS demonstration is highly successful, new low cost/high performance capture technologies are developed, and all stakeholders cooperate to ensure large scale CCS roll-out in the 2030s across multiple sectors on a pan-EU basis.
- The "CCS pragmatic" scenario sees additional efforts taken, but envisages that these build on current member state approaches.



"High" and "Low" Gas Power Scenarios were used from the ECF Power Perspectives 2030 study.



Italy, Germany, Spain, UK and France together account for 74% of the total CCGT fleet in EU27+2

Scenarios with low, medium and high levels of CCS ambition were developed following initial analysis and stakeholder discussion. Peer review subsequently confirmed their value for understanding gas CCS readiness.

Scenario	Assumptions
CCS Push (coordinated 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 ❑ Shared transport and storage with Coal and Industry CCS ❑ Storage capacity reserved for 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 ❑ No benefit from shared transport with coal and industry CCS ❑ Storage capacity reserved for 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 and very cautious storage)	❑ Implementation of meaningful CCS readiness follows demos (i.e. 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

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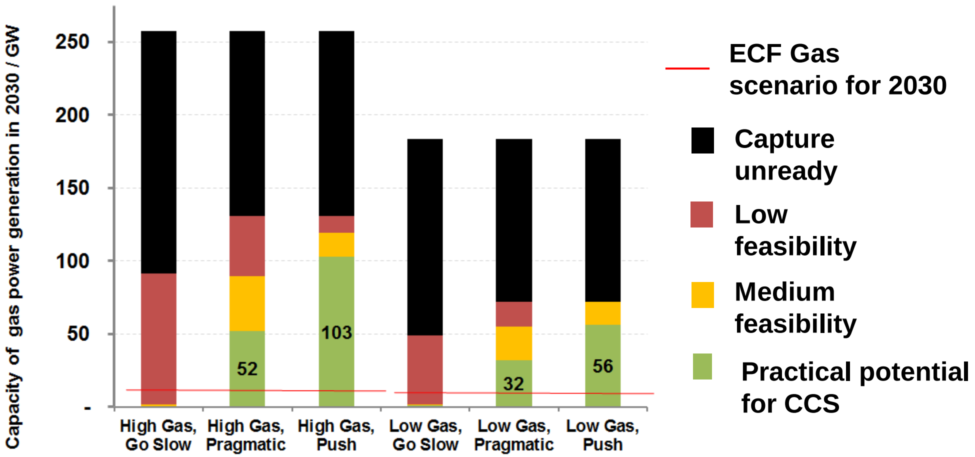
The ability to meet ECF assumptions for gas CCS in 2030 is highly scenario dependent on the level of policy effort undertaken.

- ❑ In some scenarios the practical potential for gas CCS is predicted to exceed milestone levels of 14-16 GW of operational CCS indicated for 2030.
- ❑ However, under a "Go Slow" scenario the CCGT fleet fails to reach much beyond 1GW of practical potential. This indicates that additional policy efforts will be required.
- ❑ This presents a serious risk to meaningful deployment of CCS on the gas power fleet in the 2030s and beyond, implying that other approaches to meeting carbon targets would be needed.
- ❑ The range of practical potential for gas CCS in 2030 spans <1 to 100 GW.
- ❑ Both "Pragmatic" and "CCS Push" scenarios could enable further deployment of CCS on the gas power fleet in the 2030s and beyond, but see the majority of plants still unready or unable to apply CCS.



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Even in the highest CCS scenarios, the model predicts 60% (more than 100GW) of gas capacity is unlikely to be capture ready or has limited potential for CO_2 transport and storage.

	Scenario					
	High Gas			Low Gas		
Level of potential	Go Slow	Pragmatic	Push	Go Slow	Pragmatic	Push
Capture unready	166 (64%)	127 (49%)	127 (49%)	135 (73%)	112 (61%)	112 (61%)
Low feasibility for transport and storage	90 (35%)	41 (16%)	11 (4%)	47 (26%)	17 (9%)	<1 (<1%)
Medium feasibility for transport and storage	1 (<1%)	37 (14%)	17 (6%)	0 (0%)	23 (13%)	16 (8%)
Practical potential for CCS	<1 (<1%)	52 (20%)	103 (40%)	1 (<1%)	32 (17%)	56 (31%)

❑ We next illustrate how the varying potential for CCS would be distributed geographically across Europe under the different scenarios.

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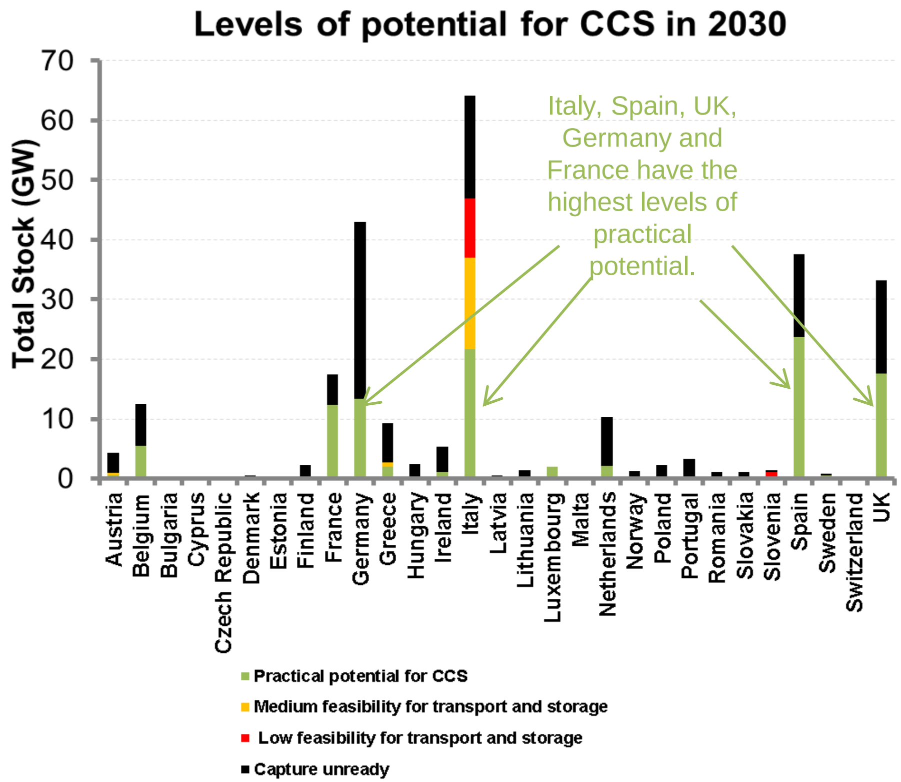
“High Gas, CCS Push” scenario



Locations of CCGT sites that are modelled to have practical potential for CCS

- Under this scenario, each of France, Germany, Italy, Spain and the UK would have more than 10GW of CCGT plant with 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 CCGT fleet failing to meet capture readiness requirements (e.g. due to plant age).

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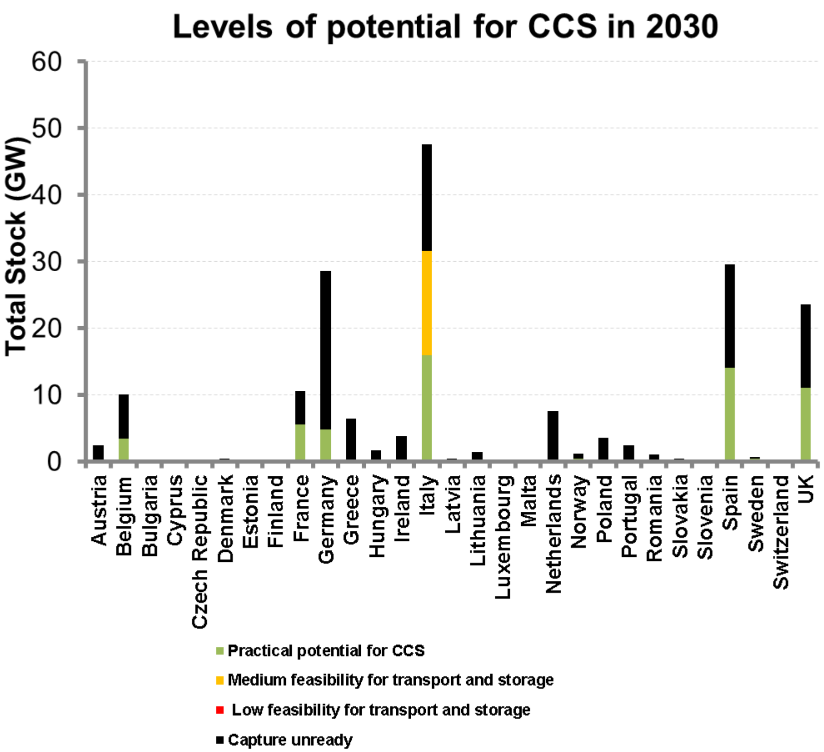
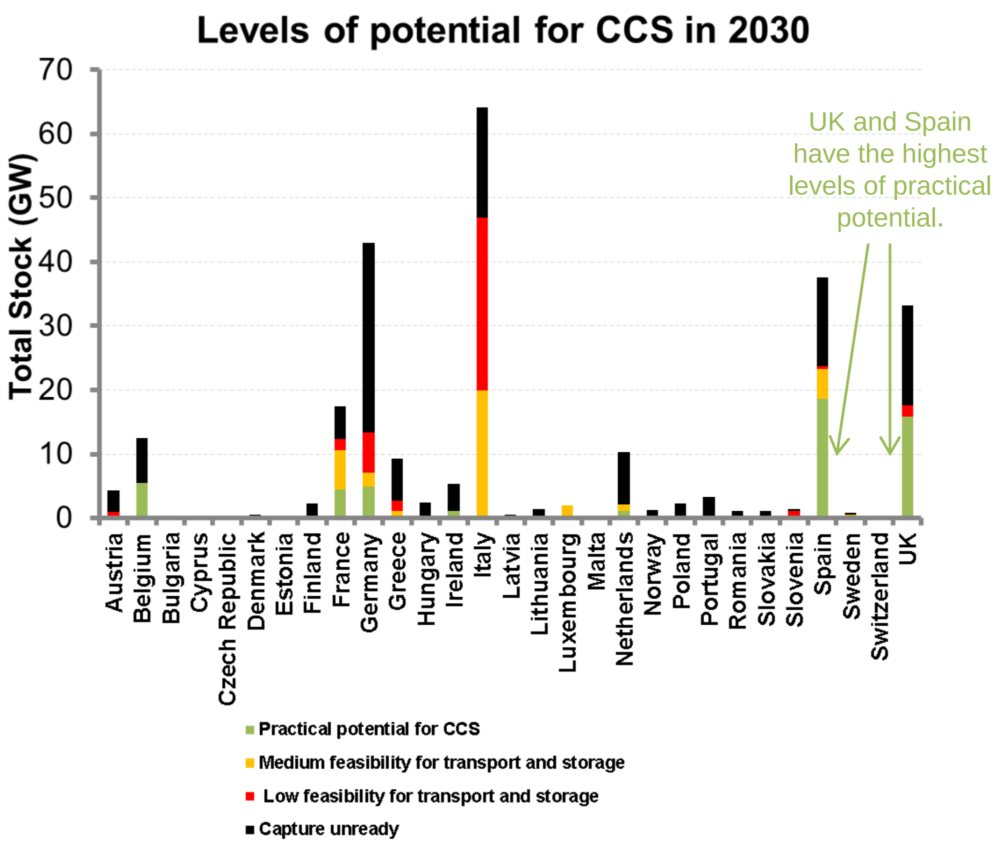
“Low Gas, CCS Push” scenario



Locations of CCGT sites that are modelled to have practical potential for CCS

- ❑ Under this scenario, France and Germany have reduced levels of practical potential for CCS due to lower levels of demand for gas.
- ❑ Italy, Spain and the UK would still have more than 10GW of CCGT plant with practical potential for CCS.
- ❑ Transport and Storage of CO_2 remains a limiting factor for Italy.
- ❑ Some countries which previously might have developed new plant with practical potential for CCS fail to do so given reduced gas demand. (Netherlands, Luxembourg)

“High Gas, CCS Pragmatic” scenario

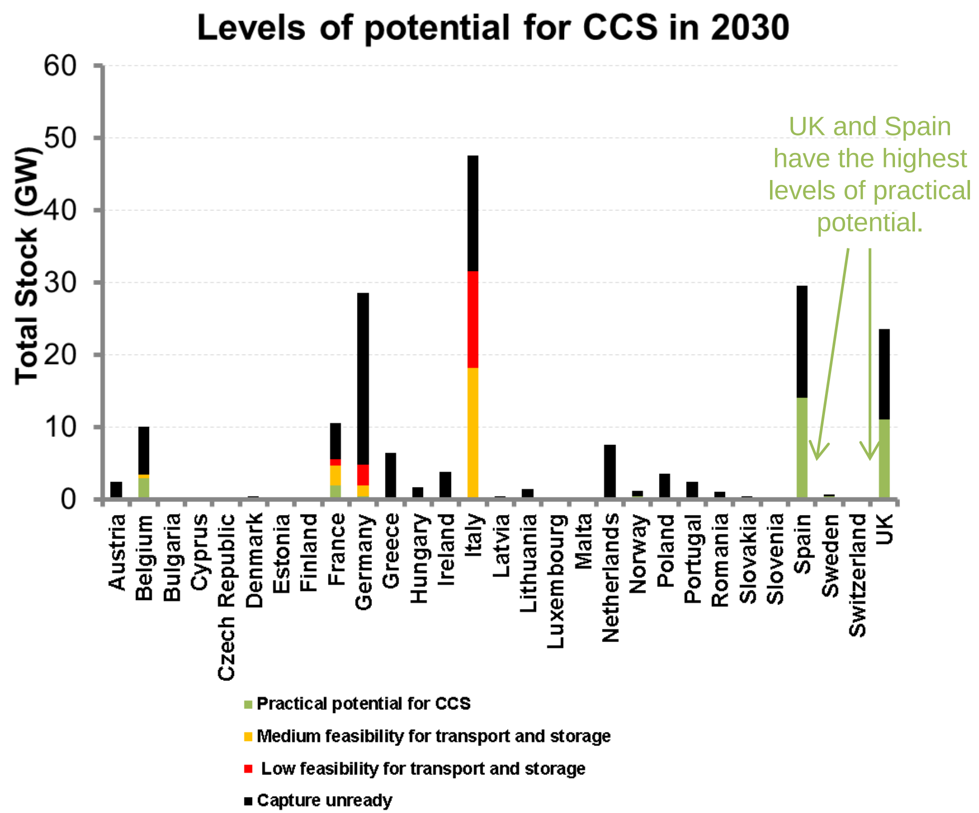


Locations of CCGT sites that are modelled to have practical potential for CCS

- Under this scenario, Spain and the UK would have more than 10GW of CCGT plant with practical potential for CCS in 2030.
- Transport and Storage of CO_2 would become a significant limiting factor for Italy, reducing its practical potential to zero. France and Germany would also see reduced practical capacity as a result.

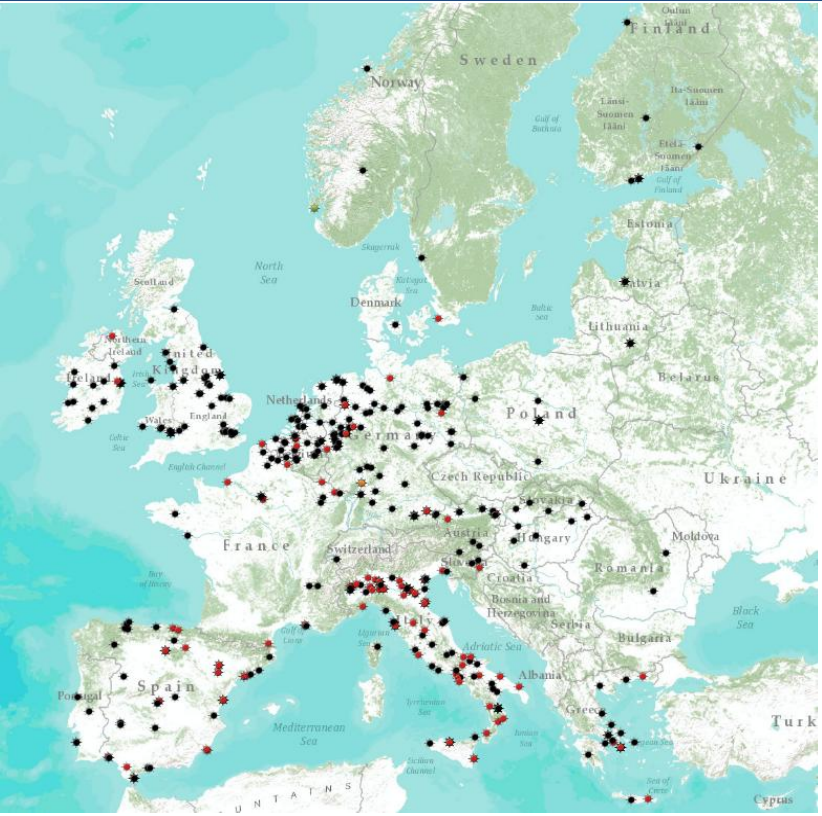
“Low Gas, CCS Pragmatic” scenario

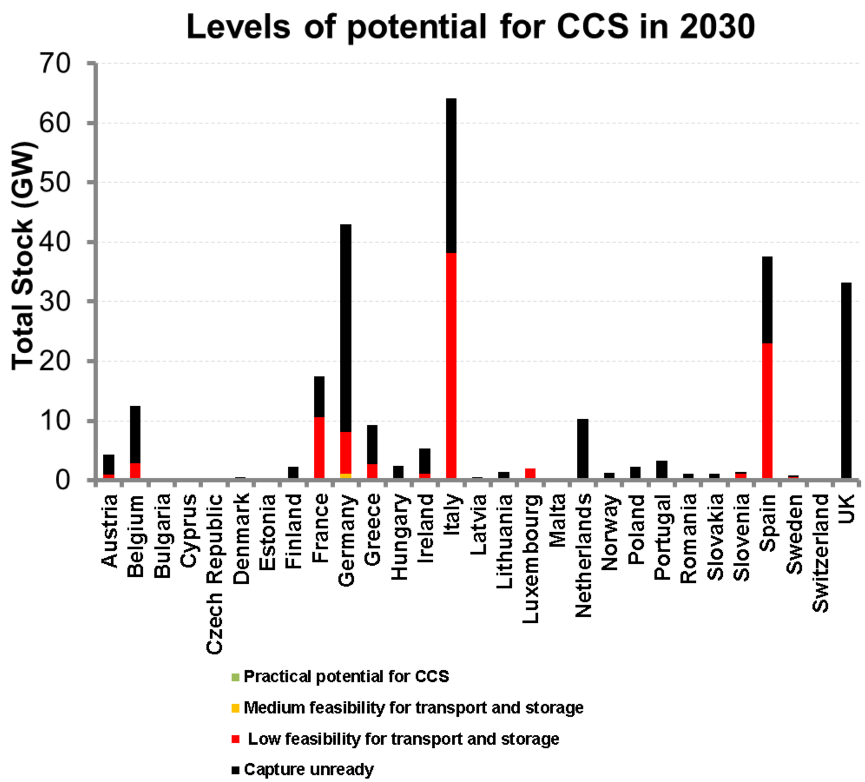
Locations of CCGT sites that are modelled to have practical potential for CCS



- Under this scenario, Spain and the UK would continue to have more than 10GW of CCGT plant with practical potential for CCS in 2030, even at lower levels of gas demand.
- Transport and Storage of CO_2 would become a significant limiting factor for Germany as well as Italy, reducing its practical potential to zero.
- As before, reduced levels of gas demand result in a number of member states seeing all of their fleets classed as capture unready.

"High Gas, CCS Go Slow" scenario





Capture unready

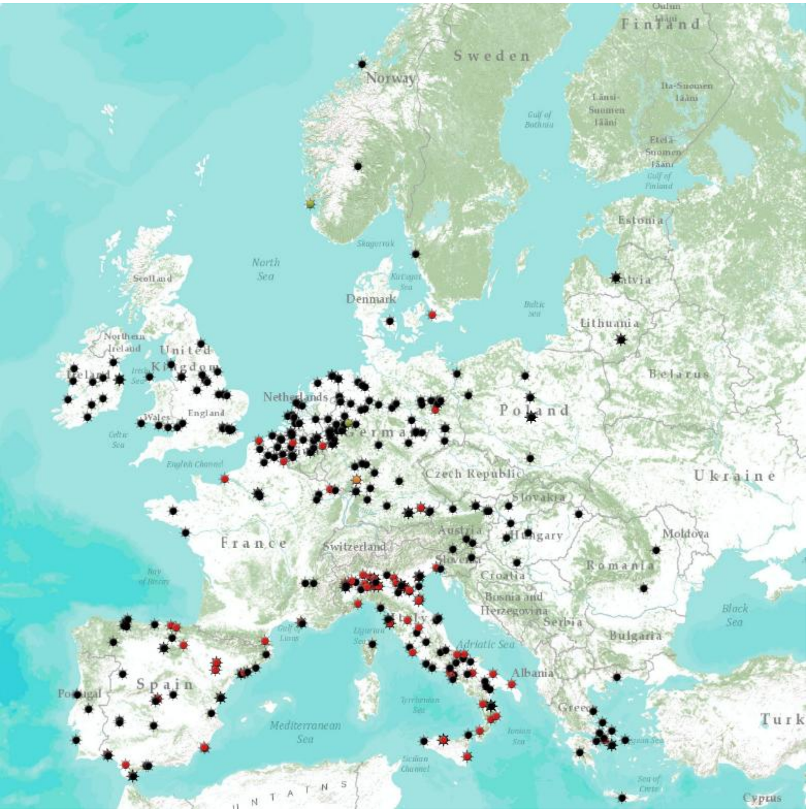
Low feasibility for T & S

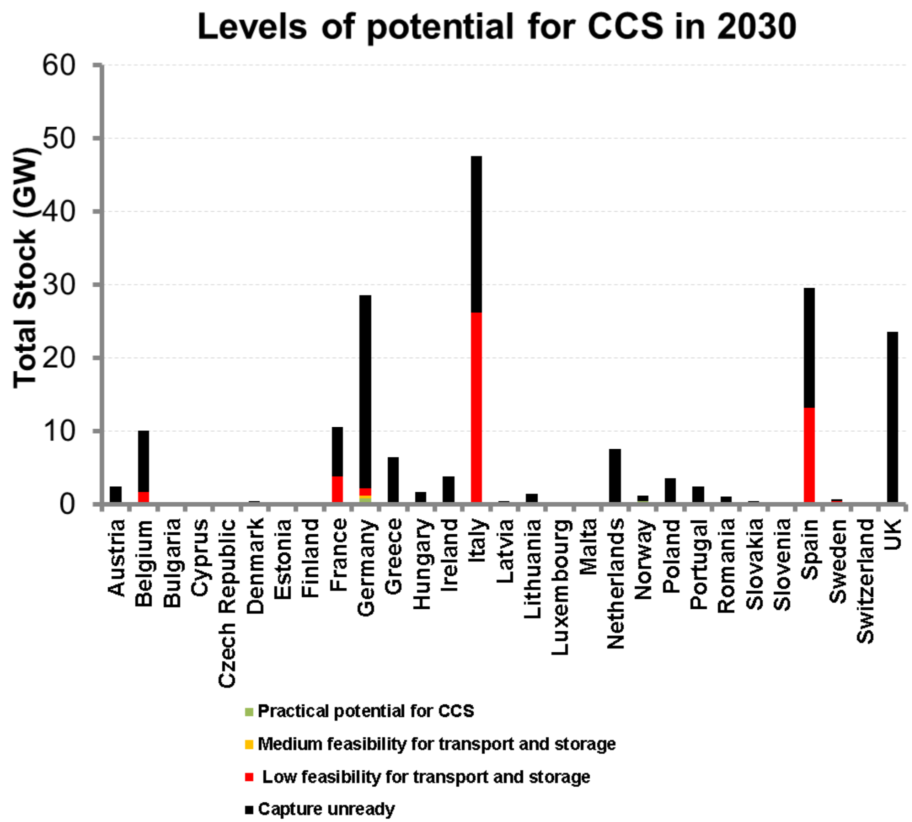
Medium feasibility for T & S

Practical potential for CCS

- Under this scenario, there is up to 1GW of CCS ready capacity in Europe, but the overwhelming picture is one of low feasibility for Transport and Storage of any plants meeting capture readiness assessment requirements. This is particularly the case for Italy and Spain.
- There are also increased levels of plant that fails to meet capture readiness requirements, for example the UK.

"Low Gas, CCS Go Slow" scenario





Capture unready

Low feasibility for T & S

Medium feasibility for T & S

Practical potential for CCS

- Under this scenario, a similar picture is presented to the previous slide, but with reduced levels of capacity due to lower levels of gas demand.
- This results in reductions in the stock which has met capture ready requirements.
- The overall level of practical potential for CCS on gas is now ca. 1GW.

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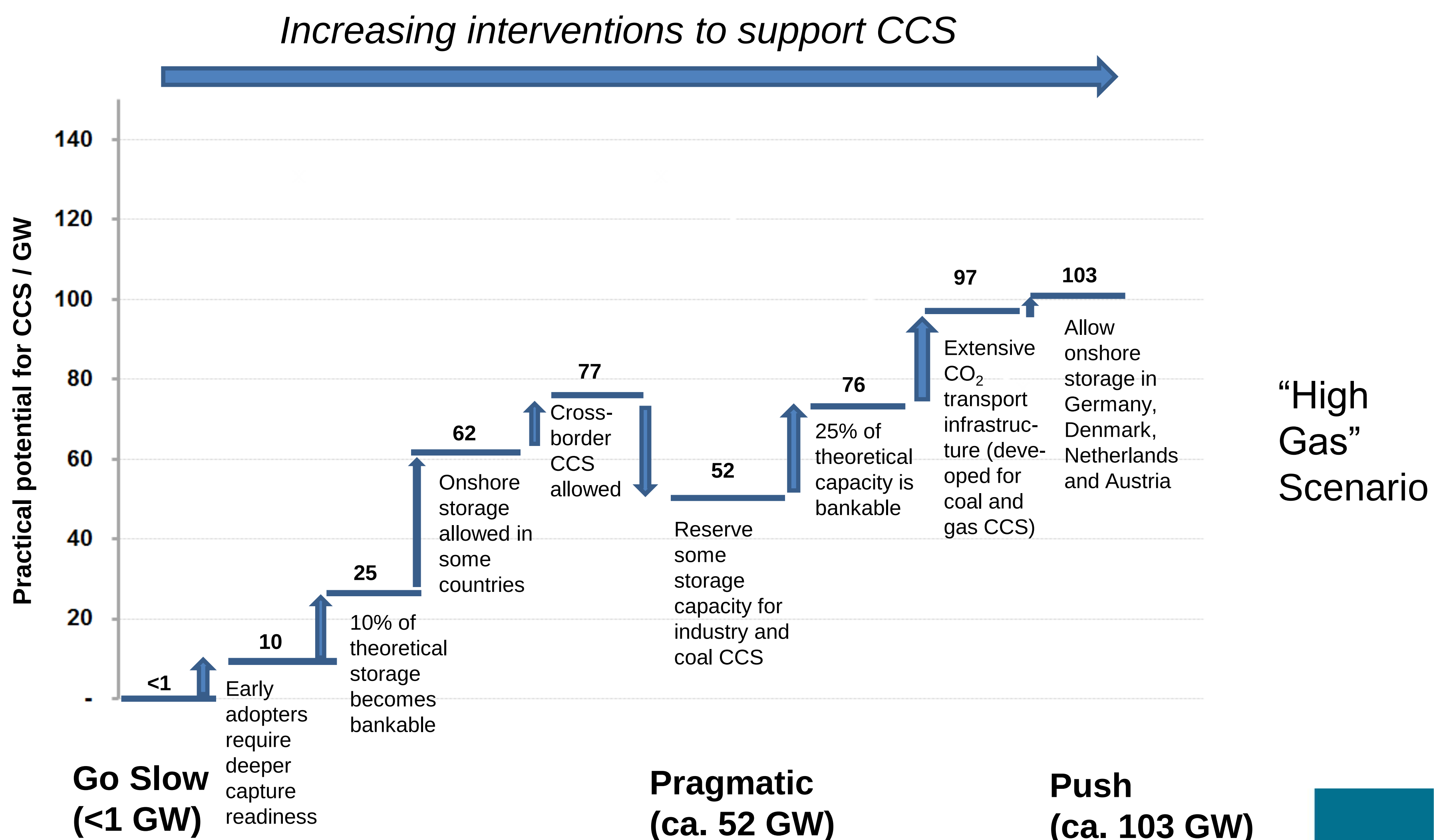
The modelling quantifies the impacts of policy choices on the level of practical potential for CCS on gas across Europe.



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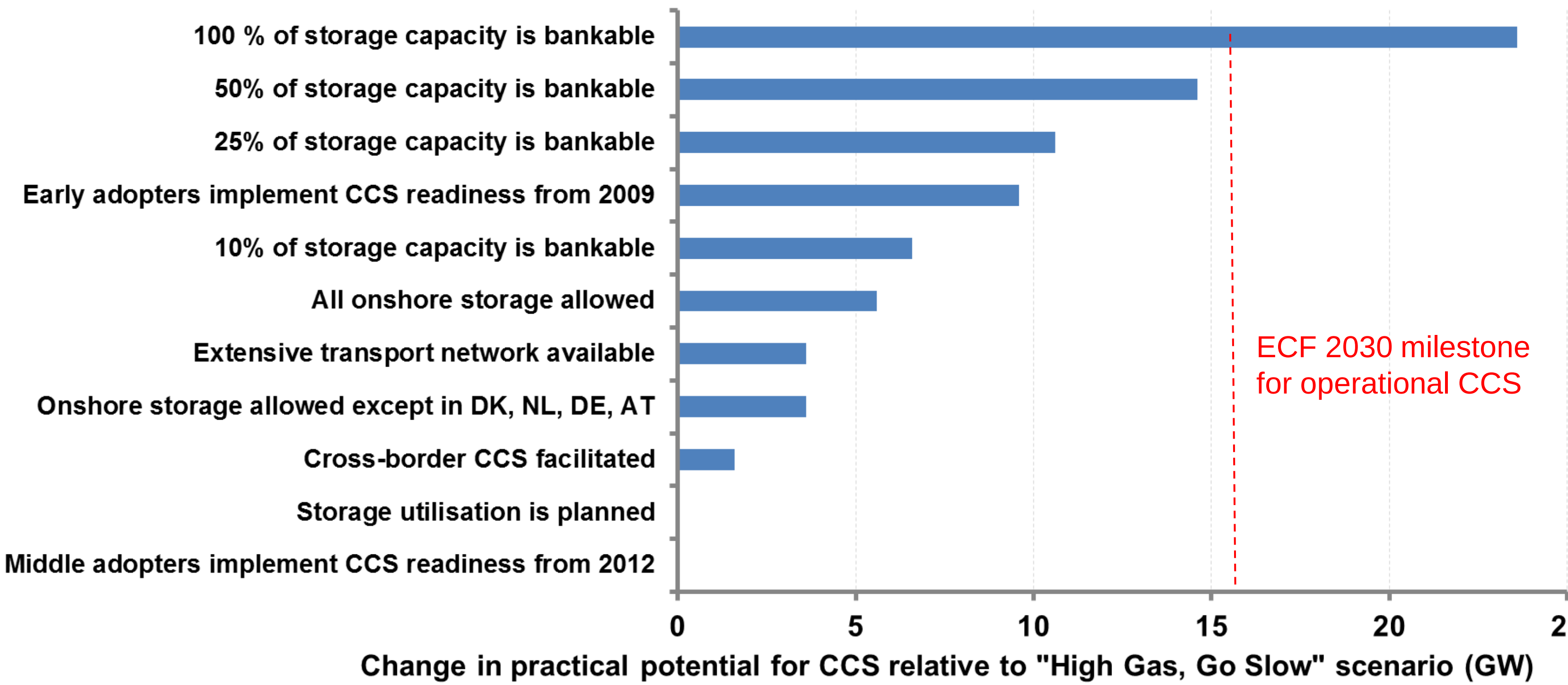
Single policy solutions efforts on capture readiness or CO_2 storage under the "High Gas, Go Slow" Scenario would be insufficient to enable the practical potential for gas CCS to meet the ECF 2030 milestone

Impacts of sensitivities on "High Gas, Go Slow" scenario



The model predicts Europe could have **<1 GW** practical potential for gas CCS under the "High Gas, Go Slow" scenario.

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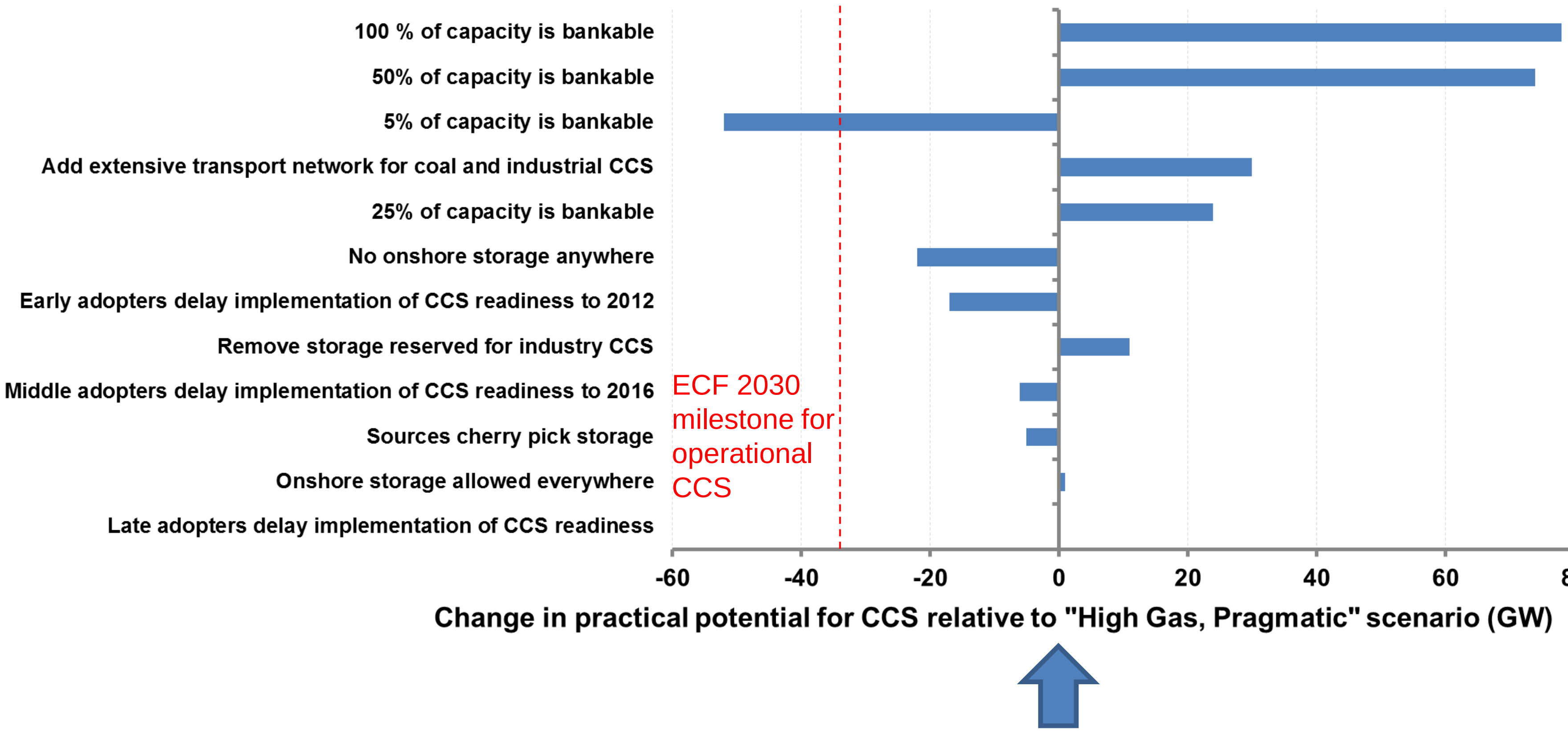
The practical potential for CCS in the "High Gas, Pragmatic CCS" scenario is vulnerable to a reduction in bankable or onshore storage capacity or delays in implementing meaningful capture readiness by early adopters.

Impacts of sensitivities on the "High Gas Pragmatic CCS" scenario



The model predicts Europe could have **52 GW** practical potential for gas CCS under the "High Gas, CCS Pragmatic" scenario.

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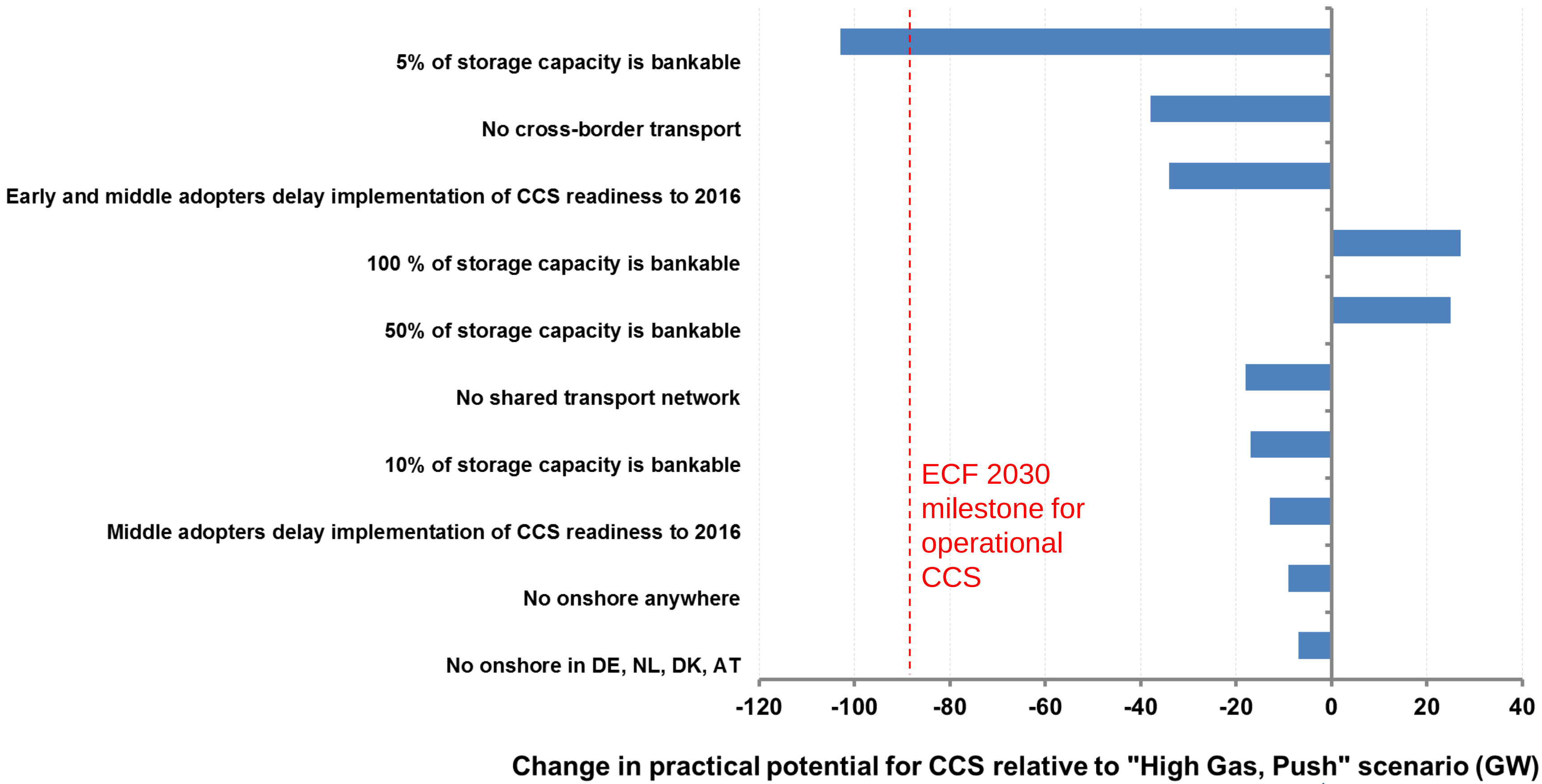
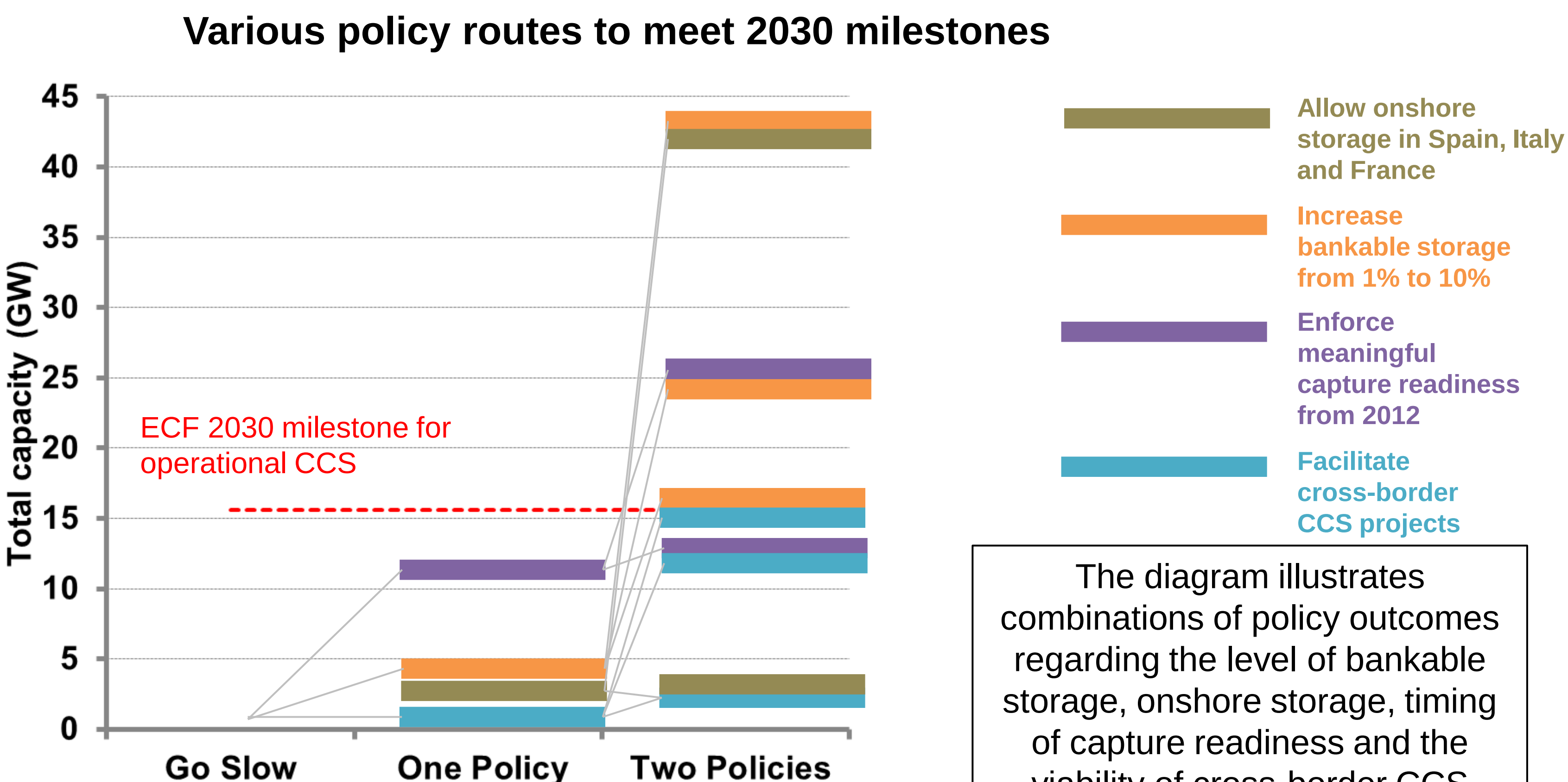
The practical potential for CCS in the "High Gas, CCS Push" scenario is most vulnerable to a reduction in bankable storage capacity, cross-border CCS and delayed implementation of meaningful CCS readiness.

Impacts of sensitivities on "High Gas CCS Push" scenario



The model predicts Europe could have **103 GW** practical potential for gas CCS under the "High Gas, CCS Push" scenario.

Considerable efficiencies can be obtained by treating capture, transport and storage as a whole – as policies to target these individually may be inefficient as impacts are not simply additive.



The diagram illustrates combinations of policy outcomes regarding the level of bankable storage, onshore storage, timing of capture readiness and the viability of cross-border CCS projects for a system with only two policies.

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The determinants affecting the practical potential for gas CCS differ between Spain, Italy, UK, Germany and France (the countries with highest CCGT levels).

Country	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	Impact of reserving storage for coal and industry CCS	Value of cross-border CCS	Value of integrated CO_2 transport networks with coal and industrial sources	Most useful policy to increase gas CCS ready capacity
Spain	++	+	+++	+++	+	+ (only if onshore restricted)	+	Increase bankable storage & acceptance of onshore storage
Italy	++	+	+++	++	+++	++	++	Increase bankable storage, acceptance of onshore storage (& cross-border if storage reserved for coal/industry)
UK	++	+++	++	No onshore	+	Not required	+	Early capture readiness
Germany	++	+	++	++	+++	+++	++	Facilitate cross-border storage e.g. with Norway if storage reserved for coal/industry
France	++	+	++	+++	+++	++ (esp. if coal and industry capacity reserved or onshore restricted)	+	Increase bankable storage & acceptance of onshore storage (& cross-border if storage reserved for coal/industry)

Key: **+++** Very High **++** Moderate **+** Limited

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High levels of practical potential for CCS in 2030 are technically feasible but multiple uncertainties will need to be addressed.

- The modelling shows that the deployment of CCS on gas cannot be assumed to be straightforward. Even if there were to be a positive business case for gas CCS plant (e.g. a sufficiently high carbon price and proven technology options) there would still be practical barriers to the deployment of CCS. These barriers affect each of the three areas of capture, transport and storage and will require policy responses that consider their interactions.
- Under the "CCS Go Slow" scenario the practical potential for gas CCS in Europe is close to just 1GW. The majority of the CCGT fleet would fail to meet requirements for the assessment of capture readiness at the plant level. Those plant that would have completed this assessment are predicted to have only low feasibility of access to appropriate CO_2 Transport and Storage options.
- Under the "CCS Pragmatic" and "CCS Push" scenarios, the modelling shows that it is possible for the CCGT fleet in Europe to exceed the 16 GW of practical potential for CCS that is assumed by ECF as required for 60% power sector decarbonisation in 2030.
- The results from these scenarios indicate that it would be practical for gas CCS to play an important and growing role in the supply of low carbon electricity in 2030 and beyond, particularly in Spain, the UK, Germany, France and Italy – the countries with the largest predicted CCGT capacity.
- These positive outcomes are however dependent on policy action to avoid the following barriers to CCS deployment:
  - 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, and
  - The absence of strong cross-border agreements.

Increasing the practical potential for gas CCS in 2030

- Currently the thresholds for CCS readiness set by the EU CCS Directive are “light touch”, reflecting the relative novelty of CCS technology and the uncertainties over future requirements. However a wide range of technical, economic, political/social, and regulatory barriers for capture, transport or storage may prevent these nominally CCS ready plants from actually being able to implement CCS in the period to 2030.
- Stakeholders who wish to ensure widespread practical potential for gas CCS in the period to 2030 and beyond must therefore consider interventions in the 2010s that ensure meaningful capture, transport and storage readiness can be undertaken. These interventions could include early enforcement of capture readiness, extensive storage characterisation, engaging with public concerns over the potential safety of onshore CO_2 storage, developing integrated CO_2 transport networks, and facilitating cross-border CCS.
- Policies specifically aimed at encouraging the development of increased levels of practical potential for gas CCS could be initially targeted at a limited number of countries for maximum efficiency, but should be holistic, i.e. covering capture, transport and storage readiness, rather than treating these independently which appears to be the case at present. As the technology and CCS capacity requirements for the gas power sector become better understood, investors and regulators should demand wider geographic coverage and more meaningful levels of readiness in capture, transport and storage to avoid the threats of lock-in or stranded assets in the 2030s and 2040s.

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Without further interventions, there is a risk that the practical CCS capacity in 2030 will fall below the ECF scenario levels.

- Policies around capture, transport and storage can change the practical potential for CCS of the CCGT fleet in 2030 from <0.1% to >40%. The analysis identifies the need for a combination of policies affecting capture readiness, storage readiness and transport readiness to deliver the highest levels of practical potential in 2030.
- However, rather than absolute and independent levels for policies for capture, policies for storage and policies for transport, the analysis reveals that the impacts of policies are highly interdependent (i.e. non-additive) and it would be efficient to tailor these for different countries.
- The analysis presented here took as a starting assumption a need for a more meaningful and proactive approach to considering CCS readiness at the plant level, including this requirement being considered at the time of major plant refurbishment.
- The CCS directive will be reviewed in 2015. Initial areas for consideration can already be identified:
  - Extent of member state requirements for meaningful CCS readiness assessments
  - Potential need to widen scope to include existing plant contemplating life extensions as well as new plant
  - Member state assessments of available CO_2 storage capacity
- The development of integrated CO_2 transport networks falls outside the scope of the CCS directive, but will be considered under the new energy infrastructure funding measures currently under negotiation.
- The planned CCS communication (Autumn 2012) provides an opportunity to identify these and other challenges.

Uncertainties around CO_2 storage propagate throughout the CCS system and pose a challenge to the practical potential for gas CCS.

- One important issue is ensuring sufficient levels of "bankable" storage capacity are in place by the 2020s to underpin multi-billion Euro investments in capture, transport and storage infrastructure.
- Improving "bankable" storage capacity will require a combination of experience from CCS demonstration projects and a programme of storage characterisation lasting several years across multiple basins. This may cost as little as €1/t 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.
- Competition for limited storage capacity among sources (other gas plants, or coal and/or industry CCS) could be a significant issue for many CCGT plants – suggesting benefits for national, and in some cases Europe-wide planning of the use of storage.
- Integrated transport networks and cross-border CCS agreements offer benefits in most countries, but will be particularly relevant where storage capacity is restricted (e.g. reduced onshore, limited site appraisal or competition from coal and industrial CCS). This is likely to be the case for Germany.
- Careful management of public engagement for onshore CO_2 storage is required for Spain, France and Italy to facilitate storage readiness in these countries.
- Given the likely distribution of gas plant across Europe, actions in the UK, Spain, Italy, France, and Germany will have the greatest impact on the overall level of practical potential for gas CCS. These countries could be considered priorities for a holistic introduction of meaningful requirements for capture readiness and the characterisation of bankable CO_2 storage options.

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- The Committee on Climate Change
- TNO
- Total
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- University of Edinburgh
- ZEP

Useful References

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Caveat

- While the authors consider that the data and opinions in this report are sound, all parties must rely on their own judgement and skill when using it.
- The authors do not make any representation or warranty, expressed or implied, as to the accuracy or completeness of the report.
- There is considerable uncertainty around the development of gas markets and CCS technology. The available data and models on sources and sinks are extremely limited and the analysis is therefore based around purely hypothetical scenarios. All models are limited by the quality and completeness of assumptions that go into these.
- The maps, tables and graphs are provided for high-level illustrative purposes only, and no detailed location-specific studies have been carried out.
- The authors assume no liability for any loss or damage arising from decisions made on the basis of this report.
- The views and judgements expressed here are the opinions of the authors and do not reflect those of ECF or the stakeholders consulted during the course of the project.
- The conclusions are expected to be most robust when considering EU27+2 aggregated data. The input data have decreasing reliability at lower levels of aggregation (e.g. national, where only broad trends would be relevant). “Over-analysis” of country-specific and site-specific assumptions is strongly discouraged.