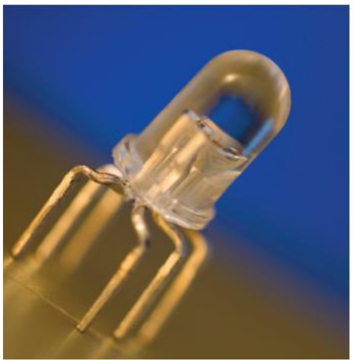

Support to the follow up of the evaluation of Directive 2009/31/EC on the geological storage of carbon dioxide (CCS Directive)

Task 3: Guidance on how to do assessments for CCS retrofit

In association with

elementenergy

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Support to the follow up of the evaluation of Directive 2009/31/EC on the geological storage of carbon dioxide (CCS Directive)

Task 3: Guidance on how to do assessments for CCS retrofit

A report submitted by ICF Consulting Limited
in association with

Element Energy

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Date	28 July 2016

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Contents

1 Purpose of Guidance Document

The purpose of this Guidance Document is to provide guidance on the assessment of the suitability, feasibility and preparation for carbon capture and storage (CCS) retrofitting, as part of implementing Article 33 of the CCS Directive. This guidance document complements the four guidance documents published by the European Commission in March 2011. [1]

This guidance document covers the:

- Technical assessment for CO_2 capture;
- Suitability of CO_2 storage;
- Technical assessment of CO_2 transport; and
- Economic assessment for CCS.

This guidance document uses the findings for the European Commission study to "Support to the follow up of the evaluation of Directive 2009/31/EC on the geological storage of carbon dioxide (CCS Directive)." Specifically, two tasks as part of the study have helped to inform this guidance document:

- Task1: The practical application of Article 33 of the CCS Directive in EU MSs; and
- Task 2: Global best practices in assessment and readiness for CCS retrofit.

The guidance does not represent an official position of the European Commission and is not legally binding. Final judgments concerning the interpretation of the CCS Directive can only be made by the European Court of Justice.

This non-legally binding document provides assistance to:

- Project operators to assess the availability of suitable storage sites and the technical and economic feasibility for CO_2 capture retrofit and of CO_2 transport infrastructure;
- The Competent Authorities to evaluate the assessments; and
- Project operators to prepare for future retrofitting.

It is important to recognise that the scientific and economic basis for CCS is evolving, as more information is gained through the on-going global research and development efforts. Thus, technical advancements and economic circumstances for CCS may change over time. As such, it is expected that this guidance document will also change in time with the circumstances.

[1] European Commission, DG Climate Action. Implementation of the CCS Directive. http://ec.europa.eu/clima/policies/lowcarbon/ccs/implementation/documentation_en.htm

2 Legislative context

2.1 CCS Directive

The significant potential for carbon capture and storage (CCS) to mitigate greenhouse gas (GHG) emissions has long been recognised by the European Union.[2] For the power sector, CCS could be a key technology for fossil fuel-based power generation, helping to achieve the substantial reductions in GHG emissions in the long term, balanced with increasing shares of renewable energy. In the industrial sector, CCS may be the only economic option available to achieve the required long term reductions in direct emissions as theoretical limits of efficiency are reached and process-related emissions are unavoidable.

In order to provide a necessary trigger for deployment, in January 2008, as part of a larger legislative package on energy and climate, the European Commission (EC) proposed a Directive on CCS to establish a legal framework to enable environmentally-safe CCS in the EU. On 23 April 2009, the CCS Directive was adopted by the European Parliament and the Council.[3] The CCS Directive provides specific requirements for Member States (MSs) to follow in order to ensure environmentally safe and permanent geological storage of CO_2 in the territory of the EU MSs, their exclusive economic zones, and on their continental shelves within the meaning of the United Nations Convention on the Law of the Sea (Article 2(1) of the CCS Directive).[4]

The key elements of the Directive include: storage site selection, storage permits (conditions, contents, review), CO_2 stream acceptance criteria, monitoring and reporting, inspections, corrective measures, closure and post-closure obligations, transfer of responsibility, financial security and financial mechanism. The CCS Directive required the MSs to develop national laws, regulations and administrative provisions on CCS in order to comply with the CCS Directive by 25 June 2011.

2.2 Article 33

One element of the CCS Directive is Article 33, which introduced an amendment to Directive 2001/80/EC. Article 33 is explained in preamble 47 of the Directive that new investments are to be made in such a way as to facilitate substantial reductions in emissions through CCS to support the transition to low-carbon power generation.

Article 33 requires MSs to issue operating licences to combustion plants rated with an electrical output equal or higher than 300 MW only after an assessment whether it is technically and economically feasible to retrofit for CO_2 capture, whether suitable CO_2 storage sites are available and whether CO_2 transport facilities are technically and economically feasible. If such an assessment is positive, “the competent authority shall ensure that suitable space on the installation site for the equipment necessary to capture and compress CO_2 is set aside.”

[2] European Commission, DG Climate Action. Carbon Capture and Geological Storage. Available at: http://ec.europa.eu/clima/policies/lowcarbon/ccs/index_en.htm

[3] Official Journal of the European Union, L 140/114, 5.6.2009. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0114:0135:EN:PDF

[4] CCS Directive only applies to projects intended to store more than 100 kilotonnes (Article 2(2)).

3 Basis for the guidance and recommendations

The guidance to project developers and competent authorities provided in this document are based on research and analysis conducted on the current (as of early 2016) practical application of Article 33 of the CCS Directive in MSs. All MSs were requested to provide responses to a questionnaire on how Article 33 has been applied and implemented in the MS. MSs that are likely to have useful insight into the practical application of Article 33 were identified taking into account a range of factors, including the amount of electricity generated from fossil fuels, CO_2 storage capacity and number of CCS projects. The eight selected MSs include: Germany, United Kingdom, Italy, Poland, Spain, Netherlands, Czech Republic, and France. Additional engagement activity (through phone calls and emails) was undertaken with these eight MSs to gather further information.

The MSs noted that the difficulty of providing meaningful insight into the key difficulties and challenges for evaluating Article 33 implementation, given the limited CCS demonstration and deployment experience across the EU and globally. The limited practical experience makes it difficult to the competent authorities to assess the technical and economic feasibility of capture ready power plants, as well as relying on outdated sources for guidance material and the basis for assumptions.

Information on how the Article 33 implementation has been perceived by the CCS project developers in the EU was gathered through a similar questionnaire. Out of thirteen power plant developers contacted across seven MSs, only three power plant developers provided responses, as of June 2016. Project developers noted that the limited experience to apply CCS technology has been a limiting factor to the practical application of Article 33. The competent authorities also stated that many developers struggle with applying for permits, given the limited prior experience of these kinds of assessments. Interviews with project developers have demonstrated that there is a high and increasing gap between the need to implement the provisions of Article 33 and the actual confidence of developers in this technology.

Global current best practice on carbon capture and storage (CCS) readiness was evaluated, drawing both on practical experience from jurisdictions around the world, and on industry literature written since the CCS Directive was passed in 2009. The lessons learned from these sources were synthesised and their relevance to MSs were considered in developing the guidance and recommendations in the following sections.

4 Guidance to developers

This section provides guidance to project operators to assess the availability of storage sites and the technical and economic feasibility for CO_2 capture retrofit and of transport infrastructure. This section provides guidance on overcoming key challenges for various aspects of the technical and economic feasibility assessment. The guidance in this section is split into the following elements:

- General guidance across CO_2 capture, storage and transport
- Technical assessment for CO_2 capture
- Suitability of CO_2 storage
- Technical assessment of CO_2 transport
- Economic assessment for CCS

4.1 General guidance across CO_2 capture, storage and transport

In this section, overall guidance across all three elements of CCS (capture, transport, and storage) is provided, taking into consideration the common themes across these aspects. The guidance is meant to support the developers in submitting licence applications that are compliant with Article 33. This section has been informed by the 2010 Global CCS Institute Report on CCS readiness.[5]

4.1.1 Environment, safety and other approvals

CCS project developers need to anticipate environmental, safety and other relevant approvals that are needed in the future. This is needed to avoid features that make obtaining those approvals difficult. Developers are recommended to:

- Identify all approvals that are needed;
- Conduct feasibility studies for relevant approvals; and
- Prepare key documents for approvals.

CCS technologies may change during the process of applying for a permit and actually developing the CCS project, thus the approvals can change throughout the planning process.

Identifying the approvals for eventual CCS provides developers with an initial assessment of the approvals needed and the expected time for receiving the future approvals. The feasibility studies needed to receive the approvals can highlight the possible obstacles that can prevent the plant from retrofitting to CCS. The availability of key documents for approvals will help advance the process to develop CCS. While the approval activities may result in higher costs to developers, they can also reduce the project's financial risk in investing in processes that may not eventually be approved.

Further information on approvals is provided in the following sections: For capture, section 4.2.4; for storage, section 4.3.4; and for transport, section 4.4.5.

4.1.2 Public awareness and engagement

Public opposition to CCS can delay or result in the cancellation of projects. Awareness raising activities and early engagement with the public can help alleviate concerns

[5] ICF International prepared for the Global CCS Institute, 2010. CCS Ready Policy: Considerations and Recommended Practices for Policymakers.

Developers are encouraged to provide information about CCS technologies and planned projects, inform the public on the risks of CCS, and explain what is being done to keep communities safe. Developers should provide accessible information on the technical matters related to CCS and also how CCS can play a significant role in low-carbon power generation.

Recommendations for public awareness and engagement activities include:

- Notifying the public of eventual CCS retrofit projects via a website;
- Early communication with the public to address concerns and raise awareness of potential positive factors such as job creation, stimulus to the local economy, and decreases in local air pollution;
- Public participation in the power or industrial plant planning process through public/community meetings, information sessions, and through engagement with any relevant NGOs;
- Build and maintain relationships with communities at each stage of the project;
- Provide information about the project in local languages;

Further information on public awareness is provided in the following sections: For storage, section 4.3.5; and for transport, section 4.4.6.

4.2 Technical assessment for CO_2 capture

4.2.1 A technical overview of the available capture technology

As part of the application, the project developer should provide a technical overview of the available capture technology. This will help make it clear which capture technology is currently considered the most appropriate for retrofit in the future to the power station. Alongside this information, developers should demonstrate that there are no currently known technical barriers to subsequent retrofit of the selected capture technology.

4.2.2 A layout of the plant which takes into account the capture and transport equipment

A detailed potential layout of the plant and the capture and transport equipment should be provided by project developers. This will help provide evidence to demonstrate that the proposed layout is suitable for subsequent CCS installation. The plans should demonstrate:

- The footprint of the combustion plant;
- The location of the capture plant including any air separation units;
- The location of the CO_2 compression equipment;
- The location of any chemical storage facilities; and
- The exit point and compressors for CO_2 pipelines from the site.

Conceptual diagrams and a description, demonstrating how the space will used, can also be provided. Basic calculations using the known volumes of CO_2 that could be processed can be included in the space description. This will help justify the size and type of the processing equipment chosen.

4.2.3 The allocation of space and footprint of the capture retrofit equipment

Developers can prepare material to demonstrate that sufficient space is available to accommodate carbon capture equipment. The space could be sized so it is capable of processing emissions from the entire power station, in the future. However, if the space will only accommodate a fraction of the total emissions, this should be stated explicitly.

When considering the space requirements, developers will need to consider:

- The type of capture technology proposed;
- The size/ number of the power generating units;
- The input fuel;
- Processing CO_2 on or off-site;
- The safe storage of chemicals;
- Impact of congestion on site for safety both during construction and operation; and
- Future progress in developing the capture technologies that can reduce the space required for the related equipment.

If developers decide to consider land that is off the core power plant station site, then the property rights of this land needs to be considered and plans for obtaining the additional land should be stated. Furthermore, developers will need to consider how any ownership rights may change over the expected lifetime of the plant.

4.2.4 Environmental, safety, and other approvals for capture facilities

As part of the assessment for the technical feasibility of carbon capture equipment, developers should provide sufficient detail to ensure that competent authorities can make informed decisions on whether the proposal is CCS ready. Developers should justify the choice of capture technology, and provide reasons why it is considered the most suitable for the associated power plant. To help demonstrate the suitability of the capture technology, developers can compare the proposed capture equipment and describe how it is more appropriate than other possible capture options.

There can be a wide variety of approvals required at the planning, construction, and operational stages of a CCS project. A CCS retrofit can impact air emissions, water effluence, solid waste generation, and water use due to the installation and operation of capture equipment. These modifications may require new permits or alterations to existing ones.

Some of the main aspects that developers need to consider include:

- Calculation and control of NOx and SO_2 emissions;
- Control of air emissions from leaking of solvents;
- Water use that may need to be modified to ensure sufficient availability;
- The calculation of efficiency losses and determination of an optimum efficiency approach;
- How the equipment will increase the site's consumption of electricity;
- The issue with collection of steam from the steam circuit and reduced performance of the steam turbine; and
- Potential changes to effluent discharge due to CO_2 capture; and
- Solid waste handling.

Additional approvals on worker safety, emergency planning, or requirements from right-to-know laws may be required too. The EU Directive notes that project developers would need to comply with existing EU directives on environment and safety.

4.3 Suitability of CO_2 storage

Suitable storage options will depend on the specific legislation and regulations in each MS, particularly if there are any bans or restrictions on CO_2 storage in the MS territory. To help demonstrate the suitability of CO_2 storage, it is important for developers to consider option for potential storage clusters/ hubs and also options of storage sites outside national boundaries. With all options, it is essential that developers utilise the best available current data for storage, given this is a dynamic aspect for the market.

4.3.1 Consideration of 'best available data' for storage site selection

Selection of suitable storage sites should be based on best available data. It is recommended that MSs increase national storage readiness levels (by carrying out a number of key activities as explained in Section 5.1) and provide project developers with detailed data on the nearby storage units. Some of the existing resources on 'best available data' in the EU are listed below:

- The CO2StoP project created a database of locations and capacities of underground geological formations in Europe that could be used to store CO_2.[6]
- The EU GeoCapacity projects assessed European capacity for geological storage of CO_2.[7]
- The Baltic Sea CO_2 Storage (Bastor2) assessed storage potential in the Baltic Sea region by procuring additional data from Latvia, Russia and Poland.[8]
- In the UK, CO_2Stored database provides detailed information on over 500 potential CO_2 storage sites around offshore UK.[9]
- In the UK, the ETI recently identified 20 specific CO_2 storage sites, which together represent the tip of a very large strategic national CO_2 storage resource potential, estimated to be around 78,000 million tonnes. Five of these sites were then selected for further detailed analysis given their potential contribution to mobilise commercial-scale CCS projects for power and industrial use in the UK. Outline storage development plans and budgets were prepared for each. The ETI published on its website the detailed reports from the project and provided access to the sub-surface geological models.[10]
- Norway published a detailed CO_2 Storage Atlas.[11]

In addition to the resources listed above, Zero Emissions Platform[12] and Global CCS Institute[13] have useful resources on CO_2 storage.

Updated storage databases are especially important for countries that have banned the storage of CO_2 or have put restrictions in place in the near future. The potential for storage sites outside the country can be identified using the potential data sources in other MSs.

4.3.2 Estimating storage potential and injectivity of selected storage sites

As part of finding suitable CO_2 storage options, developers should include an informed estimate of the potential volume of CO_2 that can be practically stored in the CO_2 storage

[6] CO2StoP, 2011, Assessment of CO_2 storage potential in Europe. Available at: https://ec.europa.eu/energy/en/studies/assessment-co2-storage-potential-europe-co2stop

[7] EU GeoCapacity, 2009, Assessing European Capacity for Geological Storage of Carbon Dioxide. Available at: http://www.geology.cz/geocapacity/publications

[8] Elforsk, 2014, CCS in the Baltic Sea region. Available at: http://www.elforsk.se/Programomraden/El--Varme/Rapporter/?rid=14_50_

[9] CO_2Stored database is available at: http://www.co2stored.co.uk/home/index

[10] ETI, Progressing Development of the UK's Strategic Carbon Dioxide Storage Resource, 2016. Available at: http://www.eti.co.uk/eti-project-identifies-cost-effective-ccs-storage-sites-off-the-uk-coast/

[11] Norwegian Petroleum Directorate. CO2 storage atlas North Sea. Available at: http://www.npd.no/en/Publications/Reports/CO2-Storage-Atlas-/

[12] ZEP's page on CO_2 storage is available at: http://www.zeroemissionsplatform.eu/ccs-technology/storage.html

[13] Global CCS Institute's publications on CO_2 storage is available at: http://www.globalccsinstitute.com/dc-search/storage

potential of the area identified by the applicant. This could include consideration of storage capacity, injectivity and integrity; any conflicting surface and subsurface land uses; required environmental, safety and other approvals; and public awareness and engagement.[14] Developers should include the amount of CO_2 that is proposed to be stored at the identified site(s), in comparison to the potential volumes. Accurate data for this is important, and can be used to help authorities determine whether the proposed storage area has sufficient capacity.

The consideration of storage requirements over time is needed to ensure that sufficient storage is available, with authorities having to take into account of any other applications which may have identified the same storage sites for the same purpose. Storage assessments should also consider "injectivity" of the storage sites (i.e. maximum feasible injection rate of the storage site for the required injection duration – e.g. based on pressure build-up within the storage unit) if the data is available.[15]

4.3.3 Existing CCS projects and potential clusters/ hubs

It is recommended that MSs and/or European Commission provide potential power plant developers with up-to-date data on existing storage sites or sites in preparation and potential clusters and hubs (as explained in Section 5.4). Specific locations of potential clusters and hubs could be identified by the Commission or the MSs considering the locations of existing industrial and power emitters, viable transport routes and locations of storage units. Project developers should consider these hubs and clusters if the data is made available by the MSs. Information on potential storage sites is provided in a 2016 report by Zero Emissions Platform (ZEP): "Identifying and Developing European CCS Hubs."[16] The report identified the following potential hubs and clusters:

- The Rotterdam CO_2 hub (that can be connected to other potential hubs including Antwerp, Duisburg, Le Havre, and Hamburg)
- UK Southern North Sea CCS hub
- The Teesside Collective
- UK Scottish hub
- Scandinavia Hub.

Other storage sites, hubs and clusters may be identified in future. Up to date information on existing CCS projects is available through the Global CCS Institute.[17]

4.3.4 Environmental, safety, and other approvals for CO_2 storage

There can be numerous potential approvals required to construct and operate CO_2 storage sites. Identifying these approvals at the planning stage can help to limit delays, as well as allow developers allocate sufficient time for the application processes.

[14] Senior, B., Bradshaw, B., Chikkatur, A., Wright, M., 2011. Planning saline reservoir storage developments – the importance of getting started early.

[15] For instance, the CO_2Stored database in the UK includes detailed technical data on various storage units including maximum injection duration for a given CO_2 injection rate, pressure calculations, number of wells required, etc.

[16] ZEP, 2016. Identifying and Developing European CCS Hubs. Available at: http://www.zeroemissionsplatform.eu/library/publication/262-zepeuhubsclusters.html

[17] Global CCS Institute, Large Scale CCS Projects. Available at: http://www.globalccsinstitute.com/projects/large-scale-ccs-projects

Global CCS Institute, Notable CCS Projects. Available at: http://www.globalccsinstitute.com/projects/notable-projects

The risks relating to storage through all the stages of the project need to be avoided or reduced. Developers need to consider these relevant risks, which include:

- Harm to human health;
- Ecological degradation;
- Contamination of underground drinking water;
- Impacts to hydrocarbon resources;
- Damage to personal property; and
- Ground heave or induced seismicity.

The criteria for each MS will vary based on each state's environmental regulations, but the Directive requires that the storage permits contain at least the following (which developers will need to comply with):

- Proof of the operator's competence;
- Characterisation and security of the proposed storage site;
- The total quantity of CO_2 to be injected and stored;
- Transport methods;
- Composition of CO_2 streams;
- Injection rates and locations of injection facilities;
- Measures to prevent irregularities;
- A proposed monitoring plan;
- Proposed corrective measures; and
- A proposed post-closure plan, consistent with the guidelines in the directive.

4.3.5 Public awareness relating to CO_2 storage

Communities near a CO_2 storage site are likely to be concerned about various potential risks, including potential harm to personal health, ecosystems and resources. Local communities may also be concerned about potential negative impacts to the value of their property. Early engagement can help provide local residents will information on the likelihood and magnitude of these risks, as well as assurances that any risks will be suitably managed.

Various actions developers can undertake include:

- Notify the public of eventual storage sites via a website, with easy to read maps and information;
- Seek public engagement in storage site planning; and
- Encourage public engagement in the storage site approval process.

4.4 Technical assessment of CO_2 transport

The technical assessment for CO_2 transport should provide indicative CO_2 transportation options (i.e. onshore/offshore pipelines and/or shipping), including technical and environmental constraints. Several main challenges for developers include ensuring proposed route corridors are clear, and transport to onshore/offshore storage sites is viable.

4.4.1 Proposed route corridors to be clear

Developers should demonstrate that a feasible route exists from the site to the storage area, and that a feasible 'way-out' exists from the power station site for the CO_2 pipeline. To help ensure this, developers are recommended to:

- Provide a marked up map at a scale sufficiently large for the proposed route corridors to be clear and a description with sufficient detail to identify the preferred form and route(s) for transport;
- Review a reasonable distance surrounding the power station (e.g. the first 10km) and identify a favoured route for the pipeline, within a 1km wide corridor.
- Identify major pre-existing obstacles, which may be due to safety or environmental concerns surrounding the station (e.g. within the 10km radius).

This can provide a degree of flexibility that may exist over the eventual pipeline.

After identifying a favoured route within a 1km wide corridor for a reasonable distance (e.g. the first 10km from the power station), developers should identify a wider corridor (e.g. 10km wide) to the onshore storage site or the point(s) on the coast (if applicable) where they envisage either a pipeline going offshore or CO_2 being transported via a ship.

Developers should consider existing CCS projects and potential clusters/hubs in their assessments as explained in Section 4.3.3; however, transport plans may provide point to point routes for an individual combustion site application if potential CCS projects or clusters are not available within the same region. If developers wish to enter into joint transport arrangements with other companies, the sufficient level of detail should still be provided as for individual plans.

4.4.2 Transport offshore to the storage site may be by pipeline or ship

The main consideration for developers when considering a transport route if CO_2 goes offshore, is whether it should be by pipeline or by ship. Developers are recommended to demonstrate that a feasible route from land to sea exists. This is of particular importance as to any coastlines that may be protected under national or European Union law. Developers should acknowledge potential barriers to the transport of CO_2 offshore and suggest how these factors can be managed.

If a developer is considering plans to move CO_2 by ship from a port or jetty to their storage area, they will need to consider and demonstrate there are no barriers to their complying with all the relevant safety factors involved in loading CO_2onto a ship.

4.4.3 Considerations for the transport route

There are a number of considerations for the transport route that developers are recommended to consider. The most challenging aspects include:

- Collisions with existing infrastructure;
- Analysis of minimising collisions with protected areas;
- Potential to use the existing corridors, e.g. high-pressure gas pipelines;
- The presence of designated sites, such as Natura 2000 areas, national parks, landscape parks, nature reserves; and
- Consideration of existing CCS projects and potential CCS hubs and clusters (as discussed previously).

4.4.4 Conflicting uses and rights

Developers need to identify any conflicting land use activity, as well as the possibility of land access for pipelines or additional port infrastructure. This includes considerations for construction activities. This information will help inform whether a feasible transport plan is possible for linking the future plant with a storage site.

Developers should ensure they can resolve any issues with conflicting surface and sub-surface uses, and land or port access.

4.4.5 Environment, safety and other approvals for CO_2 transport

Developers need to consider international and national laws and standards, when identifying the range of potential approvals required for CO_2 transport.

The issue of CO_2 pipeline safety will become increasingly important as CCS regulations and guidelines are developed that will govern the design of future CO_2 transport networks. Pipelines near populated areas will be subject to increased scrutiny. The causes for CO_2 pipeline incidents include equipment failure, corrosion, and outside force.

Pipeline construction and operation can be subject to regulatory approval and oversight. Developers may need to consider that authorities will have to approve safety plans, monitoring and inspection procedures, and emergency response plans. Transport of CO_2 across national borders, offshore pipelines, or via ships can be subject to both international and national environmental and other laws, which developers will need to consider.

4.4.6 Public awareness relating to CO_2 transport

Local communities are likely to be concerned about the associated risks of being located near CO_2 transport pipelines. In particular, residents near proposed pipeline routes may be concerned about both safety and potential impacts to their property value. Project developers may need to engage directly with landowners to secure rights of way for a pipeline.

Project developers can identify residents along potential transportation routes, and reassure them that CO_2 pipelines are a mature and safe technology. If there are plans to load CO_2 onto tankers at shipping terminals, local residents may have concerns about safety too. This concern can be reduced through effective public communication and engagement.

4.5 Economic assessment

Demonstrating the economic feasibility of CCS is challenging for developers, given the relative commercial immaturity of the technology and limited market and policy drivers in many markets across the EU. This section outlines key recommendations to help developers with demonstrating economic feasibility as part of the economic assessment.

4.5.1 An economic assessment which encompasses all relevant aspects

Project developers should prepare an economic assessment, which encompasses all relevant aspects, including retrofitting of carbon capture equipment, CO_2 transport and the storage of CO_2 to demonstrate costs and benefits associated with the CCS retrofit. Developers should outline reasonable scenarios, taking into account the overall costs which make operational CCS economically feasible for the proposed project.

4.5.2 Consistent economic assumptions

Assumptions on internal rate of return, cost of transport and cost of storage and also various macroeconomic assumptions, such as the inflation rate, the exchange rate, the market wholesale price of electricity, and the price of CO_2 emission allowances should be consistent.

There may be certain triggers that make CCS economically viable, such as a high enough EU ETS allowance price that makes the case with CCS more attractive than without. Developers are recommended to use reliable forecasts for carbon prices, given the sensitivity of the variables. It is worth noting, that high and sustained prices may be needed, and this needs to be compared with the lifetime and timing of the project. It is the combination of various variables that is likely to help make CCS more economically viable over time.

As explained in section 5.2, it is essential that MSs can provide up-to-date sources for any guidance material or to support the basis of assumptions for developers with assessments. Some of the key data sources for economic assumptions include the following:

- European Commission publishes:
  - EU energy, transport and GHG emissions trends to 2050 - reference scenario 2013; updated on a regular basis.[18]
  - Energy trends up to 2050; updated on a regular basis.[19]
- Zero Emissions Platform (ZEP) has published reports on costs of CO_2 capture, transport and storage.[20]
- The Department of Energy and Climate Change (DECC) in the UK published fuel price and carbon price projections annually.[21] In the UK, EU ETS carbon prices are projected using an in-house fundamentals-based model (i.e. DECC Carbon Price Model), which estimates European emissions allowance (EUA) prices in any given year based on the equilibrium between demand for and supply of abatement.[22]

4.5.3 Discounted cash flow approach

Discounted cash flow (DCF) approaches used to demonstrate economic feasibility is one of several methods of assessing investments. The DCF approach takes into account the expected accumulation of interest. It provides a consistent approach to compare the economic feasibility of projects, making it easy to compare the relative cost-effectiveness of projects by using net-present value (NPV) and internal rate of return (IRR) indicators. While DCF is a useful methodology, developers need to work with the competent authorities to ensure that this methodology is acceptable to them.

Another recommended method is to the levelised cost of electricity (LCOE) approach to demonstrate economic feasibility. Developers are recommended to calculate the lifetime price of electricity under various scenarios and plot this against a range of different carbon prices. The modelling should demonstrate how the price for electricity produced with CCS above a certain carbon price should be lower than the price for electricity without it. Project developers can then use a viable EU ETS price scenario/projection to decide whether the modelled carbon price will arise within the lifetime of the proposed power station.

4.5.4 Scenario and sensitivity analysis

Scenario and sensitivity analyses are recommended for the economic assessment. This helps to identify the most sensitive variables for measuring the economic viability of the CCS project. This is critical in establishing what thresholds need to be met to make projects economically viable (e.g. what carbon price is needed, or fall in the cost of CO_2 capture or storage). This analysis can be reviewed and updated on a regular basis as and when fundamental variables change.

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[18] European Commission, DG Mobility and Transport. Publications. Available at: http://ec.europa.eu/transport/media/publications/

[19] European Commission, DG Energy. EU energy, transport and GHG emissions, trends to 2050. Available at: https://ec.europa.eu/energy/en/publications/eu-energy-transport-and-ghg-emissions-trends-2050

[20] ZEP, 2011. The costs of CO_2 capture. Available at: http://www.zeroemissionsplatform.eu/library/publication/166-zep-cost-report-capture.html

[21] UK Government, Department of Energy and Climate Change, 2015. Energy and Emissions projections. Available at: https://www.gov.uk/government/collections/energy-and-emissions-projections

[22] UK Government, Department of Energy and Climate Change, 2015. Updated short-term traded carbon values used for modelling purposes. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/477541/Updated_short-term_traded_carbon_values_used_for_modelling_purposes__2015_.pdf

4.5.5 Examining CO_2 utilisation opportunities and government incentives

Important financial and market considerations should be taken into account in the economic assessment for CCS projects. Economic feasibility assessments carried out by the project developers in the EU to demonstrate CCS readiness could consider any available government incentives and potential market for any by-products including CO_2 for enhanced hydrocarbon recovery. Although the current carbon price in the EU is still low, potential government incentives and/or potential market for any by-products including CO_2-EOR may make CCS retrofit commercially feasible.

5 Guidance to Member States

This section provides guidance to competent authorities in MSs to support the evaluation of licence applications associated with Article 33 and to support developers in meeting the requirements of Article 33 cost-effectively. It is important that MSs are not overly prescriptive. Competent authorities should work with project developers keeping the overall goal of public safety and assurance of effective capture, transport and storage of CO_2.

5.1 Increasing national storage readiness levels

It is challenging for a project developer to achieve CCS readiness unless the country (or a neighbouring country) in which the power plant or industrial site is located is "CO_2 storage-ready".

EU MSs can increase their storage readiness by carrying out collaborative multi-country storage assessments, developing CO_2 storage datasets, appraising storage units and supporting CO_2 storage projects. These requirements are already called for in Article 4(2) of the CCS Directive. To comply with Article 33, all combustion plants with a rated electrical output of 300 megawatts or more are required to ensure that suitable storage sites are available. As project developers in the EU rely on the available data on storage availability developed by the MSs, it is important that detailed data on bankable/practical storage capacity is available to potential project developers.

Global CCS Institute[23] uses the following criteria in Table 5.1 to assess "national storage readiness" level.

Table 5.1 Criteria for national storage readiness

Criteria	Explanation
Storage potential	■ Whether the region has any conventional storage potential (for the MSs which do not have sufficient potential and/or banned CO_2 storage, this assessment should include other nearby MSs)
Storage assessment	■ Whether a full regional assessment has been carried out ■ Whether an extensive storage dataset has been developed ■ Whether the assessment maturity is "Regional, Country-scale/Theoretical capacity", "Basin-scale/Effective capacity" or "Site-scale/Practical capacity"
Pilot storage projects	■ Whether there are any pilot storage projects and if so; ■ Whether they are in preliminary planning stage; ■ Whether they are in active preparation stage; ■ Whether injection has occurred in one project; ■ Whether injection occurred in several projects.
Commercial storage projects	■ Whether there are any commercial storage projects and if so; ■ Whether they are in active planning stage; ■ Whether they have passed final investment decision; ■ Whether injection has occurred; ■ Whether they are mature projects.
Knowledge sharing	■ Whether the country has active targeted program of knowledge sharing and/or dissemination

As suggested by the 2015 Global CCS Institute report, the following actions could be taken in the EU to increase storage readiness:

[23] Global CCS Institute, 2015, Global storage readiness assessment: an approach to assessing national readiness for wide-scale deployment of CO2 geological storage projects, Available at: http://hub.globalccsinstitute.com/sites/default/files/publications/192183/global-storage-readiness-assessment.pdf

1) Regional collaboration on multi-country assessments, which would enable:
   - Transfer of knowledge and methodologies;
   - Solutions for nations with low or no storage potential, and allow collaborative planning for storage in neighbouring countries; and
   - Advanced nations to assist less resourced neighbours.
2) After completing regional and national studies on CO_2 potential, site-scale evaluations could be carried out to identify realistic practical storage and to identify barriers to deployment such as legal and regulatory issues.
3) Finally, MSs can either initiate or participate in a small-scale storage injection project in their region, which would help address country-specific challenges and enable technical experts to understand the fundamentals of enabling a storage project.

5.2 Up-to-date sources for guidance material and the basis for assumptions

It is essential that MSs can provide current reference sources for any guidance material or to support the basis of assumptions for developers with assessments. Project developers should be encouraged to use consistent data sources for their economic assessments. At the very least, the following data could be provided to project developers:

- Data sources for technical assessments and basis for the consent criteria;
- Fuel price forecasts;
- Carbon price forecasts;
- Cost of retrofitting capture (if project-specific data is not available);
- Cost of CO_2 transport (if project-specific data is not available);
- Cost of CO_2 storage (if project-specific data is not available);
- Detailed data on storage capacity in the region (as explained in Section 5.1); and
- Information on potential CCS projects and locations of potential hubs/ clusters (as explained in section 4.3.3).

Some of the key data sources for economic assessments include the sources previously highlighted in section 4.5.2 Consistent economic assumptions.

5.3 Sharing information on storage sites identified for potential usage

In addition to the detailed datasets on CO_2 storage sites (as explained in Section 5.1), MSs can provide project developers with information on storage sites identified for potential usage in the CCS-readiness applications to manage competing interest for the same storage units. This is useful for project developers when considering relevant storage options. The recommended required information can include:

- Storage site name;
- Estimated total CO_2 storage capacity;
- Potential capacity identified by the project developers in CCS readiness applications;
- Names of potential projects that plan to use the storage unit; and
- Remaining CO_2 storage capacity.

If MSs identify potential clusters and hubs, the same information can be provided for a “hub” rather than individual storage units. The database could show the estimated total CO_2 storage capacity of a cluster, which power plants (or industrial sites) plan to join that cluster and how much storage capacity they require.

5.4 Identifying potential hubs/ clusters

As CCS clusters are expected to be developed in the EU to minimise transport and storage costs, locations of potential clusters should be considered in the CCS readiness assessments. To achieve CCS readiness, power plants in the EU should be required to be located close to potential onshore CO_2 capture clusters and shoreline hubs.

It is recommended that MSs and/or European Commission provide potential power plant developers with up-to-date data on existing CCS projects and potential clusters and hubs. Specific locations of potential clusters and hubs could be identified by the Commission or the MSs considering the locations of existing industrial and power emitters, viable transport routes and locations of storage units. Project developers should consider these hubs and clusters if the data is made available by the MSs. ZEP's recent report on "Identifying and Developing European CCS Hubs"[24] identified some of the potential hubs and clusters.

If power plant developers can demonstrate that it is feasible to capture and transport CO_2 to a nearby potential cluster, which will likely be connected to storage sites through large-scale shared CO_2 pipelines, project developers may not be required to identify suitable storage sites specifically for their projects.

5.5 Recommendations to Member States beyond the minimum requirements of Article 33

This section highlights key recommendations to help MSs support the cost-effective retrofitting of CCS, although they are currently beyond the minimum requirements of Article 33.

5.5.1 Specific consent criteria that changes over time

Project-specific requirements can be included in the "Development Consent Orders," based on the findings and recommendations of the 'examining authorities.' This could include:

- Setting aside adequate space for the installation of the necessary equipment (as identified for the specific power plant);
- Requirements for submitting periodic progress reports (e.g. frequency of progress reports, what information should be included in each report, etc.); and
- Any other requirements for the specific power plant.

Criteria for consent can be flexible and change over time with changing circumstances. For example, permits can be made conditional and specific requirements may cease to have effect, for instance:

- If the capture equipment is installed;
- If the generating station is decommissioned; and
- If the law or planning policy changes, etc.

Also, conditions can be stipulated in permits to trigger CCS retrofit, especially if new circumstances make CCS more economically feasible. For example;

- The EU ETS carbon allowance price increases significantly, and is highly likely to be sustained at a high level over time;
- A technological breakthrough has lowered CO_2 capture, storage and or transport costs significantly; and

[24] ZEP, 2016, Identifying and Developing European CCS Hubs, Available at: http://www.zeroemissionsplatform.eu/library/publication/262-zepeuhubsclusters.html

- Access to a new CCS storage hub or cluster is realised, lowering the economic costs for storage.

5.5.2 Requiring regular progress reports

To support the evaluation responsibility for CAs, power plant developers could be required to submit periodic progress reports. These can be focused on reporting the CCS ready status of the plant considering the CCS development (e.g. new capture technologies, better data on storage potential, etc.) and market conditions (e.g. fuel prices, Government incentives, carbon price, etc.). As part of this, power plant developers may be required to review:

- The storage suitability considering the most up-to-date data on sites;
- Technical and economic feasibility of transport, considering the availability of nearby over-sized transport and storage infrastructure; and
- Technical and economic feasibility of CO_2 capture, considering cost reductions achieved.

Power plant developers can be required to submit CCS monitoring reports every two to five years (or when fundamental changes occur to the technical and economic assessments) until CCS equipment is retrofitted to the full capacity of the plant. These reports can include:

- Evidence that the developer has complied with the requirements and an explanation of how the developer will continue to comply with requirements over the next two years;
- State whether some or all of the technology referred to in the current CCS proposals will not work and identify any other impediment to the technical feasibility, explaining the reasons for any such conclusion and whether such impediments can be overcome.
- If the developer considers that technical impediments can be overcome by putting forward a revised CCS proposal, this should be included in the CCS monitoring report.
- If MSs require different levels of CCS readiness as the CCS market develops, regular progress reports can be used to demonstrate that more stringent requirements are met over time. The combination of “increasing levels of CCS readiness” and “periodic progress reports” will ensure that power plants are prepared for CCS retrofit once CCS is commercially available in the EU) and cost of CCS-readiness is distributed over time.

5.5.3 Requiring increasing levels of CCS readiness

In order to provide better guidance to project developers, the MSs could develop tailored guidance for developers based on a graduated levels of increasing CCS readiness as the CCS market develops. As an illustration, three different levels of CCS readiness for a capture, transport, and storage-ready plant are provided below, based on a 2010 Global CCS Institute report.[25] This is for illustration only, and each MS will need to adopt relevant requirements that are suitable for their particular circumstances. Criteria relevant for Article 33 has been highlighted in grey.

[25] ICF International prepared for the Global CCS Institute, 2010. CCS Ready Policy: Considerations and Recommended Practices for Policymakers.

Figure 5.1 Illustration of graduated levels of requirements for a CO_2 capture ready plant

CO_2 capture ready plant

Component	Level 1	Level 2	Level 3
Plant site selection	Locate plant in a site where transportation to storage sites is potentially feasible.		
Technology Selection	Identify one or more potential capture technologies.	Identify preferred capture technologies.	Identify chosen capture technology.
Design for Capture Facilities	Prepare a preliminary design for capture facilities and their integration into the plant.	Prepare technical feasibility study for capture facilities and their integration.	In additional to Level 2 requirement, prepare a Design Basis Memorandum (DBM) or Front End Engineering Design (FEED) for capture facilities and their integration.
Space Allowance	Allow sufficient space, as determined by design studies, for needed equipment and construction zone.		
Equipment Pre-investment	Make little or no equipment pre-investment.	Make modest level of equipment pre-investment.	Make high level of equipment pre-investment.
Cost Estimate for Capture Facilities	Prepare preliminary economic analysis of capture facilities.	Prepare preliminary economic feasibility study based on technical feasibility study.	In addition to Level 2 requirement, prepare follow-on economic feasibility study based on technical information provided in DBM.
Environmental, Safety, and Other Approvals for Capture Facilities	Identify all approvals that will need to be obtained for retrofitting capture facilities.	Conduct feasibility studies for obtaining all approvals for retrofitting.	Prepare key documents for obtaining all approvals.
Public Awareness and Engagement Related to Capture Facilities	Notify public of eventual capture facilities retrofit via web site and other actions.	Seek public engagement in planning of capture facilities.	In addition to Level 2 requirement, encourage public engagement in approval process.
Sources for Equipment, Materials, and Services for Capture Facilities	None.	Compile list of companies who can supply construction and operation services to capture facilities.	Contact companies and negotiate nonbinding letters of intent to bid on project.
Ongoing Obligations	File periodic reports with regulators on status of capture ready.		In addition to Level 2 requirement, respond to mandatory trigger mechanism to retrofit capture facilities.

Source: ICF International, prepared for the Global CCS Institute, 2010.

Figure 5.2 Illustration of graduated levels of requirements for a CO_2 storage ready plant

CO_2 storage ready plant

Component	Level 1	Level 2	Level 3
Storage Site Selection	Estimate total amount of CO_2 to be captured and stored for all years of CCS operation of the plant, and identify one or more feasible storage sites expected to accommodate the captured CO_2.	In addition to Level 1 requirement, obtain contractual options to one or more appropriate storage sites.	In addition to Level 2 requirement, obtain rights to one or more appropriate storage sites.
Verifying Injectivity, Capacity, and Integrity of Storage Site	Review existing regional prospectivity studies and show that the required capacity is theoretically available; conduct preliminary assessment of storage integrity and risks; and submit an overall plan for site assessment.	In addition to Level 1 requirement, conduct desktop study of injectivity, capacity, and integrity of storage location(s), and show that "effective" capacity is available.	In addition to Level 2 requirement, conduct geological exploration to screen and select specific site(s) for more detailed characterization of aquifers, or detailed assessment of oil/gas options; estimate "practical" capacity and conduct initial modeling of long-term reservoir behavior; and prepare Detailed Storage Integrity Risk Assessment.
Design of Storage Facility	Prepare preliminary design for storage facility.	Prepare technical feasibility study for storage facility, including preliminary monitoring and verification plan.	In additional to Level 2 requirement, prepare a Design Basis Memorandum (DBM) for storage site facility, including monitoring and verification plan.
Conflicting Uses and Rights	Identify any conflicting surface and subsurface uses, as well as feasibility of access to site(s).		Resolve any issues with conflicting surface and sub-surface uses, and site access.
Cost Estimate for Storage Facility	Prepare preliminary economic analysis for storage facility including capital and operation and maintenance costs, and estimate the cost of storage for the capture plant.	Conduct preliminary economic feasibility study based on technical feasibility study, including the cost of storage for the capture plant.	In addition to Level 2 requirement, prepare follow-on economic feasibility study based on technical information provided in DBM.
Environmental, Safety, and Other Approvals for Storage Site	Identify all approvals that will need to be obtained for storage site.	Conduct feasibility studies for obtaining all approvals for storage site.	Prepare key documents for obtaining all approvals for storage site.
Public Awareness and Engagement Related to CO_2 Storage Site	Notify public of eventual storage site via web site and other actions.	Seek public engagement in storage site planning.	In addition to Level 2 requirement, encourage public engagement in storage site approval process.
Sources for Equipment, Materials, and Services for Storage Site	None.	Compile list of companies who can supply equipment, materials and services needed for construction and operation of storage site.	Contact companies and negotiate nonbinding letters of intent to bid on project.
Ongoing Obligations	File periodic reports with regulators on status of storage ready.		In addition to Level 2 requirement, respond to mandatory trigger mechanism to develop storage site for injection.

Source: ICF International, prepared for the Global CCS Institute, 2010.

Figure 5.3 Illustration of graduated levels of requirements for a CO_2 transport ready plant

CO_2 transport ready plant

Component	Level 1	Level 2	Level 3
Transport Method	Identify and select one or more potential transport method(s).		
CO_2 Transport Corridor Selection	Identify one or more feasible pipeline and/or shipping routes.	Obtain contractual options to rights of way.	Obtain rights of way to assess the pipeline corridor or shipping route.
Conflicting Uses and Rights	Identify any conflicting land use activity, as well as feasibility of land/port access.		Resolve any issues with conflicting surface and sub-surface uses, and land/port access.
Design of Transport Facilities	Prepare preliminary design options for feasible transport method(s).	Prepare technical feasibility study for the transport method(s) including coordination of pipeline corridor use and/or shipping routes with other capture plants.	In addition to Level 2 requirement, prepare a Design Basis Memorandum (DBM) for the chosen transport method(s).
Cost Estimate for Transport Facilities	Prepare preliminary economic analysis for transport facilities, and estimate the cost of transportation for the capture plant.	Conduct preliminary economic feasibility study, based on technical feasibility study, including cost of transportation for the capture plant.	In addition to Level 2 requirement, prepare follow-on economic feasibility study based on technical information provided in DBM.
Environmental, Safety, and Other Approvals for Transport Facilities	Identify all approvals that will need to be obtained for transporting CO_2.	Conduct feasibility studies for obtaining all approvals for transportation facilities.	Prepare key documents for obtaining all approvals for transportation facilities.
Public Awareness and Engagement Related to CO_2 Transport	Notify public of chosen transport method(s) and corridor(s) via web site and other actions.	Seek public engagement in transportation planning.	In addition to Level 2 requirement, encourage public engagement in transportation approval process.
Sources for Equipment, Materials, and Services for Transport Facilities	None	Compile list of companies who can supply equipment, materials and services needed for construction and operation of CO_2 transportation.	Contact companies and negotiate nonbinding letters of intent to bid on project.
Ongoing Obligations	File periodic reports with regulators on status of transport ready.		In addition to Level 2 requirement, respond to mandatory trigger mechanism to develop transport facilities.

Source: ICF International, prepared for the Global CCS Institute, 2010.

These illustrated graduated levels of requirement can be adapted by MSs to help review progress over time. Compliance with increasing CCS readiness requirements can be demonstrated by submitting periodic progress reports.

6 Recommendations to European Commission

6.1 Extending CCS readiness requirements to emissions-intensive industry

Overall industrial emissions need to be cut significantly in order to meet the 2050 CO_2 reduction target. In order to support this effort, analogous CCS Readiness requirements for energy and emissions intensive industrial subsectors, such as cement, chemicals, refining, and steel could be developed and rolled out by the European Commission. Existing and/or new industrial facilities could then be required to be CCS ready, and the costs and benefits of retrofitting existing plant could also be assessed.

It is suggested that a separate study is commissioned to examine this in more detail. This study could consider:

- Whether industrial CCS readiness is necessary in the EU;
- Potential benefits of industrial CCS readiness (i.e. potential impact on carbon reduction and future deployment of CCS in the EU);
- Potential costs and challenges of industrial CCS readiness (i.e. cost of making an industrial site CCS-ready, implications on the existing processes, and system-level and site-level barriers);
- Potential implications of industrial CCS readiness (e.g. carbon leakage); and
- Whether existing requirements for power CCS could be extended to industrial sites or a new set of requirements would need to be developed.

6.2 Supporting Member States on technical analyses

Section 5 of this report includes guidance for the MSs to help them fulfil their obligations under Article 33 as well as the recommendations on how to go beyond the minimum requirements of Article 33 in order to have most cost efficient retrofitting with CCS. It is vital that the MSs are supported by the European Commission in the following key areas.

6.2.1 Increasing national storage readiness levels

As explained in Section 5.1, EU MSs can increase their storage readiness by carrying out collaborative multi-country storage assessments, developing CO_2 storage datasets, appraising storage units and supporting pilot/commercial CO_2 storage projects.

The European Commission can play an important role by promoting regional collaboration on multi-country assessments, and supporting pilot and commercial storage projects in various regions.

6.2.2 Identifying potential hubs/ clusters

It is recommended that MSs and/or European Commission provide potential power plant developers with up-to-date data on existing CCS projects and potential clusters and hubs. Specific locations of potential clusters and hubs could be identified by the Commission considering the locations of existing industrial and power emitters, viable transport routes and locations of storage units. ZEP's recent report on "Identifying and Developing European CCS Hubs"[26] identified some of the potential hubs and clusters.

[26] ZEP, 2016. Identifying and Developing European CCS Hubs. Available at: http://www.zeroemissionsplatform.eu/library/publication/262-zepeuhubsclusters.html

6.2.3 Up-to-date sources for guidance material and the basis for assumptions

We suggest that the European Commission gather up-to-date data on costs of capture, transport and storage; economic assumptions such as fuel price forecasts, EU ETS carbon price forecasts; storage capacity and location of hubs; and publish this on its website. MSs should then refer to this website in the CCS readiness guidance documents. This would ensure that potential project developers in various MSs use consistent assumptions and data sources in their CCS-readiness assessments.

7 Checklist for project developers and Member States

The following checklists summarises the guidance for project developers and MSs/ Competent Authorities on assessing the suitability, feasibility and preparation for CCS retrofitting.

7.1 Checklist for project developers

Item	Description
1. Approvals	a) Identify all environmental, safety and other relevant approvals that are needed for capture, storage and transport of CO_2.
	b) Conduct feasibility studies for relevant approvals.
	c) Prepare key documents for approvals
2. Public awareness	a) Notify the public of eventual CCS retrofit projects, e.g. via a website.
	b) Early communication with the public to address concerns and raise awareness of potential positive factors.
	c) Support public participation in the power or industrial plant planning process.
3. Technical assessment for CO_2 capture	a) Provide a technical overview of the available capture technology.
	b) Demonstrate that there are no currently known technical barriers to subsequent retrofit of the selected capture technology.
	c) Provide a potential layout of the plant, which includes: i. The footprint of the combustion plant; ii. The location of the capture plant including any air separation units; iii. The location of the CO_2 compression equipment; iv. The location of any chemical storage facilities; and v. The exit point and compressors for CO_2 pipelines from the site.
	d) Prepare material to demonstrate that sufficient space is available to accommodate carbon capture equipment. Consider: i. The type of capture technology proposed; ii. The size/ number of the power generating units; iii. The input fuel; iv. Processing CO_2 on or off-site; v. The safe storage of chemicals; vi. Impact of congestion on site for safety both during construction and operation; and vii. Future progress in developing the capture technologies that can reduce the space required for the related equipment.
4. Suitability of CO_2 storage	a) Select suitable storage sites based on best available data.
	b) Provide an informed estimate of the potential volume of CO_2 that can be practically stored.
	c) Use best available data to consider existing storage sites or sites in preparation and potential clusters and hubs.

Item	Description
5. Technical assessment of CO_2 transport	a) Demonstrate that a feasible route exists from the site to the storage area and that a feasible 'way-out' exists from the power station site for the CO_2 pipeline. To consider: i. Providing a marked up map at a scale sufficiently large for the proposed route corridors to be clear and a description with sufficient detail to identify the preferred form and route(s) for transport; ii. Review a reasonable distance surrounding the power station and identify a favoured route for the pipeline, within a 1km wide corridor. iii. Identify major pre-existing obstacles, which may be due to safety or environmental concerns surrounding the station.
	b) If CO_2 goes offshore, demonstrate that a feasible route from land to sea exists. i. Acknowledge potential barriers to the transport of CO_2 offshore and suggest how these factors can be managed.
	c) Ensure relevant factors are considered for any proposed transport route, including: i. Collisions with existing infrastructure; ii. Analysis of minimising collisions with protected areas; iii. Potential to use the existing corridors, e.g. high-pressure gas pipelines; iv. The presence of designated sites, such as Natura 2000 areas, national parks, landscape parks, nature reserves; and v. Consideration of existing CCS projects and potential CCS hubs and clusters.
	d) Identify and manage any conflicting land use activity, as well as the possibility of land access for pipelines or additional port infrastructure
6. Economic assessment	a) Prepare an economic assessment, which encompasses all relevant aspects, including retrofitting of carbon capture equipment, CO_2 transport and the storage of CO_2 to demonstrate costs and benefits associated with the CCS retrofit.
	b) Use consistent economic assumptions, using the best available up-to-date sources.
	c) Use credible approach to demonstrate economic feasibility: E.g. Discounted cash flow or levelised cost of electricity.
	d) Undertake scenario and sensitivity analysis, which should be updated on a regular basis and when fundamental variables change.
	e) Examine available government incentives and potential CO_2 utilisation opportunities, such as by-products including CO_2 for enhanced hydrocarbon recovery.

7.2 Checklist for Member States

Item	Description
1. Increase national storage readiness levels	a) Carry out collaborative multi-country storage assessments.
	b) Develop CO_2 storage datasets.
	c) Undertake site-scale evaluations to identify realistic practical storage.
	d) Identify and manage risks to deployment such as legal and regulatory issues.
	e) Initiate or participate in a storage injection project in their region, which can help address country-specific challenges and enable technical experts to understand the fundamentals of enabling a storage project.
2. Update sources on a regular basis	a) Provide current reference sources for any guidance material or to support the basis of assumptions for developers with assessments. This includes: i. Data sources for technical assessments and basis for the consent criteria; ii. Fuel price forecasts; iii. Carbon price forecasts; iv. Cost of retrofitting capture (if project-specific data is not available); v. Cost of CO_2 transport (if project-specific data is not available); vi. Cost of CO_2 storage (if project-specific data is not available); vii. Detailed data on storage capacity in the region; and viii. Information on potential CCS projects and locations of potential hubs/ clusters.
3. Share information on storage sites	a) Provide project developers with information on storage sites identified for potential usage in the CCS-readiness applications to manage competing interest for the same storage units. This can include: i. Storage site name; ii. Estimated total CO_2 storage capacity; iii. Potential capacity identified by the project developers in CCS readiness applications; iv. Names of potential projects that plan to use the storage unit; and v. Remaining CO_2 storage capacity.
4. Identifying potential hubs/ clusters	a) Provide potential power plant developers with up-to-date data on existing CCS projects and potential clusters and hubs. Consider the locations of existing industrial and power emitters, viable transport routes and locations of storage units.
5. Consent criteria	a) Provide project specific consent requirements that change over time.
6. Progress reports	a) Request periodic progress reports from developers. This can consider: i. The storage suitability considering the most up-to-date data on sites; ii. Technical and economic feasibility of transport, considering the availability of nearby over-sized transport and storage infrastructure; and iii. Technical and economic feasibility of CO_2 capture, considering cost reductions achieved.
7. Increasing levels of CCS readiness	a) Develop tailored guidance for developers based on a graduated levels of increasing CCS readiness as the CCS market develops

8 Acronyms and abbreviations

Bastor2	Baltic Sea CO_2 Storage
CCS	Carbon capture and storage
DBM	Design Basis Memorandum
DCF	Discounted cash flow
EC	European Commission
EUA	European emissions allowance
FEED	Front End Engineering Design
GHG	Greenhouse gas
IRR	Internal rate of return
LCOE	Levelised cost of electricity
MSs	Member States
NPV	Net-present value
ZEP	Zero Emissions Platform

References

- CO_2Stored, 2016. CO_2Stored database. Available at: http://www.co2stored.co.uk/home/index
- CO2StoP, 2011. Assessment of CO2 storage potential in Europe, available at: https://ec.europa.eu/energy/en/studies/assessment-co2-storage-potential-europe-co2stop
- Elforsk, 2014, CCS in the Baltic Sea region, available at: http://www.elforsk.se/Programomraden/El--Varme/Rapporter/?rid=14_50_
- European Commission, DG Climate Action. Implementation of the CCS Directive. http://ec.europa.eu/clima/policies/lowcarbon/ccs/implementation/documentation_en.htm
- European Commission, DG Climate Action. Carbon Capture and Geological Storage. http://ec.europa.eu/clima/policies/lowcarbon/ccs/index_en.htm
- European Commission, DG Energy. EU energy, transport and GHG emissions, trends to 2050. https://ec.europa.eu/energy/en/publications/eu-energy-transport-and-ghg-emissions-trends-2050
- European Commission, DG Mobility and Transport. Publications. http://ec.europa.eu/transport/media/publications/
- EU GeoCapacity, 2009, Assessing European Capacity for Geological Storage of Carbon Dioxide, available at: http://www.geology.cz/geocapacity/publications
- ETI, Progressing Development of the UK's Strategic Carbon Dioxide Storage Resource, 2016. Available at: http://www.eti.co.uk/eti-project-identifies-cost-effective-ccs-storage-sites-off-the-uk-coast/
- Global CCS Institute, 2015, Global storage readiness assessment: an approach to assessing national readiness for wide-scale deployment of CO2 geological storage projects, Available at: http://hub.globalccsinstitute.com/sites/default/files/publications/192183/global-storage-readiness-assessment.pdf
- Global CCS Institute, Large Scale CCS Projects. Available at: http://www.globalccsinstitute.com/projects/large-scale-ccs-projects
- Global CCS Institute, Notable CCS Projects. Available at: http://www.globalccsinstitute.com/projects/notable-projects
- ICF International prepared for the Global CCS Institute, 2010. CCS Ready Policy: Considerations and Recommended Practices for Policymakers.
- Norwegian Petroleum Directorate. CO2 storage atlas North Sea. Available at: http://www.npd.no/en/Publications/Reports/CO2-Storage-Atlas-/
- Official Journal of the European Union, L 140/114, 5.6.2009. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0114:0135:EN:PDF
- Senior, B., Bradshaw, B., Chikkatur, A., Wright, M., 2011. Planning saline reservoir storage developments – the importance of getting started early.
- UK Government, Department of Energy and Climate Change, 2015. Energy and Emissions projections. https://www.gov.uk/government/collections/energy-and-emissions-projections
- UK Government, Department of Energy and Climate Change, 2015. Updated short-term traded carbon values used for modelling purposes. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/477541/Updated_short-term_traded_carbon_values_used_for_modelling_purposes__2015_.pdf
- ZEP, 2016. Identifying and Developing European CCS Hubs, Available at: http://www.zeroemissionsplatform.eu/library/publication/262-zepeuhubsclusters.html
- ZEP, 2011. The costs of CO2 capture. Available at: http://www.zeroemissionsplatform.eu/library/publication/166-zep-cost-report-capture.html