Zep
Zero emissions platform

Accelerating the demonstration of CO_2 geological storage in Europe

The case for up to six new storage pilots

European Technology Platform for Zero Emission Fossil Fuel Power Plants

Contents

The Zero Emissions Platform (ZEP)

Founded in 2005, the Zero Emissions Platform (ZEP) is focused on CCS as a critical technology for achieving Europe's energy, climate and societal goals. A coalition of over 200 members from 19 countries – representing academics, scientists, European utilities, petroleum companies, equipment suppliers and environmental NGOs – ZEP serves as an advisor to the European Commission on the research, demonstration and deployment of CCS.

www.zeroemissionsplatform.eu

1 Introduction

1.1 CCS is on the critical path to the deliver the EU Energy Roadmap 2050

The critical role of CCS in meeting European Union (EU) and global climate targets is now indisputable: the EU Energy Roadmap 2050[1] confirms that "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 decarbonisation targets", while the IEA estimates that the global costs of achieving climate objectives *without* CCS would be 40% higher.

Yet the potential for CCS goes far beyond power, with other industrial applications expected to deliver half of the global emissions reductions required by 2050 from CCS.[2] Indeed, in some industries, such as steel and cement, it is the only means of achieving deep emission cuts. Combined with sustainable biomass, CCS can even *remove* CO_2 from the atmosphere – already recognised as a significant and attractive abatement solution.[3] Crucially, CCS will also complement intermittent renewable energy sources with low-carbon, base-load *and* balancing generation.

In short, CCS will not only deliver substantial emission reductions across a range of industries, but provide the catalyst for economic growth – creating *and* preserving jobs – while ensuring a diverse and reliable energy supply.

1.2 The wide demonstration of CO_2 storage is key to the development of CCS in Europe

CCS is on the critical path and there is no doubt it can deliver, as confirmed by international developments where final investment decision (FID) has already been taken on large-scale demonstration projects in Australia, Canada and the U.S.

However, the fall in the price of Emission Unit Allowances (EUAs) – from ~€30 per tonne in 2008 to less than €5 today – has had a severe impact on the EU CCS demonstration programme: with significantly less 'NER 300'[4] funding available, the number of projects will be considerably reduced. While the need for large-scale demonstration projects remains a priority, they may also not have the flexibility and capacity to address issues that could be more effectively addressed by smaller, research-oriented, storage pilots.

Given that the lack of proven, affordable, *local* CO_2 storage sites is a key barrier to the development of CCS, it is therefore essential that up to six pilot-scale storage projects are operational across Europe by 2020 to complement potential NER 300 and EEPR[5] projects. Ideal testing grounds for accelerating state-of-the-art technology, they will address such issues as storage optimisation, pressure management, deep saline aquifer qualification and site closure protocols. Qualifying and improving knowledge of different geological storage conditions will also greatly benefit the planning of a trans-national, European CO_2 transport infrastructure.

As showcases for the successful demonstration of CO_2 storage, a portfolio of storage pilots will not only increase financial, technical, political and public confidence, but pave the way for wide-scale CCS deployment.

This document therefore provides an overview of the key storage options available across Europe, with recommendations for how these could be incentivised.

---

[1] December 2011: http://ec.europa.eu/energy/energy2020/roadmap/doc/com_2011_8852_en.pdf

[2] International Energy Agency

[3] E.g. "Technology Roadmap – Carbon Capture and Storage in Industrial Applications", 2011: www.unido.org/fileadmin/user_media/News/2011/CCS_Industry_Roadmap_WEB.pdf

[4] In 2008, the EU agreed to set aside 300 million EUAs from the New Entrant Reserve under the EU Emissions Trading Scheme (ETS) Directive to demonstrate CCS and innovative renewable energy technologies

[5] European Energy Programme for Recovery

2 Key recommendations

2.1 Urgently establish up to six new CO_2 storage pilots, EU-wide

In order to address the full range of geographical and geological issues,[6] up to six new CO_2 storage pilots must be operational by 2020. These should be located across different Europe countries, where the geology is considered representative of structures suitable for industrial-scale storage and where further R&D can be addressed. A screening study should therefore be initiated as a matter of urgency: catalogue storage options which exist, identify research objectives, establish a budget structure, then execute the projects.

Data obtained can then be used to improve regulations, identify options for cost reduction, assess business cases and contribute to the design of the full CCS value chain.

2.2 Focus on deep saline aquifers – on- *and* offshore

Storage pilots are needed both on- *and* offshore: offshore storage is the focus of many proposed CCS demonstration projects and the main option for Member States bordering the North Sea, while onshore storage is more cost-effective and pilots will help to resolve any outstanding issues related to regulatory compliance. Both options, however, offer opportunities to investigate storage and operational characteristics that can be used generically – both on- *and* offshore.

Whilst pilots should cover the representative storage cases – pure deep saline aquifers (SA) and SA in combination with depleted oil and gas fields – the emphasis should be on SA as they hold the greatest storage potential for continental Europe, yet have generally been poorly investigated. It is particularly important that operational procedures for SA storage are developed and tested.

2.3 Select storage sites which will enable meaningful, scientific R&D

Pilot storage sites must be large enough to enable meaningful, scientific R&D on a range of issues[7] that can be extrapolated at industrial scales from representative geological structures which may contribute significantly to Europe's storage capacity. In certain cases, the storage pilot may also be used to explore industrial scale-storage in the same reservoir.

Pilots should store in the range of ~30,000 to 100,000 tonnes of CO_2 (above 100,000 tonnes would require permitting according to the CCS Directive[8]), and be able to display the issues associated with all stages of lifecycle in a condensed period of time. They should also be set up as a platform for testing cost-effective engineering solutions, in contrast to demonstration or commercial projects where the use of off-the-shelf technologies would be expected.

Sedimentary basins host fossil fuel, groundwater and geothermal energy resources, as well as providing options for gas storage and the permanent disposal of fluids. Storage pilots can therefore also provide the basis for defining key factors that affect the interaction of such resources with CO_2 storage, guiding policymakers and regulators on the allocation of pore space and resource interaction management, and clarifying the potential impact of interaction on storage capacity and availability.

2.4 Support the deployment of Europe's CO_2 transport infrastructure

Increasing knowledge of characteristic geological storage, operational conditions and restrictions will ensure potentially suitable storage sites – capacity and injectivity are much better qualified in the early

---

[6] Including reservoir and cap rock types, storage trap types and the more important depth and age ranges

[7] Including reservoir characterisation, drilling and formation testing, underground and surface monitoring (pre-syn and post-injection), pressure response, storage operations, injectivity and wellbore integrity

[8] EU Directive on Geological Storage of CO_2 (2009/31/EC)

phase of planning.[9] This will not only facilitate the planning of a European CO_2 transport infrastructure, but reduce technical and financial risks significantly.

2.5 Maximise the benefits of CCS for local communities

While a few CO_2 storage projects have been taking place successfully in Europe over the past 15 years, they are not widely known to the general public. The majority of CCS activities in Europe to date has also been carried out by the utilities who – for onshore storage projects at least – have experienced some difficulties in convincing the public and local authorities of the vital necessity of CCS for combating climate change.

However, this has proved easier when working in partnership with other CCS stakeholders and experts, e.g. research institutes to guarantee credibility and transparency; industrial actors (cement, steel, chemical, refining etc.) to highlight the importance of job preservation and synergies in CO_2 transport and storage; and policymakers and regulators to demonstrate that CCS is a critical part of the overall "green" policy for Europe.

Storage projects should therefore include professional communications activities that address critical, non-scientific issues of public perception, with local communities actively involved, in addition to regulators and policymakers. Indeed, they should be open-access laboratories that promote education and training, with independent research organisations playing a major role.

Public support is likely to be stronger where some or all of the following criteria apply:

- There is perceived to be a significant local benefit in terms of employment or the regional economy, e.g. the creation/preservation of jobs.
- The project is undertaken by an entity with an established, positive relationship with the local community.
- The project offers an open platform where all stakeholders can test new methodologies and equipments, and where results are shared widely and rapidly with the public.
- Storage is in line with other local drivers, e.g. the CO_2 stream is derived from biomass in a market that is focused on moving entirely to renewable energy sources, or enhances oil production in a region where this is an established industry.
- Storage is integrated into a regional or national plan for developing efficient, decarbonised energy systems in the context of "green growth".

Several value-generating aspects could therefore be incorporated into the design of storage projects, e.g.:

- CCS combined with sustainable biomass (Bio-CCS)
- Other uses of CO_2 (CCU and/or CCUS[10]), e.g. for greenhouses
- Cooperation between energy-intensive industries: power, iron and steel, chemicals, cement and fuel transformation
- Combining CO_2 storage with geothermal energy to benefit local communities
- The local risk to people and property is perceived to be small, e.g. due to a sparse population; a low-injected amount of CO_2.

2.6 Finance storage pilots from a combination of sources

Each storage pilot will cost €40 to €80 million (i.e. at least €30 million of capital + €10 million contingency), encompassing a large scientific component (storage optimisation, monitoring, public outreach) and an even

---

[9] "Building a CO_2 transport infrastructure for Europe", published by ZEP, May 2013: insert web-link

[10] CO_2 Capture and Utilisation (CCU); CO_2 Capture, Utilisation and Storage (CCUS)

larger component for data acquisition, drilling and CO_2 supply. This is one order of magnitude cheaper than a fully integrated CCS demonstration projects, thus delivering significant added value in return for a modest financial investment. However, in the absence of a viable business model for storage in the near future, financing these ventures will require pooling efforts from industry and other stakeholders.

Separate funding is needed for the sourcing and transport of CO_2 to the storage sites. Truck-based CO_2-sourcing could potentially be arranged by contractual agreements with ongoing or planned CO_2 capture pilots where the CO_2 otherwise would be emitted. If planned ahead, parts of the high-capex surface facilities could potentially be shared between several pilot projects.

There are several possible financing mechanisms, including:

- The upcoming *Horizon 2020 programme,* which should follow up with additional calls for the R&D component of large storage pilots, supplemented by a funding mechanism for the necessary 'hardware' investment (wells, seismic etc.)
- *National and regional funding*
- *Co-funding of projects in other Member States*: Member States may have an interest in supporting the development of storage in other countries (e.g. due to the lack of domestic storage capability). Mechanisms such as the Norwegian EEA[11] funding, which already support the Polish Belchatów project, or the so-called 'Berlin model' offer such opportunities.
- *Industrial funding* is frequently required, especially for equipment which is not R&D-specific, e.g. drilling, seismic and CO_2 sourcing.
- Although the main focus should be on SA, individual projects may combine with *Enhanced Oil/Gas Recovery (EOR/EGR)*, utilising the additional revenue from oil production. There are numerous old oil provinces in Europe and the projects could act as a precursor to offshore EOR in the North Sea and elsewhere.

However, a combination of all available resources should be targeted.

2.7 Simplify the permitting process and relieve projects of the burden of liability

Projects that fall under the CCS Directive currently have to undergo a long and complex permitting process and assume liabilities far beyond the operational period. Yet Ketzin and other storage pilots have shown that simpler regulations can be conducted without any reduction in safety. Comparable procedures, taking into account the legal situation within individual Member States, should therefore be introduced for industrial-scale projects.

Although different regulatory regimes apply to research-scale projects (<100 k tonne of CO_2 stored), storage pilots will provide useful information for ongoing work on permitting and consenting guidelines.

2.8 Maximise knowledge-sharing with EU *and* international CCS demonstration projects

Storage projects should not only share knowledge within the European CCS Demonstration Project Network, but also with international projects, e.g. the U.S. Regional Partnerships have demonstrated a successful strategy for establishing pilots.

---

[11] European Economic Area

3 Realising the vast potential of deep saline aquifers

3.1 Deep saline aquifers have an enormous capacity for CO_2 storage

Deep saline aquifers (SA) are prime targets for CO_2 storage, not only due to their wide availability worldwide, but their large static capacity – estimated to be at least 10 times greater than depleted oil and gas fields. Limited economic interest to date also creates a business opportunity as they have not yet been systematically explored.

However, with the exception of selected SA that have been investigated for specific projects (e.g. gas storage, geothermal, CCS) knowledge of the potential effective capacity, injectivity and long-term integrity for the majority of reservoirs is quite poor and needs to be proven through extensive qualification studies.

Storage pilots have a dual purpose:

1) Prove that CO_2 storage is feasible for the purposes of storage and transport permits, assessment of storage capacity, cost-effective engineering solutions, storage operation, monitoring, injectivity and storage containment, liability transfer and public awareness.
2) Explore and qualify common parameters for a range of SA which project developers can then utilise to improve the development of industrial-scale sites.

3.2 Selecting optimal storage sites

Naturally, a storage site will only be selected if prior analysis shows that under the proposed conditions of use there is no significant risk of leakage or damage to human health or the environment.

Location
There are several considerations for determining the preferred location of a storage pilot:

- The ability to address specific issues related to geological features, e.g.
  - Containments mechanism, e.g. structural or stratigraphic trapping, migration assisted trapping
  - Complex storage geology: storage reservoir and cap rock type (described in further detail below)
- Factors which make the site particularly attractive, e.g. pre-existing knowledge of the storage complex, low-cost availability of CO_2 for injection, or the potential for subsequent expansion into an industrial-size storage site
- Represents a good example of how to define the storage complex of a storage site.
- Factors which make the project cost-effective, e.g. value creation in the form of CCU and/or CCUS applications (for greenhouses, storage combined with geothermal heat production etc.).

In order to maintain project momentum, it is obviously easier if sites are selected where surveys have been conducted and exploration consents are already in place, e.g. as part of stalled or ongoing EEPR/NER 300 projects or national programmes. Data may also be available from gas and oil extraction sites where SA lie above or below the petroleum and have been characterised as part of the overall assessment of the region (as in the storage atlas published by the Norwegian Petroleum Directorate in 2011).

Geology
Ideally, pilot sites should cover the full range of potential geological environments. Reservoir rock types should span the range from siliclastic to carbonate rocks; caprocks should include shales, marls and evaporates. Reservoir flow properties should focus on pore-space permeability, but also cover fracture permeability. Structurally, it would be useful to cover at least two different types of aquifer system: those which are tightly, locally bounded and act as local storage zones; and those which are extensive, where the pressure effect of the injected CO_2 (not the CO_2 itself) has the potential to have an impact over a significant

distance. In general, SAs have little economic value, so where they have historically been detected in geological studies, they have been recorded but not fully documented. For storage to be qualified, this level of knowledge is insufficient so a substantial amount of characterisation work is needed which, in turn, requires significant consents to be in place.

Size

Typically, a site with a few injection/monitoring wells and a limited CO_2 supply (in the range of 30,000 to 100,000 tonnes[12]) should be sufficient to address remaining knowledge gaps.

CO_2 supply

In order to increase knowledge and visibility of the entire CCS chain, it would be advantageous to use CO_2 derived, at least in part, from suitably-sized capture pilots where the CO_2 would otherwise be emitted. The following (non-exhaustive) list includes some facilities with capture rates of >1 tonne/day which may be appropriate (if their geographical location is suitable and the projects overlap in time):

- Germany: Heilbronn, Niederaußen, Wilhelmshaven, Schwarze Pumpe
- UK: Ferrybridge, Aberthaw
- France: Lacq (already in use), Le Havre
- Norway: Test Centre Mongstad
- Italy: Brindisi
- Spain: Ponferrada.

If these plants are unsuitable (e.g. due to location or the fact that it is not their primary objective to produce CO_2), then other CO_2 sources may be attractive. Slipstreams of CO_2 produced as an industrial by-product in petrochemicals, gas treatment or biomass processing plants may be available at relatively low cost – although the quality may be sub-optimal for storage (e.g. natural gas processing plants in northern Croatia (Molve) and central Hungary (Szank)).

Naturally occurring CO_2 could also be used for storage projects, as it has happened with the U.S. Regional Partnerships. Substantial sources occur in Hungary (currently under production for EOR), with smaller occurrences in Slovakia, southern France and several other locations in western Europe. Alternatively, as mainly happened with the Ketzin project, high-grade CO_2 can be purchased from the gas market.

Storage operation

In SA operations the magnitude and spatial extension of the pressure response are probably the most important criteria for evaluating the storage horizon. A distinct variety of lithological, as well as structure geological cases, should therefore be covered.

In locally confined structures (e.g. by closed faults) or low permeable lithologies, rapid pressure increases may be observed, enabling the rapid testing of the full lifecycle of a storage site. Special attention should be given to the recovery phase after injection. Plume development, pressure development, longer-term trapping mechanisms, and even possibly leakage processes (via faults or caprock), are subject to investigation. On the operational side, storage/injection optimisation, remediation measures, in addition to well monitoring and abandonment methodologies, are in focus. Data gathered should serve to improve the parameterisation and verification of static and dynamic models.

In larger structures or high permeable lithologies, the pressure response may only be calculated from injectivity. In this case, caprock integrity or geochemical investigations may be of greater relevance. However, long-distance observation wells may help to study the lateral extension of the pressure effects on the SA, as well as the lateral footprint of displaced saline formation water.
The simulation of industrial cases should also be in focus: where CO_2 from capture pilots is used, the effect of process-related impurities on geochemistry can be investigated; if CO_2 is purchased from the market,

---

[12] Beyond 100,000 tonnes would require permits according to the CCS Directive

admixtures can be added to simulate industrial cases. The variable injection of CO_2 – thereby reproducing conditions in future transport systems – will also improve operational knowledge.

3.3 Research deliverables

The storage pilots will improve knowledge of various processes under different geological conditions, as well as operational issues, including:

- Spatial development of the CO_2 plume – steering, control mechanisms, saturation distribution, re-production of CO_2
- Improved resolution of geophysical mapping methods, particularly in SA with sparse data; also for tracking CO_2 plumes and saturation gradients
- Improved static and dynamic modelling tools
- The fate of the CO_2 – dissolution, residual trapping and associated time-scales, processes at pore-scale, res-sublimation of CO_2 in the pore network, saturation fronts, processes at grain surfaces, impact of wet ability and subsequent change
- Pressure build-up – monitoring and control, water production, combined CO_2 storage and geothermal heat extraction
- Integration of full value chain, including operation of CO_2 storage facility, such that CO_2 production facility has maximum availability
- Improved knowledge of hydraulic properties of faults (tight or not, methods, resolution, remediation)
- Wells and equipment: cheap wells for exploration and observation, cheap re-completion equipment (e.g. plastic liners), durable long-life monitoring sondes.
- Well closure and abandonment procedures.

In order to maximise the added value of the storage pilots, they should build on existing expertise in running or planning pilot sites as, e.g. Ketzin (Germany), Lacq (France), Hontomin (Spain) and K12-B (Netherlands). These already provide a framework of different geologic environments which the new pilots could complement by closing any remaining gaps. The diachronous evolution of the various sites will result in a portfolio of storage pilots at different stages of the lifecycle, thus consolidating knowledge gained from the entire storage operation.

Finally, in order to maximise the benefit to the European CCS community, the pilots should ideally be organised under an open platform where all stakeholders can test new methodologies and equipments, and where results are shared widely and rapidly with the public.

Annex I: Members of ZEP’S Working Group on Storage R&D

Name		**Country**	**Organisation**
Niels Peter	Christensen	Norway	Gassnova
Christian	Bernstone	Sweden	Vattenfall AB / BU R&D Projects
Robin	Irons	U.K.	E.ON New Build & Technology
Wolfgang	Rolland	Germany	Vattenfall Europe Technology Research
Owain	Tucker	U.K.	Shell
Henk	Pagnier	The Netherlands	TNO
Filip	Neele	The Netherlands	TNO
Herve	Quinquis	France	IFP Energies nouvelles
Aage	Stangeland	Norway	Norwegian Research Council
Adam	Wojcicki	Poland	Polish Geological Institute
Vit	Hladik	Czech Republic	Czech Geological Survey
Hans	Modder	The Netherlands	ZEP Secretariat
Isabelle	Czernichowski	France	BRGM
Tim	Hill	U.K.	E.ON New Build & Technology
Jonathan	Pearce	U.K.	BGS
Observer:			
Vassilios	Kougionas	Belgium	DG Research and Innovation, European Commission

This document has been prepared on behalf of the Advisory Council of the European Technology Platform for Zero Emission Fossil Fuel Power Plants. The information and views contained in this document are the collective view of the Advisory Council and not of individual members, or of the European Commission. Neither the Advisory Council, the European Commission, nor any person acting on their behalf, is responsible for the use that might be made of the information contained in this publication.

June 2013

info@zero-emissionplatform.eu
www.zeroemissionsplatform.eu