Zero emissions platform

Recommendations for research to support CCS deployment in Europe beyond 2020

Update on CO_2 Transport and Storage

European Technology Platform for Zero Emission Fossil Fuel Power Plants

Contents

1 Introduction

The critical role of CO_2 Capture and Storage (CCS) in meeting the EU's energy, climate and societal goals is now indisputable: the European Commission's Communication on CCS[1] *has confirmed that it is not only "vital for meeting the Union's greenhouse gas reduction targets", it provides a "very visible link between jobs in local communities and continued industrial production". Indeed, by 2050 CCS must account for ~20-30% of total emissions reductions in the power sector alone, which means that "For all fossil fuels, Carbon Capture and Storage will have to be applied from around 2030 onwards".*[2]

1.1 R&D plays a critical role in accelerating CCS deployment in Europe

In 2010, ZEP published its landmark report, "*Recommendations for research to support the deployment of CCS in Europe beyond 2020*",[3] which identified key R&D areas requiring support in order to drive down costs and accelerate deployment via well-targeted programmes. FP7-ENERGY calls have taken into account several key recommendations, proving various individual components of the CCS value chain. Much learning has been achieved and industry is today confident that CO_2 transport and storage can be safely introduced on a commercial scale.

However, further targeted R&D is essential in areas that can significantly reduce costs and commercial risks. ZEP has therefore published an update on R&D priorities for CO_2 capture,[4] while this report covers R&D priorities for CO_2 transport and storage, taking into account advances achieved to date. (N.B. These are prioritised independently of the source of capture.) ZEP has also published a separate report outlining the urgent need for up to six new large storage pilots, EU-wide.[5]

Work on R&D priorities must be initiated now and/or continued in order to enable the wide deployment of CCS by 2030. This includes all the key development steps (laboratory – small/large pilot – demonstration – pre-commercial). To this end, CCS must be fully represented in Horizon 2020 as a critical low-carbon technology for delivering EU climate goals.

1.2 Parallel European R&D initiatives ensure effective joint programming

In addition to ZEP, there are two other parallel initiatives for setting R&D priorities in Europe: the European Industrial Initiative (EII) on CCS[6] and the European Energy Research Alliance (EERA) Joint Programme on CCS (CCS-JP) – see Figure 1.

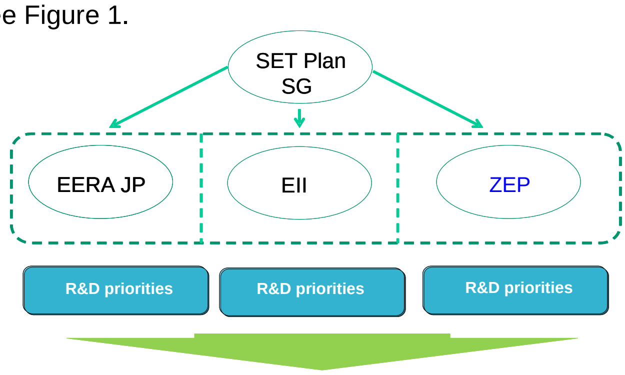

Figure 1: Parallel work on setting R&D priorities by EERA, ZEP and the CCS EII, under the 'umbrella' of the SET Plan Steering Group (SG)

[1] http://ec.europa.eu/energy/coal/ccs_en.htm
[2] http://ec.europa.eu/energy/energy2020/roadmap/doc/com_2011_8852_en.pdf
[3] www.zeroemissionsplatform.eu/library.html/publication/95-zep-report-on-long-term-ccs-rad
[4] www.zeroemissionsplatform.eu/library/publication/236-zepcapturereport.html, October 2013
[5] www.zeroemissionsplatform.eu/library/publication/224-storagepilotsreport.html, June 2013
[6] Launched by the European Commission as part of its Strategic Energy Technology (SET) Plan. CCS Implementation Plan 2013-2015: http://setis.ec.europa.eu/set-plan-implementation/european-industrial-initiatives-eiis/eii-implementation-plans

1.3 R&D should now focus on improving efficiency and reducing costs

R&D projects to date have been effective in showing that CO_2 storage is safe and technically feasible. R&D must therefore now focus on improving efficiency and reducing the costs of CO_2 transport and storage – and the CCS chain as a whole.

Key remaining challenges and long-term R&D needs (where optimisation can be made) have been identified by ZEP building on experience from existing pilots and developing CCS demonstration projects. This includes the urgent need to build up to six large CO_2 storage pilots and overcome barriers to infrastructure development in order to create confidence in large-scale CCS.

ZEP recommendations are structured to follow the development stages of a storage project, including the linked delivery of CO_2 to a storage site:

- Exploration of storage sites
- Appraisal of storage sites
- Development of transport infrastructure and storage sites
- Operation: a) contingency measures to reduce project risks b) processes for leakage scenarios c) dynamics, monitoring and remediation
- Post-injection: monitoring and remediation
- Liability
- Plus CCU/CCUS[7] options which could accelerate CCS deployment.

The aim: to address the main areas of uncertainty or optimisation where costs can be reduced. R&D needs for each step are summarised in sections 2.1-2.7. As there are a multitude of R&D topics, and pursuing R&D in all areas would be costly, an evaluation has been made as to which topics could have a positive impact on investment decision parameters considered by project developers. Some topics, of course, do not concern technology improvement and are therefore inappropriate for evaluation against cost efficiency or risk reduction. However, they are still important in that they will accelerate the delivery of commercial CCS projects.

It should be emphasised that conclusions and recommendations are based on *estimates* of the impact of R&D topics and the current level of knowledge within ZEP. For example, operability and availability are still to a large extent unexplored research areas.

1.3.1 Definition of timeframe

The timeframe for long-term R&D has been categorised in intervals according to the needs of the European energy system, i.e. by 2020, 2030 and beyond:

- *Period I, up to 2020*: as the availability of proven storage capacity is a prerequisite for any investment decision in commercial capture plants and transport infrastructure, the long-term R&D plan for transport and storage places emphasis on work to be conducted over the next 5-10 years.
- *Period II, 2020-2030*: second-generation technologies brought to commercial operation within this period are likely to be based on improvements and refinements of first-generation technologies used in Period I.
- *Period III, 2030 and beyond*: third-generation (long-term) technologies brought to commercial operation within this period are likely to be based on optimised and refined technologies from Periods I and II. In particular, demonstration phase technologies from Period II should become commercial.

[7] CO_2 Capture and Use (CCU), CO_2 Capture, Use and Storage (CCUS)

1.3.2 Definition of validation status

In Chapter 2, summary tables are provided where colour coding has been used to define the validation status of the technologies applied to the various project development phases. As in ZEP's "Matrix of Technologies",[8] validation status is divided into three levels:

- **Green** Fully validated: commercially available for application in large power plants
- **Yellow** Partly validated: ready for demonstration plants
- **Red** Not validated: not tested/less advanced than pilot scale. However, no key R&D needs have been identified.

1.4 Key R&D priorities for CO_2 transport and storage

Key R&D priorities for CO_2 transport and storage identified by ZEP include:

- Establishing up to six new large storage pilots EU-wide in order to accelerate state-of-the-art technology, drive down costs and increase public confidence in CO_2 storage.
- Developing CO_2 transport and storage network configurations in order to maximise economies of scale and build confidence in large-scale CCS infrastructure
- Establishing common procedures for maturing CO_2 storage sites to the level where there is significant certainty of storage capacity
- Providing project developers with a suite of contingency measures for the assessment of technical business risks
- Developing key performance criteria for the guidance of project developers, regulators and policymakers
- Reducing uncertainty regarding liability and the long-term performance of storage sites
- Maximising the benefits of CCU/CCUS as an enabling technology for CCS, e.g. the combination of CCS with Enhanced Oil Recovery (EOR), geothermal heat production.

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.

This report has been developed by experts in CO_2 transport and storage within ZEP's Taskforce Technology; ongoing, parallel activities via ZEP's membership of the CCS EII have also been taken into account.

www.zeroemissionsplatform.eu

[8] www.zeroemissionsplatform.eu/extranet-library/publication/4-matrix-technologies.html

2 Recommendations for research on CO_2 transport and storage

2.1 Reduce time for storage site characterisation

A wide range of CO_2 storage options exists across Europe. The FP7 CO2StoP project[9] is currently building a second-generation database on storage potential for deep saline aquifers and hydrocarbon fields for policymaking purposes, based on national or regional updates since the FP7 Geocapacity project (first generation). Several other ongoing initiatives are also developing the knowledge base in certain regions, e.g. the UK continental shelf, the Norwegian sector of the North Sea and the Nordic region.

However, the resources available limit the ambition level. Yet it is essential that project developers have a tool for identifying and prioritising options for long-term CO_2 storage. A comprehensive, web-based European CO_2 storage atlas is therefore urgently required.

Key challenges and long-term R&D targets

- Integrate and standardise national approaches to estimations of storage capacities.
- Generalise and transfer knowledge from well-investigated sites to poorly-investigated geologies in order to obtain a regional coverage.

Rank	Key R&D needs: exploration of CO_2 storage sites	-2020	2020-2030	2030+
PR	Reduce time required to characterise storage sites adequately. Classify storage sites in terms of a reserves maturation process similar to SPE petroleum maturation.	Yellow	Green	Green
PR	Define key factors (spatial constraints) that affect the interaction between other subsurface resources. Allocation of pore space and resource interaction management.	Yellow	Green	Green

Rankings: PR – Prioritised, M – Medium, L – Low
Colour codes: Green – Validated, Yellow – Partly Validated, Red – Not Validated

2.2 Establish common procedures for maturing storage sites

It is recognised in the oil, gas and mineral extractive industries that a set of common standard definitions is needed that can be applied consistently by international financial, regulatory, and reporting entities.[10] The same is true for CO_2 storage resources, where an agreed set of definitions would benefit all stakeholders and provide greater consistency, transparency and reliability.

The key challenge is to establish common procedures for maturing CO_2 storage sites to a level where significant certainty of storage capacity exists, in line with the existing Petroleum Resources Management System which provides the basis for classification and categorisation of all petroleum reserves and resources. As well as qualifying individual storage sites, this information (in combination with the storage atlas) is also crucial for developing a European CO_2 transport infrastructure.

Key challenges and long-term R&D targets

- Establish common procedures for maturing CO_2 storage sites to the level where significant certainty of storage capacity exists.

[9] www.co2geonet.com/UserFiles/file/Open%20Forum%202012/Posters/CO2StoP%20poster%20Poulsen%20et%20al%202012.pdf
[10] SPE (2011), Guidelines for Application of the Petroleum Resources Management System

Rank	Key R&D needs: appraisal of storage sites	-2020	2020-2030	2030+
PR	Better near well-bore understanding and improved coupling of multi-phase flow, thermodynamics, geochemistry and geomechanics (including in faults and fractures). Of these two components, geomechanics (combined with geochemistry in certain reservoirs) are key.			
PR	Validation of models, i.e. calibration, verification and sensitivity analysis of large-scale simulations. There is a need for real data sets/performance (i.e. at the time data is available from the operation of the storage pilots).			
PR	Improve knowledge of hydraulic properties of faults (tight or not, methods, resolution): - Estimate fault permeabilities, fault development and induced seismicity during CO_2 injection at a fault permeability test site into a fault at realistic depths. - Study the coupling of geomechanical and geochemical processes, and the correlation between the seismic data and the energy injected.			
PR	Strategies to define the storage complex			
M	Storage appraisal and development strategies for early (post-demonstration) deployment			
L	Benchmarking exercises to compare capabilities of different modelling tools and more clearly define the appropriateness of their application to specific storage issues			

Rankings: PR – Prioritised, M – Medium, L – Low
Colour codes: Green – Validated, Yellow – Partly Validated, Red – Not Validated

2.3 Enable cost-efficient development of transport infrastructure and storage sites

2.3.1 Transport infrastructure

A CCS cluster (i.e. the sharing of transport and storage infrastructure by more than one capture proponent and more than one storage proponent) provides a nucleus for ‘first mover’ projects to gain critical mass. Such clusters provide a platform for the wide-scale deployment of the CCS industry, benefitting significantly from economies of scale. Only when large volumes of CO_2 share a common infrastructure will the infrastructure costs per tonne come down.

There are technical blockers for infrastructure components, especially regarding technical regulations for pipeline integrity. Other issues occur due to different sources of CO_2, which results in the combination of different CO_2 qualities, different transport modes (e.g. ship or pipeline) and connected operational issues (e.g. the volatility of CO_2 production vs. possible continuity needs of storage sites, or challenges due to different physical conditions of CO_2).

In FP7, important CO_2 transport R&D has focused on key conditions needed to enable the large-scale deployment of CCS in the EU and techno-economic assessments of the impact of impurities in the CO_2 (fluid properties, phase behaviour and chemical reactions in pipelines). A key challenge is to incorporate these learnings into the development of transport and storage network configurations suitable for Europe.

Key challenges and long-term R&D targets

- Establish CCS transport and storage network configurations and build confidence in the infrastructure aspects of the operational performance of these chains.

Rank	Key R&D needs: cost-efficient development of transport infrastructure	-2020	2020-2030	2030+
PR	Improve understanding of multi-phase flow			
sPR	Develop conceptual design for offshore unloading/injection of CO_2 transport by ship (including compression to, for example, 100 bar)			
PR	Risk assessment for CO_2 pipelines with a focus on cost-efficient mitigation measures and opportunities			
PR	Integrity of large-scale CCS infrastructures: improve understanding of material issues, corrosion, solid formation and interaction of CO_2 on seals for both top-side and down-hole applications. Continued R&D should focus on setting tolerances.			
PR	Establish an open access database holding experimental data on thermodynamic properties of CO_2 mixtures and data from corrosion tests of pipeline materials etc.			
PR	Improve understanding of CO_2 transport leakage scenarios, with special emphasis on cost-efficient mitigation measures			
PR	Assess and propose business models (led by economics research) for regional multi-user clusters of CO_2 sources. The chain-integration and build-out of the corresponding infrastructure should be studied (including connecting transport of CO_2 out from densely populated areas, cost-efficient CO_2 hubs, cross-border issues, operational issues of these complex systems and CCUS)			
M	Efficient large-scale infrastructures for CO_2 (cost reduction aspects)			
M	Cost-efficient and smart design of interim storage to respond to flexibility requirements			
L	Meter technology and meter accuracy			

Rankings: PR – Prioritised, M – Medium, L – Low
Colour codes: Green – Validated, Yellow – Partly Validated, Red – Not Validated

2.3.2 Storage drilling and subsurface facilities

Continued R&D can contribute significantly to further cost efficiency through innovative solutions and the overall learning curve of pilot (and demonstration) projects. Today, there is a high degree of uncertainty in estimating the costs for CO_2 storage projects because of significant variations between projects' technical characteristics, scale and application.

There is also uncertainty as to how costs will develop over time with respect to the range of learning rates and scale benefits. The key challenge is to provide the basis for future cost reductions, taking into account location and type of storage site, reservoir capacity and quality. The UK Cost Reduction Task Force has recently concluded that early projects have high capital costs for several reasons, including:

- There are no commercial-scale projects to provide financiers with confidence.
- Storage risks are perceived as significant for early projects.
- Chain risks in the event that one component in the chain fails.

Key challenges and long-term R&D targets

- Build confidence in the operational performance of the CCS chain – particularly storage.
- Urgently establish up to six new CO_2 storage pilots EU-wide in order to accelerate state-of-the-art technology, drive down costs and increase public confidence in CO_2 storage.

Rank	Key R&D needs: storage drilling and subsurface facilities	-2020	2020-2030	2030+
PR	Establish up to 6 new large CO_2 storage pilots, EU-wide: compared to the variety of potential geological settings for CO_2 storage, the number of operational onshore pilots is very low. With 3 operational pilots (Ketzin, Lacq and Hontomin), only limited research and operational knowledge is possible. The flexibility of such sites offers R&D opportunities over the whole lifecycle of a storage project – from exploration to compliance, including closure and post-injection targets. The identification of research objectives should be based on previous Framework Programme research and national CCS R&D programmes in, for example, Germany, France, The Netherlands, Norway, Spain and Denmark. The CO_2 for injection experiments must come from sources other than the commercial market, i.e. CO_2 streams that can be provided to and injected at the storage pilots need to be identified.			
PR	Improve effective, low-cost monitoring systems			
PR	Long-term monitoring (passive and active), plus cost-effective monitoring strategies			
PR	Efficient 3D and 4D seismic onshore, including for use in permanent installations			
PR	Improve drilling for cost-effectiveness and to reduce formation damage			
M	Test cost-effective engineering solutions (compared to demonstration projects where off-the-shelf technologies would be expected). If planned ahead, parts of the high-capex surface facilities could potentially be shared between several pilot projects.			
M	Wells and equipment: low-cost wells for exploration and observation, low-cost re-completion equipment (e.g. plastic liners) and durable long-life monitoring sonds			
L	Quantify the effects of up-scaling on static and dynamic modelling on predictions of storage performance			

Rankings: PR – Prioritised, M – Medium, L – Low
Colour codes: Green – Validated, Yellow – Partly Validated, Red – Not Validated

2.4 Accelerate state-of-the-art technology for transport and storage site operation

2.4.1 Contingency measures to reduce project risks

A CCS business case holds as long as all parts of the capture, transport and storage chain operate to design requirements at all times. The failure of any one part – while taking contingency measures into account – compromises the whole operation.

The FP7 RISCS project is one example of research where its "Guide to Impacts of Potential Leaks from CO2 Storage" informs project developers on contingency measures that cannot be 'appraised away'. It is particularly important that operational procedures for storage facilities and transport networks are developed and tested such that the CO_2 production facility has maximum availability.

Key challenges and long-term R&D targets

- Provide project developers with a suite of contingency measures that can used to assess technical business risks, i.e. research to concretise these risks, and plan for and cost the consequences of mitigation.

Rank	Key R&D needs: contingency measures for CO_2 storage and transport	-2020	2020-2030	2030+
PR	When storage capacity is lower than assessed: requires pressure management, especially for deep saline aquifers, to maximise the storage resource and monitor the effects of pressure build-up. Understand pressure responses and pressure management techniques (e.g. by water extraction).			
PR	When the plume does not behave as expected: requires spatial development of the CO_2 plume (steering, control mechanisms, saturation distribution, re-production of CO_2). Assess economic and technical cut-off for extraction of water in order to make more efficient use of the pore space (including disposal and re-use opportunities).			
PR	When there is poor sustained injectivity: requires research on the consequences of the migration of fines, geochemical impacts			
PR	Re. transport modes: extraordinary transport operational procedures are required in case of upstream and/or downstream disturbances			

Rankings: PR – Prioritised, M – Medium, L – Low
Colour codes: Green – Validated, Yellow – Partly Validated, Red – Not Validated

2.4.2 Processes for leakage scenarios

Research and experience provides indicative evidence that areas that might be affected by leakage from a storage complex would be small in size and limited to localised areas. Nevertheless, comprehensive knowledge of processes that would be active in different leakage scenarios is required (e.g. the consumption of CO_2 along leakage pathways). The licence holder of a storage site needs guidance as to whether a detected leakage will lead to binary consequences for the operation, i.e. a complete stop of operation, or given that the environmental impact is low, that operation can continue with restrictions.

Key challenges and long-term R&D targets

- Provide comprehensive knowledge on processes that would be active in different leakage scenarios.

Rank	Key R&D needs: potential migration pathways and environmental impacts of CO_2 leakage	–2020	2020-2030	2030+
PR	Improved prediction (based on controlled release experiments) of geologically-controlled CO_2 leakage mechanisms (rate, timing, consequences, probability). Consumption of CO_2 along leakage pathways.			
M	Gain further experience on the impact of leaked CO_2 on crops etc., as currently being undertaken in the FP7 RISCS project.			

Rankings: PR – Prioritised, M – Medium, L – Low
Colour codes: Green – Validated, Yellow – Partly Validated, Red – Not Validated

2.4.3 Dynamics, monitoring and remediation

There are additional operational challenges to those covered in sections 2.4.1 and 2.4.2. To a large extent, these would have been addressed in the discontinued demonstration projects, including the effects of transient operational scenarios imposed by the CO_2 capturing plant in the flow line and wells, and monitoring and remediation technologies.

Key challenges and long-term R&D targets

- Flexible injection schemes without harming the well-bore (micro seismicity, thermal cycling well-bore, thermal wave-chocks)
- Technologies for remediation and mitigation of significant irregularities and leakage
- Extended offshore baseline data.

Rank	Key R&D needs: dynamics, monitoring and remediation	-2020	2020-2030	2030+
PR	Assessment of the impact from micro-seismicity, thermal cycling and thermal wave-chocks on the well-bore and its installation from flexible injection schemes			
PR	Technologies for remediation and mitigation of significant irregularities and leakage			
PR	Remediation testing facility: field-scale tests are needed to demonstrate the effectiveness of technologies for controlling permeability, implementing hydraulic barriers and fluid management to remediate geologically-mediated migration for CO_2 storage applications			
PR	Extended gathering of offshore baseline data, building on the FP7 ECO2 project (e.g. in the Baltic Sea)			
M	Remote sensing (InSAR, EM etc.) for leakage detection and geomechanical stability; plus cost reduction opportunities			
M	Biological monitoring for environmental impact			
M	Reservoir and over seal monitoring (resolution/sensitivity) – Time lapse seismic techniques for increased resolution – Micro-seismic design – Monitoring bore design and down-hole sensors			
M	Well closure and abandonment procedures			
L	Automated statistical procedures to define deviation thresholds in monitoring data sets compared to baseline (data mining)			

Rankings: PR – Prioritised, M – Medium, L – Low
Colour codes: Green – Validated, Yellow – Partly Validated, Red – Not Validated

2.5 Establish clear post-injection procedures

Projects require certainty as to the degree of monitoring and activity required in the period covering post-closure stewardship. Post-injection monitoring is essential to verify expectations regarding long-term stability and storage permanence. The results of that monitoring determine when the site is returned to the public authorities.

Developers of commercial projects therefore need clarity regarding procedures and criteria in the early phase of project development in order to evaluate how and when targets can be met to reduce overall project risks. This also facilitates the setting of storage tariffs. The key challenge is to understand the processes taking place which lead to stability and a reduction in risk.

Key challenges and long-term R&D targets

- Develop key performance criteria for the guidance of project developers, regulators and policymakers.

Rank	Key R&D needs: post-injection monitoring and remediation	-2020	2020-2030	2030+
PR	Define clear post-injection procedures and performance targets			

Rankings: PR – Prioritised, M – Medium, L – Low
Colour codes: Green – Validated, Yellow – Partly Validated, Red – Not Validated

2.6 Reduce uncertainty for site operators regarding liability

Research to date points to two sources of uncertainty with regard to handling liability: performance of the physical system itself and policy measures to handle liability. The latter is linked to the risks of the former, i.e. uncertainty over the long-term performance of storage sites needs to be reduced so that the liability provision of policy measures can be better judged by project developers.

Research is needed on the likelihood of irregularities occurring and their consequences. Further evidence is needed that irregularities – if they occur – do not have detrimental consequences for a storage project, thereby de-risking projects. Indeed, the more work undertaken on the potential consequences, the better informed the debate surrounding HSE issues.

Key challenges and long-term R&D targets

- Reduce uncertainty over the long-term performance of CO_2 storage sites, guiding informed liability policy measures.

Rank	Key R&D needs: liability	-2020	2020-2030	2030+
PR	CO_2 plume tracking, leakage detection and quantification of leakage at surface (especially offshore)			
PR	Pressure propagation into potable aquifers			
M	The fate of the CO_2: dissolution, residual trapping and associated time-scales, processes at pore-scale, residual saturation of CO_2 in the pore network, saturation fronts, processes at grain surfaces, impact of wetability and subsequent change. Validating predictions of CO_2-fluid reactions against data obtained at scale in realistic injection and storage scenarios.			
M	Longer-term trapping: natural CO_2 reservoirs can be used to evaluate the potential for these processes to contribute to long-term site safety cases by constraining predictions of site behaviour with analogue data. Provide reference data sets from natural reservoirs which have been produced for benchmarking predictive simulations and newly acquired monitoring data.			
M	Ecosystem recovery			
M	Well integrity and flow monitoring facility: gain experience of the long-term stability of well completion materials			

Rankings: PR – Prioritised, M – Medium, L – Low
Colour codes: Green – Validated, Yellow – Partly Validated, Red – Not Validated

2.7 Maximise the benefits of CCU/CCUS as an enabling technology for CCS

There is a range of CO_2 storage options available. A key challenge is therefore to further assess options that – in addition to deep saline aquifers and depleted oil/gas fields – have attractive benefits from an industrial perspective, e.g. the use of CO_2 to enhance recovery efficiency in oil fields, combining aquifer storage with geothermal energy.

Key challenges and long-term R&D targets

- Further assess options that have attractive industrial and societal benefits.

Rank	Key R&D needs: additional CO_2 storage concepts	-2020	2020-2030	2030+
PR	Co-optimisation of CO_2 storage and EOR			
M	Combine CO_2 storage and geothermal heat extraction (water production to control pressure build-up)			
M	Reproduction of part of the stored CO_2 for CCUS			

Rankings: PR – Prioritised, M – Medium, L – Low
Colour codes: Green – Validated, Yellow – Partly Validated, Red – Not Validated

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