State of play on CO_2 geological storage in 28 European countries

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CGS Europe
FP7 Pan-European Coordination
Action on CO_2 Geological Storage

CO_2GeoNet
The European Network of Excellence
on the Geological Storage of CO_2

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Austria; Belgium; Bulgaria; Czech Republic; Croatia; Denmark; Estonia; Finland; France; Germany; Greece; Hungary; Ireland; Italy; Latvia; Lithuania; The Netherlands; Norway; Poland; Portugal; Romania; Serbia; Slovakia; Slovenia; Spain; Sweden; Turkey; United Kingdom 31

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1 Introduction

The "Pan-European coordination action on CO_2 Geological Storage (CGS Europe)" (www.cgseurope.net) started in November 2010 and is funded within the 7th Framework Programme of the European Community for three years. In CGS Europe, the established expert networks CO_2GeoNet Association (www.co2geonet.com), CO_2NET EAST (co2neteast.energnet.com) and ENeRG (www.energnet.eu) are joining forces and pooling their expertise to build a credible, independent, and representative pan-European scientific body of expertise on CO_2 geological storage. CGS Europe provides an independent platform and reference source where national, European and international experts, institutes and regulators are able to

- access the most up-to-date results of CO_2-storage-related studies,
- share experiences and good practises,
- discuss the implementation of regulations,
- identify research needs to face upcoming challenges, and
- build new projects.

Partners of CGS Europe comprise members of the CO_2GeoNet Association and 22 other participants covering most of Europe with 24 EU Member States as well as Croatia, Norway, Serbia and Turkey (Tab. 1).

The objectives of CGS Europe are, among others, to support the implementation of the European Directive on the geological storage of CO_2 and other regulatory regimes and to facilitate the large-scale demonstration and industrial deployment of CCS. In addition, CGS Europe is contributing to reducing the gap between the 'forerunner' countries, where CCS activities have been started or planned, and the 'follower' countries where these actions are not yet happening.

As one of CGS Europe's activities, information was collated about the state of play on CO_2 geological storage in the 28 countries covered by CGS Europe. The following topics have been addressed:

i) research activities and national funding opportunities for research on CO_2 storage;
ii) current pilot, demo and test sites in the CGS Europe countries;
iii) state of transposition of the EU Directive on the geological storage of CO_2;
iv) public awareness in the CGS Europe countries.

The current state of play on CO_2 geological storage in the CGS Europe countries is summarised in this report. More detailed country-specific information is provided in Annex I. In this report, a brief overview of the CO_2 storage options, potentials and capacities in Europe is provided in Chapter 2. Structure and organisation of research funding related to CO_2 storage on a national level are outlined in Chapters 3 and 5 of the current report. Research topics addressed by the CGS Europe partners and other research institutions in the CGS Europe countries are introduced in Chapter 4, followed by a summary of current pilot, demo and test sites (Chapter 7) and an overview of the current state of transposition of the EU Directive on the geological storage of CO_2 in the CGS Europe countries (Chapter 8). Information on a national level is complemented by an overview of ongoing EU-funded research projects related to CO_2 storage (www.cordis.eu) and a summary of activities of the European Energy Research Alliance (www.eera-set.eu) in Chapter 6.

This report reflects the state of play in Europe as of July 31st 2012 unless indicated otherwise.

Tab. 1: Institutions of CGS Europe.

Short name	Name	Country
GBA	Geologische Bundesanstalt	Austria
RBINS-GSB	Institut Royal Des Sciences Naturelles De Belgique	Belgium
SU	Sofiiski Universitet Sveti Kliment Ohridski	Bulgaria
UNIZG-RGNF	University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering	Croatia
CzGS	Ceska Geologicka Sluzba	Czech Republic
GEUS	Geological Survey of Denmark and Iceland	Denmark
TTUGI	Tallinna Tehnikaulikool	Estonia
GTK	Geologian Tutkimuskeskus	Finland
BRGM	Bureau De Recherches Geologiques Et Minieres	France
IFPEN	IFP Energie Nouvelles	France
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe	Germany
EKBAA-IGME	Ethniko Kentro Viosimis Kai Aeiforou Anaptyxis	Greece
IMFGI (former ELGI)	Magyar Földtani és Geofizikai Intezet	Hungary
GSI	Department of Communications, Energy and Natural resources – Geological Survey of Ireland	Ireland
OGS	Istituto Nazionale di Oceanografia e di Geofisica Sperimentale	Italy
URS	Università di Roma “La Sapienza”	Italy
LEGMC	Latvijas Vides, Geologijas Un Meteorologijas Centrs SIA	Latvia
GTC	Gamtos tyrimų centras	Lithuania
TNO	TNO – Netherlands Organisation for Applied Science	The Netherlands
NIVA	Norwegian Institute for Water Research	Norway
IRIS	International Research Institute of Stavanger	Norway
SINTEF	SINTEF Petroleum Research	Norway
PGI-NRI	Panstwowy Institut Geologiczny - Panstwowy Institut Badawczy	Poland
LNEG	Laboratorio Nacional de Energia e Geologia I.P.	Portugal
GEOECOMAR	Institutul National De Cercetare-Dezvoltare Pentru Geologie Si Geoecologie Marina - GEOECOMAR	Romania
AGES	Association of Geophysicists and Environmentalists of Serbia	Serbia
SGUDS	Statny Geologicky Ustav Dionyza Stura	Slovakia
GEO-INZ	Geoinzeniring, druzba za geoloski inzeniring d.o.o.	Slovenia
S-IGME	Instituto Geológico Y Minero De España	Spain
SGU	Sveriges geologiska undersökning	Sweden
METU-PAL	Middle East Technical University - Petroleum Research Centre	Turkey
BGS	British Geological Survey	United Kingdom
IMPERIAL	Imperial College Consultants Ltd.	United Kingdom
HWU	Institute of Petroleum Engineering, Heriott-Watt University	United Kingdom

2 Storage options, potentials and capacities in Europe

For the geological storage of CO_2, three main storage options are commonly considered: i) deep saline aquifers, ii) depleted hydrocarbon fields, iii) coal seams. In general, these geological storage options are bound to sedimentary rocks which were deposited in sedimentary basins. These basins can contain up to several thousands of meters of sedimentary fill that could in parts act as potential reservoir or sealing rock units. Hence, the first step in storage capacity assessments is the identification of potentially suitable sedimentary basins.

In Europe, sedimentary basins are widely distributed (Fig. 1). One striking exception is the Fenno-scandian shield, where magmatic and metamorphic crystalline rocks are prevalent at or near the surface. Due to the complex geological development of Europe, the sedimentary basins feature different structural designs and sizes. One of the large basins, for example, is the Southern Permian Basin in Northern Europe, which is located around the southern part of the North Sea and extends from England to Poland. Other examples are the Paris Basin in Northern France, the Alpine Foreland Basin north of the Alps and the Pannonian Basin in East-Central Europe.

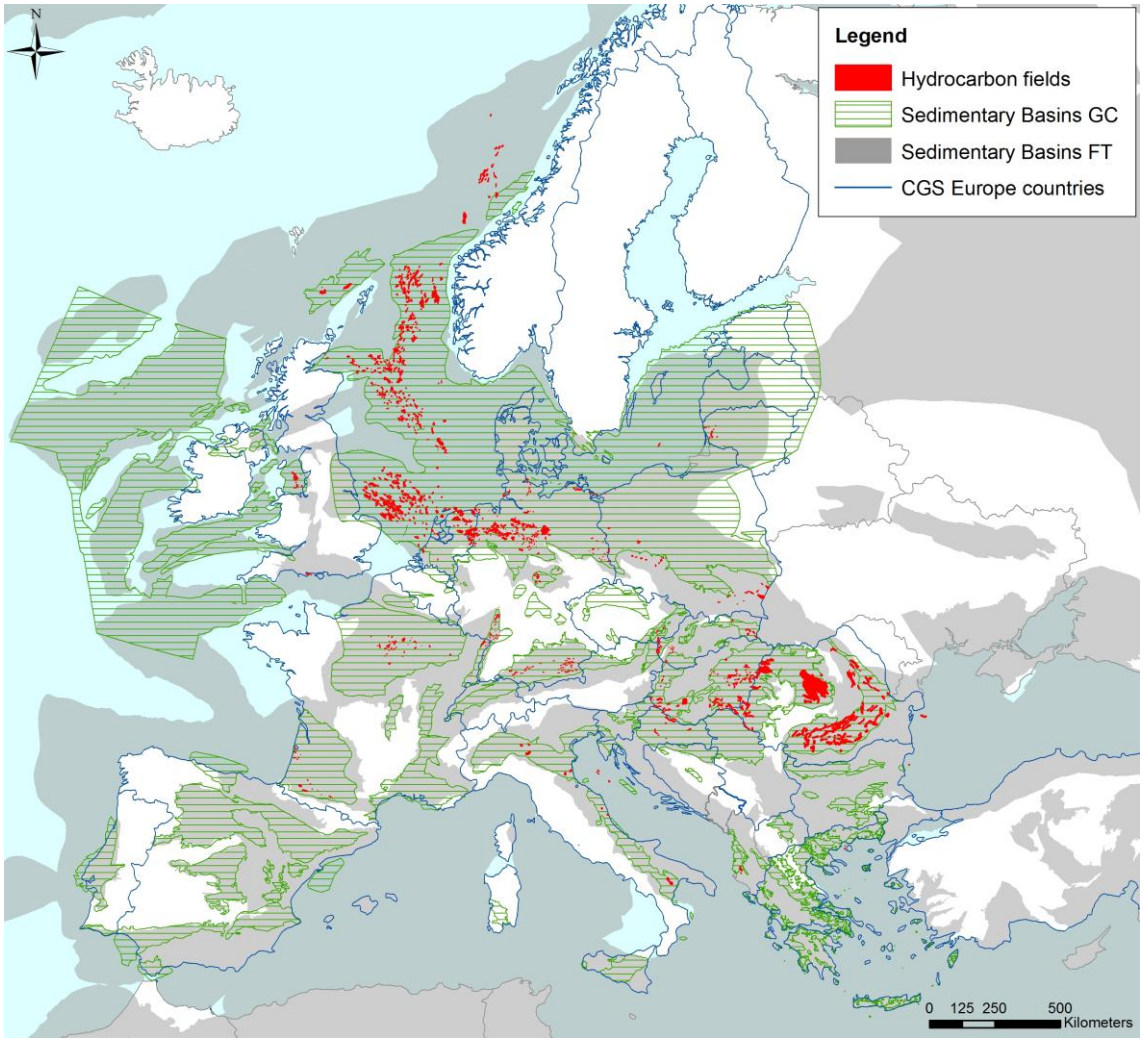

Fig. 1: Extent of sedimentary basins (in grey: Fugro Tellus (FT), 2008; in shaded green: GeoCapacity (GC), 2009) and potential hydrocarbon fields for CO_2 storage in Europe (GeoCapacity, 2009). CGS Europe countries are marked by blue borderlines. Note that countries that are completely surrounded by CGS Europe countries, but are not member of CGS Europe, also appear with blue borderlines as is the case for Switzerland, Luxemburg, San Marino, The Vatican State, Lichtenstein, Monaco and Andorra.

Hydrocarbon fields are located in several of those sedimentary basins. In particular, the North Sea area is of great economic importance, containing numerous significant hydrocarbon fields (mostly in the Norwegian and British sectors). Also in the Netherlands, Germany, Hungary and Romania, hydrocarbon fields are plentiful. The GeoCapacity project focussed on depicting "potential hydrocarbon fields for CO_2 storage" (Kirk et al., 2009; cf. Fig. 1). Data for Belgium, Bosnia-Herzegovina, Estonia, Latvia, Luxembourg, Macedonia and Spain were not included in the GeoCapacity representation as there is no suitable hydrocarbon field storage availability in these countries (Kirk et al., 2009).

Large coal fields are prevalent in Great Britain, in the variscan molasse basin in Belgium, the Netherlands and Germany and in Poland and Hungary. Further coal fields can be found for example in France or Spain. The distribution of "potential coal fields for CO_2 storage" (Kirk et al., 2009) is given in Fig. 2. Note that this map does not display the extent of coal-bearing sedimentary rocks or mining areas, as the GeoCapacity representation focussed on coal fields in Europe that are potentially suitable for CO_2 storage and enhanced coal bed methane operations.

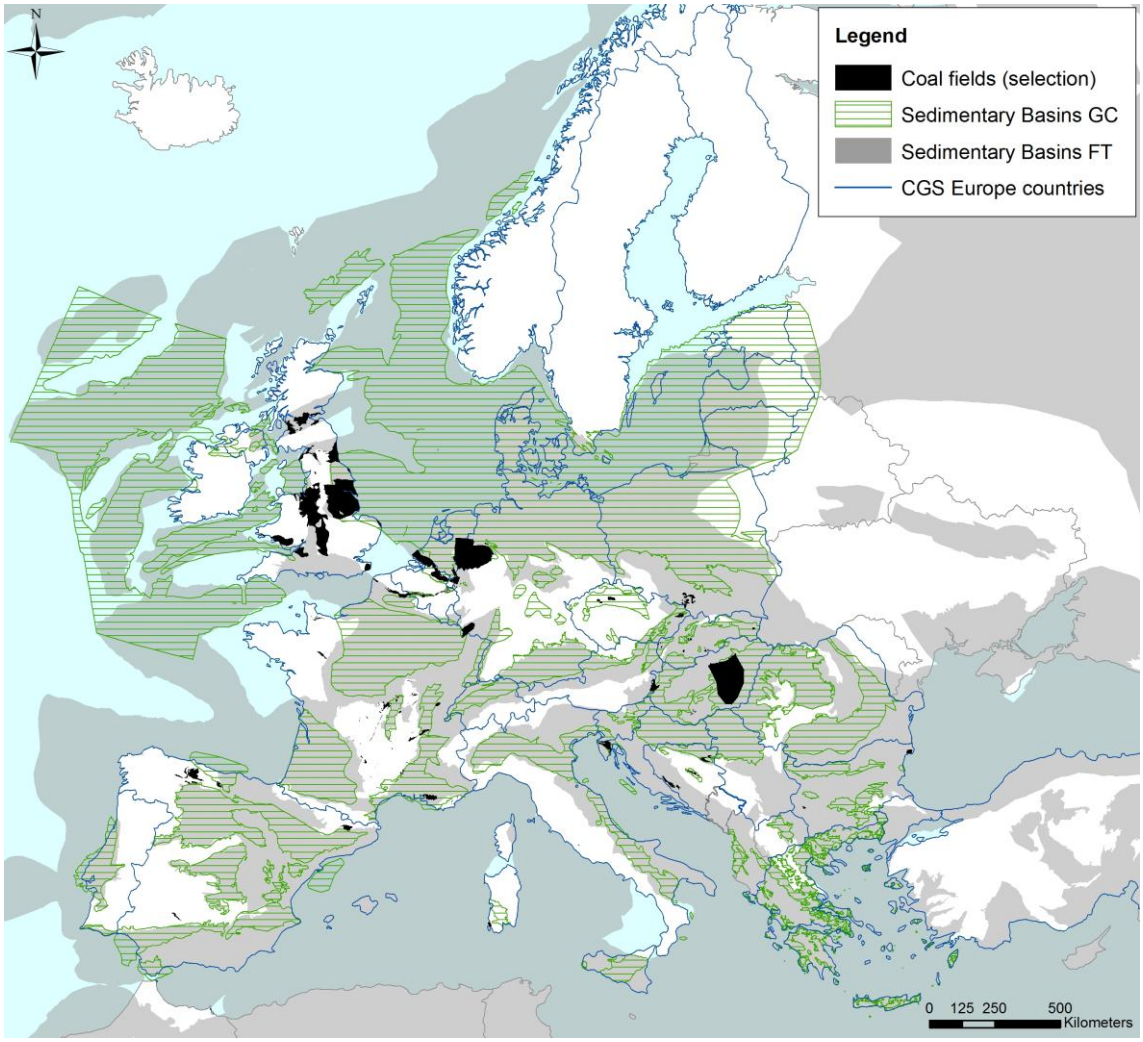

Fig. 2: Extent of sedimentary basins (in grey: Fugro Tellus (FT), 2008; in shaded green: GeoCapacity (GC), 2009) and potential coal fields for CO_2 storage in Europe (GeoCapacity, 2009). CGS Europe countries are marked by blue borderlines. Note that countries that are completely surrounded by CGS Europe countries, but are not member of CGS Europe, also appear with blue borderlines as is the case for Switzerland, Luxemburg, San Marino, The Vatican State, Lichtenstein, Monaco and Andorra.

Thus, mineable and un-mineable coalbeds may extend beyond the depicted areas (Fig. 2) in various countries. Data for Albania, Denmark, Estonia, Greece, Latvia, Lithuania, Luxembourg, Macedonia, Norway, Romania and Slovenia were not included in the GeoCapacity representation as there is no suitable coal field storage availability in these countries (Kirk et al., 2009).

Storage capacity assessment in Europe

Since the 1990's several CO_2 storage potential assessments have been carried out in Europe on regional and national scales. Through such activities the state of knowledge about geological storage potential in Europe is continually expanding. However, different methodologies were used in these studies and the results display a large variation of the level of detail and, hence, of accuracy.

The first quantification of CO_2 storage potential in European regions has been performed in a study supported by the EU JOULE II programme (Holloway, 1996). This was followed in the years 2000 – 2003 by the EU-funded project GESTCO, which covered eight European countries. One task of this project was to identify CO_2 storage potential in saline aquifers, oil and gas fields, deep coal seams and abandoned mines in the partner countries (Christensen & Holloway, 2004). The GESTCO project was followed by EU-funded projects CASTOR and GeoCapacity (www.geocapacity.eu) in the years 2004 – 2008, which covered the majority of the EU member states and neighbouring countries. The results of the assessments for 25 European countries indicate a considerable potential for CO_2 geological storage in Europe. The conservative storage capacity estimates for the various storage options amount to 96 Gt CO_2 in saline aquifers, 20 Gt in hydrocarbon fields and about 1 Gt in un-mineable coal seams. Overall, the storage capacity equals to 117 Gt of CO_2 of which approximately 25% is offshore Norway (Vangkilde-Pedersen et al., 2009).

The significance of these figures, however, is limited because the country-specific capacity estimates vary in terms of availability, quantity and quality of incorporated data and in the scale of assessment. Some countries have estimated their capacity on the basis of mapped individual structures, whereas other countries used regional or national distributions of potential reservoir formations as a basis for capacity estimates. Similarly, in capacity assessments for other regions of the world a wide range of methodologies have been applied, therefore producing a wide range of capacity estimates.

In consideration of these facts, the wish to harmonize assessment methods to enable a better comparability of the quantified storage capacities is growing. The development of internationally accepted standards for the assessment of storage capacities was first initiated by the International Energy Agency's Greenhouse Gas Programme (IEAGHG) and the Carbon Sequestration Leadership Forum (CSLF) in the middle of the last decade. The EU-funded project GeoCapacity also had a focus on developing standardised methodologies for calculating CO_2 storage capacity. Currently, the International Energy Agency (IEA) is working to develop uniform standards and procedures (Brennan et al., 2012).

A next step towards a more harmonised assessment of the European CO_2 storage potential is the EU-funded specific targeted research project "Assessment of CO_2 Storage Potential in Europe (CO_2StoP)" involving the majority of CGS Europe partners. The main objective of this project is to compile and provide a data set of geological parameters to be held in an EC Joint Research Centre database. The goal is to enable the assessment of geological CO_2 storage capacities of European countries on a common basis. The project will build on the results of the previous projects mentioned above that have assessed CO_2 storage capacities in Europe. This project is a further step towards the compilation of a European CO_2 Geological Storage Atlas in the future.

3 Research activities related to CO_2 geological storage in CGS Europe countries

In order to get an overview about the level of research activity in the CGS Europe countries, major and minor research institutions in each country, that are concerned with CO_2 storage-related research, were listed by the project partners (see Annex). This number of major and minor research institutions in each country was used as an indicator for the level of national research activity using weighting factors for major and minor institutions of 1 and 0.25, respectively. By mapping the weighted total counts, research "hot spots" and "colder" areas with less research activity were identified (Fig. 3). It must be pointed out, however, that this overview is based on a very coarse proxy only, and other factors were neglected such as country size, number of inhabitants etc. As such, the reader is kindly asked to consider more the overall trends and not to place too much emphasis on the meaning of the individual numbers.

Inferred research "hot spots" are Norway (score: 10.5), followed with distance by France, Italy, Germany, Spain, the Netherlands and U.K. (score: 7.75 to 4.5), and by Denmark, Poland and Slovenia (score: 2.5 to 2.25). In the remaining countries, scores achieved were <2.

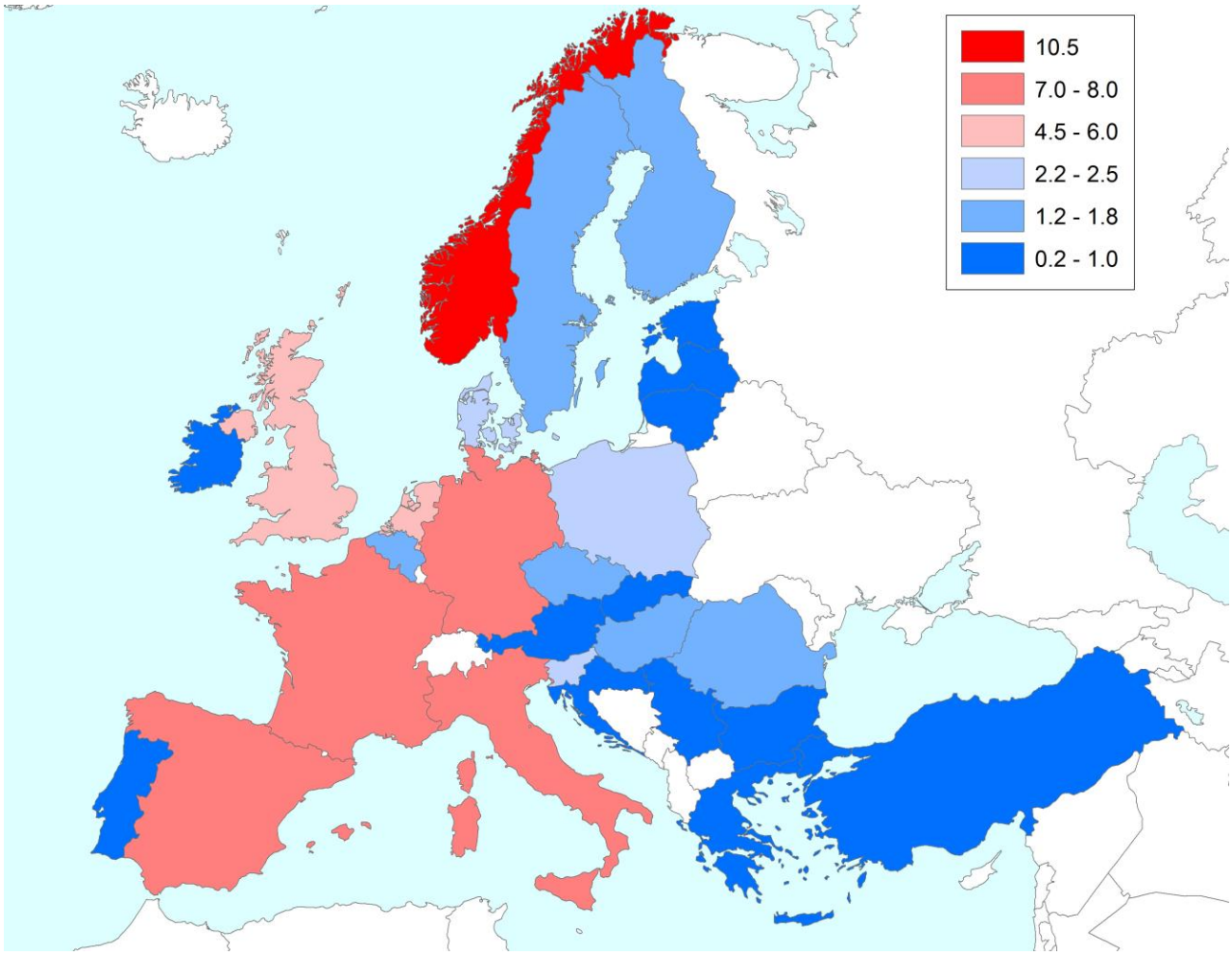

Fig. 3: Research hot spots in CGS Europe countries. Colour-coding reflects the weighted number of major and minor research institutions performing research related to CO_2 storage in each country (as of July 31st 2012).

Looking in more detail at the kind of institutions involved in CO_2 storage-related research, an interesting difference can be seen (Fig. 4): In some countries (Ireland, Estonia, Austria, Bulgaria, Serbia, U.K. Sweden and Portugal) research related to CO_2 geological storage is predominately carried out by universities, whereas, e.g., in Norway, Italy, Spain and Poland, mainly national research institutes are concerned with this research area. In, e.g., The Netherlands and Denmark, there is approximately a balance between active universities and national research institutes. It must be noted that this overview may be skewed in case of countries with a low overall number of research institutions active in CO_2 storage-related research and hence, a low weighted total count (cf. Figs. 3 and 4). Research activities of industrial enterprises have not been taken into account, as information on these projects is partly confidential and not always available for evaluation.

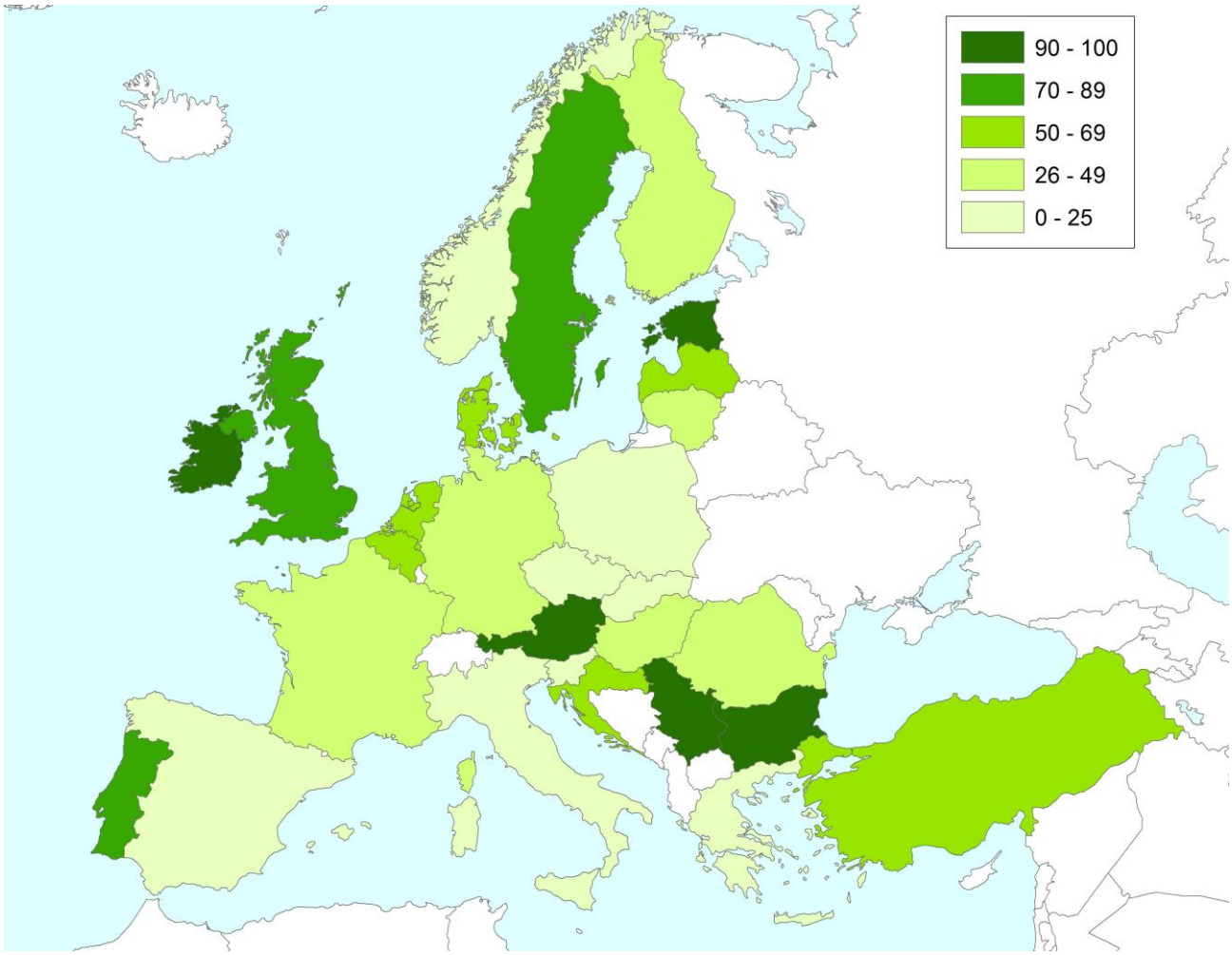

Fig. 4: Share of universities out of the total number of research entities involved in CO_2 storage-related research in CGS Europe countries as of July 31st 2012 [weighted count as % of the weighted total count].

4 Research topics related to CO_2 storage addressed by CGS Europe partners

Research topics related to geological CO_2 storage are manifold. In the document "Recommendations for research to support the deployment of CCS in Europe beyond 2020" prepared by the Zero Emission Technology Platform (ZEP, 2010) research topics related to CO_2 storage were assigned to the following thematic complexes:

- *Storage capacity assessment;*
- *Land planning and infrastructure;*
- *Complex management;*
- *Well technologies;*
- *Environmental impact;*
- *Mitigation and remediation;*
- *Modelling;*
- *Monitoring.*

The IEAGHG thematic networks also reflect major fields of research activities, which broadly correspond to the complexes identified by the ZEP. Though, the international experts of IEAGHG consider *Risk Assessment* as an important topic, justifying an own thematic network.

The focus of the research activities varies from one country to another. In the following, major findings from a questionnaire survey among the CGS Europe partners are summarised and assigned to the thematic complexes listed by the ZEP:

Storage capacity assessment

Storage capacity assessment is a key issue in many political decisions since estimated capacities are a major determining factor in defining the feasibility of geological CO_2 storage in each country. Capacity assessments are performed at various levels that may include consideration of different storage options such as saline aquifers, depleted hydrocarbon fields or coal seams depending on each country's specific geological conditions. Volumetric capacity assessments are constrained by further – often country-specific – technical, economic and regulatory factors.

The majority of the CGS Europe partners, in particular national geological surveys, consider capacity assessment as part of their core business or at least as a part of their activities. Most of the partners are or will soon be participating in national programmes for CO_2 storage capacity assessment. Moreover, a large number of CGS Europe partners are involved in the current initiative CO_2StoP, in order to create a European database of CO_2 storage potential locations and capacities, as an important step towards the creation of a CO_2 Storage Atlas in Europe, similar to those already published in the United States or Australia. Less effort is put in the CGS Europe countries in the development of methodological standards for capacity assessment, because many national programmes tend not to fund methodological research, such as refining storage coefficients in order to establish more precise capacity estimates.

Land planning and infrastructure

One of the most recently included aspects in CO_2 storage-related research activities is the planning of land use and infrastructure and underground spatial planning. This includes possible conflicts of interest between different natural (geo) resources and CO_2 storage, and the development of tools for designing and optimizing integrated networks of CO_2 capture, transport and storage infrastructure. Adequate land planning is essential in order to efficiently integrate industrial activities, resource management and environmental protection. Furthermore, CCS may turn into an international activity that may comprise CO_2 sources and capture in one country and storage facilities in a neighbouring one. Even if this will not be the case, near-border storage projects in aquifers can influence storage site availability in neighbouring countries.

An observable trend in Eastern and Northern Europe is that there is only limited research activity on land and infrastructure planning. In contrast, in Western European countries, there is strong activity, partly supported by the EC, in developing models for integrated CCS networks and combined land uses including cross-border transport and/or storage.

Storage complex management

Storage complex management comprises optimization of capacity and injectivity of the storage reservoir and safety of geological storage by geotechnical operations and pressure management. For example, injectivity may depend on the interaction of injected CO_2 with reservoir rocks and formation water. Careful characterization and simulation of these interactions is needed in order to sustain and potentially enhance permeability.

Research on storage complex management is a core activity of those CGS Europe partners involved in pilot or demonstration projects or in field tests.

Well technologies

Wells are the key tools needed to get access to reservoirs, both at the exploration stage and in the injection phase. Existing wells can be/become potential pathways for leakage. This needs to be considered particularly when using existing oil and gas fields for CO_2 storage. New wells have to be drilled with safety factors that enable operators to isolate reservoir blocks from leakage pathways. Well completion has to be done using corrosion-resistant materials.

Only three out of 28 CGS Europe partners consider research on well-related technologies as part of their core business, with six partners having no activity related to this topic at all. The remaining partners reported some activities focussing on exploration, monitoring and leakage characterization.

Environmental impacts

A detailed assessment of environmental impacts is required by the EU Directive on the geological storage of CO_2 and by the already-implemented national laws. Overall, research about potential environmental impacts of geological CO_2 storage, potential leakage pathways and early remediation actions is addressed by half of the partners. In particular, in Western Europe, environmental impact research is part of the core activities of most CGS Europe partners. Among the topics included, only minor activities were reported for the development of remote sensing techniques. Environmental impact studies are based mainly on studies of natural analogues and controlled release experiments. These studies were focussed on potential impacts of CO_2 migration/leakage, whereas potential impacts of brine migration have received less attention.

Mitigation and remediation

Mitigation and remediation measures aim to ensure safe geological storage of CO_2 even in case of an irregularity or leakage. Many of the potentially applicable technologies related to well failure have been developed by the oil and gas industry. Research is needed to show that these technologies are applicable to CO_2 storage. With the exception of three partners, most of the CGS Europe partners do not consider this research topic part of their core business. For failures of cap rocks or leakage along extended natural pathway, such as faults or spill points, mitigation strategies have not been tested in practice.

Modelling

The EU Directive on the geological storage of CO_2 requires modelling of storage site performance not only including a geometrical description of the storage complex, but also predicting capacity and injectivity, designing monitoring programmes and providing key information for risk assessment. Current research activities are mostly related to dynamic modelling, including multi-physics analysis and upscaling methodologies.

90% of CGS Europe partners carry out modelling activities of some kind including flow, geomechanical and geochemical modelling. An improved understanding of trapping mechanisms, reactive transport and effects of heterogeneities on storage or leakage processes are addressed.

Monitoring

Monitoring techniques have to be implemented for health and safety purposes, performance assessment and closure and post-closure control. Research has to include designing of appropriate monitoring systems for early leakage detection that are able to survey large areas. After the end of injection non-intrusive monitoring methods will be needed.
Research related to monitoring is part of the core activities of about a half of CGS Europe partners. Some partners are specifically interested in leakage detection and quantification while others are developing new monitoring methods and standards. Monitoring research activities are high in “forerunner” countries and in those countries where EEPR demo projects are planned.

Summary
In summary, research activities are not well balanced on a country-level or regarding the topics addressed: Most of the participants of CGS Europe are engaged in the topic of storage capacity assessment which is the prevailing topic due to the need for specifying the volume available for CO_2 storage in each country. Capacity data are essential information for operators and policy makers for the planning and the implementation of CCS. Particularly in so-called “follower” countries, hardly any research on development of new methods has been carried out so far, in many cases due to the lack of funding (schemes) at a national level. In countries with ongoing or planned demo projects much more effort is put into development of technologies that are needed to facilitate CCS deployment.

5 National research funding in CGS Europe countries

In most of the 28 countries covered by CGS Europe research related to CO_2 storage is funded by the governments (Fig. 5). In three countries, namely in Sweden, Serbia and Latvia, there is no governmental funding for this research field (as of July 31st 2012). In addition to governmental funding, CO_2 storage-related research is also funded by the National Research Foundations/National Agencies in about a third of the CGS Europe countries (Fig. 5). In Denmark, Portugal and Slovenia, private foundations also provide research funding.

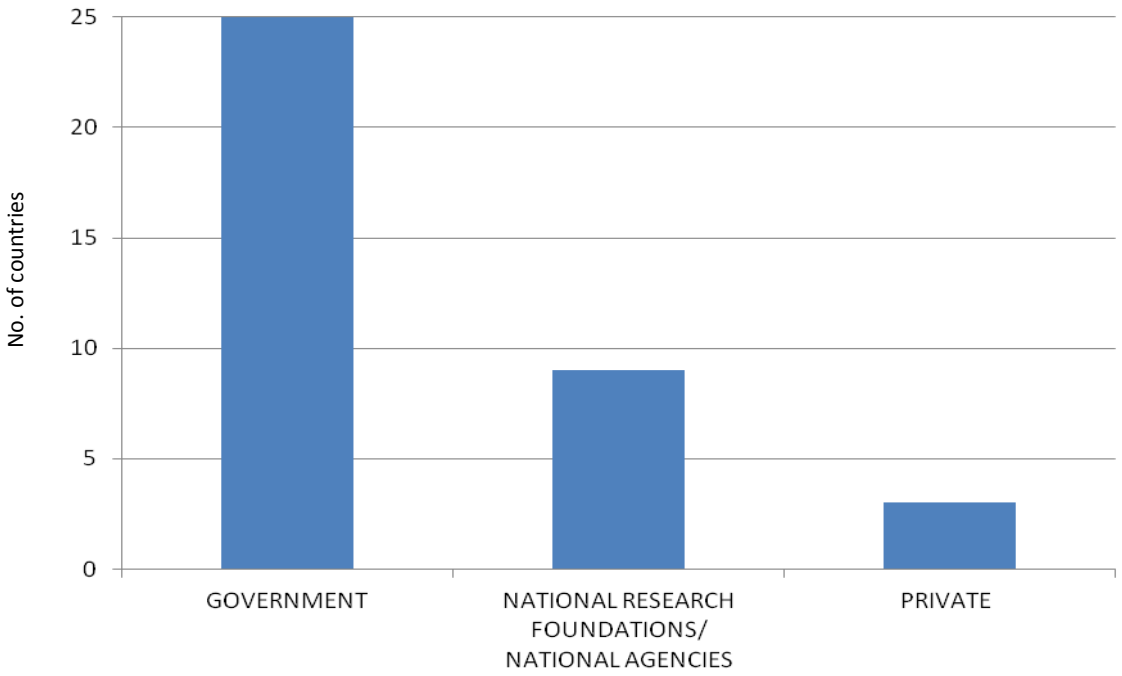

Fig. 5: Funding sources for research related to CO_2 storage in CGS Europe countries (as of July 31st 2012).

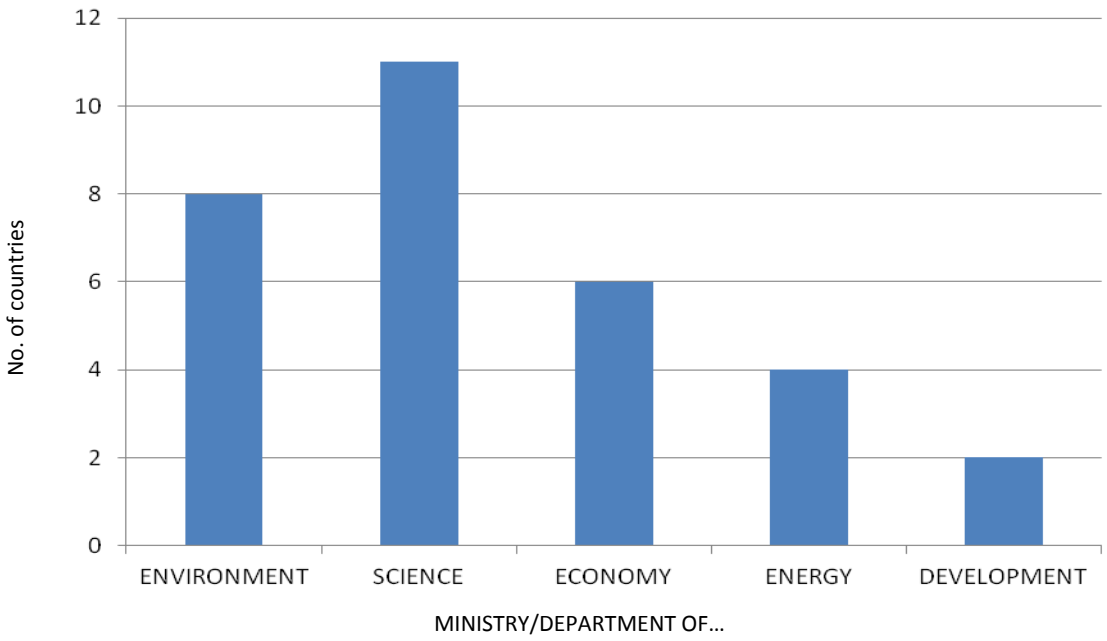

Fig. 6: National research funding by different Ministries/Departments of CGS Europe countries (as of July 31st 2012).

In countries with governmental funding of CO_2 storage-related research, mostly one or two different ministries/departments/agencies provide funding for research projects or are financing national research programmes for CO_2 storage or CCS. Generally, in these cases, the ministries responsible for the environment or science and ministries on charge of economy, energy, industry or national development are involved in funding CO_2 storage-related research (Fig. 6). It is worth noticing that the structural organisation of agencies, departments and ministries is unique in each country. Departments may be assembled in different ministries in different countries.

Dedicated research programmes addressing CO_2 geological storage have been established in four countries only. These countries are France, Norway, Germany and the Netherlands. In Finland, there is a national research programme on CCS considering mineral carbonation instead of geological storage, since Finland lacks sedimentary basins suitable for geological storage (cf. Chapter 2). In particular in the "follower" countries, only capacity assessments are funded by national funding agencies whereas other research activities related to CO_2 geological storage are mainly funded by the EU.

In the following, examples of the national research programmes on CO_2 storage/CCS are introduced in more detail following the respective presentations of I. Czernichowski-Lauriol, U. Münch, J. Brouwer, T.U. Riis and N. Nordbäck at the CO_2GeoNet Open Forum in 2012 (presentations available at www.co2geonet.com).

France

In France two funding agencies are funding research related to geological CO_2 storage:

- Agence Nationale de la Recherche (ANR; www.agence-nationale-recherche.fr),
- Agence De l'Environnement et de la Maitrise de l'Energie (ADEME; www.ademe.fr)

ANR is funding research project in all scientific fields including both fundamental and industrial research. With respect to CCS, 33 projects were funded in ANR's CO_2 programme from 2005 to 2008 with a total funding by ANR of 27 Mio € focussing on capture and storage-related topics. In 2009 ANR launched a new programme called "Energy Efficiency and CO_2 emissions reduction in Industrial Systems (EESI)" that funded three CO_2 capture projects in 2009 and 2010 with a total funding by ANR of 3.3 Mio €. Currently seven CCS projects are funded with a total volume of 5.4 Mio € in the frame of the "SEED programme (Efficient and Decarbonised Energy Systems)" that started in 2011 (two calls for projects in 2011 and 2012):

- DALMATIEN – Degradation of liquid amines and analytical methods: toxicity or harmlessness for the environment?
- CIPRES – Characterisation of potential impacts of CO_2 geological storage on groundwater quality.
- EM-HONTOMÍN – Electrical/CSEM methods for monitoring the CO_2 and application to the Hontomín pilot site (Spain).
- FISIC – Hydromechanical behaviour of faults and induced seismicity during CO_2 injection.
- CGSµLab – The « GLoC » concept for studying key processes of multiphase reactive transport applied to CO_2 geological storage.
- CO_2-DISSOLVED – CO_2 dependable injection and storage system optimized for local valorization of the geothermal energy delivered.
- H-CUBE – Hydrodynamics, heterogeneity and homogenization in modeling of CO_2 storage in saline aquifers.

ANR strongly encourages projects involving international collaboration, e.g., by realising co-funded projects. Further information can be found in ANR's CO_2 programme booklet available at www.agence-nationale-recherche.fr/programmes-de-recherche/energie-durable/systemes-energetiques-efficaces-et-decarbones/axes-thematiques/captage-stockage-et-valorisation-du-co2-cscv/.

ADEME's mission is to encourage, supervise, coordinate, facilitate and undertake operations for protecting the environment and managing energy. Since 2003 ADEME has funded 30 CCS research projects and techno-economic studies (total ADEME funding: 5.7 Mio €), among which 13 are on storage and three are CCS research demonstration projects (total ADEME funding: 38 Mio €), namely the "C2A2" capture demo project, the "TGR-BF" CCS project by Arcelor Mittal and the "France Nord" storage demo project.

Germany

In Germany research related to CCS is funded by

- the Federal Ministry of Education and Research (BMBF, www.bmbf.de) together with the German Research Foundation (DFG; www.dfg.de) in their joint programme "GEOTECHNO-LOGIEN" (www.geotechnologien.de);
- the Federal Ministry of Economy and Technology (BMWi, www.bmwi.de) as part of the "CO_2 reduction technologies for fossil-fired power plants (COORETEC)" programme (www.cooretec.de);
- the Federal Environment Agency (UBA, www.umweltbundesamt.de).

The COORETEC programme, as part of the German Federal Government's Energy Research Programme, focuses on technologies for improving power plant efficiency and for the separation and transport of CO_2. In the framework of the GEOTECHNOLOGIEN programme, primarily projects relating to geological storage of CO_2 are funded. The Federal Environment Agency initiates projects and studies that cover different aspects of the entire CCS chain.

Overall the R&D programme GEOTECHNOLOGIEN is supporting research projects that contribute to the development of concepts for a sustainable use of the Earth's resources and the protection of our planet. The programme's key research areas include very different geo-scientific topics. 33 interdisciplinary joint projects related to the key research area "Technologies for Sustainable Storage of Carbon Dioxide in Geological Formations" have been supported since 2005 with an allocated budget of 30 Mio €. The third funding phase of this key research area started in mid 2011. The current projects deal with the long-term safety of geological storage sites and cover the following thematic complexes:

- Ground water/brine (projects: **BRINE** – Carbon Dioxide-storage in Eastern Brandenburg: implications for geothermal potential and concept for an early warning system for salt water intrusions into groundwater, **CO_2BRIM** – Multi-stage and regional-scale characterisation of potential CO_2 storage formations with particular focus on brine migration risks – an integrated natural and social science approach, **SAMOLEG** – Salt water monitoring with LE-Geoelectrics);
- Migration, tracer and biology (projects: **PROTECT** – Prediction of deformation to ensure Carbon traps; **CO_2IsoLabel** – Carbon and oxygen isotopes under extreme conditions – laboratory evaluations for CO_2 storage monitoring; **CO_2BioPerm** – Influence of bio-geochemical CO_2 transformation processes on long-term permeability changes in storage and cap rock formations as well as in borehole concrete);

- Monitoring concepts, innovative sensors, risk analysis (projects: **CO_2SENSOR** - Development of a high-resolution CO_2 sensor, **MONACO** - Monitoring concepts for the geological storage of CO_2 based on a hierarchical monitoring approach, **CO_2RINA** - Integrated risk analysis for geological CO_2 storage).

In addition, development of and research related to the pilot site in Ketzin has been supported by 10.5 Mio € so far. Research related to Ketzin is supported further on (project CO_2MAN – Carbon dioxide reservoir management).

The Netherlands

Currently CCS research in the Netherlands is aligned in the national programme CATO-2 (www.cato2.nl) in the Netherlands. The CATO-2 programme is coordinated by the Netherlands Organization for Applied Scientific Research TNO (www.tno.nl). The five-year programme is running until the end of 2013. Total funding of the programme is ca. 62 Mio € half of which is provided by the NL Agency (www.agentschapnl.nl) of the Dutch Ministry of Economic Affairs, Agriculture and Innovation. The other half is financed by industrial partners and through own funds provided by the research institutes. CATO-2 is a demand driven and flexible programme in which nearly 40 partners from industry, SMEs, universities and NGOs cooperate. CATO-2 builds upon the results of the CATO programme, that lasted from 2004 – 2008 (total budget of 25.4 Mio €, 50 % of which was funded by the Ministry of Economic Affairs).

The programme consists of five subprojects (plus a coordination part) covering the complete CCS chain:

1. Capture
2. Transport and chain integration
3. Storage and monitoring
4. Regulation and safety
5. Public perception

The objective of subproject "Storage and Monitoring" is to demonstrate technical feasibilities and monitoring of underground CO_2 storage in depleted gas fields, saline aquifers, coal seams and porous rock. More specifically, activities are associated with injection and storage capacity, gas-fluid-rock interactions, integrity of wells, reservoir and overburden and issues dealing with monitoring, health safety and environment. The research activities in this subproject are organised in the following work packages:

- WP 3.1 Geological models
- WP 3.2 Reservoir behaviour
- WP 3.3 Cap rock and fault integrity
- WP 3.4 Well integrity
- WP 3.5 Additional benefits of CO_2 injection
- WP 3.6 Shallow (sub)surface monitoring
- WP 3.7 Permanent geophysical monitoring
- WP 3.8 Geophysical Laboratory experiments
- WP 3.9 Site specific monitoring.

Two future phases of CCS research in the Netherlands are planned for the periods 2012 – 2020 and from 2020 onwards tackling the deployment of large-scale demo projects and commercial deployment, respectively.

Norway

In Norway, the R&D programme CLIMIT (www.climit.no) is concerned with research into capture, transport and storage of CO_2 from fossil fuel power plants and industrial sources. The programme is administered by Gassnova (www.gassnova.no) and the Research Council of Norway (www.forskningsradet.no). It started in 2005 and has funded about 200 projects with a total budget of 120 Mio €. In 2012, CLIMIT and the research centres (see below) received public funding of about 27 Mio €.

The overall objectives of CLIMIT are to

- accelerate the commercialisation of the CCS technology,
- establish new knowledge essential for building full-scale demonstration plants in Norway,
- support international cooperation.

Projects that are conducted within the CLIMIT programme include, e.g.:

- **CO_2FieldLab**: At Svelvik near Oslo a field lab has been established at which CO_2 can be injected at shallow depths to study CO_2 migration in the shallow subsurface, identify possible leakage pathways and assess the suitability of different monitoring techniques.
- **Longyearbyen CO_2 Lab**: After reservoir characterisation and well drilling, water injection tests were performed at Longyearbyen. The first injection of CO_2 is planned for 2013. R&D activities will give new insights into CO_2 migration and interactions with aquifers.
- **MatMoRA**: Geological Storage of CO_2: Mathematical Modelling and Risk Assessment. This project aims to improve the understanding of storage mechanisms and to develop analytical and numerical tools for risk assessment of CO_2 storage.
- **Ramore**: Subsurface Storage of CO_2 – Risk assessment, monitoring and remediation: In this project the caprock of the Johanson Formation that will be used for large scale CO_2 storage is being characterised. Characteristics to be investigated include, e.g., geochemical reactions.

To focus competence, centres for environmental-friendly energy research (CCER) have been established in Norway. Two of the eleven centres deal with CCS:

- **BIGCCS** – www.sintef.no/Projectweb/BIGCCS: The vision of the BIGCCS Centre is to enable sustainable power generation from fossil fuels based on cost-effective CO_2 capture, safe transport, and underground storage of CO_2. The BIGCCS Centre is set to achieve the following goals: 90% CO_2 capture rate, 50% cost reductions, less than six percent fuel-to-electricity penalty compared to state-of-the-art fossil fuel power generation. The BIGCCS Centre is developing new knowledge and technology required to accelerate deployment of large scale CCS through international co-operation. Innovation and value creation throughout the CO_2 value chain is also promoted by the centre. Research areas include CO_2 capture, CO_2 transport, CO_2 storage, and the CO_2 value chain.
- **FME SUCCESS** - www.fme-success.no/index.cfm: The SUCCESS centre addresses several important areas for CO_2 storage in the subsurface: storage performance, sealing properties, injection, monitoring and consequences for the marine environment. The "CO_2 School" is in addition a major educational programme. The selected activities will involve fundamental experimental and theoretical work, analysis of samples from outcrops and case studies, development of mathematical models, modelling activities and testing in case study environments. The centre will as far as possible try to bridge gaps from details to concepts and applications, from small to large scale, and to transfer data and knowledge between many related fields.

Finland

The Finish CCS programme (CCSP) was launched in 2011 to develop CCS-related technologies and concepts that will lead to the establishment of pilot and demo plants by 2014/2015.
Since Finland lacks sedimentary basins suitable for geological storage of CO_2, one option for storing CO_2 considered is mineral carbonation, i.e. the reaction of CO_2 with calcium and magnesium-based silicate minerals to form carbonates. The large amounts of material involved and the low reaction rates have been the major hold-up for this technology. Alternatively, Finland may store captured CO_2 on an interim basis and transport it abroad for storage. In the CCSP, options for the latter case are considered in more detail suggesting (joint) transport by pipeline and potentially export by ship. Geological storage options are identified focussing on the nearest available options in the North Sea and in the Baltic Sea. For the latter, the Finnish CCS programme and a Swedish CCS project consortium started a project to assess storage options in saline aquifers below the sea bed in the Baltic Sea area.

6 Research activities on a regional and European level

European Activities

Information about ongoing (as of July 31st 2012) EU-funded projects related to CO_2 storage was retrieved from the CORDIS website (cordis.europa.eu/projects) considering the following projects (in alphabetical order):

CARBFIX	Creating the technology for safe, long-term carbon storage in the subsurface
CARBOLAB	Improving the knowledge of carbon storage and coal bed methane production by "in situ" underground tests
CGS EUROPE	Pan-European coordination action on CO_2 Geological Storage
CO_2CARE	CO_2 Site Closure Assessment Research
CO_2-MATE	CO_2 Multiphase reActive Transport modElling
CO_2PIPEHAZ	Quantitative failure consequence hazard assessment for next generation CO_2 pipelines
CO_2SHALESTORE	CO_2 Sorption and Flow in Shale Reservoirs
CO_2TRAP	Microbially enhanced geologic carbon capture, trapping and storage
COCATE	Large-scale CCS Transportation infrastructure in Europe
COMET	Integrated infrastructure for CO_2 transport and storage in the west Mediterranean
ECCSEL	European Carbon Dioxide Capture and Storage Laboratory Infrastructure
ECO_2	Sub-seabed CO_2 Storage: Impact on Marine Ecosystems (ECO_2)
MUIGECCOS	Modelling and Understanding the Influence of Geological Complexity on CO_2 Storage
MUSTANG	A multiple space and time scale approach for the quantification of deep saline formations for CO_2 storage
PANACEA	Predicting and monitoring the long-term behaviour of CO_2 injected in deep geological formations
RISCS	Research into Impacts and Safety in CO_2 Storage (RISCS)
SITECHAR	Characterisation of European CO_2 storage
ULTIMATECO_2	Understanding the long-term fate of geologically stored CO_2

Most of these are collaborative projects funded in the framework programme (FP) 7 in the programme FP7-Energy, whereas the projects ECCSEL and ECO_2 are funded in the frame of FP7-Infrastructure and FP7-Environment, respectively. In the programme FP7-People the so-called "European Reintegration Grants" CO_2SHALESTORE and CO_2TRAP, the "Intra-European Fellowship" MUIGECCOS and the "International Outgoing Fellowship" CO_2-MATE are granted. The CARBOLAB project is funded by the Research Fund for Coal and Steel (RFCS; cordis.europa.eu/coal-steel-rtd).
An overview of the current FP7-ENERGY collaborative projects (as of July 2012) and the topics addressed is given in the following (Tab. 2). The grouping of the addressed topics follows the classification introduced in Chapter 4.
More information on the project objectives can be found on the CORDIS website (www.cordis.eu) and in the project presentations at the CO_2GeoNet Open Forum 2012 (cf. www.co2geonet.com).

Tab. 2: FP7-ENERGY collaborative projects – calls and topics.

Project Acronym	Subprogramme	Research topics							
		Storage capacity assessment	Land planning & infra-structure	Complex manage-ment	Well tech-nologies	Environ-mental impact	Mitigation and remediation	Modelling	Monitoring
MUSTANG	ENERGY.2008.5.2.4 Development of a suitable methodology for the qualification of deep saline aquifers for CO_2 storage	x		x				x	x
CO_2PIPEHAZ	ENERGY.2009.5.2.2 Towards an infrastructure for CO_2 transport and storage		x			x		x	x
COCATE			x			(x)		x	(x)
COMET		x	x			(x)		x	
RISCS	ENERGY.2009.5.2.1 Safe and reliable geological storage of CO_2			(x)		x		x	x
SITECHAR	ENERGY.2010.5.2-1 CCS – storage site characterisation	x		x	(x)	(x)	(x)	x	x
CO_2CARE	ENERGY.2010.5.2-3 CCS – site abandonment			x	x	(x)	(x)	x	x
CARBFIX	ENERGY.2011.5.2-1 Understanding the long-term fate of geologically stored CO_2			x	x	x		x	(x)
PANACEA				x	x	x		x	x
ULTIMATECO$_2$				x	x	x		x	

EERA activities

The European Energy Research Alliance (EERA) is an alliance of leading organizations in the field of energy research (www.eera-set.eu) established in 2008 as part of the European Strategic Energy Plan (SET-Plan; see ec.europa.eu/energy/technology/set_plan/set_plan_en.htm).
The primary objective of EERA is to accelerate the development of new energy technologies to the point where they can be embedded in industry-driven research. For this, EERA aims to strengthen, expand and optimize EU energy research capabilities, e.g., by sharing premier national research facilities and by streamlining and coordinating partners' national and European energy R&D activities. Partners' research activities are organised in pan-European research programmes (so-called EERA Joint Programmes) that are pooling and integrating activities and resources, combining national and Community sources of funding to maximize complementarities and synergies.

One of the EERA Joint Programmes is dedicated to Carbon Capture and Storage that is split in two sub-programmes dealing with carbon capture and geological CO_2 storage, respectively. This Joint programme was launched at the SET-Plan Conference in Brussels in November 2011. The Carbon Capture and Storage Joint Programme (CCS-JP) involves over 30 members from more than 12 countries who have committed more than 270 person years per year to carry out joint R&D activities.

The EERA sub-programme CO_2 storage is organised in three areas:

- Monitoring;
- Static modelling,
- Dynamic modelling.

The R&D activities in this sub-programme will focus on the following issues:

- identification and characterization of suitable geologic complexes that may be used for storing CO_2, with no interference with other human activities, no impact on the ecosystem, having capacities that match the sources and that guarantee safe conditions for the whole period of storage operations, closure and post closure;
- development of tools that allow better understanding and evaluation of the behaviour at different time scales of the injected CO_2 and its interactions with the storage complex and the surrounding formations up to the surface;
- further development and integration of a large set of currently available monitoring techniques and the definition of recognised protocols for their use in a variety of geological, environmental and operative contexts.

The EERA CCS-JP also interacts closely with international partners and initiatives such as the ZEP technology platform, the CCSEII and the ESFRI-listed ECCSEL project.

The information on EERA was retrieved from the EERA website (www.eera-set.eu) and taken from the CO_2 storage sub-programme's description of work.

Regional activities

The information on current regional activities was compiled from the respective presentations by R. Martinez, B. McConnell, and K.L. Anthonsen at the CO_2GeoNet Open Forum 2012 (see www.co2geonet.com) and supplemented by the CGS Europe partners.

Western European countries: One example of a regional project is the FP7 project COMET (www.comet.lneg.pt) that investigates the techno-economic feasibility of integrating CO_2 transport and storage infrastructures in the West Mediterranean (Iberia and Morocco). In the project, a harmonised inventory of present and future CO_2 sources and storage capacities was set-up. Then, a least-cost model of national and regional energy systems was generated, optimising source-sink matches and related transport infrastructure.

Irish Sea: The Department of Communications, Energy and Natural Resources – Geological Survey of Ireland and the British Geological Survey are currently jointly assessing the storage potential in saline aquifers in the Irish Sea (total budget of 1 Mio € over three years until 2014). A major outcome of the project will be a transnational Irish-UK GIS containing spatial and geological data that will form a major repository for project data and results. Basins assessed in the first project phase include the East Irish Sea Basin, the Central Irish Sea Basin and the Cardigan Bay/St. Georges Channel Basin.

Nordic countries: The Nordic CCS Competence Centre (NORDICCS) is a Nordic virtual CCS research and innovation platform involving the major CCS stakeholders in the five Nordic countries. It started in autumn 2011 and is funded for five years with a total budget of 6.2 Mio € by Nordic Innovation and the partners' own resources. The overall objective of NORDICCS is to boost the deployment of CCS in the Nordic countries by creating a durable network of excellence integrating R&D capacities and relevant industry. To this end, the project will develop strategies for CCS realisation in the Nordic region. In addition, feasibility studies on industrial CCS cases will be performed, considering industrial sources (cement, metal, oil refineries), power generation based on fossil fuels and BioCCS.

Baltic Sea: Most of the CGS Europe partner countries in the Baltic Sea region (Denmark, Estonia, Germany, Finland, Latvia, Lithuania, Norway, Poland and Sweden) are in a very specific situation in comparison to other European countries: In the Baltic Sea region onshore storage has less prospects of success than offshore storage because of absent or insufficient onshore storage capacities in several countries and/or problems with public acceptance in some countries. Urgent actions are needed to promote and implement the CCS technology in the Baltic Sea region. Latvia and Sweden temporarily prohibited CO_2 storage, while other EU member states in the region (with the exception of Lithuania) permit CO_2 storage under restrictions or for research purposes only. Changes in national CCS laws will depend on the successful demonstration of CCS in Europe and the Baltic Sea region.
In this situation, the Baltic Sea regional initiative has been launched creating the network "CO_2 Free Energy Technologies Baltic - CO_2FetBaltic" with the participation of industry, academia, legal authorities and all other interested parties. The aims of the network are to increase public awareness and acceptance of CCS and CO_2 industrial use, to increase political and industrial support for an implementation of CCS, to include CCS in national research and educational programmes, to transfer research expertise from the more "advanced" countries to the "follower" countries (including Russia), to plan and develop transboundary CCS scenarios including pipelines networks and storage sites, and to implement transboundary demonstration and industrial projects in the Baltic Sea Region. The initiative is coordinated by TTUGI.

7 Current pilot, demonstration and test sites in CGS Europe countries

Large-scale projects are defined by the Global CCS Institute (GCCSI) as those involving capture, transport and storage of CO_2 at a scale of at least 800 000 t of CO_2 per year for a coal-based power plant, or at least 400 000 t of CO_2 per year for industrial facilities including natural gas-based power generation (GCCSI, 2012). For Europe, twenty large-scale integrated CCS projects are recognised by GCCSI, the CO_2 injections from natural gas processing at Sleipner and Snøhvit (Norway) being the only active ones (cf. Fig. 7). According to GCSSI, 18 large-scale CCS projects are planned and being prepared for in the U.K., The Netherlands, Poland, Italy, France, Spain, Romania, and Bulgaria. The majority of these planned projects will involve CO_2 capture from power plants. Post-combustion capture is the preferred option for most of these projects. Geological storage is planned in saline aquifers – either onshore or offshore, in depleted hydrocarbon reservoirs (only offshore), and as part of enhanced oil recovery activities.

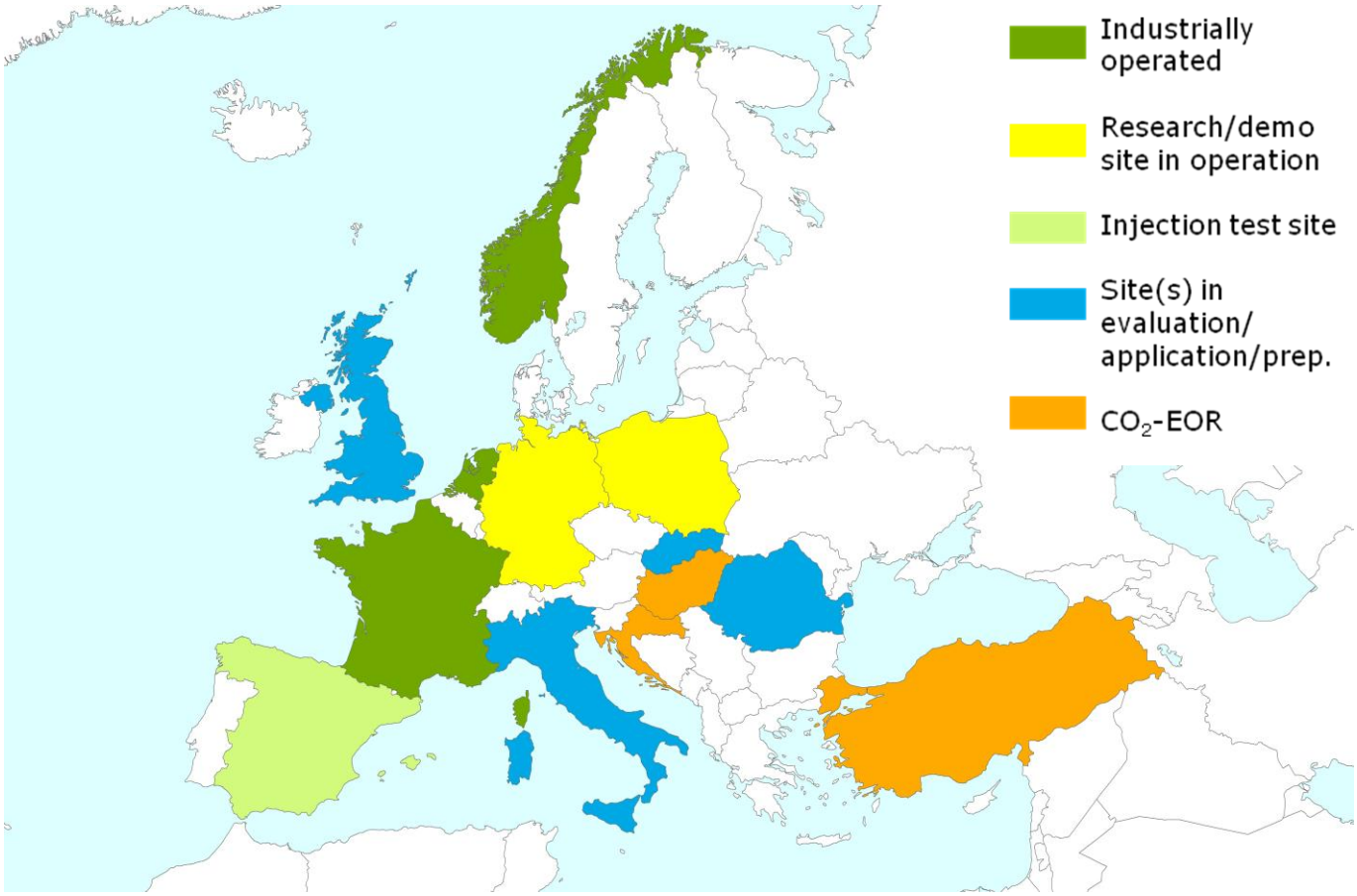

Fig. 7: Current demonstration, pilot and test sites for CO_2 storage in CGS Europe countries (as of July 31st 2012). Note that country colouring only reflects the most "advanced" stage, i.e. other sites may be in preparation in countries with CO_2 storage sites where injection is already taking place.

Six European large-scale projects have received funding in the frame of the European Energy Programme for Recovery (EEPR) (EC, 2009):

- Jänschwalde (Germany),
- Porto-Tolle (Italy),
- Rotterdam (The Netherlands),
- Belchatow (Poland),
- Compostilla (Spain),
- Hatfield (U.K.).

However, only five of these six projects are still viable, since the project "Jänschwalde" has been withdrawn by the applicant.

Candidates to the first call for proposals for the so-called "NER300 funding programme" were the following CCS projects (EC, 2012a):

- Don Valley Project (U.K.; former "Hatfield project"),
- Bełchatów CCS Project Poland),
- Green Hydrogen (The Netherlands),
- The Teeside CCS Project (U.K.),
- UK Oxy CCS Demo (U.K.),
- C.GEN North Killingholme Power Station (U.K.),
- Zero Emission Porto Tolle (Italy),
- ULCOS-BF (France).

In this funding programme, awarded projects are co-financed with revenues obtained from the sale of 200 million emission allowances from the new entrants' reserve (NER) of the EU Emissions Trading System. Unfortunately, no CCS project has been awarded under the first call as announced in December 2012 (EC, 2012b). A substantial advancement for the deployment of CCS projects in Europe can be expected when CCS projects will be funded in the second phase of the programme.

On a smaller scale, demo or pilot sites for geological CO_2 storage are in operation in Europe (Fig. 5). These include the industrially operated demo projects in depleted gas reservoirs "K12-B" (www.k12-b.nl) and "Lacq" (www.total.com/en/special-reports/capture-and-geological-storage-of-co2/capture-and-geological-storage-of-co2-the-lacq-demonstration-200969.html) in The Netherlands and France, respectively. Research pilots are in operation at Ketzin, Germany (saline aquifer storage; www.CO2ketzin.de), and at Kaniów, Poland (CO_2 storage in coal beds). In Spain, the Hontomín injection test site is in preparation as part of the OXYCFB300 Compostilla Project (www.compostillaproject.eu). Enhanced oil recovery operations are ongoing in the Ivanic Oil Field in Croatia, in the Batı Raman Oil Field in Turkey and in the Szank Oil Field in Hungary.

8 State of transposition of the EU Directive on the geological storage of carbon dioxide in CGS Europe countries

The Directive 2009/31/EC of the European Parliament agreed by the Council on April 23rd 2009 on the geological storage of carbon dioxide was published on June 5th 2009, and entered into force on June 25th 2009. This directive established a legal framework for the environmentally safe geological storage of CO_2. In article 39 "Transposition and transitional measures" it is stated that "Member States shall bring into force the laws, regulations and administrative provisions necessary to comply with this Directive by June 25th 2011", that they "shall communicate to the Commission the text of the main provisions of national law which they adopt in the field covered by this Directive" and they "shall ensure" that the storage sites "are operated in accordance with the requirements of this Directive by June 25th 2012" (Directive 2009/31/EC).

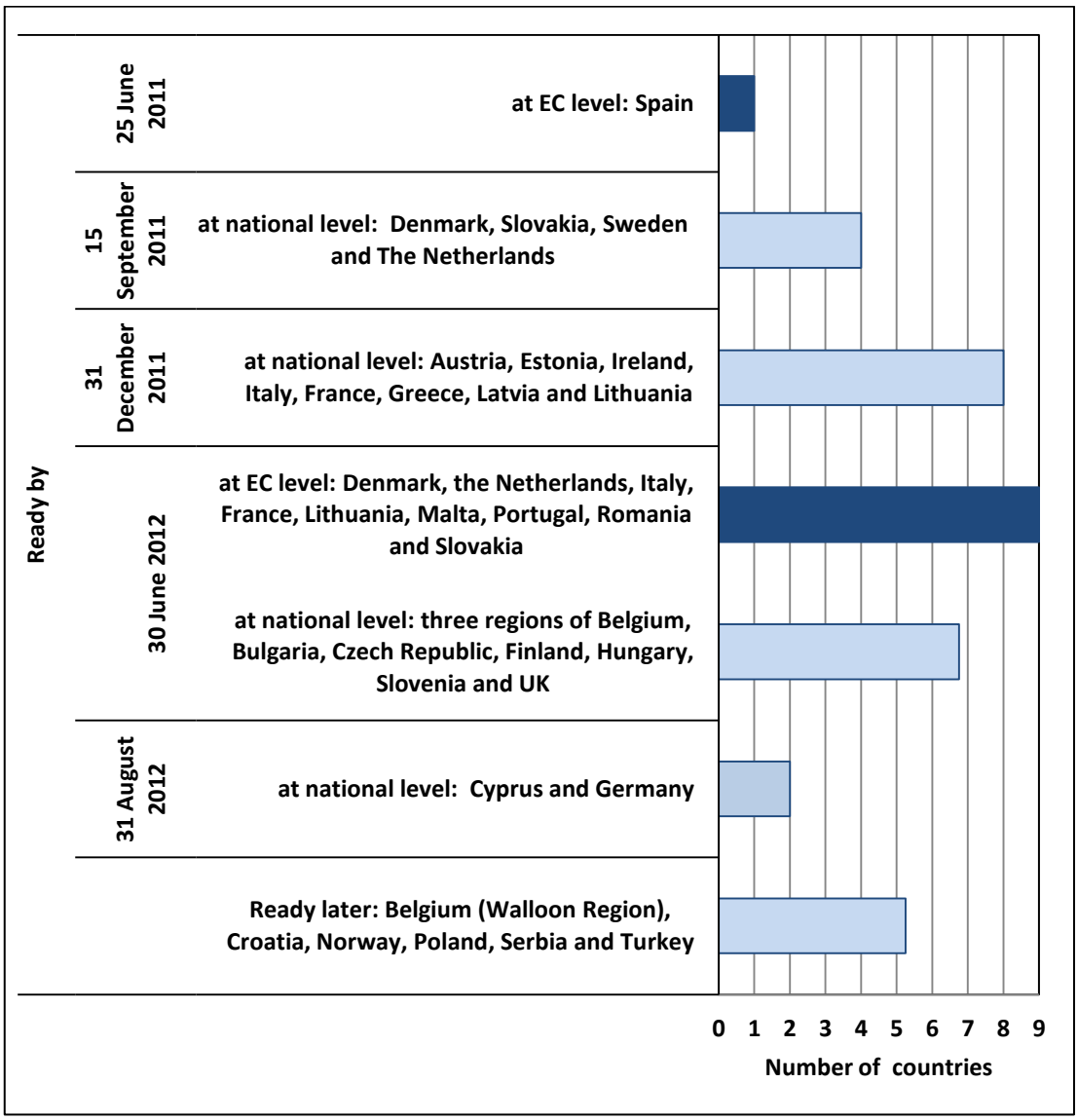

Fig. 8: Status of the transposition of EU Directive on the geological storage of CO_2 in CGS Europe countries, Malta and Cyprus at national and European Commission (EC) levels by the end of 2012 (updated from Shogenova et al., 2012 & in press).

By the end of 2011, the transposition of the directive into national law had been approved by the European Commission (EC) for Spain only, but had been approved at national/jurisdictional level in 13 other countries (Austria, Denmark, Estonia, France, Greece, Ireland, Italy, Latvia, Lithuania, Malta, Slovakia, Sweden and The Netherlands; Fig. 8).

By June 2012, the European Commission had assessed and approved national submissions of CCS legal acts transposing the Directive in Denmark, France, Italy, Lithuania, Malta, the Netherlands, Portugal, Romania and Slovakia. National CCS laws entered into force in Bulgaria, Finland, Hungary, Slovenia, U.K. and three regions of Belgium by June 30th 2012. Transposition was completed at a national level in Cyprus and Germany by the end of August 2012.

As a result of the on-going transposition process, CO_2 storage is now (as of July 31st 2012) permitted by regulations of nine of the countries considered here (France, Lithuania, Portugal, Romania, Slovakia, Spain, the Netherlands, U.K. and Hungary; Fig. 8). In addition, CO_2 storage is permitted in Italy, excluding seismic areas, permitted in Belgium except in selected areas (without storage capacity), and in Greece excluding areas where the storage complex extends beyond Hellenic territory.

In Denmark regulations temporarily forbid storage until 2020, but offshore CO_2-enhanced oil recovery (EOR) operations are permitted. The size of the exploration area for each individual CO_2 storage site is limited in Bulgaria. CO_2 storage is permitted with limitations in Germany (up to 4 Mt annually until 2018). CO_2 storage is temporarily forbidden in Austria (until 2018), Latvia (until 2013), Sweden (until January 2013), and the Czech Republic (until 2020). CO_2 storage is forbidden in Estonia, Finland and Ireland. It is planned that CO_2 storage will be prohibited in Poland until 2024. CO_2 storage is neither prohibited nor permitted in Slovenia. In all countries where CO_2 storage is prohibited or planned to be prohibited an exception from Article 2 of the Directive is included in the national laws for activities "with a total intended storage below 100 000 t undertaken for research, development or testing of new products or processes" (Shogenova et al., 2012 & in press).

In addition, all countries had to transpose article 33 of the EU Directive on the geological storage of CO_2, amending the Directive 2001/80/EC. According to this amendment, operators of all new large combustion plants (rated electrical output ≥ 300 MW) must assess availability of suitable storage sites, feasibility of transportation and of retrofitting for CO_2 capture. In case of feasibility of CCS, these new plants must be built capture-ready.

The Walloon Region of Belgium, Norway and Poland had not finished the transposition of the Directive on the geological storage of CO_2 by end of 2012. In some of these countries the process had been complicated and delayed by ongoing political debates, and public opposition. Croatia, expected to become EU member state on July 1st 2013, Serbia having been a full EU candidate state since March 1st 2012 and Turkey as an associated EU member will transpose/start to transpose the EU Directive on the geological storage of CO_2 at a later date.

9 Summary and conclusions

The overall achievements and the current state of the CO_2 storage activities (as of August 31st 2012) in the CGS Europe countries were assessed in a semi-quantitative way. In this assessment the criteria listed in Tab. 3 were applied for weighting of activities and achievements.

Tab. 3: Weighting criteria for the overall assessment of achievements regarding CO_2 storage in the CGS Europe countries.

Criteria	Score
institutions active in CO_2 storage research	major*: 1 point per institution; minor**: 0.25 points per institution
national research programmes on CCS/CO_2 storage	3 points per programme; 2 points if extensive public funding (without programme)
transposition of EU Directive on the geological storage of CO_2	national CCS act in place permitting CO_2 storage: 5 points; national CCS act in place prohibiting CO_2 storage: -5 points; transposition in progress: 3 points; transposition at a later date (in case of EU candidates or associated EU members): 0 points
pilot and demo projects (injection volume <100 kt/year and >100 kt/year, respectively)	pilot, planned: 1 point; pilot, permit application filed: 2 points; pilot, injecting: 3 points; demo, planned: 4 points demo, permit application filed: 6 points; demo, injecting: 8 points CO_2-EOR operations : 3 points

*: major: several person years per year and institution devoted to CO_2 storage-related research;
**: minor: few person years per year and institution devoted to CO_2 storage-related research.

Depending on the overall score the situations in the CGS Europe countries with respect to CO_2 geological storage are categorised as “advanced” (>20 points), “progressing” (20 to >10 points), “emerging” (10 to 1 points) or “rejecting” (<1 points).

Tab. 4: Classification of the CGS Europe countries according to their overall achievements regarding CO_2 storage (as of August 31st 2012).

Category	Countries
Advanced	Norway, Italy, United Kingdom, France, The Netherlands
Progressing	Germany, Spain, Poland, Romania
Emerging	Hungary, Portugal, Slovakia, Lithuania, Greece, Bulgaria, Croatia, Belgium, Turkey
Rejecting	Finland, Serbia, Denmark, Slovenia, Sweden, Czech Republic, Ireland, Austria, Latvia, Estonia

The "advanced" and "progressing" countries mainly include those with operating CO_2 storage projects (full industrial scale or smaller scale pilot and/or demo projects). Countries with (numerous) storage projects in advanced stages of development also belong to these groups. These countries are also the ones with the highest annual CO_2 emissions (Fig. 9). An exception is Norway where the state re CO_2 storage is very advanced, as reflected in the high total score, despite low annual CO_2 emissions. In contrast, the score for the situation and achievements re CO_2 storage in Germany is not proportional since their annual CO_2 emissions are the highest in Europe.

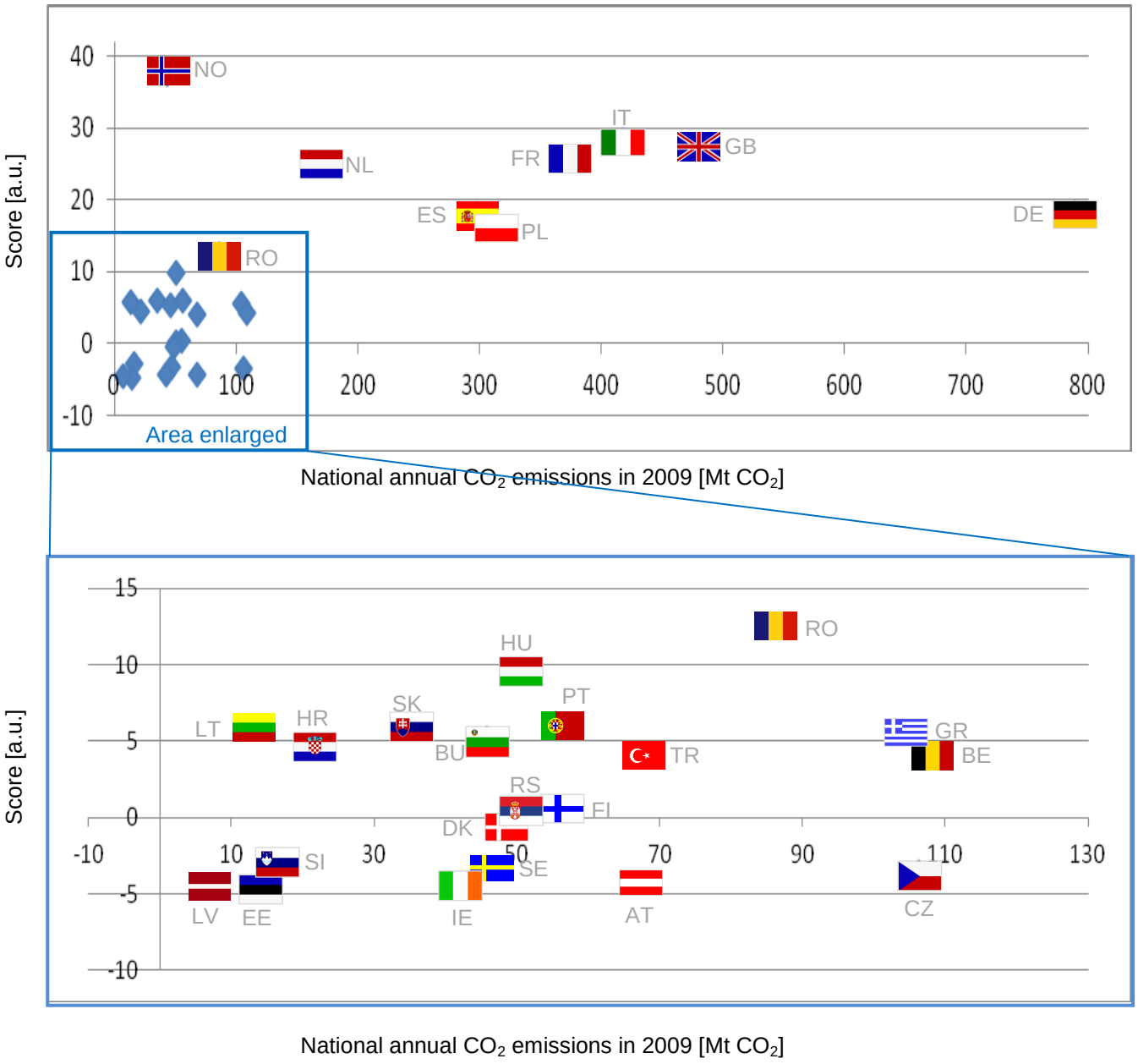

Fig. 9: Assessment of CGS Europe countries' achievements regarding CO_2 storage (as of August 31st 2012) as a function of national annual CO_2 emissions in 2009 (UNFCCC, 2012). (AT: Austria; BE: Belgium; BG: Bulgaria; CZ: Czech Republic; HR: Croatia; DK: Denmark; EE: Estonia; FI: Finland; FR: France; DE: Germany; GR: Greece; HU: Hungary; IE: Ireland; IT: Italy; LV: Latvia; LT: Lithuania; NL: The Netherlands; NO: Norway; PL: Poland; PT: Portugal; RO: Romania; RS: Serbia; SK: Slovakia; SI: Slovenia; ES: Spain; SE: Sweden; TR: Turkey; GB: United Kingdom).

These two examples (Norway and Germany) demonstrate that CCS is just one option in a portfolio of technologies which may be used for the transition to a reliable and climate friendly energy supply. Individual countries may choose a mixture of different options. The focus in such roadmaps may vary, depending on a country's available energy resources, storage potential, energy intensive industries and general socio-economic development.

Normalisation of the annual national CO_2 emissions the number of inhabitants of each country results in a different picture (Fig. 10): For many countries a correlation between the countries' total scores and their annual CO_2 emissions per capita can be deduced (indicated by dashed lines in Fig. 10). This means that many countries with high annual CO_2 emissions per capita are also very active in advancing research for and deployment of CO_2 storage. On the contrary, countries with low CO_2 emissions are often less active and less advanced. Countries plotting in the lower right corner of the diagram do not follow this trend.

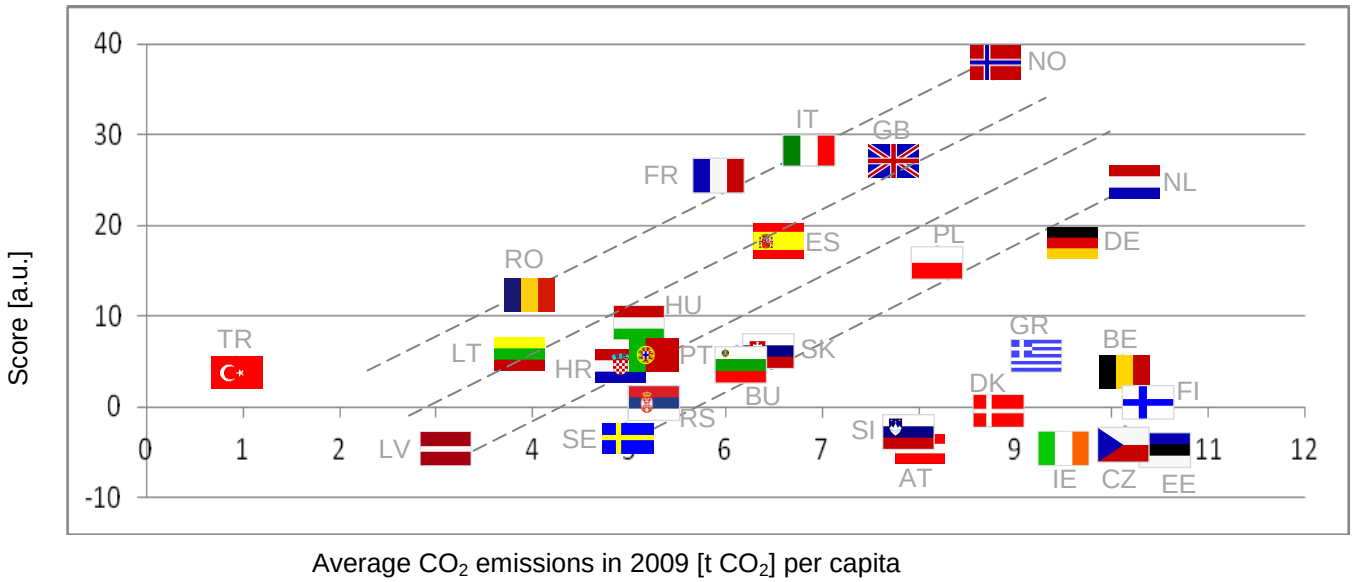

Fig. 10: Assessment of CGS Europe countries' achievements regarding CO_2 storage (as of August 31st 2012) as a function of national annual CO_2 emissions per capita in 2009 (using UNFCCC (2012) and population data from BPB, 2011). (AT: Austria; BE: Belgium; BG: Bulgaria; CZ: Czech Republic; HR: Croatia; DK: Denmark; EE: Estonia; FI: Finland; FR: France; DE: Germany; GR: Greece; HU: Hungary; IE: Ireland; IT: Italy; LV: Latvia; LT: Lithuania; NL: The Netherlands; NO: Norway; PL: Poland; PT: Portugal; RO: Romania; RS: Serbia; SK: Slovakia; SI: Slovenia; ES: Spain; SE: Sweden; TR: Turkey; GB: United Kingdom).

As of today, there are only few large-scale demo projects in operation in Europe and world-wide. Reasons for the slow deployment of CCS and, in particular, of CO_2 geological storage in Europe comprise

- economic considerations since the price for the European Emission Allowances is currently lower than expected (price as of October 2012: 7.25 €/t CO_2) due to the economic crisis making investments for a reduction of CO_2 emissions less attractive,
- the delayed transposition of the Directive on the geological storage of CO_2 or unfavourable results of the transposition,
- timing issues related to the support decisions by the EC, e.g., allocation of the "NER300" subsidies,
- local public opposition.

Because of these constraints the deployment of some storage pilot projects are considered more viable and potentially helpful to facilitate the future realisation of commercial-scale projects (e.g., ZEP, 2012).

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ANNEX: Summarising the state of play on CO_2 geological storage in the CGS Europe countries (as of July 31st 2012) - country-specific information provided by CGS Europe partners

1) Austria
2) Belgium
3) Bulgaria
4) Czech Republic
5) Croatia
6) Denmark
7) Estonia
8) Finland
9) France
10) Germany
11) Greece
12) Hungary
13) Ireland
14) Italy
15) Latvia
16) Lithuania
17) The Netherlands
18) Norway
19) Poland
20) Portugal
21) Romania
22) Serbia
23) Slovakia
24) Slovenia
25) Spain
26) Sweden
27) Turkey
28) United Kingdom

Summarising the state of play on CO_2 geological storage in AUSTRIA

(as of July 31st 2012)

National funding for research related to CO_2 storage

No national funding for CCS research in the moment.

National research programmes for research related to CO_2 storage

No national research programmes for CCS research in the moment.

Research institutions involved in research related to CO_2 storage

Currently there are no Austrian institutions involved in research on CCS. However, there have been some projects related to CO_2 storage and the institutions given below took part and can be considered possible interested parties for further investigations of CCS in Austria. Due to the fact that so far the possibilities of CO_2 geological storage in Austria are limited to gas and oil reservoirs, the hydrocarbon exploration companies represent the biggest players for CCS technology. Yet their main focus is on using the depleted hydrocarbon fields as natural gas storage sites.

- **RAG** is one of the two hydrocarbon exploration companies in Austria. A big part of the estimated possible storage capacities are situated in their concession area in the Molasse zone. RAG was involved in the last major R&D project related to geological CO_2 storage in Austria named "Castor (CO_2 from Capture to Storage)".
- **OMV** is the second hydrocarbon exploration company in Austria and was involved in the first study estimating the storage capacities in Austria. The study (Scharf & Clemens, 2006) was conducted in cooperation with the University of Leoben and was presented at the 68th EAGE conference and exhibition in June 2006 in Vienna.
- The **Austrian Energy Agency** was involved in the development of a decision-making basis including both the technical and legal conditions for an implementation of the CCS technologies due to the EU directive 2009/31/EG.
- The **universities of Vienna and Graz** were engaged in the PhD thesis by Mag. Margit Kapfer 2005 about "Geological Carbon Sequestration – Costs, Feasibility and the use of CCS as a possible climate protection measure".

In preparation regarding the transposition of the EU Directive on the geological storage of CO_2 in Austria an **interdisciplinary expert group** (universities, governmental authorities and industry) has been set up in Austria. This group was working in the time period between 2009 and 2011 and was suspended after the transposition had been accomplished. This expert group produced an internal strategy paper on several general issues on CCS covering the capture, transport and storage aspects. However, a nationwide estimation of storage capacities has not been executed.

Storage options and capacities

Storage options and capacities in Austria are solely presented in the paper by Scharf & Clemens (2006). The following information summarizes the paper which serves as the only data source so far: The study concluded, that in Austria a number of oil and gas reservoirs suitable for CO_2 storage exist, which are furthermore located in the proximity of industrialized areas in the Vienna Basin and the Molasse zone. Adding the cumulative oil, water and gas production and subtracting the pore volume of injected water a first approximation of 400 Mt CO_2 for storage capacities could be derived. Considering that each year additional capacities are generated due to production, the total storage volume after total depletion of all reservoirs was estimated to 510 Mt CO_2.

Regarding economic factors (some reservoirs are too small to justify an installation of facilities), the lack of data on depleted and abandoned reservoirs and the physical and chemical behaviour of CO_2 in the formation the more reliable number of 465 Mt CO_2 was calculated. Still more detailed studies on economic feasibility, reservoir performance and injection risks are required.

Due to the lack of data, aquifer storage was not considered in the estimated figures above. There are some possible capacities, for example the formation of the Aderklaa conglomerate, but it is connected to important hydrocarbon reservoirs and therefore represents a conflict of interest with the oil & gas company.

Salt domes or mined cavities are not considered suitable for the purpose of CO_2 sequestration, because the Austrian formations consist mainly of a breccia of clay, anhydrite and salt. They have small vertical extension and are supposedly instable.

Current situation in Austria with respect to i) current demo/pilot projects & projects/sites in preparation, ii) state of the transposition of the EU Directive on the geological storage of CO_2, iii) public awareness

There are no current demo/pilot projects in operation nor in preparation. Any exploration relating to underground storage of CO_2 is prohibited except for exploration for research or the development/testing of new methods with a maximum total storage volume of 100 000 t.

Since 2010, several media campaigns criticizing CCS were conducted in Austria until the transposition of the EU Directive on the geological storage of CO_2 was realized in Austria in December 2011. This may also be seen as a reason why the Austrian government finally decided to ban the industrial use of geological CO_2 storage in Austria except for scientific purposes. Since then the public interest in CCS has vanished in Austria.

Summarising the state of play on CO_2 geological storage in BELGIUM

(as of July 31st 2012)

National funding for research related to CO_2 storage

No national funding available.

National research programmes for research related to CO_2 storage

No national research programmes ongoing.

Research institutions involved in research related to CO_2 storage

- Royal Belgian Institute of Natural Sciences – Geological Survey of Belgium (RBINS-GSB)
- University of Mons (UMons)
- Catholic University of Leuven (KULeuven)
- University of Ghent (UGent)
- Flemish Institute for Technological Research (VITO)

Storage options and capacities

Storage options in Belgium are located roughly in two areas: north-east (Flemish region) and central-south (Walloon region). The exploration state of these reservoirs is poor; (practical) capacity estimates were made using geo-techno-economic simulations, P5 & P95 values are also given.

- The Houthem and Maastricht Formations of Upper Cretaceous to Lower Palaeocene age are an aquifer consisting of mainly calcarenites, occurring in the north-east of Belgium (Campine Basin & Roer Valley Graben). Sealing is provided by Tertiary clays, but in some areas shallow reservoir depth might be an issue. Average porosity and permeability are 29% and 65mD.
  Estimated storage capacity: 8 Mt (3 – 71).
- The Triassic Buntsandstein is a sandstone aquifer occurring in the north-east of Belgium. Sealing is provided by Upper Triassic and Jurassic shales in the eastern part, in the western area sealing is compromised. Average porosity and permeability are 13% and 37mD.
  Estimated storage capacity: 31 Mt (12 – 189).
- The Upper Carboniferous Neeroeteren Formation is a sandstone aquifer occurring in the north-east of Belgium, consisting of coarse river deposits with shale and coal intercalations. Average porosity and permeability are 15% and 115mD.
  Estimated storage capacity: 33 Mt (18 – 170).
- Upper Carboniferous coal seams or sequences in both the north-east and a central east-west band (Namur parautochton) could provide storage capacity if some technical issues are overcome, created by low permeability and legacy wells.
  Estimated storage capacity: north: 91 Mt (3 – 576); capacity south: 108 Mt (3 – 802).
- Storage might also be possible in abandoned coal mines in these coal deposits.
  Estimated storage capacity: north: 10 Mt (6 – 126); south: 8 Mt (5 – 63).

- Karstified limestones with underlying dolomites of Lower Carboniferous (Dinantian) occur in the south-west (Mons Basin). Because of the difference in reservoir properties, capacity estimates were made for the two separate parts. Average porosity is 5%. A geothermal field is also present in these strata, and sealing is provided by the Westphalian coal sequences.
  Estimated storage capacity: karstified limestones: 37 Mt (11 – 285); dolomites: 51 Mt (14 – 455).
- In the Campine Basin in the north-east, the karstified limestones and dolomites of the Lower Carboniferous (Dinantian) are underlain by and connected with the poorly known but potentially interesting Devonian carbonates. Average porosity of the Dinantian strata is 2.4% and average permeability ranges between 100 and 1000 mD. Small dome trapping structures are present and a natural gas storage site is present in these strata. Sealing is provided by Namurian and Westphalian mudstones and coal sequences.
  Estimated storage capacity: karstified limestones: 37 Mt (2 – 324); dolomites: 17 Mt (13 – 165); Devonian: 17 Mt (11 – 285).
- A potential reservoir is present in the Middle-Devonian carbonates in the Dinant synclinorium in the south of Belgium. Sealing is provided by Upper-Devonian shales.
  Estimated storage capacity: 11 Mt (6 – 342).

Current situation in Belgium with respect to i) current demo/pilot projects & projects/sites in preparation, ii) state of the transposition of the EU Directive on the geological storage of CO_2, iii) public awareness

There are no operational demo or pilot projects in Belgium. A NER300 phase 2 proposal is in preparation to capture CO_2 in the Antwerp harbour area from industrial sources, and to largely transport it to an off-shore storage location outside Belgium, and to partly use it as an industrial resource.

Status of transposition: Flanders: transposed; Brussels Capital Region: no storage possible (only limited transposition necessary, and in place); Federal level (off-shore): will claim that no storage is possible, but it is unclear what actions they have taken so far, the Directive is probably not yet transposed; Walloon region: will try to avoid transposition, not yet transposed.

CCS is currently not a focus point for energy debate, which is mainly considering nuclear and renewables (and potential black-outs). Public awareness regarding CCS is therefore very low. The NER300 phase 2 project hopes to avoid public opposition by linking CCS to industrial sources/growth.

Summarising the state of play on CO_2 geological storage in BULGARIA

(as of July 31st 2012)

National research programmes and funding for research related to CO_2 storage

To date there are no national research programme(s) and funding for research related to CO_2 storage in Bulgaria. The main reason for this is the volume of industrial CO_2 emissions in the country, which is much less than the limit fixed by the Kyoto agreement.

However, storage capacity estimations and studies of CO_2 geological storage options in the country have been performed in the frame of European projects Castor WP-2 (2005), GeoCapacity (2006 – 2009) and CO_2StoP (2012), as well as within two business projects, supported by Bulgarian Government (respectively by Ministry of Economy, Energy and Tourism):

1. Project "Towards Zero Emission Demonstration Power Plant with Carbon Capture and Storage (CCS) Technologies in Bulgaria, Task 2: Assess the Bulgarian capacity for storage of CO_2", funded by EBRD and accomplished by WorleyParsons resources & energy, INYPSA and Sofia University (2010).
2. "Feasibility Studies for Development of Projects Applying Systems Making Highly Efficient Use of Coal", a programme sponsored by Japan's New Energy and Industrial Technology Development Organization (NEDO). The FS has been conducted by Toshiba Corporation with support from other parties, including Schlumberger Carbon Services, Sofia University and Taisei Corporation.

Research institutions involved in research related to CO_2 storage

The Sofia University "St. Kliment Ohridski", Department of Geology through team of Prof. Dr. Georgi Georgiev is the only Bulgarian institution, which up to now has performed assessments of CO_2 storage potential in Bulgaria in the frame of EU projects Castor WP2 (2005), GeoCapacity (2006 – 2009) and CO_2StoP (2012), as well as within the two above mentioned business projects, supported by the Bulgarian Ministry of Economy, Energy and Tourism.

Storage options and capacities

The Bulgarian CO_2 storage capacity estimate is based on a large data base, including mainly original seismic and borehole results, integrated with knowledge on the subsurface and was calculated in a unified way accepted in the frame of EU GeoCapacity project.

The largest capacity of potential CO_2 storage options in Bulgaria is related to saline aquifers, coal fields have considerably less opportunities, while possibilities to use depleted hydrocarbon fields are practically absent.

The evaluation of CO_2 storage capacity in deep saline aquifers in Bulgaria is based on the assessment of four individual structures and six local zones. They relate to Devonian, Lower Triassic, Middle Jurassic, Upper Jurassic – Valanginian and Middle – Upper Eocene reservoirs, respectively. Six of the selected aquifers are located in Northern Bulgaria, the other four in Southern Bulgaria. Their total estimated CO_2 storage capacity is about 2 560 Mt.

Most of unmined coal reserves in Bulgaria occur at shallow depths, not favourable for safe injection of CO_2. Deeper occurrence of coal-bearing formations (>800 m), suitable for CO_2 storage, exists only in two fields – Dobudja and Bobov Dol, of which the total estimated CO_2 storage capacity is about 27 Mt.

Most Bulgarian hydrocarbon fields lie outside the depth interval for effective CO_2 storage, i.e. 800 – 2500 m. Only in two gas fields, namely Tchiren and Galata, do the reservoirs lie at favourable depths. However, the Tchiren field was converted into sub-surface gas storage in 1974 and is still operating. Thus, only the Galata gas field (located offshore) was considered for CO_2 storage. Assessment of this field suggests good opportunities for CO_2 storage (excellent reservoir parameters and depth) and an estimated CO_2 storage capacity of about 6 Mt. However, there is considerable interest in converting this field into a sub-surface gas storage facility.

Current situation in Bulgaria with respect to i) current demo/pilot projects & projects/sites in preparation, ii) state of the transposition of the EU Directive on the geological storage of CO_2, iii) public awareness

After the accomplishment of the above mentioned assessments of CO_2 geological storage options and especially after the two business projects, supported by the Bulgarian Ministry of Economy, Energy and Tourism, Bulgaria is prepared to apply for demo/pilot project.

The transposition of the EU Directive on the geological storage of CO_2 is still in progress, first acceptance in the Bulgarian parliament has been achieved.

The two brochures on CCS published in Bulgarian language have been accepted positively by the public.

Summarising the state of play on CO_2 geological storage in CROATIA

(as of July 31st 2012)

National funding for research related to CO_2 storage

Non- existent. Currently all governmental research funds are frozen/not active due to restrictions. INA Oil company is funding its EOR project but with slow progress.

National research programmes for research related to CO_2 storage

See above.

Research institutions involved in research related to CO_2 storage

Minor:

- UNIZG-RGNF - University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering
- EIHP - Energy Institute "Hrvoje Pozar"

Storage options and capacities

- Deep saline aquifers in continental Croatia, Upper Miocene sandstones with intergranular porosity, ca. 4 Gt.
- Depleted oil and gas fields in continental Croatia and Adriatic offshore, small to medium sized reservoirs, Palaeozoic to Pliocene age, altogether circa 170 Mt.

Current situation in Croatia with respect to i) current demo/pilot projects & projects/sites in preparation, ii) state of the transposition of the EU Directive on the geological storage of CO_2, iii) public awareness

There is actually no CCS demo project but there is an extensive EOR project in the construction phase in continental Croatia (SW corner of Pannonian basin). Two depleted oil fields will be equipped with numerous injection wells, a WAG scheme is planned, duration of injection will be 25 years, total retention of CO_2 without reinjection in that period is expected to be around 1 Mt. Trenches for injection lines are being dug out now, and equipment is being purchased.

Croatia is expected to become EU member state on 1 July 2013 and will transpose/start to transpose the EU Directive on the geological storage of CO_2 afterwards. Responsibility has been shifted from the Ministry of Environment to Ministry of Economy, Office for Mineral Resources. Progress has been much delayed apart from the fact that there is a change planned in the new Mining Law whereby injection of CO_2 for permanent storage would be regarded as exploitation of a resource. This change in procedure is not yet finalised. The new Mining Law has not yet been passed.

Summarising the state of play on CO_2 geological storage in the CZECH REPUBLIC
(as of July 31st 2012)

National funding for research related to CO_2 storage

The only institution funding CCS research at the moment is the Ministry of Industry and Trade through its TIP programme (www.mpo.cz/cz/podpora-podnikani/vyzkum-a-vyvoj). There is one CCS-related research project (5-year-long) currently running, its storage part amounts to ca. € 95 000 per year.

National research programmes for research related to CO_2 storage

There is no special research programme dedicated to CO_2 storage at the moment. Funding opportunities exist within more general topics like 'Energy' or 'Energy resources' in programmes dedicated to applied research:

- TIP programme of the Ministry of Industry and Trade (www.mpo.cz/cz/podpora-podnikani/vyzkum-a-vyvoj),
- Technology Agency of the Czech Republic (www.tacr.cz/en).

A special CCS research programme has been proposed for the next round of EEA/Norway grants, starting in 2012/2013 (not yet approved; www.eeagrants.cz).

Research institutions involved in research related to CO_2 storage

There are three research institutions with continuous research activity in the CO_2 storage area:

- Czech Geological Survey (www.geology.cz)
- Institute of Nuclear Research Rez (www.nri.cz/web/ujv)
- VSB Technical University of Ostrava (www.vsb.cz/cs)

Storage options and capacities

Potential storage capacities of the Czech Republic were evaluated within the EU GeoCapacity project; all three basic storage options are available – aquifers (conservative capacity estimate 766 Mt), hydrocarbon fields (33 Mt) and coal seams (54 Mt). The aquifer capacity is uncertain due to lack of data. Recent studies revealed low permeability (= low injectivity) of the biggest aquifer structure. The country might lack storage capacity if CCS is deployed at larger scale.

Current situation in the Czech Republic with respect to i) current demo/pilot projects & projects/sites in preparation, ii) state of the transposition of the EU Directive on the geological storage of CO_2, iii) public awareness

At present, there are no plans for a pilot or demo CCS project. Preparations for a possible storage pilot might potentially be started within the next round of EEA/Norway grants where a special CCS programme is foreseen (not yet approved).

The EU Directive on the geological storage of CO_2 has been transposed as of March 2012 when the Act No 85/2012 Sb. 'on storage of carbon dioxide in natural rock structures' was published. The Act includes significant limitations making CO_2 storage more difficult, like, e.g., the provision limiting the amount of stored CO_2 to 1 Mt per storage site and year. After an intervention by the Senate, the Act bans geological storage of CO_2 on the territory of the Czech Republic until 1 January 2020.

Public awareness of CCS is generally low, mostly due to limited activities in the area. According to EUROBAROMETER (2011), only 6 % of the respondents claimed to know what CCS is, while 76 % of them have never heard of it.

Summarising the state of play on CO_2 geological storage in DENMARK

(as of July 31st 2012)

National funding for research related to CO_2 storage

CO_2 storage related research in Denmark is funded through diverse national programmes under the different councils below the Danish Agency for Science, Technology and Innovation. The independent councils (the Danish Council for Independent Research, the Danish Council for Strategic Research, the Danish Council for Technology and Innovation and the Industrial PhD Programme Committee) support a wide range of research and innovation projects.

The Danish Council for Independent Research funds specific research activities, within all scientific areas, that are based on the researchers' own initiatives and that improve the quality and internationalisation of Danish research. There is about CCS one project funded each year, the project size is usually about 0.5 Mio €. The main receiver of this funding is the Technical University of Denmark.

The main task of the Danish Council for Strategic Research is to allocate funds for thematically defined research reflecting national priorities determined by the Danish Parliament. The council is funding research activities relating to sustainable and environmental topics within the themes "Energy Systems of the Future" and "Competitive Environmental Technologies" including CO_2 capture and handling technologies. The council has supported technology for geological storage of CO_2 with around 2.5 Mio € per year.

The Danish Council for Technology and Innovation has two main tasks, to advise the Minister of Science, Technology and Innovation about technology and innovation policy, and to administer the initiatives given to the council by the Minister. The objectives of the council are to promote collaboration and dissemination of knowledge between researchers, research and educational institutions, advanced technology groups, knowledge institutions and enterprises, to promote innovation and commercialization of new research and technology and international collaboration.

The Danish National Advanced Technology Foundation is an independent body within the government administration that offers grants in the form of co-funding for high-technology research and innovation initiatives and projects. Projects must have obvious commercial potential, include technology transfer, and involve collaboration between public-sector research institutions and private-sector companies. The foundation is, amongst other projects, supporting research on enhanced oil recovery (EOR) from the North Sea chalk. The foundation funding on EOR has been 3 – 4 Mio € per year, however the research has also been supported by the Maersk Oil Company.

ENERGINET.DK operates research and development activities in many areas. The overall aim is to develop the Danish energy systems, primarily the gas and electricity systems, and to ensure that the Danish society benefits from world-class energy research. ENERGINET.DK collaborates with other Danish energy research programmes and research institutions in Denmark and other countries. The activities include funding for external energy research projects financed by all electricity consumers in Denmark. The purpose is to promote the development of environmentally friendly power generation technologies so as to facilitate the transfer to a society based on renewables. ENERGINET.DK's own research activities aim to promote the development of new environmentally friendly gases and to limit the environmental impact of using natural gas. ENERGINET.DK also participates in international energy research collaboration projects in Europe and the rest of the world. The objective is to gain access to world-class research and to use Danish funds to conduct large projects in cooperation with other countries.

ENERGINET.DK also supports research on geological storage of CO_2 in the Danish subsurface and evaluation of the response of caprock and reservoir rocks on CO_2 storage. Funding has been around 300 000 € per year.

Denmark participates in the Nordic research foundation "Top-level Research Initiative," a major Nordic venture for climate, energy and the environment. The Top-level Research Initiative (TRI) is the largest joint Nordic research and innovation initiative to date. The initiative aims to involve the very best agencies and institutions in the Nordic region, and promote research and innovation of the highest level, in order to make a Nordic contribution towards solving the global climate crisis. The Top-level Research Initiative consists of six sub-programmes; one of these is CO_2 capture and storage. The Nordic countries are involved in a number of CCS research projects. The objective is to initiate cooperation, concrete actions and implementation of Nordic know-how and technology within CCS. The focus is on the Nordic region and Nordic activities and possible relationships to the EU and international activities. The budget for the CCS programme is approximately 5.25 Mio € over five years.

Research institutions involved in research related to CO_2 storage

In terms of research institutes in Denmark involved in CCS studies and research in CO_2 geological storage, the main institutes are the Geological Survey of Denmark and Greenland (GEUS) and the Technical University of Denmark (DTU), particularly within the DTU Chemical Engineering, Department of Chemical and Biochemical Engineering, and the DTU Centre for Energy Resource Engineering (CERE).

GEUS has conducted research pertaining to geological storage of CO_2 since 1993, being one of the European pioneers in this area. The research areas include characterisation and capacity assessment of potential underground storage reservoirs, investigation into potential chemical interactions of injected CO_2 with the surrounding rocks, enhanced (increased) oil recovery (EOR and IOR), storage site monitoring technologies and integrated monitoring strategies and assessment of long-term site performance including evaluating consequences of potential leakage.
The research at DTU combines a range of disciplines of great importance in oil and gas production and CO_2 capture and storage. A substantial part of the research has been dedicated to EOR.

Some minor research activities relating to CCS are found at the Aalborg University, Faculty of Engineering and Science, and at the University of Copenhagen, Niels Bohr Institute.

Storage options and capacities

In Denmark storage in depleted offshore hydrocarbon fields can be considered as the most important option in the near future. Several studies have been carried out on EOR and IOR in the chalk of the North Sea. A significant potential for CO_2-EOR is present in chalk, even after earlier water-flooding. Ekofisk chalk that is non-economic for water-flooding may have potential for CO_2-EOR.

The Mesozoic succession in onshore Denmark (Norwegian-Danish Basin) contains several formations with sandstones that may offer potential reservoirs for CO_2 storage (Anthonsen and Nielsen, 2008; Anthonsen et al., 2009 & 2011; Frykman et al., 2009). These include the Triassic Bunter Sandstone and Skagerrak Formations, the Upper Triassic-Lower Jurassic Gassum Formation, the Middle Jurassic Haldager Sand Formation, and the mainly Jurassic Frederikshavn Formation. Additional storage potential may locally occur in the Upper Jurassic Flyvbjerg Formation. Investigations have shown that amongst these formations, the potential of the Gassum and Haldager Sand Formations is probably the highest. This is related to their distribution and burial depths, the potential storage volume, the presence of overlying

cap rocks with suitable seal capacity and the presence of large structures at suitable depths. The reservoirs are expected to be sealed by Lower and Upper Jurassic marine mudstones with excellent lateral continuity and excellent sealing capacity. Based on the detailed depositional models and the sequence stratigraphic framework established for the Danish part of the basin (Nielsen, 2003), and the Danish well data on reservoir and cap rock properties reported here, it is possible to define predictive models and interpretations for undrilled areas in the basin based on available seismic data.

A conservative estimate for Denmark was calculated in the D16, WP 2 Report of the GeoCapacity project (Vangkilde-Pedersen, 2009). An estimate was calculated for eleven structural traps in saline aquifers with a storage efficiency factors ranging between 5 % and 10 % resulting in a total effective storage capacity of 2.553 Gt CO_2. The storage capacity of the Danish offshore hydrocarbon fields was estimated assuming that only 25 % of the produced hydrocarbons can be replaced by CO_2. This results in a total storage capacity of 203 Mt CO_2 for 17 fields (Vangkilde-Pedersen, 2009).

Current situation in Denmark with respect to i) current demo/pilot projects & projects/sites in preparation, ii) state of the transposition of the EU Directive on the geological storage of CO_2, iii) public awareness

At present, there are no demo/pilot projects in Denmark. The strong influence of Green parties and NGOs, and their ability to involve the public in debates, may have negatively influenced the transposition process in Denmark, and may have contributed to a ban on onshore storage in Denmark until 2020 when results from demonstration projects elsewhere in Europe will be available. As a result the plan for an onshore demonstration project in Denmark (Nordjylland Coal Power Station) were stopped.

Maersk Oil was planning to develop enhance oil recovery (EOR) with CO_2 sourced from carbon capture projects as an addition to conventional oil and gas extraction. The project has temporary been stopped as there is not enough CO_2 being captured to make it practical to undertake EOR in the Danish North Sea. EOR was otherwise seen as the technology that could help to sweep more of the remnant oil of the Danish underground in the North Sea. The problem is that the power plants have not launched the projects in which they had to capture the large amounts of CO_2 that Maersk Oil was planning to use.

The existing Danish Subsoil Act addresses the use of the subsoil. The first Subsoil Act was adopted in 1932 and has been amended several times subsequently. The Subsoil Act lays down the basic framework for petroleum exploration and recovery. The Act is formulated as a 'general terms act' allowing for adaptations and more detailed regulations. It regulates exploitation and recovery activities in the Danish subsoil and the Danish Continental Shelf concerning minerals and specifically hydrocarbons. The Act covers: Prospecting, exploration for and recovery of raw materials (and hydrocarbons in particular), government rights for purchasing liquid hydrocarbons, other manners of exploration, supervision and other provisions. The Danish parliament implemented the EU Directive on the geological storage of CO_2 into Danish legislation on May 25th 2011. The implementation was made by an amendment of the Danish Subsoil Act. The latest amendment addressed several points: It implements the EU Directive on geological storage of CO_2, exploration for and production of geothermal power, an injunction of third-party access to facilities for extraction, processing and transportation of oil and gas etc. As a consequence, Denmark temporarily forbids storage until 2020, but permits offshore CO_2-enhanced oil recovery (EOR) operations.

Summarising the state of play on CO_2 geological storage in ESTONIA

(as of July 31st 2012)

National funding for research related to CO_2 storage

National funding of research related to CO_2 storage in Estonia is finishing in 2012. One PhD researching aspects of CO_2 geological storage is still supported (only through a PhD stipendium) until June 2013. Nothing is available for research in 2013 when the PhD finishes.

National research programmes for research related to CO_2 storage

None.

Research institutions involved in research related to CO_2 storage

Institute of Geology, Tallinn University of Technology.

Storage options and capacities

National capacity for CO_2 geological storage in Estonia is close to zero. This is a result of unfavourable geological and hydrogeological conditions; shallow sedimentary basin and potable water in potential reservoir rocks are not favourable for CO_2 storage (Sliaupa et al., 2008; Shogenova et al., 2009a & b & 2011b). However, some promising possibilities for CO_2 mineral carbonation by oil shale ash and waste water are available, and technology has been developed for testing and implementation (Kuusik et al., 2005 & 2010; Uibu et al., 2009 & 2010; Velts et al., 2011).

Possibilities for cross border CO_2 storage could be available in the neighbouring countries, depending on their CCS regulations and policy. Economic modelling of cross border onshore storage of Estonian CO_2 emissions in Latvian structures was made in the frame of FP6 EU GeoCapacity project and updated recently (Shogenova et al., 2011a). Due to public acceptance problems, more likely prospects for cross border storage appear to be offshore in the southern Baltic Sea (Latvian, Swedish and Danish areas) and North Sea (Norway). Cooperation with Russia, the eastern neighbour to Estonia, could be especially prospective in the field of EOR (Shogenova et al., 2011b).

Current situation in Estonia with respect to i) current demo/pilot projects & projects/sites in preparation, ii) state of the transposition of the EU Directive on the geological storage of CO_2, iii) public awareness

No demo/pilot projects in operation or in preparation.

Dissemination of information on CCS is on-going using CO_2East websites in Estonian and Russian languages, presentations at the local and regional events, radio interviews (in 2011 and 2012) and teaching of CGS spring-term course in Tallinn University of Technology for national and international students in 2012. One of the national PhD students studied the course was T. Meriste from the national energy company Eesti Energia (main Estonian stakeholder). All these activities are supported only by the CGS Europe project.

The Estonian Ministry of Environment has introduced a draft act as of August 23rd 2011 about changing the Act of Ambient Air, Water Act, Earth's Crust Act, Environmental Liability Act, Environmental Impact Assessment and Environmental Management System Act and Integrated Pollution Prevention and Control Act. The act states that the geological storage of CO_2 in the Estonian Republic territory and continental shelf is prohibited with the exception of cases where the total amount of stored CO_2 is less than 100 000 t and where the projects are undertaken for scientific or development purposes, or for testing new processes or products. Storage in marine areas is also prohibited. As a result, the transposition of the Directive was reduced to articles that are not directly related to storage. As storage of CO_2 is prohibited, the important issue of regulation is transportation. The Act defines regulations for CO_2 transportation pipelines, pipeline owner legalities, party merger requirements and information availability and reporting rules. Transposition of the EU Directive on the geological storage of CO_2 was accepted by Estonian Parliament on December 6th 2011, signed by president of Estonia on December 13th, published on December 21st 2011 and came into force in Estonia on December 31st 2011.

According to this Act, the operator of large combustion device with electrical power generation of 300 MW or more whose building permit is newer than June 24th 2009 has to present an assessment to the Ministry of Environment by March 31st 2012 at the latest if a location for CO_2 storage is available and if CO_2 capture system modernisation and exploitation of transportation facilities are technically and economically feasible. On the basis of this assessment and other available data including information about human health and environmental protection, the ministry decides if CO_2 capture and transportation is feasible for each plant. If the ministry determines storage is feasible, the operator of the large combustion device has to warrant that there is enough space for CO_2 capture and compression facilities at the location of the large combustion device. The Ministry of Environment of Estonia will publish all information about CO_2 capture and transportation for geological storage on its website.

The construction of the new power block of the Eesti Power Plant started in April 2012 by Alstom. The capture technology being planned and investigated is oxyfuel, while any decision about possible cross border transportation routes and storage sites are still pending. In addition to the traditional local oil shale used as a fuel in Estonia that produces the highest CO_2 emissions compared to other fossil fuels, biofuel will be added for combustion. This will help to decrease CO_2 emissions and probably, CCS will not be applied any time soon.

Summarising the state of play on CO_2 geological storage in FINLAND

(as of July 31st 2012)

National funding for research related to CO_2 storage

- Tekes – the Finnish Funding Agency for Technology and Innovation
- Cluster for Energy and Environment (CLEEN)

National research programmes for research related to CO_2 storage

The CCSP (Carbon Capture and Storage programme): The objective of the CCSP (Carbon Capture and Storage Programme) is to develop CCS-related technologies and concepts, leading to essential pilots and demonstrations by the end of the programme 2014 – 2015. Commercial applications that promote Finnish CCS innovations will be available from 2020 onwards. A further objective is to create a strong scientific basis for the development of CCS components, concepts and frameworks, and to establish strong international networks that enable active international CCS co-operation.

The scope and structure of the CCSP have proven to be an effective starting point for the creation and focusing of new research in the field of CCS – the views based on international collaboration in CCSP support this statement. The main focus areas defined are:

- CCS in industry
- CCS in CHP with BioCCS as a special issue
- Chemical Looping Combustion (CLC)
- Mineral Carbonation.

Project website: www.cleen.fi/en/ccsp

Research institutions involved in research related to CO_2 storage

- Geological Survey of Finland
- Mineral carbonation: Åbo Akademi, Aalto University

Storage options and capacities

In Finland all deep rocks are expected to be crystalline basement rock and not suitable for CO_2 storage. The same situation applies for the regions of the Baltic Sea nearest to Finland. The closest potential storage sites for Finland are the formations in the southern Baltic Sea, but these cannot be considered Finnish territory (Teir et al., 2010).

Current situation in Finland with respect to i) current demo/pilot projects & projects/sites in preparation, ii) state of the transposition of the EU Directive on the geological storage of CO_2, iii) public awareness

Possible pilot project related to mineral carbonation is being prepared in the Åbo Akademi research project in Singapore.

The transposition of the EU Directive on the geological storage of CO_2 to national laws was carried out by July 4th 2012.

According to Eurobarometer (2011), in Finland the level of awareness and understanding of what was meant by CCS was the third highest (12 %). Additionally, more than one in five people had heard of CCS but did not really know what it was.

Summarising the state of play on CO_2 geological storage in FRANCE

(as of July 31st 2012)

National funding for research related to CO_2 storage

State funding agencies are mainly:

- Agence Nationale de la Recherche - ANR (*French National Research Agency ;* www.agence-nationale-recherche.fr);
- Agence de l'Environnement et de la Maitrise de l'Energie - ADEME (*French Environment and Energy Management Agency* ; www2.ademe.fr),

  They provide funding through calls for proposals. ANR is the main agency providing funding. ADEME has a more restricted budget for research projects and is centred around energy and environmental topics. However, ADEME is providing significant funding for CCS pilot and demonstration projects.

- Fonds Unique Interministériel - FUI (*French Single Interministerial Fund* ; depending on the Department of Economy, Finances and Employment).

Industrial research: Some industrials fund research under contract.

National research programmes for research related to CO_2 storage

ANR: The current active programme dealing with CCS is the SEED programme.

SEED Programme – Systèmes énergétiques efficaces et décarbonés 2011 – 2013 (*Efficient and decarbonised Energy Systems;* www.agence-nationale-recherche.fr/en/research-programmes/aap-en/efficient-and-decarbonized-energy-systems-seed-2012/nc):
The aim of the SEED programme is to strengthen academic and industrial French communities in the field of energy efficiency and of their capacity to answer to the challenges associated with the climate change and the dependence on fossil fuels. The programme objectives are:

- Reduction of primary energy consumption and associated CO_2 emissions by increasing energy efficiency in industry and buildings;
- Valorise heat, whether rejected by industry or generated from renewables, and particularly through storage;
- Contribute to the development of the CO_2 capture, storage and valorisation technologies, in order to remove emissions from industrial sources and to achieve the stated goals of reducing global emissions.

Other programmes from ANR can be also applicable to CO_2 storage like for instance: "Société innovantes" for social acceptance, "White" for more fundamental research, or "Information and Communication Science and Technology" for developing computing capabilities.

Since its creation in 2005, ANR has supported:

- 33 CCS projects funded in the CO_2 Programme (annual calls for projects from 2005 to 2008) – ANR funding 27.5 Mio € (programme « CO_2 capture and storage »). Among these 33 projects:

  - 13 were dedicated to capture and among these, 8 have integrated transport;
  - 17 were dedicated to storage whilst 12 integrated the monitoring;
  - 1 was dedicated to transport;
  - 1 was dedicated to risk management and safety criteria; and
  - 1 concerned a socio-economic and public awareness study.
- 3 CO_2 capture projects funded in the EESI Programme (calls for projects in 2009 and 2010) - ANR funding of 3.3 Mio € (« Energy Efficiency and CO_2 emissions reduction in Industrial Systems »)
- 7 CCS projects funded in the current SEED programme (2011 and 2012 calls for projects) - ANR funding of 5.4 Mio € (« Efficient and Decarbonized Energy Systems »). CCUS, including reuse of CO_2, is one of the three sub-programmes. Among the seven projects selected:
  - 1 is dedicated to capture;
  - 5 are dedicated to storage;
  - 1 is a combined CCS & geothermal project.

ADEME (*French Environment and Energy Management Agency*):
The ADEME supports initiatives on CCS and devotes special attention to energy efficiency, socio-economic issues, and environmental impacts. ADEME has several programmes that can fund CCS activities:

- PhD funding programme: 2.8 Mio €/year for all energy and environment topics. 17 PhD thesis on CCS between 2003 and 2012;
- Research projects: 40 Mio €/year for all energy and environment topics. 30 CCS research projects (total budget 22 Mio €, ADEME funding 5.7 Mio €) between 2003 and 2012. Thirteen are dedicated to capture, one to transport, 13 to storage, one to social perception, and two techno-economic studies for two industrial areas (Le Havre, Fos-Gardanne);
- Pilot and demonstration projects , through two types of instruments:
  - Research demonstration funds ("Fonds démonstrateur recherche") in 2008: Three CCS projects (total budget 104 Mio €, ADEME funding: 38 Mio €) – post-combustion capture for coal-fired power plants (pilot-scale, EDF/ALSTOM), CO_2 storage in deep saline aquifers (TOTAL), CCS for steelmaking (integrated industrial-scale project, ARCELOR MITTAL).
  - Investments for the Future ("Investissements d'avenir " see below) in 2011. Still under evaluation.

Investissements d'avenir *(Investments for the future)*:
Following the Juppe-Rocard Commission's work, the Investissements d'avenir programme (investissement-avenir.gouvernement.fr) was granted an overall budget of 35 billion €, to place France at the forefront of innovation. Different calls for creation of research platforms, research institutes and for demonstrators have been issued. CCS was indicated as one of the possible technologies of interest. The calls and the funds are operated partly by ANR, partly by ADEME.
Demonstrators for CCS (capture and storage) and the creation of a new institute (GEODENERGIES) have been funded through this programme. GEODENERGIES is dedicated to the development of geotechnologies for CO_2 storage, geothermal energy, and energy storage.

Chaire CTSC on Capture, Transport and Storage of CO_2:
The CTSC Chaire (www.chaire-ctsc.fr/home) is a research programme initiated in 2009 and headed by industrial partners, academic and research institutions. Initially funded for five years, it contributes to the evolution of French education and knowledge on carbon capture, transport and storage by funding doctoral and post-doctoral research and by supporting CCS-related scientific animation actions. Its primary objective is to develop CTSC-related knowledge in order to highlight strategic options and choices for the future, and more generally to facilitate the emergence of efficient technologies aimed at reducing CO_2 emissions.

Research institutions involved in research related to CO_2 storage

Major research institutes
- BRGM (www.brgm.fr),
- IFPEN (www.ifpenergiesnouvelles.fr)
- Institut National de l'EnviRonnnement industriel et des rISques, INERIS (www.ineris.fr)
- Institut national des sciences de l'univers Centre national de al recherché scientifique, CNRS (www.insu.cnrs.fr)
- Mines de Paris (www.ensmp.fr)
- Institut de Physique du Globe de Paris, IPGP (www.ipgp.jussieu.fr)
- Under creation: GEODENERGIES

Minor research institutes
- Université de Lorraine,
- Université de Pau,
- Laboratoire Navier, École des Ponts ParisTech
  etc.

Storage options and capacities

France has three main onshore basins: the Paris, Aquitaine and South-east basins. The potential storage capacities have been mapped for the Paris Basin, partly for the Aquitaine Basin (aquifers not evaluated), while the south-east area is currently being assessed. Storage potential is essentially in saline aquifers in the Paris basin and in depleted gas fields in the Aquitaine Basin. Offshore possibilities have not been studied yet. France has sufficient capacity to implement CCS. Please visit Metstor website which presents French storage capacities for more information: www.metstor.fr

Current situation in France with respect to i) current demo/pilot projects & projects/sites in preparation, ii) state of the transposition of the EU Directive on the geological storage of CO_2, iii) public awareness

TOTAL Lacq Pilot Project – Pyrénées-Atlantique, France. This 30 MW_{th} gas boiler project uses oxy-combustion capture technology. CO_2 is transported from the Lacq site via an existing 30 km pipeline and stored in a very deep (4 500 m) depleted gas field (Rousse). This project will capture and store up to 90 000 t of CO_2 over the test period. The site has been operational since January 2010 and the last injection of CO_2 is planned for mid 2013. See also: www.total.com/en/special-reports/capture-and-geological-storage-of-co2/capture-and-geological-storage-of-co2-the-lacq-demonstration-200969.html

ARCELORMITTAL integrated large-scale CCS demonstration project for steelmaking – Lorraine, France. The project will capture CO_2 from a blast furnace at industrial scale for storage in deep saline aquifers. The project is currently in its early stages and it is of particular interest for steelmaking and other industrial sectors where only limited or no alternative options for massive reduction of CO_2 emissions exist today. The project is funded by ADEME and is a NER300 candidate as well.
Another proposed demonstration for storage, funded partly by ADEME, "France NORD" led by Total and GDF-SUEZ, has been discontinued.

The EU Directive on the geological storage of CO_2 is fully transposed. Law level provisions came into force in 2010. Regulatory provisions which finalise transposition have been enacted since the end of 2011.

Generally awareness of CCS is low in France. Currently there is no intense public debate, probably due to the absence of concrete storage projects in the country. Some local resistance around the first pilot in Lacq occurred, but this was managed successfully by Total. First actions have been taken by ArcelorMittal to contact the local communities in the frame of its demonstration project. The legislation requires that a wide debate is organized. The national commission for public debates will be responsible for this.

Summarising the state of play on CO_2 geological storage in GERMANY

(as of August 31st 2012)

National funding for research related to CO_2 storage

- Bundesministerium für Bildung und Forschung – BMBF (*Federal Ministry of Education and Research*; www.bmbf.de);
- Bundesministerium für Wirtschaft und Technologie – BMWi (*Federal Ministry of Economics and Technology*; www.bmwi.de);
- Deutsche Forschungsgemeinschaft – DFG (*German Research Foundation*; www.dfg.de);
- Umweltbundesamt – UBA (*Federal Environment Agency*; www.umweltbundesamt.de)

Also some Federal States provide funding for research projects, e.g. State of Brandenburg supporting the Joint Research Project on GeoEnergy Research (www.geoen.de) and the State of Lower Saxony funding the Energie-Forschungszentrum Niedersachsen (www.efzn.de).

National research programmes for research related to CO_2 storage

- BMBF/DFG Programme GEOTECHNOLOGIEN (www.geotechnologien.de);
- BMWi Programme COORETEC (www.cooretec.de); predominately funding research on technologies for improving power plant efficiency and on technologies for the separation and transport of CO_2.

Research institutions involved in research related to CO_2 storage

- Deutsches GeoForschungszentrum, Potsdam (GFZ; www.gfz.de),
- Karlsruhe Institute of Technology (KIT; www.kit.edu),
- Bundesanstalt für Geowissenschaften und Rohstoffe (BGR; www.bgr.bund.de),
- University of Stuttgart (www.uni-stuttgart.de),
- GEOMAR (www.geomar.de),
- Technical University of Clausthal (TUC; www.tu-clausthal.de).

- Christian Albrechts University of Kiel (CAU; www.uni-kiel.de),
- Bergakademie Freiberg (www.tu-freiberg.de),
- Leibniz Institute for Applied Geophysics (LIAG; www.liag-hannover.de),
- RWTH Aachen University (www.rwth-aachen.de),
- Friedrich Schiller University of Jena (www.uni-jena.de)

  and others.

Storage options and storage potential

Due to their large extent, deep saline aquifers have the largest potential for CO_2 storage in Germany. Because of their depth and high salinity, they are not used for drinking water production. Their storage potential is estimated to be roughly 20 Gt. The storage capacity of depleted gas fields in Germany is estimated to be about 2.75 Gt. The storage potential of depleted oil reservoirs is only about 130 Mt.

Current situation in Germany with respect to i) current demo/pilot projects & projects/sites in preparation, ii) state of the transposition of the EU Directive on the geological storage of CO_2, iii) public awareness

Currently the Ketzin research pilot (www.KetzinCO2.de) is the only active CO_2 injection site in Germany. No further pilot or demo projects are currently in preparation.

Transposition of EU Directive is completed. The national CO_2 Storage Act has been approved by the parliament on August 17th 2012 and came into force on August 24th 2012. According to this Act geological storage of CO_2 is allowed in Germany for projects involving storage of not more than 1.3 Mt CO_2 per year. Overall, the annual amount of CO_2 stored in Germany shall not exceed 4 Mt CO_2.

In general, the public acceptance of CCS is low, but also the knowledge about this technology is limited. Local public protests against CCS occurred at proposed storage sites. Local public protests together with a slow transposition of the EU Directive on the geological storage of CO_2 into national law were reasons for Vattenfall returning their exploration license for the Birkholz site to the mining authority, though their proposal had been selected as one of the project within the EEPR.

Summarising the state of play on CO_2 geological storage in GREECE

(as of July 31st 2012)

National funding for research related to CO_2 storage

CO_2 storage-related research in Greece is not funded through national programmes.

Recently (2008 – 2009), the Public Power Corporation of Greece funded a study concerning the installation of a lignite supercritical power plant, with CO_2 capture and geological storage in Western Macedonia and Evia Island: Economic analysis of CO_2 capture and storage technologies.

The Greek State has co-funded various EU projects for research and studies related to CO_2 storage.

National research programmes for research related to CO_2 storage

There are no national research programmes related to CO_2 storage.

Research institutions involved in research related to CO_2 storage

Institutes involved in research related to CO_2 storage, are:

- I.G.M.E. (Institute of Geology and Mineral Exploration) and
- I.S.F.T.A. (Institute for Solid Fuels Technology and Applications) of the Centre for Research and Technology Hellas (CERTH).

Both have participated in EU projects related to CO_2 capture and geological storage.

Storage options and capacities

In Greece, the assessment of CO_2 storage capacity has been carried out in the framework of the EU GeoCapacity Project. The CO_2 storage capacity has been estimated in deep saline aquifers and hydrocarbon fields.

- The assessment of CO_2 storage capacity in deep saline aquifers was performed in three Tertiary sedimentary basins (Prinos, Western Thessaloniki and Messohellenic) in various levels of the resource pyramid. For each of the three basins, an estimated whole basin storage capacity was calculated. Following on from this, some local estimations have been performed for the Western Thessaloniki basin based on the evaluation of some individual structures using seismic and borehole data. For the basin-scale estimations, the area of the basins was determined based on the geological maps and delimited by the extent of the porous formation at depths greater than 800 m. The area of the structural closures was determined based on contour maps of stratigraphic horizons near or at the top of the reservoir formation. In some cases, the calculation of the available volumes was carried out based on the isopach maps of the porous formations. For the estimations at basin scale, a conservative efficiency factor was used ranging from 3 – 6% according to the quality of the reservoir. The theoretical storage capacity in these aquifers has been assessed to be at 1.936 Gt. For the estimation of individual structures or traps, the aquifer systems surrounding and connected to the reservoir formations were assumed to be open (unconfined) aquifers. The total effective storage capacity in aquifers was estimated to be around 184 Mt.

- The assessment of CO_2 storage capacity in Greek hydrocarbon fields has been performed for six fields based on data from published sources. The capacity was calculated according to the methodology described for hydrocarbon fields in the GeoCapacity Project. The storage capacity of the Greek hydrocarbon fields has been estimated assuming a 1:1 volumetric replacement ratio between hydrocarbons and CO_2. There is no distinction made between effective and theoretical storage capacity for these fields. A number or 1 producing, 1 exhausted and 4 non-producing hydrocarbon fields have been assessed and the total CO_2 storage capacity of these 6 fields (Prinos, South Kavala, Kallirachi, Epanomi, Katakolon, East Katakolon) was estimated to be 70 Mt.
- No CO_2 storage capacity estimation has been performed for lignite deposits (coal fields). Greece has only lignite fields which are extensively mined for power generation. Their geological setting is deposition in intramontane Tertiary basins and they occur at depths up to 800 m in highly fractured rock sequences.

The total CO_2 storage capacity in deep saline aquifers and hydrocarbon fields has been estimated to be 2.190 Gt.

Current situation in Greece with respect to i) current demo/pilot projects & projects/sites in preparation, ii) state of the transposition of the EU Directive on the geological storage of CO_2, iii) public awareness

There are currently no demo/pilot projects and no project/sites for CCS in preparation.

Concerning the status of legislation, on November 7th 2011, a Common Ministerial Decision was signed for transposition and implementation of the EU Directive on the geological storage of CO_2. According to this Ministerial Decision (Official Gazette, 2516/B/7 November 2011):

(i) The Ministerial Decision is applied to the geological storage of CO_2 within the territory of Greece, including the seabed, continental shelf and subsurface to the boundaries of the area where the Hellenic Republic has sovereign rights and/or exercising jurisdiction under the United Nations Convention on the Law of the Sea (UNCLOS). Therefore, Greece permits CO_2 storage onshore and off-shore within the territory of Greece where the Hellenic Republic has sovereign rights. The storage of CO_2 is not permitted (a) in a storage site with a storage complex extending beyond the area pre-referred, and (b) in the water column and aquifers (Article 2). This general prohibition of CO_2 storage in aquifers may need to be revised since such a prohibition is not dictated by the EU Directive on the geological storage of CO_2.

(ii) Monitoring is included in the Ministerial Decision (article 14). The operator should carry out monitoring of the injection facilities and the storage complex (including where possible the CO_2 plume). The monitoring strategy will be based on a monitoring plan designed by the operator pursuant to the requirements laid down in Annex II. The monitoring plan is submitted to and approved by the competent authority and it can be updated pursuant to the requirements laid down in Annex II and in any case must be reviewed every five years (article 14). In Annex II, criteria for establishing and updating the monitoring plan and for post-closure monitoring are described based on the EU Directive.

CCS is now increasingly discussed as a possible tool to achieve emission mitigation in Greece. Some forums have been organized to instigate a dialogue. Some interviews and articles have been published in newspapers, magazines and electronic media. Technology providers, private energy companies and other industrial players have already expressed an interest in CCS but this interest has yet to culminate into a concrete project. Aegean Energy, the current operator of Prinos, an offshore mature oil field near Kavala in the Aegean Sea, has indicated that this reservoir has all necessary characteristics to accommodate the injection of CO_2 as part of a CCS project.

In 2006, the General Secretary of the General Secretariat of Research and Technology of the Hellenic former Ministry of Development signed the CSLF (Carbon Sequestration Leadership Forum) Charter on behalf of the Hellenic Republic and Greece became a CSLF member. Recently, the Ministry of Environment, Energy and Climate Change have shown an increased interest in CCS. It is expected that the political leadership of the Ministry will sign the revised CSLF Charter in the near future after the recent positive suggestions from I.G.M.E. and I.S.F.T.A.

Major environmental non-governmental organizations (NGOs) in Greece generally approach CCS in an outright negative or suspicious manner. Other NGOs, although acknowledging the necessity of CCS for emission reductions if it appears to be viable, will avoid being vocal about their perspectives on this technology.

Concerning public awareness, the Institute of Geology and Mineral Exploration (I.G.M.E.) has translated one leaflet and one brochure into Greek language:

- The 4-page leaflet entitled 'A 'Down-To-Earth' Solution to Climate Change' edited by CO_2NET was translated by I.G.M.E. in 2006. The Greek version of this leaflet is available at the following link: portal.igme.gr/portal/page?_pageid=33,56866&_dad=portal&_schema= PORTAL: http://www.geology.cz/geocapacity/downloads
- The brochure entitled 'What does CO_2 geological storage really mean?' edited by CO_2GeoNet has been translated by I.G.M.E. in the framework of the EU Project 'CGS Europe' and will be printed very soon.

Summarising the state of play on CO_2 geological storage in HUNGARY

(as of July 31st 2012)

National funding for research related to CO_2 storage

Over the last eight years, research funding dedicated to CO_2 storage in Hungary has been undergoing a massive transformation. In the early stages (2004 – 2007) of activity, research was solely funded by European sources, namely FP5 and FP6 R&D projects. One major effect of early-stage EU funded research was the increasing awareness, especially observed at industrial stakeholders and research institutes. In these early times governmental bodies and NGOs simply overlooked the potential of CCS technology. As a result of this increasing awareness in industry, from 2007 a considerable portion of research (40 – 50%) was financed by private companies. The main advantages of private financing were an increased research capacity due to more accessible funds and also an increased availability of high quality data. However, the drawback of this phenomenon was that many of the research results remain confidential. Nevertheless, the increased research activity has awakened the governmental stakeholders, who realized the importance of CCS research as well as the obligations of the country to conduct national research activity in this field. From 2008 to recent times the financing of CO_2 storage related research has rapidly moved from 50:50 to 95:5 government financing/private financing, respectively.

National research programmes for research related to CO_2 storage

National CO_2 storage research programmes started with privately funded activities in 2007. The main aim of the 2007 – 2008 research projects was to conduct a general assessment and mapping of CO_2 storage potential in Hungary, concerning depleted hydrocarbon, saline aquifer and depleted coal storage opportunities as well as utilization options of industrial CO_2 in EOR activities. The oil company, financing the research provided access to high-quality reservoir and well data. However the timescale only enabled general assessment of the storage potential. From 2008 to recent times, when the research was partly government financed, a more thorough, systematic assessment, mapping and databasing of potential storage sites and storage capacity started. From 2011 onwards, the detailed and systematic study of natural CO_2 occurrences has been also included in the research activity.

Research institutions involved in research related to CO_2 storage

The main research institution involved in CO_2 storage research is the Geological and Geophysical Institute of Hungary (the former Eotvos Lorand Geophysical Institute – changed on April 1st 2012). In the very early stages of research, the Geological Institute of Hungary (which is now merged into the Geological and Geophysical Institute of Hungary along with former Eotvos Lorand Geophysical Institute) was also involved in EU-financed research. During the private-financed 2007 – 2008 research period, the University of Miskolc, Research Institute of Applied Earth Sciences, was also involved in the project. From 2008 onwards, a wider range of minor actors have been included in research: e.g.

- Eotvos University, Budapest, Department for Petrology and Geochemistry;
- Technical University, Budapest, Department of Chemical and Environmental Process Engineering

Storage options and capacities

- aquifer storage : approx. 2 Gt
- depleted hydrocarbon fields: approx. 100 + 50 Mt
- un-mineable coal: not considered to have storage potential.

Current situation in Hungary with respect to i) current demo/pilot projects & projects/sites in preparation, ii) state of the transposition of the EU Directive on the geological storage of CO_2, iii) public awareness

There is growing agreement among stakeholders that a pilot project would significantly improve knowledge about the viability of CCS options. There is much work being undertaken to prepare for a Hungarian full chain CCS pilot project.

The EU Directive on the geological storage of CO_2 has been completely transposed into national legislation (since the end of May 2012) and has now come in to force.

Public awareness is slowly, but continuously increasing. The dramatic processes and features in climate change that were felt by the general public and that are undoubtedly related to greenhouse gas emissions have clearly changed the view and attitude towards CCS.

Summarising the state of play on CO_2 geological storage in IRELAND

(as of July 31st 2012)

National funding for research related to CO_2 storage

Funding by the Department of Communications, Energy and Natural Resources - Geological Survey of Ireland:
A joint project with the British Geological Survey is assessing storage potential of saline aquifers in the Irish Sea, with total budget of 1 M € over three years until 2014.
GSI is also funding PhD/post-doctoral research through its Griffith Awards scheme – currently there are two studentships.

Department of Education and Skills – Higher Education Authority:
PhD research projects in aspects of CO_2 storage are run through the UCD Earth Institute – currently two studentships.

A completed (2008) assessment of storage potential of Ireland was funded by the Sustainable Energy Authority of Ireland, and an assessment of storage potential in the Clare basin at the site of the Moneypoint power station (2010) was funded by the Environmental Protection Agency and GSI.

National research programmes for research related to CO_2 storage

Storage potential assessment of the Irish Sea referred to above (jointly with BGS, UK):
Earth Institute PhD programme referred to above.

Research institutions involved in research related to CO_2 storage

University College Dublin, Trinity College Dublin, Dublin Institute for Advanced Studies, through the research funding referred to above.

Storage options and capacities

All storage options currently considered are offshore (following the negative EPA onshore Clare Basin study, 2010). An all-Island Ireland assessment completed in 2008 identified the following potential: the almost depleted Kinsale Head natural gas field in the Celtic Sea Basin has a calculated practical capacity of 330Mt CO_2; Permo-Triassic basins in the Irish Sea with similar geology to the East Irish Sea gas and oil field (U.K.) have theoretical capacity. The current joint Irish Sea assessment project seeks to identify suitable closures and calculate practical capacities for these Permo-Triassic basin as well as potential sites with similar Cretaceous geology to the Kinsale Head gasfield; large but unquantified storage potential exists in the Mesozoic basins on the western shelf.

PSE Kinsale Energy Limited, operators of the Kinsale Head area gasfields, has conducted its own assessment of CO_2 storage potential of the depleted "A" sand reservoir. A capacity of 286 Mt CO_2 has been calculated to fill the main field structures, considering Kinsale Head and Ballycotton as a single storage complex, over a 60-year injection phase to return the field to its original pressure. Approximately 180 Mt could be injected over the first 30 years, which is more than adequate capacity for the emissions equivalent of Moneypoint power station (Ireland's largest point-source emitter) over the same time period.

Current situation in Ireland with respect to i) current demo/pilot projects & projects/sites in preparation, ii) state of the transposition of the EU Directive on the geological storage of CO_2, iii) public awareness

There are no current or planned demonstration or pilot projects.

Statutory Instrument No. 575 of 2011, European Communities (Geological Storage of Carbon Dioxide) Regulations 2011, was published on 18th November 2011 and it was laid before the Oireachtas on November 22nd 2011. The SI transposes Directive 2009/31/EC by prohibiting storage of CO_2 in amounts greater than 100 000 t in the territory of the State, its exclusive economic zone and on its continental shelf. The SI has not been accepted by the EC as an adequate transposition of the Directive.

Public awareness of CCS in Ireland is low, reflecting the lack of any major industrial initiatives in CCS. An awareness-raising session was held at the European Science Open Forum in Dublin in July 2012, co-convened by CGS Europe.

Summarising the state of play on CO_2 geological storage in ITALY

(as of July 31st 2012)

National funding for research related to CO_2 storage

The Italian Ministry of Economic Development (MSE) provides funding for CCS R&D activities in the framework of the National Fund "Applied Research for Electric Power System" (in short "RdS Fund"), which is fed by a very small (a few €cents per MWh) charge on the electricity bill of all customers.
In the framework of the RdS Fund, R&D activities on CCS are financed on a project basis: over the three-year period 2012 – 14, a total of 20 Mio € for CCS R&D projects has been made available, including both capture and storage.
The Sardinia Region is evaluating possibilities for the regional government to co-finance some CCS activities in the Sulcis coal basin: a demo project (with up to 1 Mt CO_2/year to be captured and stored) and a pilot project (with up to 100 000 t CO_2/year to be captured and stored).

National research programmes for research related to CO_2 storage

Italian universities and research centres started specific studies and programmes regarding various aspects of CCS over 10 years ago. Such initiatives have been financed by European (FP5, FP6, FP7) and national funding, essentially from the Ministry of University and Research and from the Ministry of Economic Development. The latter in particular, has financed a vast programme based on a strong synergy between national stakeholders that was intended to increase the competitiveness of the Italian industrial system, including by supporting Italian participation in international initiatives like the Carbon Sequestration Leadership Forum (CSLF) and the European Technological Platform for Zero Emission Fossil Fuel Power Plants (ZEP). The main projects underway are described below:

Initiatives co-funded by the Ministry of Economic Development: "CERSE PROGRAM" for R&D on the electricity system:

- Italian National agency for New Technologies, Energy and Sustainable Economic Development (ENEA) **"Coal fired power plants for electricity and hydrogen combined production project**". The main goals are: a) research on pre-combustion capture technologies and CO_2 storage (with ECBM and also CO_2 injection in deep saline aquifers); b) testing technologies on pilot installations; c) to support the national industry and research system with the aim of increasing their cooperation with a view to them playing a stronger role at the international level; d) to define the Italian national path on CCS; e) to stimulate the cooperation among national stakeholders in order to increase public acceptance.
- ENEA/SOTACARBO **"Coal gasification with CO_2 capture and storage"**. The main goals are: a) to carry out experimental activities on two main test rigs. The first one consists of a coal gasification and CO_2/H_2 separation system operating with a 30 kg/h coal feed. The second one is a 6 MWth coal gasifier. The aim of these test rigs is to qualify advanced gas cleaning and CO_2 separation processes, as well as gasification processes using mainly CO_2; b) to study real installations equipped with CO_2 capture systems, with a view to constructing a demonstrative power installation in Sardinia; c) to study the feasibility of CO_2 storage in the Sulcis coal basin.
- Ricerca sul Sistema Energetico (RSE) **"Characterization of CO_2 storage sites"**. The project has the objectives of pinpointing areas potentially suitable for geological storage of CO_2, creating a Geographic Information System for the National Inventory of Potential Storage Sites, refining calculation systems and tuning up instrumentation. The project also involves the monitoring of marine sites and activities favouring communication and outreach of CCS technology.

- ENEA **"Oxy-combustion for coal fired power installations".**
- RSE **"Development of membranes for the separation of hydrogen from syngas".**
- RSE **"Sorbent solids suitable for the capture from combustion fumes".**

Research institutions involved in research related to CO_2 storage

- Universities and research centres like ENEA, RSE Spa (Research on Energy System), OGS, Univeristà di Roma "La Sapienza", INGV, ISPRA (Institute for Environmental Research and Protection), Sardegna Ricerche, CNR Geoscienze Roma, CNR IGG Pisa, Massa spin-off, Università di Perugia, Ingegneria industriale, Sotacarbo, beside national and local government organizations.
- Diverse, technologically inclined groups, like Assocarboni, the recently founded CO_2 Club and environmentalist associations.
- Industrial companies like ENEL, ENI, Ansaldo, Carbosulcis, ITEA, Techint, Foster Wheeler.

Storage options and capacities

Saline aquifers: In Italy the geological conditions suitable for CO_2 storage are linked to its geodynamic evolution. Most of the 14 identified areas lie in the major Italian sedimentary basins, i.e. the Apennine foredeep and the Adriatic foreland, which are characterized by thick accumulations of sediments. The potential reservoirs mainly comprise permeable terrigenous deep saline formations, whose capacity ranges from 30 to more than 1 300 Mt. Based on very conservative estimates these areas would be able to contain the entire volume of CO_2 emitted in Italy for at least the next fifty years. However, this evaluation should not be considered definitive as it does not include the CO_2 potential storage in carbonate formations, which is still under investigation.

Hydrocarbon fields: Hydrocarbon production in Italy is associated with the three main tectono-stratigraphic systems:
1. biogenic gas in the terrigenous Pliocene-Quaternary foredeep wedges;
2. thermogenic gas in the thrusted terrigenous Tertiary foredeep wedges;
3. oil and thermogenic gas in the carbonate Mesozoic substratum.

The potential storage capacity of 14 depleted fields, which represent only a small proportion of the total number of Italian hydrocarbon fields, has been estimated as:
Gas reservoirs: min: 1.6 Gt; max:3.2 Gt;
Oil reservoirs: min: 210 Mt; max: 226.5 Mt.

Coal fields: The main coal basin in Italy is the so called "Sulcis Coal Basin"; it is Eocene in age and located in SW Sardinia. At present it hosts the only active Italian coal mine, the "Monte Sinni u/g" mine. Preliminary studies on coals extracted from the mine show promising developments for ECBM technologies here. Storage capacity of CO_2 by ECBM has been estimated as 42 Mt for the onshore area and 29 Mt for the offshore area giving a total estimated storage capacity of 71 Mt.

All these evaluations have been performed within the Geocapacity project, funded within EU FP6, the 6th Framework Programme of the European Community for Research, Technological Development and demonstration activities.

Current situation in Italy with respect to i) current demo/pilot projects & projects/sites in preparation, ii) state of the transposition of the EU Directive on the geological storage of CO_2, iii) public awareness

Europe, and Italy with it, is a front line competitor on CCS technologies. The research system operators are able to offer respectable competencies and resources, both in medium to long term activities and in industrial programmes. In fact, Italy is offering a wide ranging of demonstrative projects:

- ENEL has developed **the Zero Emission Porto Tolle (ZEPT) Project**; the plant will be owned by Enel Produzione and located in the Municipality of Porto Tolle, Province of Rovigo, Region of Veneto, 160 km south from Venice, Italy. It is planned that the demo CCS plant employing post-combustion capture will be installed on a USC 660 MW_e unit at the Porto Tolle power plant. The captured CO_2 will be transported by a carbon steel pipeline from an onshore pipeline terminal at Porto Tolle to an offshore injection platform through a subsea pipeline of about 100 km length. Regarding storage location, the pre-FEED studies have been based on a saline aquifer reservoir, located around 25 km from the Adriatic coast.
  The project is co-financed by European Union's EEPR (European Energy Programme for Recovery); the phase which was going to use NER funding has been temporarily suspended.
- Sotacarbo and ENEA have carried out a feasibility study for the **SULCIS project**, a commercial-scale (450 MW_e) power generation plant fed with local low rank coal and equipped with a demonstration scale (250 MW_e) CCS system (CO_2 capture and storage in the Sulcis coal basin, S-W Sardinia). The project is currently in the evaluation phase by the EC for authorizing Italian public funding.
  The aim of the project is to build and operate a 450 MW_e power generation plant strictly integrated with the Sulcis coal mine that is fed with at least 50% (lower heating value) local low rank coal and equipped with CO_2 capture and storage sections. The plant is to be equipped with a post-combustion CO_2 absorption system based on an aqueous solution of monoethanolamine (MEA). As for the CO_2 geological storage, two different technologies are proposed: storage in saline aquifers below the Sulcis coal basin and storage through ECBM (enhanced coal bed methane). Storage in the saline aquifers would involve injection of compressed CO_2 at a depth of about 1000 – 1200 m in the southern area of the Sulcis coal basin. In the same area of the basin, the ECBM technique would be tested at a depth of about 800 – 1000 m; for this, compressed CO_2 is injected into the un-mineable coal seams and is adsorbed by the mineral material, thus displacing methane.
- **ENI – Feasibility study and pilot project of injection into a depleted hydrocarbon field.** ENI has run various studies and preliminary evaluations as part of the design of surface infrastructure for CO2 injection and monitoring in the Cortemaggiore field (Piacenza). ENI has also analyzed the legal and societal aspects linked to storage here. The injection of 8000 tonnes of CO_2 per year will follow over a three-year period, followed by two years of post injection monitoring. Studies on the utilization of the CO_2 will also be run in order to increase the recovery factor from Italian hydrocarbon fields.
- **ENEL** is carrying out the **CO_2 Capture Plant – Brindisi**. The CO_2 capture plant is located in Cerano, Municipality of Brindisi, and it is integrated within area of the Federico II power plant, which is a coal power plant consisting of four units with a capacity of 660 MW_e each (total capacity 2640 MW_e). The pilot plant is designed for a nominal gas flow rate of 15 000 Nm^3/h.
  The project is co-financed by European Union's EEPR (European Energy Programme for Recovery).
- **Sotacarbo and ENEA** are carrying out activities on pre-combustion CCS and plan to realize a pre-combustion and coal to liquid zero emission pilot plant with CO_2 capture and storage.

A draft legislative decree was approved by the Council of Ministries in March 2011. This text was then discussed in the State-Regions Permanent Conference and evaluated by the pertinent Parliament Commissions. Finally, after the formal approval by the Council of Ministries (July 2011), the decree was published on the National Official Journal, in October 2011 (legislative decree no. 162/2011).
It must be stressed, however, that the legislative decree 162/2011, in its final form, refers some issues to forthcoming implementation decrees, to be issued between 6 and 24 months from that date. In particular, some of the main aspects that are not yet exhaustively clarified, refer to identifying suitable sites for CO_2 storage, the terms and conditions for transfer of responsibility to the Ministry of Economic Development after the post-closure phase, the definition of criteria which must be matched in the technical evaluation of the documentation submitted by the proponents for the exploration and storage permits, and tariffs / financial guarantees presented by the owner of the storage permit.
In order to issue these additional decrees, the Ministries involved have established several working groups, each one with specific priorities and time frames to complete the regulation framework.

Public awareness about CCS in Italy is very low (Eurobarometer, 2011) and this technology has not yet become a relevant part of the public debate on low carbon technologies. NGOs in Italy are generally not in favour of CCS, since they see it as an alternative way of prolonging coal use, which is strongly opposed at the local level, except for in the Sardinia region, where Italian coal mines are located.
Work at national level on CCS public awareness is being performed in the context of European FP7 projects while national funding resources are still to be developed.

Summarising the state of play on CO_2 geological storage in LATVIA

(as of July 31st 2012)

National funding for research related to CO_2 storage

National funding for research related to CO_2 storage is absent in Latvia.

National research programmes for research related to CO_2 storage

Special national research programmes devoted to CO_2 storage in Latvia do not exist. However, research is carried out to a minor extent within other national programmes. For example, within the state comprehensive programme of power engineering 2010 – 2013, simulation of CO_2 storage and transportation was executed by the Institute of Physical Energetics; research work in the same area was performed in a doctoral dissertation (Riga Technical University).

Research institutions involved in research related to CO_2 storage

- Institute of Physical Energetics, Riga Technical University
- Latvijas Vides Geologijas Un Meteorologijas Centrs Sia (LEGMC)

Storage options and capacities

The opportunities for CO_2 geological storage in Latvia were studied within the EU GeoCapacity project.

The existing geological data confirm that Latvia possesses the whole set of geological conditions favourable for establishment of underground storage both for natural gas and for CO_2. The potential for gas storage is confirmed by the existing Inchukalns underground gas storage, which is used for the storage of natural gas.

The main criteria for determination of prospective storage sites were as follows: the existence of a local structural high identified using seismic data, the size and depth of the trap, reservoir properties and existence of reliable caprock. Based on the geological conditions, the storage sites, which are prospective for the establishment of storage of CO_2, are situated in Western and Central Latvia, where local structural highs are widespread and where the Cambrian reservoir is developed on a regional scale. The Cambrian reservoir is represented by water-saturated sandstone which has good filtration and capacity properties and lies at an optimum depth (700 – 1168 m) with total thickness ranging from 48 m to 60 m. This is overlain by Ordovician tight clayey-carbonaceous sediments (over 40 m thick) which form a safe and impermeable (to fluids) caprock which prevents gas from migrating into the overlying deposits. As a result 16 prospective structures suitable for underground storage of CO_2 were identified – Dobele, Blidene, North Blidene, Snepele, South Kandava, Degole, Kalvene, Luku-Duku, Vergale, Edole, N. Kuldiga, Viesate, Aizpute, Usma, Liepaja, and N. Ligatne.

Thus, the assessment of CO_2 storage capacity in Cambrian deep saline aquifers in Latvia is based on evaluation of 16 individual structural traps and could be as high as 400 Mt.

Current situation in Latvia with respect to i) current demo/pilot projects & projects/sites in preparation, ii) state of the transposition of the EU Directive on the geological storage of CO_2, iii) public awareness

In Latvia there are no pilot projects and Latvia is currently not participating in any pilot projects.

The EU Directive on the geological storage of CO_2 is implemented under the Latvian legislation and confirmation from the European Union that the Latvian legislation is acceptable was received. As a consequence, CO_2 geological storage is forbidden in Latvia until 2013.

For public awareness concerning CO_2 capture and storage as an available and safe option for mitigation of influence of greenhouse on the environment, some publications (for example, Estonian Journal of Earth Sciences, Energy Procedia), have been issued. Additionally, the translation of the brochure " What does CO_2 geological storage really mean?" was carried out.

Summarising the state of play on CO_2 geological storage in LITHUANIA

(as of July 31st 2012)

National funding for research related to CO_2 storage

There is no official CCS research programme in Lithuania. For the moment being there is one ongoing research project financed by Ministry of Environment. Budget: 40 000 €. Duration: 2011 – 2012.

National research programmes for research related to CO_2 storage

Project title: "Inventory of previously obtained geophysical data"
Objectives: collect and analyse geophysical data previously obtained from the sites prospective for geological storage of CO_2 in Lithuania.
Institution: Geological Survey of Lithuania.

Research institutions involved in research related to CO_2 storage

- Nature Research Centre (Gamtos tyrimu institutas) (GTC),
- Geological Survey of Lithuania (LGT),
- Kaunas Technological University (KTU).

Storage options and capacities

The potential capacity for geological storage of CO_2 in Lithuania (onshore and offshore) is assessed as being rather minor due to (1) absence of sufficiently large structural straps (due to the cratonic setting of the Baltic basin) and conflict of interests (priority is given to underground gas storage as regards the most prospective structures) and (2) high risk related to specific structural setting of major structures (they are fault-controlled).
The alternative technology of mineral carbonation using ultramafic rocks is being investigated (by KTU, GTC).

Current situation in Lithuania with respect to i) current demo/pilot projects & projects/sites in preparation, ii) state of the transposition of the EU Directive on the geological storage of CO_2, iii) public awareness

At present there are no prospects in view with regards to demo/pilot projects or sites in preparation.

The EU Directive on the geological storage of CO_2 was fully implemented in 2011.

The public awareness on CCS in Lithuania is close to zero due to poor geological conditions for geological storage of CO_2; in other words there are no reasons for public interest. If implementation of geological storage was proposed in Lithuania, high public opposition is expected based on experience from nuclear waste disposal proposals and similar studies.

Summarising the state of play on CO_2 geological storage in THE NETHERLANDS
(as of July 31st 2012)

National funding for research related to CO_2 storage

CO_2 storage-related research in the Netherlands is funded through the national programme CATO2 (CO_2 Afvang, Transport en Opslag – CO_2 capture, transport and storage) that is coordinated by TNO and runs until the end of 2013 (for PhD research until the end of 2014). The total funding of the five-year programme is around 62 Mio €, of which half is financed by the Dutch government (through AgentschapNL). The other half is financed by industrial partners and through own funds of the research institutes.
Besides the national programme, individual research institutes, universities and companies also take part in various EU projects.

National research programmes for research related to CO_2 storage:

The national research programme CATO2, coordinated by TNO and running from 2009 – 2013 (2014 for PhD research), is the national programme on CCS. It is a demand driven and flexible programme with partners from industry, SMEs, universities and NGOs. The objectives are:

- to build a strong knowledge network for CCS;
- to facilitate the integrated development of CCS demo sites in The Netherlands;
- to work on innovation for new CCS generations.

The programme consists of five subprojects (plus a coordination task), covering the complete CCS chain:

- Capture
- Transport and chain integration
- Storage & monitoring
- Regulation and safety
- Public perception.

Each subproject is coordinated by different partners. Subproject 3 on storage and monitoring is coordinated by TNO. More information can be found on www.cato2.nl.

Research institutions involved in research related to CO_2 storage

Research institutes involved in CATO2, particularly in subproject 3 on CO_2 storage and monitoring, are: TNO (coordinator), Delft University of Technology, University of Utrecht, VU University Amsterdam, The Energy Research Centre of the Netherlands (ECN).

Furthermore large industrial partners involved in CATO2, particularly in subproject 3 on CO_2 storage and monitoring, include: Shell, E.ON, RWE, Electrabel GDF-Suez, TAQA, EBN, Wintershall, Schlumberger.

And smaller partners include: Panterra, IF, DAP and the Rotterdam Climate Initiative.
A full list of participants to CATO2 can be found at www.cato2.nl.

Storage options and capacities

In the Netherlands storage in depleted hydrocarbon fields can be considered as the most important option. Several studies have been carried out, a good overview can be found in the EBN-Gasunie report entitled "CO_2 transport – en opslagstrategie" (in Dutch). This paragraph summarizes the data in this report.
It must be noted that besides total (theoretical) storage capacity, a number of scenarios have been developed to match CO_2 sources and sinks in time for specific regions in the Netherlands (West Netherlands and North Netherlands).

The estimated capacities for the depleted hydrocarbon fields, the most important option for the Netherlands, are: The total effective capacity offshore for the Netherlands in depleted gas and oilfields is estimated at about 1 160 Mt CO_2. Additionally about 110 Mt CO_2 could be stored onshore in the Westen part of the Netherlands in depleted hydrocarbon fields. For the Northern part of the Netherlands a total capacity of about 850 Mt in depleted gasfields is estimated (excluding the large Groningen gasfield, where production is expected to continue until approximately 2070 !). It must be noted that most of this capacity consists of gasfields currently still in production, expected to gradually become available over the next 20 years.

For undepleted aquifer storage, estimated capacities have a much larger uncertainty. Figures estimated by TNO in 2007 are in the order of 430 Mt CO_2. However, a large part of this capacity is in relatively minor structures (< 5 Mt) making the option less cost-effective. Only four structures of 30 Mt or more were identified, of which one lies onshore. This reduces the estimated total capacity in undepleted aquifers to about 150 – 70 Mt CO_2. A larger potential might be available in aquifers underlying known gas and oilfields, partially depleted through gas and oil production. A good example is the aquifer in the offshore Q1 block, where an estimated 100 Mt CO_2 could be injected and stored until the original formation pressure is restored. Other similar aquifers require further study.

The option of EOR is not considered to have much potential for the Netherlands, TNO estimated a capacity of only 7 Mt CO_2, excluding the larger Schoonenbeek field. The application of CO_2-EOR would require further site-specific studies.

Options for storage in coal layers in the Eastern and Southern part of the Netherlands are also marginal, TNO estimated a theoretical capacity of 50 – 60 Mt CO_2. However, the technical feasibility requires more research.

Finally the option of salt caverns has also been considered. These caverns are mostly used for salt production or temporary gas storage (peak shavers). A theoretical capacity of 40 Mt CO_2 is estimated, but this would be spread over more than 100 caverns.

Current situation in the Netherlands with respect to i) current demo/pilot projects & projects/sites in preparation, ii) state of the transposition of the EU Directive on the geological storage of CO_2, iii) public awareness

In the Netherlands the following pilots are all fully operational for CCS (including capture):

- CAPTURE: CATO catcher (E.on, post combustion),
- CAPTURE: Buggenum pilot (Nuon, pre-combustion),
- STORAGE: K12-B pilot (GdF Suez, offshore re-injection of CO_2 in a nearly depleted gasfield).

Concerning the first storage pilot project K12-B, the reservoir lies at a depth of approximately 3800 m below mean sea level in the Dutch sector of the southern North Sea. The temperature at that depth is about 128°C. The K12-B Field has produced 12 billion m^3 of gas, about 90% of the initial gas in place (GIIP). Through production, the initial reservoir pressure of 400 bar has dropped to less than 40 bar. The top seal of the K12-B reservoir is provided by the Zechstein Group, which consists of a thick evaporitic sequence dominated by rock salt. The reservoir is compartmentalized by sealing faults. After an injection test in 2004, continuous injection started in 2005, with the total amount of CO_2 injected to date (2012) reaching about 80 kt. Note, that the field is still producing gas as well.

Furthermore, near the coast of Rotterdam, it is planned that CO_2 storage in the depleted gasfield P18-4 will start in 2015 as one of the six indicated European EEPR demonstration projects. This project is generally referred to as the ROAD project. ROAD (a Dutch acronym for Rotterdam Capture and Storage Demonstration project) is a joint project by E.ON Benelux and Electrabel Nederland/GDF SUEZ Group and is financially supported by the European Commission and the Dutch state.
A post-combustion carbon capture unit will be retrofitted to E.ONs' Maasvlakte Power Plant 3 (MPP3), a new 1100 MW_e coal-fired power plant in the port of Rotterdam. The capture unit has a capacity of 250 MW_e equivalent and aims to capture 1.1 million tonnes of CO_2 per year. A 20 km long insulated pipeline will be constructed to the existing offshore platform operated by TAQA and an existing well will be worked over and re-used for injection. Natural gas production in the P18-4 field is projected to end just before the start of the CO_2 injection.
Current status of this project is that it is waiting for a financial investment decision from the industrial partners. In terms of license applications, a provisional storage license has been provided, that has been approved by the European Commission (the first of its kind).

A number of onshore demonstration projects has been initiated and prepared in the Netherlands over the last few years, including storage in the depleted gasfield of Barendrecht by Shell, storage below coal layers in the Limburg area (on the DSM industrial terrain Chemelot) by DSM and storage in the depleted gasfields Boerakker, Eleveld and Sebaldeburen in the Northern part of the Netherlands. However, mainly due to the lack of public support, onshore storage has stalled for the moment, since sufficient offshore storage capacity is available. Probably, Barendrecht is the most well-known case study currently available for its issues around public acceptance.

One application has been submitted for the first round of the NER 300 funds, namely Air Liquides Green Hydrogen project (GHP). This project concerns the design, construction, and operation of CO_2 capture plant from a stream of a hydrogen plant located at Rozenburg in the municipality of Rotterdam, followed by the transport and storage of the CO_2 captured to a Dutch depleted gas field. Very recently this project has been listed third in the first outcomes of the evaluation of the NER 300 applications by the European Commission.

Concerning the status of the legislation, in September 2011 the Mining Act and subordinate legislation were amended in order to implement the EU Directive on the geological storage of CO_2 and the OSPAR Decision 2007/2. The Act of June 6th 2011 on the amendment of the Mining Act and the Decree of August 29th 2011 on the amendment of the Mining Decree came into force on September 10th 2011. Subsequently, the Regulation of September 13th 2011 on the amendment of the Mining Regulation came into force on September 16th 2011.

Summarising the state of play on CO_2 geological storage in NORWAY

(as of July 31st 2012)

National funding for research related to CO_2 storage

The CLIMIT programme (www.climit.no) manages two funding schemes, with a total of nearly NOK 200 million at their disposal in 2010:

- "Pilot and demo" administered by Gassnova: A gas technology fund of NOK 2 billion was established by the Storting in 2004 to secure the funding of Gassnova's financial allocations to pilot and demonstration projects. The annual returns of the fund are in the order of NOK 82 million.
- R&D activities administered by the Research Council receive annual national budget allocations. For 2010 this amounted to NOK 100 million.

National research programmes for research related to CO_2 storage

In addition to funding by the CLIMIT programme (see above), two centres for environmental-friendly energy research (CCER) have been established dealing with CCS:

BIGCCS – www.sintef.no/Projectweb/BIGCCS
Project period: 2009 – 2016
Project Budget: 400 MNOK
22 international partners.
The vision of the BIGCCS Centre is to enable sustainable power generation from fossil fuels based on cost-effective CO_2 capture, safe transport, and underground storage of CO_2. The BIGCCS Centre is set to achieve the following goals: 90% CO_2 capture rate, 50% cost reductions, less than six percentage points fuel-to-electricity penalty compared to state-of-the-art fossil fuel power generation. The BIGCCS Centre develops new knowledge and technology required to accelerate deployment of large scale CCS, through international co-operation. Innovation and value creation is promoted throughout the CO_2 value chain. Research areas include CO_2 capture, CO_2 transport, CO_2 storage, and the CO_2 value chain.

FME SUCCESS – www.fme-success.no/index.cfm
The SUCCESS centre addresses several important areas for CO_2 storage in the subsurface: storage performance, sealing properties, injection, monitoring and consequences for the marine environment. The "CO_2-School" is in addition a major educational program. The selected activities will involve fundamental experimental and theoretical work, analysis of samples from outcrops and case studies, development of mathematical models, modelling activities and testing in case study environments. The centre will as far as possible try to bridge gaps from details to concepts and applications, from small to large scale, and to transfer data and knowledge between many related fields.

Research institutions involved in research related to CO_2 storage

Major:

- SINTEF Energy AS & SINTEF Petroleum Research AS (www.sintef.no),
- IRIS International Research Institute of Stavanger (www.iris.no),
- NIVA Norwegian Institute for Water Research (www.niva.no),
- NGI Norwegian Geotechnical Institute (www.ngi.no),
- CMR Christian Michelsen Research (www.cmr.no),
- IFE Institute for Energy Technology (www.ife.no),

- Det norske Veritas (www.dnv.com),
- Tel-tek (www.tel-tek.no),
- Centre for Integrated Petroleum Research **(**CiPR; www.cipr.uni.no).

Minor:

- University of Bergen,
- University of Oslo,
- University Centre of Svalbard,
- NTNU Norwegian University of Science and Technology,
- Høgskolen i Telemark,
- Geological Survey of Norway (NGU).

Storage options and capacities

All potential storage sites are located offshore, and include deep saline aquifers as well as both depleted and producing (EOR) oil and gas fields. The total storage capacity of the evaluated DSAs is 45.4 Gt. The estimated capacity in depleted fields is about 3 Gt. Source: Norwegian Petroleum Directorate – CO_2 Storage Atlas (see www.npd.no/Templates/OD/Article.aspx?id=4046&epslanguage=en).

Current situation in Norway with respect to i) current demo/pilot projects & projects/sites in preparation, ii) state of the transposition of the EU Directive on the geological storage of CO_2, iii) public awareness

Current demo/pilot projects and projects/sites in preparation comprise:

- Sleipner: Since 2006, 1 Mt/year of CO_2 has been injected at ca. 800 m below sea level (mbsl) into the Utsira sandstone.
- Snøhvit: Injection of 0.7 Mt/year of CO_2 since 2008, first into the into Tubåen sandstone then into the Stø formation ca. 2 500 mbsl.
- Longyearbyen CO_2 Field Laboratory, Svalbard: Under pressurized, fractured reservoir of marine sandstone layers at 670 – 90 m depth. The facility includes a well park of six smart wells and extensive permanent monitoring equipment. Water injection tests have been performed, gas injection tests are planned in 2013.
- Svelvik CO_2 Field Laboratory: Small-scale field laboratory to study CO_2 migration (not storage) in the shallow subsurface (20 m and 100 m).

Regulatory aspects are summarised from Bugge & Ueland (2011): Norway is widely supportive of carbon capture and storage (CCS) technologies as a climate change mitigation measure, both at the national and international level. The country benefits from a large offshore CO_2 storage capacity in its North Sea continental shelf (i.e. saline aquifers and depleted oil and gas fields) which could exceed its storage needs and provide storage opportunities to neighbouring EU countries. Norway has been a pioneer in developing the first 'full' CCS projects at the Sleipner (1996) and Snøhvit (2008) offshore natural gas fields.

In 2009, Norway started the process of developing the necessary rules and regulations to implement the provisions of the Directive within its national legal system. A royal decree of March 13th 2009 refers to the Directive and states that the government aims to develop rules comparable with the Directive's regime. As of 2011, there is no comprehensive legislation regarding CCS in Norway. Apart from some minor amendments to existing laws, no dedicated legislative work has been undertaken to regulate this technology. This may be partly due to the fact that the most relevant existing acts applicable to CCS seem to provide a sufficiently broad legal basis for more specific regulations, if necessary.

These are: the 1963 Act on Research, Exploration and Exploitation of other Natural Resources than Petroleum on the Ocean Floor (hereafter 'the Continental Shelf Act'); the 1981 Pollution and Waste Act; and the 1996 Petroleum Activities Act.

According to Ryvik (2011) the Norwegians' attitudes towards CCS in Norway were investigated in a Gassnova-sponsored master thesis by A. Berg-Hansen, Institute of Psychology at the Norwegian University of Science and Technology (NTNU). Most Norwegians are neither especially positive nor negative towards CCS. Berg-Hansen is of the opinion that many Norwegians have not yet made up their minds about CCS, and that people are not well-enough informed.
People perceive the benefits of CCS as fairly moderate, but the risk is perceived as below average, and lower than in other countries where such surveys have been conducted. While personal risk is perceived as lowest, the profit to society scores highest. This might have to do with the fact that Norway wants to store CO_2 in the North Sea instead of on land. Nonetheless, the Norwegian public has more faith in solar energy, wind power and energy-saving equipment to help us curb climate change.

Summarising the state of play on CO_2 geological storage in POLAND

(as of July 31st 2012)

National funding for research related to CO_2 storage

Polish Ministry of Environment is funding the national programme "Assessment of formations and structures suitable for safe CO_2 storage including monitoring plans" by 100% (about 7 Mio €, excl. V.A.T.). Also the Ministry funds a smaller project "Research programme on enhanced oil and gas recovery for domestic fields with the use of underground CO_2 injection".

A pilot injection project on the assessment of injectivity of a Jurassic aquifer in central Poland was expected to be funded by nine Polish energy companies (some minor input was already provided in the frames of the national programme on preparing geological permit/geological study) but one partner withdrew and the project is being revised.

PGE Bełchatów has been funding 100% of the research necessary for the first stage of the storage part of their demonstration project (some part is to be reimbursed by the EEPR grant but the research contract has been paid by PGE's own funds anyway), i.e. site screening, selection, evaluation and ranking (PGI-NRI involved, Schlumberger, and to a lesser extent other Polish research partners).

Prefeasibility studies on storage component of "CCS ready" (with research activities to some extent) are ordered and paid for totally by various operators of power plants.
Also research institutions (e.g., PGI-NRI, MEERI, AGH-UST) use funding provided by Ministry of Science and Higher Education in their statutory activities or research grants related to geological storage of carbon dioxide.

National research programmes for research related to CO_2 storage

The four-year (X 2008 – IX 2012) national programme "Assessment of formations and structures for safe CO_2 geological storage, including monitoring plans", ordered by Ministry of Environment, is being carried out by a consortium consisting of PGI-NRI, AGH UST, CMI, OGI, MEERI PAS and PBG. The strategic goal of the national programme, covering practically the whole territory of Poland and the Baltic economic zone, is to deliver to the Ministry information necessary for future permits after full implementation into national law of the EU directive on geological storage of carbon dioxide. Also an important goal was to provide a "kick-off" for two Polish demo projects planned in 2008 (PGE Bełchatów, ongoing, and PKE-ZAK Kędzierzyn, cancelled in the meantime).

The scope of the national programme covers a number of aspects, not only geological studies. The geological part consists of regional and case studies, based on archive data and available drill cores. The methodology utilised by EU-funded projects (JOULE2, GESTCO, CO_2STORE, EU GeoCapacity, etc.) has been used.
The regional studies (eight subprojects on areas of specific geology for saline aquifers, one subproject for hydrocarbon fields and one for coalbed methane fields) include the following packages:

- evaluation of formations and structures suitable for geological storage of CO_2;
- elaboration (update) of CO_2 sequestration capacity for Poland (including GIS);
- elaboration of 3-D models of reservoir and caprock formations;
- analysis of tectonic zones;

- petrological and petrophysical laboratory analyses of rock samples (new analyses and the use of available archive ones);
- hydrogeological characterisation of aquifers and properties of reservoir fluids, including CO_2-rock-brine analyses;
- determining areas excluded from the viewpoint of CO_2 sequestration;
- 3-D models of sequestration systems, zones and structures of optimal properties;
- assessment of propagation of injected CO_2 within reservoir fluids for selected areas;
- elaborating databases;
- recommending of localisation of CO_2 storage sites.

The case studies (four for saline aquifers, three gas fields and one oil field, one coalbed methane field) include preliminary characterization of possible storage sites, to be used by ongoing and future demo and industrial projects:

- collection of detailed geological, geophysical, hydrogeological, reservoir and geomechanical data;
- building detailed static geological earth models for the storage complexes;
- dynamic simulations of CO_2 injection processes (incl. leakages) within the storage complexes;
- preliminary risk assessment for CO_2 geological storage;
- establishing the baseline monitoring plan for the storage site, and assumptions for operational and post-closure monitoring.

Other activities include generation of information essential for public acceptance of geological storage of CO_2 (meetings and seminars with local authorities, journalists and NGOs; brochures, papers, website, interviews, etc.).

Last, but not the least, there is a general workpackage on coordination, contacts with partners beyond the consortium, dissemination of results, advice on implementation of the Directive on geological storage of carbon dioxide in Poland, maintenance of the project website, data standardisation and quality control.

Research institutions involved in research related to CO_2 storage

Currently, the major research institution in CCS is the Polish Geological Institute – National Research Institute (PGI-NRI). The minor ones, though not unimportant, are: AGH University of Science and Technology (AGH UST), Central Mining Institute (CMI), Mineral Economy and Energy Research Institute of Polish Academy of Sciences (MEERI PAS), Oil and Gas Institute (OGI) and PBG Geophysical Exploration Company Ltd. (PBG)

Storage options and capacities

Storage options being considered are saline aquifers (principal option), depleted hydrocarbon fields (far less important) and un-mineable coalbed methane fields (marginal).
Ongoing research of the National Programme and other projects provides the following conclusions:

- CO_2 storage capacity of Poland is sufficient in terms of realistic capacity (equals over 50 years of ETS emissions, or about 11 Gt); the matched ("exploitable") capacity is explored in case studies for a few sites only;

- The most of usable storage potential is located onshore (over 95%), a small part offshore – mostly in eastern part of Polish sector of Baltic sea, in westernmost part NATURA2000 protected areas would prevent any storage;
- Saline aquifers offer about 89% of the total storage capacity (or almost 10 Gt) – these are Lower and Middle Jurassic (the most important), locally Lower and Upper Triassic, Lower Cretaceous, Middle Cambrian, Upper Carboniferous and Miocene (ranked in relation to coverage and properties). All of them appear onshore, the only usable offshore aquifer is of Middle Cambrian age.
- Depleted hydrocarbon fields offer rather limited storage capacity and EHR (enhanced hydrocarbon recovery) potential. Oil fields are rather small and only a few could be used for EOR. Gas fields are slightly larger but their potential is insignificant compared to saline aquifer structures. Hydrocarbon fields represent about 10% of the country's realistic storage capacity or about 1 Gt (gas fields about 90%, oil fields no more than 10% of the previous figure).
- Un-mineable coalbed methane fields only have potential for storage in a small part of Polish Upper Silesian Coal Basin and their realistic storage capacity is about 1% of the total CO_2 storage capacity of Poland.

Current situation in Poland with respect to i) current demo/pilot projects & projects/sites in preparation, ii) state of the transposition of the EU Directive on the geological storage of CO_2, iii) public awareness

One demo CCS project is being developed in Poland – PGE Bełchatów where a new CCS-ready 858 MW block was completed in 2010 (1.8 Mt CO_2 per year will be captured which is equivalent to 250 MW). It is anticipated that the basic CCS chain infrastructure will be built by 2016. The phase of site screening, evaluation and selection was completed by February 2012 and the contractor for management of site characterization phase is being selected. A contractor to provide the technical blueprint for the CO_2 pipeline from the power plant to the storage site was chosen (relevant contract signed in July 2012).

A pilot injection project on assessment of injectivity of Jurassic aquifer in central Poland was expected to be funded by nine Polish energy companies but one of the stakeholders withdrew and the project is being revised. In May 2011 geological permit on drilling and CO_2 injection was awarded by Ministry of Environment. The wells would be placed within real estate owned by PGI-NRI.

The Ministry of Environment, the competent authority in Poland, prepared the first assumptions for the Directive transposition in November 2009. After public consultation and consultations with ministerial agendas the assumptions were presented to the cabinet in March 2010. After several revisions the assumptions were accepted by the government in February/March 2011. Then National Legislative Centre has prepared a draft of actual law in summer 2011. However, in October 2011, the parliamentary elections took place. After consultations between the National Legislative Centre, the Ministry of Environment and the Ministry of Economy, the proposal has been published on the Ministry of Environment website. Thus, presumably the law will be presented to the Parliament by the end of this year (2012). The law consists of an amendment of the geological and mining law and, to a lesser extent, other laws: environmental protection, environmental impact information, energy, economic activities, etc. Storage is allowed for demo projects only (excluding research, as in the Directive) until 2024.

The status of public awareness is as unsatisfactory. A couple of NGOs are still disseminating the case of the Lake Nyos eruption as an analogue for potential risks associated with geological storage of CO_2. Fortunately, in the area of the demo project (central Poland) the positions adopted by local authorities and residents are more diverse and it appears that the opponents of CCS are the minority, though a very loud one.

Summarising the state of play on CO_2 geological storage in PORTUGAL
(as of July 31st 2012)

National funding for research related to CO_2 storage

CO_2 storage related research in Portugal is funded through the participation of research institutes, universities and companies in EU projects.

National research programmes for research related to CO_2 storage

There are no specific Portuguese research programmes to support studies related to CO_2 storage.

Research institutions involved in research related to CO_2 storage

- Laboratório Nacional de Energia e Geologia (LNEG)
- University of Évora
- University of Lisbon – Science Faculty
- University Fernando Pessoa

Storage options and capacities

The storage capacity in Portugal is mainly located in deep saline aquifers, since there are no exploited oil and gas fields, and coal seams only exist in a very restricted area. The total storage capacity of the saline aquifers is estimated to be in the range of 3.8 to 7.5 Gt of CO_2, enough to store more than 100 years of the current national CO_2 emissions. Three sedimentary basins along the coast represent 95% of the total storage capacity in:

- the *Porto Basin* with a total area of 2 150 km^2. It is located entirely offshore in the North West of Portugal. It has an estimated storage capacity of 1.0 – 2.1 Gt CO_2.
- the *Lusitanian Basin* with a total area of 22 000 km^2, the basin occurs both onshore and offshore, along most of the western coast of the country. It has an estimated storage capacity between 2.1 and 4.2 Gt CO_2.
- the *Algarve Basin* with a total area of 8500 km^2 which occurs both onshore and offshore along the Southern coast of Portugal. The estimated storage capacity is 0.7 to 1.2 Gt CO_2. This transboundary basin continues into Spanish territory where it is called the Cadiz basin.

An interesting point is that although onshore storage opportunities are limited (around 0.2 – 0.3 billion tonnes), they are located close to a large number of industries that emit a lot of CO_2. Therefore, they could prove of strategic importance for industrial-scale demonstration of CCS in Portugal.

Current situation in Portugal with respect to i) current demo/pilot projects & projects/sites in preparation, ii) state of the transposition of the EU Directive on the geological storage of CO_2, iii) public awareness

Preliminary contacts have been made to propose a future pilot project in Portugal. No funds sre currently available.
In March 2012, Portugal transposed the EU Directive on the geological storage of CO_2 at the national level.
There are no major concerns related to public awareness.

Summarising the state of play on CO_2 geological storage in ROMANIA

(as of July 31st 2012)

National funding for research related to CO_2 storage

The Ministry of Economy, Trade and Business Affairs has funded research related to CO_2 storage through two projects, "National Programme for Carbon Capture and Storage (CCS) time horizon 2020" (2010 – 2011) and "Optimal integration of CCS technology" (2012).
The National Authority for Scientific Research has also funded a project called "Identification of suitable geological structures for storing carbon dioxide in Romania. Establishment of proper methodology" starting in 2009 within the Scientific Core Programme of GeoEcoMar (National Institute of Geology and Geo-ecology).
Research related to CO_2 storage was also budgeted in several commercial contracts between GeoEcoMar and ISPE (Institute for Studies and Power Engineering) including "Identification of storage possibilities for the CO_2 emitted by Rovinari and Isalnita power plants" and "Feasibility Study for GETICA CCS".

National research programmes for research related to CO_2 storage

The "National Programme for Carbon Capture and Storage (CCS) time horizon 2020" project (2010 – 2011) investigated the legislative, economic and scientific aspects of implementing CCS technology in Romania. This project's main results were the submission of a NER 300 application for GETICA CCS and a road map for CCS implementation.

Under the "Identification of suitable geological structures for storing carbon dioxide in Romania – establishment of proper methodology" project, it is intended that a detailed screening of the storage possibilities for every sedimentary basin in Romania will be carried out and that the relationship between CO_2 sources and possible storage sites will be assessed. Guidelines for monitoring will be prepared in which investigation of natural analogues will be included. No website is available.

Research institutions involved in research related to CO_2 storage

- National Institute of Geology and Geo-ecology – GeoEcoMar,
- University of Bucharest, Faculty of Geology and Geophysics,
- University of Ploiesti.

Storage options and capacities

For Romania only saline aquifers and depleted oil and gas fields have been found to offer suitable storage options. The storage capacity is considered sufficient to store emissions for many years and was estimated to be 18.6 Gt in saline aquifers and 4 Gt in depleted hydrocarbon fields.

Current situation in Romania with respect to i) current demo/pilot projects & projects/sites in preparation, ii) state of the transposition of the EU Directive on the geological storage of CO_2, iii) public awareness

Romania has submitted an application for NER 300 funding for the GETICA CCS demo project. This project is currently ready to begin the appraisal phase (due to lack of funding the appraisal phase has not started).

The EU Directive on the geological storage of CO_2 has been transposed into Romanian legislation through Government Emergency Ordinance no 64 as of 2011.

Several social studies have been conducted, especially in the area of GETICA CCS project (around Turceni power plant) in order to inform the local people about the project and to analyse the degree of CCS awareness and acceptance. The conclusion of these studies was that the awareness is low, but people are still receptive to the idea of carbon capture and storage.

Summarising the state of play on CO_2 geological storage in SERBIA

(as of July 31st 2012)

National funding for research related to CO_2 storage

There is no funding in Serbia.

National research programmes for research related to CO_2 storage

No national research programmes.

Research institutions involved in research related to CO_2 storage

There are no major research projects related to CO_2 storage. There is a Ph.D. being undertaken at the Faculty of Ecology and Environmental Sciences, Belgrade, relating to CCS. All research is being performed by the Association of Geophysicists and Environmentalists (AGES) through the CGS Europe Project.

Storage options and capacities

No storage options defined.

Current situation in Serbia with respect to i) current demo/pilot projects & projects/sites in preparation, ii) state of the transposition of the EU Directive on the geological storage of CO_2, iii) public awareness

There is no activity in Serbia related to CO_2 storage. AGES representatives are promoting the idea of CCS at the Ministry of Energy and through media, but there is no political appetite yet.

Summarising the state of play on CO_2 geological storage in SLOVAKIA

(as of July 31st 2012)

National funding for research related to CO_2 storage

The governmental organisation funding research related to CO_2 storage is the Ministry of Environment of the Slovak Republic. The aggregate sum is below 1 Mio €. A small amount of funding was also gained from the sector of industry – metallurgy, ammonium production (30 000 € in total). The attempt to gain funding from the other sources (e.g., Ministry of Education of Slovakia and other sector of industry) has been unsuccessful.

National research programmes for research related to CO_2 storage

The national research programme is now attenuated due to the fact that the national project regarding CO_2 storage has finished. Nowadays, only one project is funded from governmental sources that deals with mineral carbonation in suitable rocks and waste disposal.

Research institutions involved in research related to CO_2 storage

The main research institution in Slovakia is the State Geological Institute of Dionyz Stur. They have an excellent cooperative link with a private company, the Nafta Bratislava plc, which participated in the national research programme by offering data from depleted hydrocarbon fields and their hydrocarbon processing facilities for CO_2 storage research.

Storage options and capacities

Storage options comprise regional aquifers and deleted hydrocarbon fields.

The potential storage capacities calculated for the GeoCapacity project are as follows:

- Regional aquifers ……1 716 Mt
- Depleted hydrocarbon fields…… 134 Mt

These data represent pessimistic estimated capacities which are believed to be more realistic than optimistic estimates based on geological experience in the basin.

Current situation in Slovakia with respect to i) current demo/pilot projects & projects/sites in preparation, ii) state of the transposition of the EU Directive on the geological storage of CO_2, iii) public awareness

The situation in Slovakia regarding CCS is a little awkward: there is an approved and valid national law concerning CO_2 storage, storage is not prohibited, but this law will be not serve its purpose because pilot project stage cost is unbearable for the current economy (there is an issue with obtaining co-financing). Additionally, the industrial sector is indifferent towards CCS as reflected by the very low prices of the carbon market. It is expected that more concrete activities for CO_2 storage lie more than perhaps ten years ahead.
In the framework of the CGS Europe project four potential future pilot sites were proposed in Slovakia selected together with Nafta Bratislava plc.

Public attitude is inert because pilot/demo CCS projects are not imminent.

Summarising the state of play on CO_2 geological storage in SLOVENIA

(as of July 31st 2012)

National funding for research related to CO_2 storage

In Slovenia, there is no national programme on geological storage of CO_2. Up to July 2012, the research activities were limited to an industrial initiative (mostly formulated by the power plant and the coalmine operators) through the project "Implementation of Climate and Energy Package into Slovenian Thermoenergetics". This complex project incorporated many aspects of reducing the emission of greenhouse gases: the entire CCS chain, implementation of the European legislation, potential cooperation with related international platforms and communication plan for CCS. Not all project tasks have been realised to date.

National research programmes for research related to CO_2 storage

In the above mentioned project "Implementation of Climate and Energy Package into Slovenian Thermoenergetics", one of the project tasks was "Possibilities of Geological Storage of CO_2 in Slovenia and Outside Slovenia". This project task was realised in the period November 2009 – December 2011. There have been no further activities related to CO_2 storage since that time.

Research institutions involved in research related to CO_2 storage

Research institutions involved in CO_2 geological storage issues come from public and private sector:

- Geoinženiring d.o.o.,
- Geological Survey of Slovenia,
- ERICO d.o.o.,
- Nafta Geoterm d.o.o.,
- HGEM d.o.o,.
- University of Ljubljana – Faculty of Natural Sciences and Engineering.

Storage options and capacities

Slovenia's storage options were first assessed in 2006 in the frame of CASTOR project. The potential storage capacities were assessed more precisely within EU GeoCapacity project (2006 – 2009). The national storage potential was evaluated in the frame of the national project 2009 – 2011 (see above).
Seven major (i.e. emitting > 100 000 t CO_2 /year) stationary emitters were identified: three of them were power plants and the remainder were from the manufacturing sector (cement, paper & pulp, metal). The largest point source emitted approximately 4.8 Mt CO_2 /year (2008). Total annual CO_2 emissions from point sources were around 7 Mt/year. The existing pipeline infrastructure in Slovenia is relatively favourable. No economic factors, potential conflicts of use, public acceptance or safety conditions have been considered and/or assessed to date. Slovenia's geological features are rather complex, particularly from a structural and tectonic point of view.

In EU GeoCapacity, the effective storage capacity available in aquifers was estimated to be 92 Mt. However, few reliable data were available for the calculations for each particular aquifer. The individual structures are relatively small and scattered. In the national project, the potentiality of Slovenian territory was indeed studied for all most prosperous regions and structures. However, the storage capacity was evaluated only on a theoretical level for three individual locations (Pečarovci, Dankovci and Besnica structure). Their total theoretical storage capacity was approximately 63 Mt. Both studies concluded that

further investigations would be required in order to confirm and to improve the storage capacity assessment of individual fields.

The most reliable data were available for the assessment of storage capacities in hydrocarbon fields. The two most prosperous locations were identified in NE Slovenia: oil and gas fields Dolina and Petišovci. Their total capacity lay between 1.8 – 5.3 Mt. Some additional formations would be potential tasks for further CO_2 storage-related studies.

Despite the fact that Slovenia is a relatively well-developed coal province with a long mining tradition, the prospects for CO_2 storage in un-mineable layers and/or ECBM are limited due to several reasons. Different studies gave capacities ranging 0 – 100 Mt. The more conservative figures are more likely to be realistic, because low permeability and swelling effects (clearly identified for the Velenje lignite within MOVECBM project) were not taken into consideration, when these calculations were made. Some attention and further investigation may consider the coal layers in the Mura formation in NE Slovenia as these may have some potential.

The conclusions from the EU GeoCapacity study stated that the effective storage capacity of 94 Mt could basically accommodate all stationary emissions in the country for about 13 years. However, the individual structures are relatively small and are therefore less appropriate for energy sector. Their suitability for emitters in the range of (few) 100 000 t/year would need to be examined.

Current situation in Slovenia with respect to i) current demo/pilot projects & projects/sites in preparation, ii) state of the transposition of the EU Directive on the geological storage of CO_2, iii) public awareness

Slovenia is following the global progress in the field of CCS. In particular, industrial entities are interested in the outcomes and in the knowledge gained through existing and future demo/pilot projects. According to initial investigations, the geological features would allow a small scale pilot project on the Slovenian territory to be carried out. However, no support from national authorities of any kind has been identified as yet. Moreover, past experience suggests rather long and complicated administrative procedures in licensing are to be expected.
Slovenia transposed the EU Directive on the geological storage of CO_2 in February 2012 within the novel Energy Law (EZ-E). In order to implement the Directive, a series of legal acts were prepared, which concern CCS and wider issues. A Slovenian standpoint via Dir2009/31 is that “Slovenia does not foresee and does not plan CO_2 storage capacities on its territory". However it recognize that "a need for CO_2 pipeline may arise which would a) enable connecting Slovenian manufacturing plants with storage capacities abroad and/or b) enable connecting CO_2 pipeline of two neighbouring countries". The EZ-E explicitly states the provisions and conditions to enable transport of CO_2 on Slovenian territory, the relevant authority (Energy Agency of the Republic of Slovenia), procedures in case of disputes and fines in case of trespassing the regulations. In the official comments it is also explicitly stated that no additional resources will be necessary within Energy Agency. Any environmental impacts of the transport lines are treated within the environmental Acts.

Summarising the state of play on CO_2 geological storage in SPAIN

(as of July 31st 2012)

National funding for research related to CO_2 storage

Funding of CO_2 storage research activities has been very variable over the last few years. The greatest amount of funds has come from the European Programme for Economic Recovery and, at a national level, funds have come from two main sources: the Ministry of Industry and the Ministry of Science and Innovation. The Ministry of Industry has supported several programmes for technological demonstration (CENIT, INNPACTO) and also some specific work on site selection and characterization. Total Investment of this Ministry has been around 20 Mio € over the last six years. The Ministry of Science and Innovation, now included in the Ministry of Economy, funds projects concerning basic research, lab tests, computer simulation etc. Investment has been about 10 Mio € over the last six years. It is very likely that the amount of funds available from the public sector will be decreasing in the near future.
Regarding private companies investment, the main actor in Spain has been Endesa, the power company with highest emission rates in the country. Other power companies like Gas Natural Fenosa or Iberdrola have also done some work but with much lower investment.

National research programmes for research related to CO_2 storage

Currently, no specific research programmes for CO_2 storage are underway in the country. Research in this field has to be developed under programmes about energy research or climate change abatement programmes.

Research institutions involved in research related to CO_2 storage

Major research institutions:

- **City of Energy Foundation (Ciuden)**: Created as a clean coal research foundation, it is undoubtedly the main actor in CCS research in Spain. The CO_2 storage programme includes the pilot injection at the site of Hontomín where many different aspects and technologies will be implemented.
- **Spanish Geological Survey (IGME)**: The main centre for research in Earth Sciences in Spain. IGME has developed an intensive work programme for site selection and characterization at different scales, participating both in European Projects (GeoCapacity, COMET) and following national initiatives as CENIT CO2, ALGECO2 and INNSONDA.
- **Petrophysical Institute (IPF)**: A very advanced laboratory for research on petrophysical properties of rocks, mainly focused on deep reservoirs (oil & gas and CO_2 storage)
- **Scientific Research Superior Council (CSIC)**: The main institution in Spain in all fields of basic research. Some of the institutes integrated in the Council have specific works on research related to the geological storage of CO_2, for example in geophysics.
- **AITEMIN:** A technological centre specializing in mining and environmental research. In the field of geological storage of CO_2 they have a programme on the implementation of exploration and monitoring boreholes.
- **CIEMAT**: The main research centre of Spain in the field of energy. Although most of their activity is developed around nuclear and renewable energies, they are developing some impact research in natural analogues and risk assessment relating to CO_2 storage.

Other research actors in Spain:

Several departments of Spanish universities are involved in different fields of research related to CO_2 geological storage (this list is not exhaustive): Schools of Mines in Oviedo and Madrid and several Faculties of Geology are developing studies, for example, about safety of storage, modelling or shallow aquifer protection. The Groundwater Department in the School of Civil Engineers of La Coruña have published some impact articles about CO_2 behaviour under deep geological storage conditions. The Polytechnic University of Catalonia is developing research on several hydrogeological aspects and tests, in close cooperation with Ciuden in Hontomín.

Storage options and capacities

Spain suffers an almost complete lack of native hydrocarbon resources. Oil and gas fields onshore are very small and frequently shallow with no relevance at all for CO_2 storage. There are some oil and gas reservoirs in the Mediterranean and the Gulf of Cádiz that may offer potential for storage. Storage capacity in these fields has been estimated at 150 Mt.

The main storage potential in Spain is located in deep saline aquifers. A detailed IGME study concluded that there are storage possibilities in the four main sedimentary basins (Duero, Ebro, Madrid and Guadalquivir) and in their associated mountain ranges (Cantabrian, Pyrenees, Iberian and Bethic). The total capacity has been estimated to be in the range of 7 to 22 Gt of CO_2.

The GeoCapacity project also studied the storage potential of Spanish coal basins, obtaining an estimated capacity of 200 Mt of CO_2, mainly concentrated in the North-western basins.

Current situation in Spain with respect to i) current demo/pilot projects & projects/sites in preparation, ii) state of the transposition of the EU Directive on the geological storage of CO_2, iii) public awareness

At the moment there are two projects that are being developed in Spain, although they are linked through an agreement between the two main actors, Ciuden and Endesa. Ciuden is leading the implementation of a pilot test in Hontomín (Burgos) and Endesa is in the first stages of site characterisation, having performed geophysical investigation campaigns and exploration boreholes. These two projects are considered part of the so-called Compostilla Project.

The Spanish Law on Carbon Dioxide Geological Storage was issued December 30th 2010, completely transposing the EU Directive.

Public awareness is not high in Spain. In several surveys conducted by Ciuden and CIEMAT it was stated that more than 75% of the population is not aware of Carbon Capture and Storage as a Climate Change mitigation option. On the other hand, in areas where pilot and demonstration projects are planned, Ciuden and Endesa have carried out public awareness campaigns and the result is a mostly favourable public opinion about the application of these technologies.

Summarising the state of play on CO_2 geological storage in SWEDEN

(as of July 31st 2012)

National funding for research related to CO_2 storage

- Swedish Energy Agency,
- The Swedish Research Council,
- The Swedish Research Council FORMAS.

National research programmes for research related to CO_2 storage

There are none.

Research institutions involved in research related to CO_2 storage

- University of Uppsala,
- Geological Survey of Sweden,
- The Royal Institute of Technology (KTH),
- Luleå Technical University.

Storage options and capacities

The Baltic Sea offers some storage potential; there have been various figures for capacity calculated: 100 Mt – 4 Gt, depending on what data are used in the estimates. Generally, it is suggested that there are not enough data, on for instance cap rock properties, to actually do any reliable estimates.

Current situation in Sweden with respect to i) current demo/pilot projects & projects/sites in preparation, ii) state of the transposition of the EU Directive on the geological storage of CO_2, iii) public awareness

There are no demo or pilot projects in Sweden to date. There is one abandoned geothermal well in Malmö where available data from the well has been used in the MUSTANG project during modelling.

Transposition has been completed (according to the national authorities). The new law was accepted by the Parliament in June 2012 and will come into force in early January 2013.

Public awareness of CCS is currently very low in Sweden.

Summarising the state of play on CO_2 geological storage in TURKEY

(as of July 31st 2012)

National funding for research related to CO_2 storage

University funds or TUBITAK (Turkish Scientific and Technology Council) are available for interested researchers.

National research programmes for research related to CO_2 storage

There is no specific national programme for research related to geological storage of CO_2.

Research institutions involved in research related to CO_2 storage

- Turkish Petroleum Corporation (Research and field application),
- Middle East Technical University - Petroleum Research Center,
- Izmir Technology Institute.

Storage options and capacities

The main possibilities identified presently lie in the oil fields. The only CO_2 injection currently underway is in the Batı Raman oil field for EOR. The CO_2 for EOR in Batı Raman comes from a natural CO_2 reservoir which could also potentially be used for CO_2 storage in the future.
Recently, a project to estimate storage capacities in coal mines has been completed. Estimated storage capacities are 3.7 – 13 Mt and 5.6 – 32 Mt CO_2 for the Soma and Zonguldak fields, respectively.

Current situation in Turkey with respect to i) current demo/pilot projects & projects/sites in preparation, ii) state of the transposition of the EU Directive on the geological storage of CO_2, iii) public awareness

Presently there are no demo or pilot projects and none are foreseen for the next few years. The Ministry of Environment and Urbanisation is preparing a programme for the industry to officially and centrally monitor national CO_2 emissions. This programme is expected to start in 2014 and will form a foundation for the European Trading Scheme (ETS) system.

Summarising the state of play on CO_2 geological storage in the UNITED KINGDOM
(as of July 31st 2012)

National funding for research related to CO_2 storage

The Engineering and Physical Science research Council (EPSRC) is the main UK government agency for funding research and training in engineering, physical sciences and information and communication technologies. EPSRC are investing £10 Mio over a five year period, along with £3 Mio from the Department for Energy and Climate Change (DECC) to establish the UKCCSRC – the UK Carbon Capture and Storage Research Centre (see description under National Research Programmes) who will decide on appropriate projects, some of which will be focussed on CO_2 storage.

The Energy Technologies Institute (ETI) is a partnership between global industrial partners and the UK Government. The ETI is funded 50:50 by the UK government and industrial partners, with an annual total investment of around £60 Mio per year. The ETI issues calls for CCS proposals, over the last few years there has typically been one per year relating to geological storage.

The NERC (Natural Environment Research Council) also funds projects relating to CO_2 storage e.g. the CRIUS project (homes.esc.cam.ac.uk/crius/home)

National research programmes for research related to CO_2 storage

UK CCS Research Centre (UKCCSRC; www.ukccsrc.ac.uk)
The UKCCSRC is supported by the EPSRC and is currently in its first year of operation. The aim of the UKCCSRC is to provide a national focal point for CCS research by bringing together the UK's leading CCS research centres. The founding partners are the University of Edinburgh (lead), the Universities of Cambridge, Cranfield, Durham, Leeds, Newcastle, Nottingham and Imperial College London, the British Geological Survey and the Plymouth Marine Laboratory. It is intended that the number of partners will grow to include over 100 research organisations and SMEs (Small-Medium Enterprises). CO_2 storage projects are currently being formulated for funding from the UKCCSRC.

Research institutions involved in research related to CO_2 storage

Major research institutes:

- **British Geological Survey (BGS**; www.bgs.ac.uk**)**: a major player in CO_2 storage research, with involvement in many of the large EU funded research projects
- **Scottish CCS (SCCS**; www.sccs.org.uk**)** is a partnership of the British Geological Survey, The University of Edinburgh and Heriot-Watt University.
- **Nottingham Centre for CCS (NCCCS**; www.ncccs.ac.uk/ncccs/home.aspx) is a partnership between the British Geological Survey and Nottingham University.

Minor research centres:
There are many universities researching CO_2 storage including Bristol, Cambridge, Durham, Edinburgh, Heriot Watt, Imperial College London, Leeds, Newcastle, and Nottingham.

Storage options and capacities

The majority for storage in the U.K. lies offshore. Onshore, there are a few small oilfields and aquifers which might be suitable for a test injection on a small scale, but offshore storage in hydrocarbon fields and aquifers is much more promising. The main geological formations of interest are the Triassic Bunter Sandstone (and equivalents) and the Permian Leman Sandstone. The estimated storage capacity for offshore hydrocarbon fields is estimated to be over 7 000 Mt in the UK North Sea and aquifer storage looks potentially to be an order of magnitude larger, (although there is greater uncertainty in these estimates). The estimated storage potential for the Irish Sea is around 1 505 Mt in hydrocarbon fields and 2 840 Mt in aquifer storage sites, there are also several large basins with unquantified/ theoretical storage estimates also.

Current situation in the U.K. with respect to i) current demo/pilot projects & projects/sites in preparation, ii) state of the transposition of the EU Directive on the geological storage of CO_2, iii) public awareness

The first DECC competition was launched in 2007. The aim was to fund a full chain demonstration or post-combustion capture. Through the evaluation process, four bidders were selected, however, as time went on this was reduced to one and negotiations were concluded when DECC "considered that it could not agree a deal that would represent value for money" (www.nao.org.uk/publications/1012/carbon_capture_and_storage.aspx). The competition was then re-launched in April 2012 as the 'CCS commercialisation Programme' with funding of up to £1 billion for capital costs and additional support through low carbon Contracts for Difference. The timing of the application process is complementary to the NER300 schedule in order to allow consortia to bid for funding from both sources. The demonstration project can be full-chain or part-chain but must be operational by 2016 – 2020 and must comprise a power plant and capture facility in Great Britain with offshore storage.

Implementation of the Directive was completed for all regions of the U.K. in February 2012.

Media articles, including television, newspapers, magazines and electronic media on CCS are commonplace and so the UK public is potentially well-informed.

CO_2GeoNet
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on the Geological Storage of CO_2

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