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Developments of CO_2 geological storage in Europe and the role of CO_2GeoNet

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Abstract

Since the very first European research project initiated in 1993, much progress has been made in Europe on the development of CO_2 geological storage as a key tool for combating climate change. A review of the main achievements and remaining obstacles in Europe is proposed, with a glance at what is going on at global level. Scientific, technical, economic, regulatory and policy aspects are considered. The increasing role of the growing CO_2GeoNet Association, a reference pan-European scientific body on CO_2 geological storage, is emphasized, with actions both on the EU and global scene for enabling efficient and safe storage.

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Keywords: CO_2 storage ; CCS technology ; storage pilots ; demonstration projects ; research ; scientific advice ; training ; communication ; CO_2GeoNet Association ; CGS Europe

1. Introduction

The EU Energy Roadmap 2050 states that CO_2 Capture and Storage (CCS) needs to be applied from around 2030 in the power sector in order to reach emission-reduction targets [1]. Furthermore, it recognizes CCS as an important option for the decarbonization of several heavy industries that, when combined with biomass, could deliver "carbon negative" values. Since the very first European research project on CCS initiated in 1993 under the EC 3rd Framework Programme (FP) and called Joule II “The underground disposal of carbon dioxide” [2], much progress

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has been made in Europe towards the development of CO_2 geological storage as a key tool for combating climate change. However, where do we stand now, are we still on track for meeting the target?

Key dates in Europe and the world for the development of the CCS technology are shown in Figure 1. This timeline will serve as a guide to analyze the progress made in terms of climate and energy policy, research, preparation of demonstration projects, regulatory and socio-economic aspects. We will draw up perspectives and emphasize the efforts of the European research community, mobilized around the CO_2GeoNet Network of Excellence, to help enable the deployment of CO_2 storage.

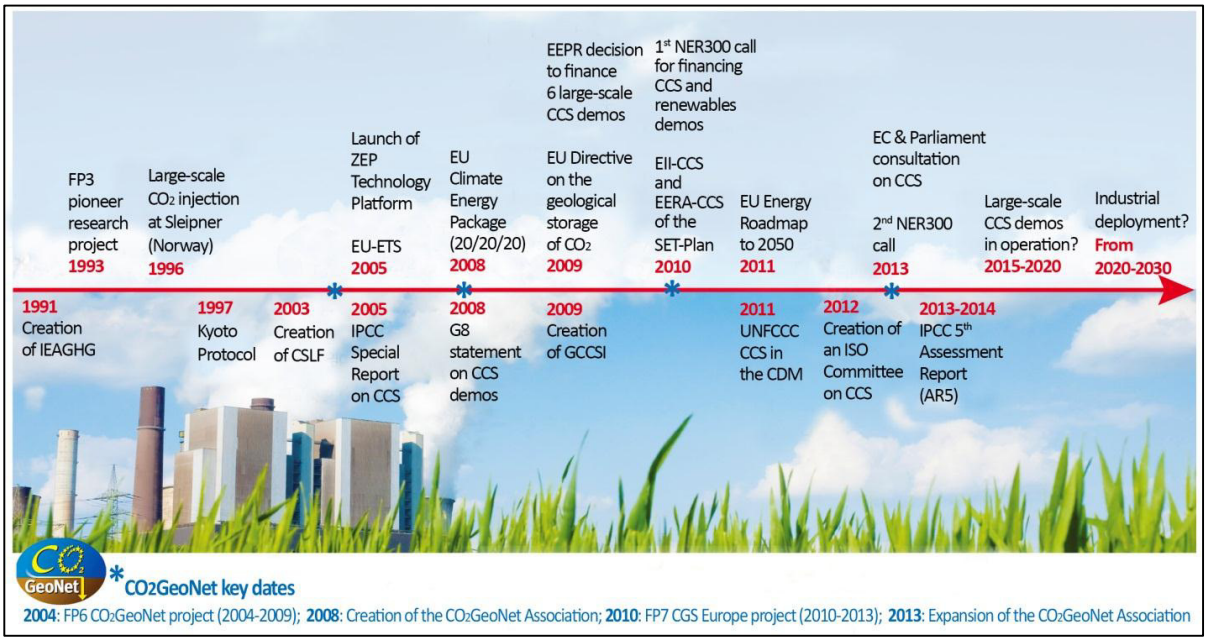

Fig. 1. Key milestones for CCS development at EU (top) and global (bottom) levels.

2. An overview of CO_2 geological storage developments in Europe

2.1. CCS in the energy and climate policies

Following the signature of the Kyoto Protocol in 1997 and ratification in 2005, the European Union was committed to achieving an 8% reduction in greenhouse gas (GHG) emissions between 2008 and 2012 compared to 1990 levels, and it is now preparing for drastic but necessary reductions in order to limit global climate change to two degrees Celsius. In the context of the envisaged global reduction of GHG emissions of 50% by 2050, meaning a reduction of 60-80% in the developed world, a portfolio of all mitigation options must be deployed.

The Special Report on Carbon Dioxide Capture and Storage published in 2005 by the Intergovernmental Panel on Climate Change (IPCC)[1]has given international recognition to this emerging technology as a mitigation option [3]. In 2008, the International Energy Agency (IEA) showed that CCS is an essential part of the portfolio of technologies that is needed to achieve substantial global emissions reductions in the most cost-effective manner [4]. Under the IEA Energy Technology Perspectives 2012 2°C scenario (2DS), CCS contributes 17% of total CO_2 emissions reductions required by 2050, and 14% of the cumulative emissions reductions up until 2050 against a business-as-usual scenario (6DS) [5].

The 2020 climate and energy package, a set of measures agreed by the EU in 2008 to implement the so-called "20-20-20" targets, aims at transforming Europe into a highly energy-efficient, low carbon economy [6]. Binding

targets to be met by 2020 are i) a reduction in EU GHG emissions of at least 20% below 1990 levels, ii) 20% of EU energy consumption coming from renewable resources, and iii) a 20% reduction in primary energy use compared with projected levels, achieved by improving energy efficiency. The package, which became law in June 2009, entails a legal framework to promote the development and safe use of CCS and a revision and strengthening of the Emission Trading Scheme (ETS), the EU's key tool for cutting emissions cost-effectively that started in 2005.

A European Strategic Energy Technology Plan (SET-Plan) was set up in 2008 with the objective of accelerating innovation in cutting-edge European low-carbon technologies, including CCS [7]. To accelerate the development and market introduction processes, the SET-Plan created the European Industrial Initiatives (EIIs) and the European Energy Research Alliance (EERA). The CCS EII, launched in 2010 and bringing together industry, the Member States, and the European Commission, aims at demonstrating the commercial viability of CCS technologies in an economic environment driven by the EU ETS. The EERA-CCS Joint Programme, launched in 2010 and bringing together research centres and universities, aims at coordinating research towards efficient and cost-effective capture and storage technologies. The SET-Plan is preparing an Integrated Roadmap to be endorsed by end 2014 in order to prioritize the development of innovative holistic solutions that will respond to the needs of the European energy system by 2020, 2030 and beyond. In this framework, the Roadmap will address the entire energy system in an integrated way, including supply chains of the proposed innovative solutions and research and innovation chains consolidated at EU level.

The 2030 policy framework for climate and energy proposed by the European Commission in January 2014, for agreement by EU leaders in October 2014 at the latest, sets the ambitious target of reducing EU domestic GHG emissions by 40% below the 1990 level by 2030. This target will ensure that the EU is on the cost-effective track towards meeting its objective of cutting emissions by at least 80% by 2050. The framework states that increased R&D efforts and commercial demonstration of CCS are essential over the next decade so that the technology can be deployed in the 2030 timeframe. A reform of the EU ETS has been recently proposed to make it more robust and effective in promoting low-carbon investment at the least cost to society.

All these actions are in line with the objectives of the EU Energy Roadmap 2050, i.e. to reduce GHG emissions to 80–95 % below 1990 levels by 2050 in the context of necessary reductions by developed countries as a whole, while at the same time ensuring security of energy supply and competitiveness. Their timing is on track for preparation of the upcoming negotiations on a new international climate agreement that should take effect in 2020. A major step towards this will be the upcoming UNFCCC COP-21 Conference in Paris in 2015.

2.2. Research

Since 1993 and onset of the European pioneer research project to establish the feasibility of the concept of capturing and storing CO_2 to fight against global warming (FP3 Joule II Project), significant scientific advances have been made through:

- Cooperative research programmes on CO_2 geological storage: European projects from FP3 to FP7, national research programmes, such as the Dutch CATO programmes and the French ANR and ADEME programmes.
- Studies of many natural subsurface CO_2 accumulations and natural CO_2 releases at the ground surface or the seabed, such as at Montmiral (France), Latera and Panarea (Italy), Maria Laach (Germany).
- Transfer of know-how in industrial practice, such as many years of CO_2 injection by the Oil & Gas industry for Enhanced Oil Recovery (CO_2-EOR), and of seasonal natural gas storage (CH4).
- Pioneer large-scale industrial CCS projects (injection of >1 Mt/CO_2/year): Sleipner (Norway) from 1996, Weyburn (Canada) from 2000, In Salah (Algeria) from 2004, Snohvit (Norway) from 2007.
- Small-scale CO_2 storage pilots (injection of a few kilo tons of CO_2 over a limited period): Ketzin (Germany), Lacq-Rousse (France) and very recently Hontomín (Spain), supplemented by pilots outside Europe, such as Frio (USA), Nagaoka (Japan) and Otway (Australia).
- CO_2 injection tests in deep and shallow formations to study migration and leakage processes (injection of a few tons of CO_2 over a limited period), such as CO2FieldLab (Norway), PISCO2 (Spain), ASGARD (UK).

- Best practice manuals and guidelines covering the various stages of the storage site life cycle from assessment & characterization through to development & operation and finally closure & post closure: some examples resulting from European projects include SACS and CO2STORE, SiteChar, RISCS and CO2CARE.
- Networking & knowledge-sharing activities at national (e.g. French, Italian and Romanian CO_2 Clubs), European (ZEP, CO_2GeoNet, CO2NET, EERA…) and international (IEAGHG, CSLF, GCCSI) levels.

Thanks to the pioneering operations and major research programmes on CCS conducted in Europe, the United States, Canada, Australia and Japan since the 1990s, researchers and industry have already gained a lot of knowledge and expertise: criteria for selecting appropriate storage sites, as well as methods and tools for site characterization, modeling, monitoring, control of risks and environmental impacts, assessment of storage capacity. However, further research is needed for a safe and wide deployment of CO_2 storage, as stated by the EERA-CCS Joint Programme in 2013, namely concerning:

- Identification and characterization of geological complexes that are suitable for storing CO_2 and that i) do not cause conflict with other human activities or impacts on the ecosystem, ii) have capacities that match the sources, and iii) guarantee safe conditions for the whole period of storage operations, closure and post closure;
- Development of tools that allow a 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 recognized protocols for their use in a variety of geological, environmental and operative contexts.

Following recognition of the need for specific research on CCS infrastructure, the ECCSEL initiative (European Carbon Dioxide Capture and Storage Laboratory Infrastructure) was initiated in 2011 to develop a network of facilities distributed across Europe, comprising the most advanced laboratories, test sites and pilots, and to enable open access and use by a wide range of European researchers. The start of the operational phase of ECCSEL is planned for 2015.

Horizon 2020, the new EU Framework programme for funding research and innovation which will run from 2014 to 2020 as a follow up of the previous FPs, includes CCS research and innovation actions under the key societal challenge "secure, clean and efficient energy".

2.3. The urgent need for both pilot and demonstration sites

Current CO_2 injection operations in Europe include two large-scale plants (about 1 Mt CO_2/year) both in offshore saline aquifers in Norway (Sleipner and Snohvit), and four small-scale pilots (less than 0.1 Mt CO_2 over a limited duration of injection) in onshore saline aquifers in Germany (Ketzin) and Spain (Hontomín) and in depleted gas reservoirs onshore in France (Lacq-Rousse) and offshore in the Netherlands (K12B).

To enable commercial deployment from 2020-2030 at hundreds of sites, more experience on real field data has become a priority in order to support technical development, but also societal dialogue and the legislative, regulatory, economic and political frameworks that are being developed. The G8 leaders in 2008 supported the recommendation that 20 large scale CCS demonstration projects need to be launched globally by 2010, with a view to supporting technology development and cost reduction for the beginning of broad deployment of CCS by 2020.

In Europe two funding instruments for large-scale CCS demonstration projects were set up: the European Energy Programme for Recovery (EEPR) with the decision in 2009 to finance 6 projects, and the NER300 programme funded by a reserve of 300 ETS allowances to support CCS and innovative renewables. However, for a variety of reasons, the 6 EEPR projects were either cancelled or are in stand-by: Jaenschwalde (Germany), ROAD (NL), Don Valley (UK), Porto Tolle (IT), Compostilla (Spain) and Belchatow (Poland). Furthermore, no CCS projects among the 13 submitted in the first call of the NER300 issued in 2010 were selected. But the White Rose project (UK), the only CCS project submitted in the second call in 2013, was selected and awarded up to 300€ million funds in 2014. In addition, the UK government selected in 2014 the Peterhead CCS Project (UK) for funding under the UK CCS Commercialization Programme.

Due to the failure of the first NER300 call and slow progress in Europe, CO_2GeoNet, as well as the European Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP), recently stressed the urgency for both:

- CO_2 storage pilots, where a CO_2 injection into a deep geological formation of usually less than 0.1 Mt over a few months or years is performed in order to carry out research experiments in a variety of geological contexts [8],
- CCS demonstration projects that implement the full chain of technologies for CO_2 capture, transport and storage at an industrial scale of several Mt of CO_2 per year, as a stepping stone to commercial deployment, e.g. on a power plant or a steel plant.

The lighthouse CO_2 storage pilot in Europe is currently the Hontomín pilot (Spain), where injection at 1500 m depth in a carbonate reservoir in an anticlinal dome-shaped structure began in 2014. The site has been developed and equipped through the EEPR scheme and national funding, and offers new promising opportunities for the European research community. Other new initiatives are emerging, such as in Svalbard (Norway) and in the Sulcis coal basin in Sardinia (Italy).

Recognizing that CCS is taking off slower than expected in Europe for a variety reasons, such as economic and political difficulties, the European Parliament and the European Commission both launched in 2013 a wide consultation inviting stakeholders to submit proposals and recommendations for developing and applying the CCS technology in Europe. This is feeding into the 2030 Framework for climate and energy policies that should be adopted by end 2014.

2.4. The European Directive 2009/31/EC on the geological storage of CO_2

A European Directive on the geological storage of CO_2 was issued in 2009 and was transposed in national legislations [9]. By end 2013, this process was complete for the majority of Member States. A report from the Commission to the European Parliament and Council on the implementation of the Directive was adopted in February 2014.

This Directive gives the legal framework for the permanent geological storage of CO_2, whilst preventing or reducing as far as possible negative effects on the environment and any resulting risk to human health. Criteria for the characterization and assessment of storage sites are given, as well as criteria for establishing and updating the monitoring plan. The Directive requires an exploration permit then a storage permit for each storage site.

In 2014, a review of the Directive was launched by the European Commission to assess the effectiveness, efficiency, ease of application and legal practicality of several of the Directive provisions, as well as to provide an assessment on how the enabling policy of CCS at European level has in practice worked out so far. This will lead to the preparation of a proposal for revision where necessary.

2.5. Socio-economic issues

The storage costs range between 1 and 20 € per ton of CO_2 stored, depending on the storage types and characteristics [10]. Onshore storage is cheaper than offshore storage. Storage costs represent 10-20% of the costs of the full capture-transport-storage value chain. The CO_2 price in the EU ETS is currently much below 10 € per ton (€2.5-5/t CO_2 in Q2 2013). This low level does not provide a secure environment for long-term investment. The selection, characterization and permit application for a storage site is a long process that takes several years, as well as its connection to a CO_2-emitting power or industrial plant via the set-up of an appropriate transport infrastructure. The need for early planning and the high costs of capital and operational costs means that other incentives will be needed. The ZEP Technology Platform has issued some propositions in 2013, such as public grants to incentivise CCS 'first movers', feed-in premia and CCS certificates [11]. The European Commission is currently investigating possible solutions, including a structural reform of the EU ETS.

Demonstration projects and further deployment will require support from all stakeholders. A few pilot and full-scale projects have already been implemented successfully in Europe, although others have been cancelled, mainly for financial reasons. However, some societal and policy issues still need to be addressed, such as the NIMBY syndrome for onshore storage, denial of climate change or of the role of CCS, alternative perspectives on energy

mix and economic development. A constructive societal dialogue demands early and continuous interaction involving national and local stakeholders in the decisions, so that they contribute to elaborating tailored solutions to the climate and energy issues facing their territories and see the socio-economic benefits, including the creation or preservation of local jobs. The scientific community can play a key role in such a dialogue by providing advice and high quality information.

3. The role of CO_2GeoNet and achievements made through the FP7 CGS Europe project

The European scientific community has a key role to play in developing, sharing and disseminating the knowledge required for CO_2 storage implementation. The storage component of CCS requires multidisciplinary expertise, which demands strong research collaboration and integration, and a site-specific approach adapted to the local context in terms of geology, hydrogeology, socio-economics, etc. Furthermore, the large-scale feasibility of CO_2 geological storage –in terms of capacity, efficiency and safety over thousands of years– still remains to be fully proven.

CO_2GeoNet, the European Network of Excellence on CO_2 geological storage, began as an EC FP6 project (2004-2009) to support widespread understanding of the technology, and to foster knowledge development and sharing. CO_2GeoNet became a non-profit scientific association under French law in 2008, with all 13 founding members from 7 European countries onboard. CO_2GeoNet initiated and participated in the EC FP7 CGS Europe project (2010-2013), a transnational coordination action on CO_2 geological storage gathering together 34 key research institutes, including the 13 CO_2GeoNet members, and spanning 28 countries. The objective of CGS Europe was to develop a durable and pan-European scientific body of expertise on CO_2 geological storage, and the best solution for durability was through the expansion of CO_2GeoNet. In 2013, towards the end of the CGS Europe project, CO_2GeoNet opened up its membership and now comprises 25 members over 17 European countries.

With activities encompassing joint research, training, scientific advice, and information & communication on CO_2 geological storage issues, CO_2GeoNet has a valuable and independent role to play in enabling the efficient and safe geological storage of CO_2. Recent activities carried out by CO_2GeoNet, including with CGS Europe partners, are described below.

3.1. Strategy and values

In 2011, after three years as a stand-alone Association and the rapidly moving CCS landscape in Europe and worldwide, CO_2GeoNet decided to refine its strategy for addressing new upcoming challenges. The strategy and values were formulated and adopted by the members at the end of 2012. CO_2GeoNet is a large and growing group of leading research institutions, and increasingly regarded as the only integrated scientific community with comprehensive multidisciplinary expertise focused on CO_2 storage and independent of political, industrial or societal pressures. CO_2GeoNet's ambitions are to:

- Provide and disseminate integrated scientific research results and synthesized knowledge to contribute to the improvement of technical, economic, regulatory aspects and public awareness of CO_2 storage;
- Be the preferred source of impartial scientific and technical information and advice for the European Union, industry, regulators, the general public and other CCS stakeholders;
- Contribute to the identification of knowledge gaps and the formulation of new research targets;
- Foster interaction and exchange of information and views between CO_2 storage researchers and CCS stakeholders;
- Foster the training of upcoming generations of scientists that will be needed for a widespread deployment of the technology, by being a source of unbiased information, excellent tutors and training programmes in the science of CO_2 storage;
- Expand membership in order to provide an excellent, robust, multidisciplinary and pan-European knowledge/skills base for the implementation of the geological storage of CO_2.

3.2. Research

An important challenge in the development of CO_2 storage is the need to discuss, integrate and share research results produced by the European and international community, then to synthesize and disseminate the knowledge. CO_2GeoNet plays a key role in this respect and was recently involved in the publication of three key reports under the CGS Europe project summarizing the progress made on three important topics: monitoring methods [12], site selection & characterization methods [13], operational & safety risk regulations [14]. CO_2GeoNet also recently produced three reports for IEAGHG on potential impacts on groundwaters [15], quantification of any CO_2 leakage [16], and mitigation and remediation strategies [17].

In 2013 CO_2GeoNet and CGS Europe partners published a major report highlighting the state of play on CO_2 geological storage in 28 European countries [18]. The report gives a brief overview of the CO_2 storage options, potentials and capacities in Europe. It summarizes information on research activities and organization of research funding related to CO_2 storage in each country. Information on a national level is complemented by an overview of activities on a regional and European level. Current pilot, demo and test sites are listed, followed by an overview of the state of transposition of the EU Directive on the geological storage of CO_2 and the level of public awareness in the individual countries.

The identification of knowledge gaps, research needs and the preparation of new research projects are also a key activity of CO_2GeoNet. Collaboration with EERA-CCS, ZEP and ECCSEL is ongoing for that purpose in order to effectively pool resources and efforts. In particular, CO_2GeoNet identified two major challenges. First, the need for CO_2 storage pilots in order to boost the development of the technology based on real-field experience. CO_2GeoNet with CGS Europe partners published in 2013 a report on the opportunities for CO_2 storage pilots across Europe [19], presenting 22 projects over 15 countries. Second, a more in-depth assessment of CO_2 storage capacities in Europe is needed. This led to the further analysis of the results of the FP6 EU Geocapacity project through the new CO2StoP project, funded by the European Commission in 2012-2013. The result is a database of estimated CO_2 storage locations, capacities and injection rates throughout Europe including GIS and tools for data analysis/interrogation. The database is housed by the Joint Research Centre - EC (http://iet.jrc.ec.europa.eu/). However, there is still progress to be made in terms of moving from theoretical to realistic assessments in order to better enable investors and policy makers to deploy CCS. The need for a European CO_2 storage Atlas is being discussed, as interesting atlases have been already produced by North America, Queensland region of Australia and the Norwegian North Sea.

The CO_2GeoNet Open Forum held annually in Venice is a unique opportunity for stakeholders and major players in the CCS arena to meet and interact directly with Europe's largest group of researchers working on CO_2 geological storage, to hear the latest developments in CO_2 storage and to take part in lively debates. Research and knowledge-sharing workshops are also organized on current issues. Two recent workshops were held in Bratislava (Slovakia) in September 2013 on promising options for CO_2 storage and the future of CO_2 storage research, in the framework of CGS Europe, and in Le Havre (France) in June 2014 where CO_2GeoNet was a co-organizer of the European CCS Day, organized by the French Club CO_2, to discuss lessons learned from CCS pilots and demonstration projects as well as the way forward.

3.3. Scientific advice

The multi-disciplinary, vast and independent nature of CO_2GeoNet means that expert assessments can be provided by a pool of unbiased scientists covering a variety of issues and European contexts. Activities include the joint preparation of position papers, reaction papers to controversial issues, and expert advice when needed.

CO_2GeoNet gave input to the implementation by Member States of the CO_2 storage Directive, assisted the European Commission to analyse the status of the implementation of the Directive in each Member State, and is currently taking part in the stakeholder consultation organized by the EC for the revision of the Directive. In 2013, CO_2GeoNet answered the consultations on the future of CCS in Europe organized by both the European Commission and the European Parliament. CO_2GeoNet is also participating in the EU CCS Demo Network Advisory Forum. CO_2GeoNet has recently become involved in the ISO international technical committee preparing international standards for CCS.

3.4. Training

A ZEP study estimates that 330,000 jobs could be created or preserved in Europe if CCS deployment takes off at the level needed to reach mitigation targets. One ambition is to foster the training of upcoming generation of scientists that will be needed for the widespread deployment of CCS. CO_2GeoNet has experience in running training courses, presenting lectures at international events and facilitating staff exchange. Two one-week training spring schools on CO_2 geological storage targeting young scientists and postgraduate students were organized under the CGS Europe project, in Poland in 2012 and in Romania in 2013.

3.5. Information and communication

In line with the ambition to provide and disseminate integrated scientific research results and to foster the exchange of information and views between CCS stakeholders, CO_2GeoNet has developed a strategy in order to reach out as an independent body to industry, regulators and the public and communicate on CO_2 geological storage issues. Activities include the preparation of brochures and magazine articles for various types of audience, a website, newsletters, knowledge-dissemination workshops on CO_2 storage and CCS awareness-raising workshops. The main communication event is the annual Open Forum in Venice and the 10th anniversary event is scheduled for May 2015. The CO_2GeoNet brochure 'What does CO_2 geological storage really mean?' now exists in 27 languages.

Interaction with media is regarded as a main channel for effective dissemination, with the creation of opportunities for direct interaction between researchers and scientific journalists, where learning and dialogue about the technology is possible. Several specific workshops have been organized with European or national associations of scientific journalists, and the Venice Open Forum welcomes journalists.

3.6. International collaboration

CO_2GeoNet is highly active on the international CCS scene. CO_2GeoNet, as was CGS Europe, is a project recognized by the Carbon Sequestration Leadership Forum (CSLF). CO_2GeoNet, as a legal association representing the European scientific body on CO_2 storage, signed a cooperation agreement with the IEA Greenhouse Gas R&D Programme (IEAGHG) in 2008 during the GHGT-9 conference in Washington and, in 2013, became a member of the Global CCS Institute (GCCSI). In 2013 CO_2GeoNet also became a Category A Liaison organization in the ISO CCS Technical Committee, and was accepted as Observer Organization (Research NGO) at UNFCCC. In this latter context, CO_2GeoNet participated in the COP-19 Conference in Warsaw in November 2013 with invited participation in three CCS side events and intends to participate actively in the COP-21 Conference in Paris in 2015.

4. Conclusion

Although the developments of CO_2 storage in Europe over the last 20 years are impressive, many difficulties and obstacles were encountered, and challenges still remain to be overcome for certain technical, regulatory, economic, political and societal issues. Collaboration at global level is also strong. Efforts, however, must now be reinforced as IPCC, in its Fifth Assessment report published in 2014, has again sounded the alarm concerning the rapid and wide-spread nature of climate change, and recognizes CCS as an essential component in the portfolio of mitigation technologies.

Therefore, the CO_2GeoNet Association, with its enlarged membership, will continue with more intensity to interact with stakeholders at national, European and global level in order to respond to future research, training, scientific advice and information needs in the area of CO_2 geological storage, in accordance with its "Strategy and Values".

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