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Global Status of Geological CO_2 Storage

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Abstract

It has become accepted that anthropogenic greenhouse gas emissions are the main cause for the current global warming and that urgent and broad actions are needed to tackle the problem of climate change. According to most scenarios a wide portfolio of technologies will be needed. CCS is one of the many available technologies to combat the problem. Most of the scenarios indicate that in order to reach a full decarbonatisation of society, at lowest cost, CCS should be deployed at large scales. Given that cheap and abundant fossil fuels will most likely continue to provide a significant proportion of energy supply in the near future, reductions enabled by CCS need to be realized and especially in developing countries.

Currently there is a total of 40 large-scale projects in various stages (planned or in operation) in the world. The number of CCS project would need to rise substantially to help meet longer-term climate goals. During recent years however, the amounts of projects have been steadily declining. CCS projects for the sole purpose of emission reduction have clearly fallen short of the ambitions held for the technology.

The development of CCS has mainly been held back by lacking economic incentives, missing political support and in some regions also by public opposition. To enhance actions in the field of CCS, governments would need to demonstrate a clear, long-term commitment to CCS that is underpinned by detailed policy, legal and regulatory frameworks that would provide predictability for investors.

Helsinki, May 2016

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1 Introduction

During the last decades it has become more and more accepted that anthropogenic activities are disturbing the natural carbon cycle. Large point emissions of fossil CO_2 is internationally primarily from large-scale power generation, where coal, natural gas or oil is used as fuel. Also steel, cement, petroleum and paper industries have large CO2 emissions. The concentration of CO2 in the athmosphere has gone from 280 ppm (Indermühle et al. 1999) in pre-industrial time to 400 ppm today. Experts believe that 450 ppm (corresponding to a temperature increase of about 2°C (2DS)) is a limit beyond which drastic environmental consequences are inevitable (IPCC 2007).

There are multiple mitigation pathways that are likely to limit warming to below 2°C relative to pre-industrial levels. These pathways would require substantial emissions reductions over the next few decades and near zero emissions of CO2 and other long-lived greenhouse gases by the end of the century. To achieve the mitigation goal of limiting warming to below 2DS, several tools and technologies are needed.

Carbon Capture and Storage (CCS) is one of the available climate change mitigation tools and involves the capture of CO_2 emissions from power plants and industrial processes, transportation of CO2 via pipeline or by shipping and permanent CO2 storage in depleted oil and gas fields or deep, underground saline formations or other suitable underground layers. Recent research makes a strong case that CCS should play a key role in producing cost effective, low-carbon electricity and reducing greenhouse gas emissions from major point sources. The development of CCS has however been held back by lacking economic incentives, missing political support and public opposition.

This report is part of the Finnish Carbon Capture and Storage Programme (CCSP), managed by CLIC Innovation Ltd. The CCSP covers the whole carbon capture and storage chain from carbon capture to geological storages including public acceptance issues, health and safety aspects and legislative framework of CCS. Timetable of the program is 2011 – 2016. The objective for the Carbon Capture and Storage Program (CCSP) is to develop CCS-related technologies and concepts, leading to essential pilots and demonstrations by the end of the program. A further objective is to create a strong scientific basis for the development of CCS technology, concepts and frameworks, and to establish active, international CCS co-operation. This report aims at providing an updated overview of the global status of CCS.

2 Climate Change

2.1 Introduction

During 10 000 years before the industrialisation the balance between the geosphere, the biosphere, the ocean and the atmosphere, resulted in small CO_2 concentrations around 280 ppm in the atmosphere (Indermühle et al. 1999). Over the last three centuries the consumption of fossil fuels and land use has increased this amount. About half of the human induced emissions has been absorbed by vegetation and dissolved in the oceans, the latter causing acidification and negative effects on marine life. The remainder has accumulated in the atmosphere where it contributes to the greenhouse effect. Today the concentration in the atmosphere is 400 ppm and experts believe that 450 ppm is a limit beyond which drastic environmental consequences are inevitable (IPCC 2007).

The Intergovernmental Panel on Climate Change (IPCC), established in 1988, declared in its fifth assessment report (IPCC, 2014) that human influence on the climate system is clear and growing and with a 95 percent certainty humans are the main cause of current global warming. The IPCC also highlights that there are ways to limit climate change that at the same time allow for continued economic and human development. However, stabilizing temperature increase will require urgent and fundamental actions. Moreover, the longer we wait to depart from business as usual, the more it will cost and the greater the technological, economic, social and institutional challenges we will face. As such, the IPCC calls for the urgent attention of both policymakers and citizens of the world to tackle this challenge.

2.2 Climate Change Mitigation

Despite great efforts in the industrialized world to reduce emissions of carbon dioxide, the global CO2 emissions continue to grow. According to many organizations, such as the International Energy Association (IEA) and the Organisation for Economic Cooperation and Development, the global energy consumption will continue to grow at such a rate that, even though a switch towards renewable energy is pursued, fossil fuels will continue to be the most common energy source for the foreseeable future. Newly installed coal-fired power plants will emit CO2 into the atmosphere for 40-50 years. Some sectors of the industry will also continue to use fossil fuels or have otherwise unavoidable large CO2 emissions (e.g. steel, cement and pulp and paper).

According to most scenarios (IPCC, IEA etc.) a wide portfolio of technologies is needed to achieve the targets of mitigating the effects of climate change. The scenarios also indicate that CCS is needed to achieve the most cost-effective solution. While it may be possible to reduce emissions in the electricity sector by the amount needed to limit global temperature increase to below 2DS without using CCS, this would necessarily involve using more expensive technologies. In Figure 2-1 (IEA, 2015) the IEA scenario displays the potential of each technology in contributing to CO2 reductions in different sectors, highlighting the need for a broad portfolio of low-carbon technologies to reach the 2DS target. Some solutions are broadly applicable, while others need to target specific sectors.

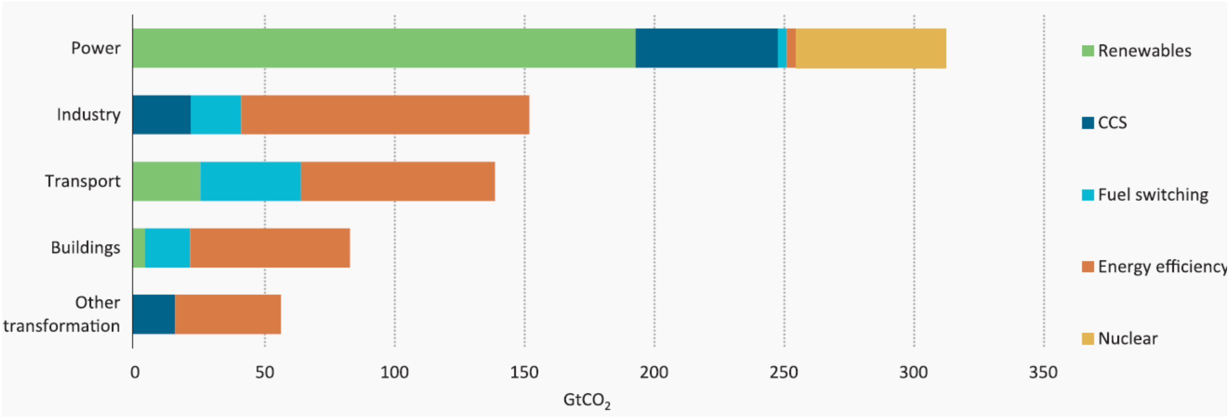

Figure 2-1. Cumulative CO2 reductions by sector and technology in the 2DS to 2050 (IEA, 2015).

According to the Global CCS Institute (GCCSI, 2015) only some of the climate model runs produce a 2DS scenario in the absence of CCS and the IPCC (IPCC, 2014) estimates that without CCS the cost of achieving 2DS target could become 138 percent more costly compared to scenarios that include CCS. Many recent models also indicate that we might need net negative technologies that remove CO2 that has already been emitted to the atmosphere, such as Bio Energy with CCS (BECCS).

However, the deployment of climate change mitigating solutions will vary across the globe: the portfolio of solutions in one location may be different in another location. CCS will be most effectively deployed where it is cost-effective and practical to implement (i.e. where CO2 sources match available storage resources).

3 Global Status of CCS

3.1 Introduction

Since the shift in energy production to renewable cannot be accomplished overnight, CCS technology could play an important role during this transition. The need for CCS will eventually decline when alternative energy sources such as nuclear, hydro, solar and wind power have enjoyed sufficient technological progress as to become economically viable and capable of supporting a national grid.

The GCCSI has by May 2016 identified 40 large-scale projects in various stages (planned or in operation). The CO2 capture capacity of all projects in the Operate, Execute and Define stages is at around 46 Mtpa. This is multiples below the levels necessary for CCS to play a key role in combating climate change in the longer term (GCCSI, 2015) and therefore the number of CCS project would need to rise substantially. The International Energy Agency (IEA), in modelling its 2°C Scenario (2DS), has CCS capturing around four gigatonnes (Gt) of CO2 emissions per annum by 2040 (as a point of comparison, energy-related CO2 emissions in the US are presently at around 5 Gt). The recent years however, the amount of planned projects has been steadily declining (Figure 3-1).

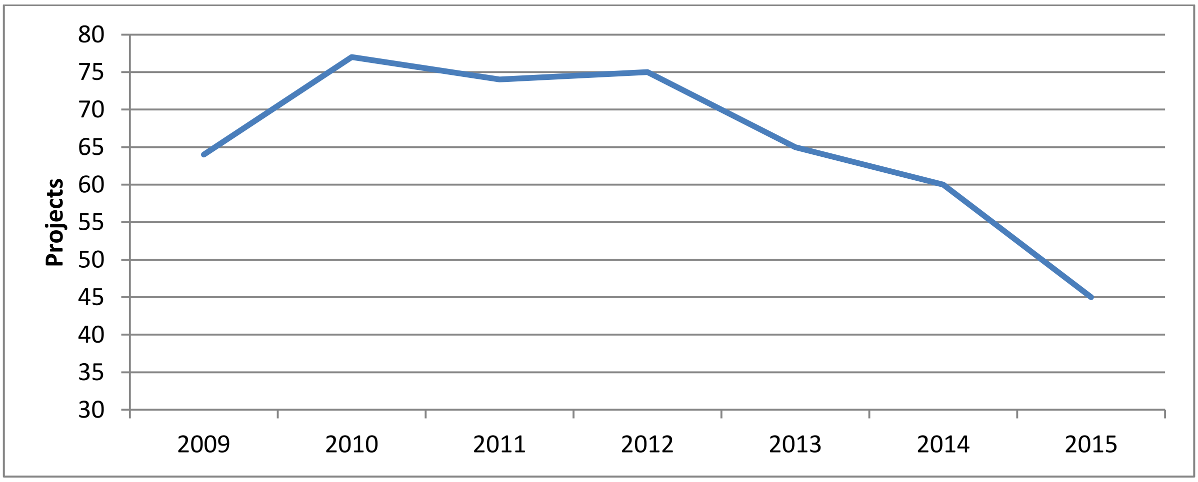

Figure 3-1. Number of large-scale CCS projects (Based on data from the GCCSI).

3.2 Storage Potential

Despite the currently lacking incentives, it is still very likely that CCS will be required in the future and especially when considering the complete decarbonisation of society. While awaiting a more positive climate for CCS technology to be rolled out it would be important to increase the readiness of the CCS technology by boosting current activity in the area of storage (IEA, 2014).

Storage is critical to any project design and must be addressed up front. While storage is the last of the three steps of a CCS project, it must be developed simultaneously with capture and transport, from the very beginning. This is because reservoir characteristics and behavior may determine the design and operation of the whole CCS chain. Also, available experience shows that it can take 5-10 years to qualify a new saline formation for CO2 storage, even when theoretical estimates are already available and look promising. To characterize storage formations, significant at-risk investment is usually required (IEA, 2014).

Estimates of global storage capacity indicate that 675 – 900 $GtCO_2$ can be stored in oil and gas fields, 3 – 200 $GtCO_2$ in unminable coal seams and 1000 – 10000 $GtCO_2$ in deep saline formations (IPCC 2005). This means that the theoretical storage capacity for CO_2 in geological formations is significantly higher than the global annual CO_2 emissions, which were 35.7 Gt CO_2 in 2014 (PBL NEAA, 2015). A large part of current estimates indicate what is theoretically or technically available, but what is technically available and accessible may not be economically feasible (IEA, 2014). Sedimentary basins and potential storage sites are quite unevenly distributed worldwide (Figure 3-2) which will affect the cost of implementing CCS in different regions.

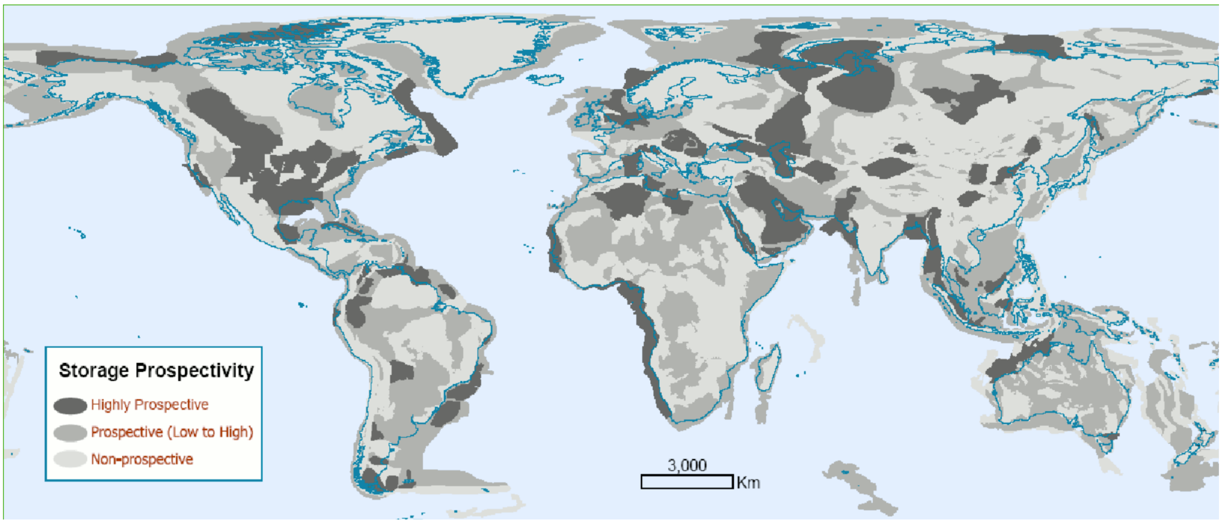

Figure 3-2. Map of global geological CO_2 storage prospectivity (IPPC, 2005).

Different methodologies also exist for estimating storage capacity and consequently there is some uncertainty which methods are most appropriate. In some cases storage estimates also conflict with each other. There has currently been work done on harmonising assessments and methodologies to ensure a more robust worldwide storage capacity estimates (IEA, 2014).

3.3 Policies

Though many experts have recognized CCS as a critical tool for deep emission reductions and while it would be important, for large-scale deployment in the 2020s, that different CCS options are demonstrated at progressively larger scale, there has been a lack of support and progress in political and economical terms (IEA, 2014). Many past and present CCS projects have expressed a need for more clear and stable emissions reduction policies, together with comprehensive legal and regulatory arrangements (GCCSI, 2015).

Overall, government support for CCS has been strongest in the US, Canada and the UK. This has largely been due to strong regulatory approaches (eg emission performance standards or age restrictions for power stations), direct public funding, modest incentives and, in the case of the UK, various market mechanisms that generally have encouraged decarbonisation of the power sector (GCCSI, 2015).

The legal and regulatory frameworks for CCS deployment are strongest in Australia, Canada, Denmark and the US. The governments of a number of other countries including Norway, the Netherlands, China and Japan also support CCS deployment through a combination of direct funding for projects, R&D activities and varying degrees of carbon pricing or environmental taxes. China and Japan in particular are devoting considerable effort in R&D activities and demonstration-scale projects (GCCSI, 2015). UK has also been at the forefront of CCS deployment in Europe, but the cancellation of the UK CCS competition in 2015 for funding a full scale project with £1 billion, could lead to abandonment of several UK CCS project plans.

In the EU, the CCS Directive (EC, 2009) was revived during 2014 and a key finding was the need for policies to enable transition from demonstration to commercially viable projects. A structural reform of Europe's emission trading scheme (ETS) is currently underway, with changes designed to ensure it sets a price on carbon sufficient enough to support the transition to a low-carbon economy. The European Union’s (EU) New Entrants Reserve (NER) financial mechanism has also been renewed, with 400 million emission allowances to be dedicated to establishing an Innovation Fund in the post-2020 period. For the period pre-2020, the market stability reserve (MSR) places 50 million allowances for low-carbon innovation projects to supplement the existing NER300. In October 2014, the European Council set a 40 per cent greenhouse gas (GHG) reduction target by 2030 to 1990 levels (GCCSI, 2015).

The so called Paris agreement was reached on December 12th 2015, at the United Nations conference on climate change (COP-21) in Paris. The agreement establishes that global warming should be limited to 1.5°C, to protect island states, which are the most threatened by the rise in sea levels. According to the agreed actions shown by States, the rate of global warming would still be between 2.7°C and 3°C at the end of this century. The Paris agreement therefore asks all countries to review these contributions every five years from 2020; they will not be able to lower their targets and are encouraged, on the contrary, to raise them. The agreement also identifies a relationship between climate change action and sustainable development. The Paris agreement specifically emphasizes the role of renewables and enhancement of sinks and reservoirs, clearly including forests but not explicitly geological sinks (CCS) .

3.4 Status of CCS

3.4.1 Globally

The Boundary Dam CCS Project represented in 2014 an important step for the CCS technology when it begun its operations in the fall of 2014 to become the world's first post-combustion coal-fired CCS project integrated with a power station (CO2 capture capacity of 1 Mtpa). During 2015, two new CCS projects became operational. One is the the Quest Project in Alberta, Canada (CO2 capture capacity of 1 Mtpa) which was launched in early November 2015 and captures CO2 from three hydrogen manufacturing units that produce hydrogen to upgrade bitumen into synthetic crude oil. This is the first large-scale CCS project in Canada to pursue CO2 storage exclusively in a deep saline formation and the first one to do so globally since the Snøhvit CO2 Storage Project became operational in 2008 (as all the other large-scale CCS projects that have become operational since that time have undertaken CO2-enhanced oil recovery (EOR)). The other one is the Uthmaniyah CO2-EOR Demonstration Project in Saudi Arabia (CO2 capture capacity of 0.8 Mtpa) which was launched in July 2015. This is the first large-scale CCS project to become operational in the Middle East. The project, which captures its CO2 from a gas processing facility, is located in a small area at the Uthmaniyah production unit, which forms part of the giant Ghawar field. This project is focused on a number of sequestration research aspects and includes a comprehensive monitoring and surveillance plan.

There are globally now 22 CCS projects in operation or under construction, with a combined CO2 capture capacity of around 40 Mtpa (Figure 3-3 & Table 3-1). The Americas remain the front-runner in large-scale CCS projects accounting for 20 of the 45 identified projects (Figure 3-4). There are nine projects in China, six in Europe, three in Australia, two in Korea, two in the Middle East and one in Africa (GCCSI, 2015).

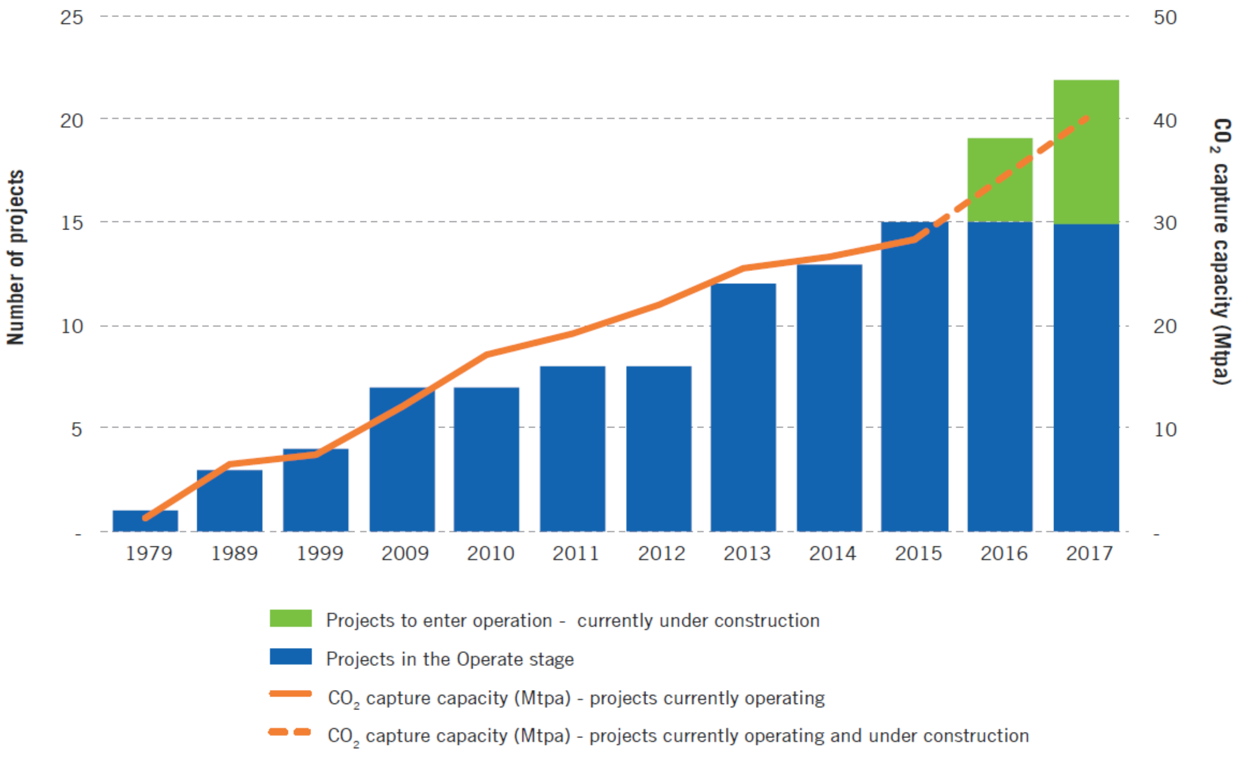

Figure 3-3. Number of large-scale CCS projects in operation and under construction.

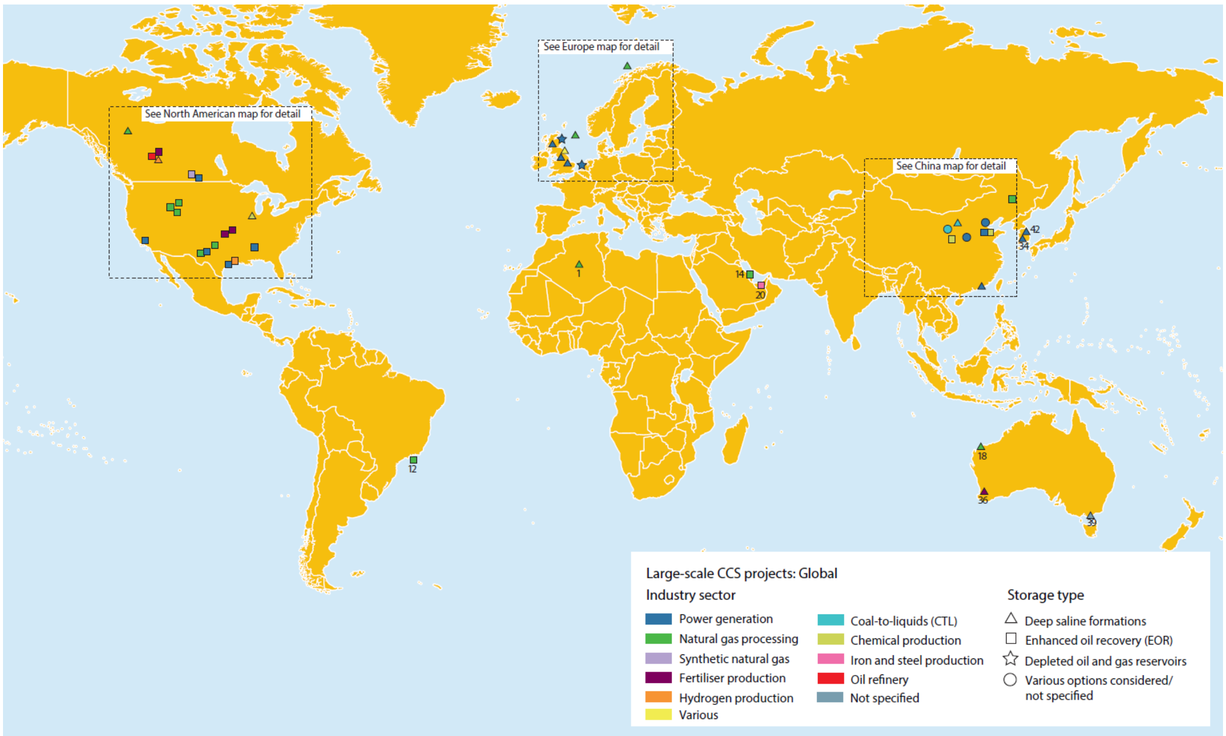

Figure 3-4. World map of large-scale CCS projects (GCCSI, 2015).

Table 3-1. Large-scale CCS projects in operation or under construction (GCCSI database)

Project Name	Location	Primary Feedstock	Year of Operation	Capture (Mtpa)	Capture Type	Transport Distance (KM)	Primary Storage Option	Injection Depth (metres)
Val Verde	US	Natural gas	1972	1.3	Pre-combustion	356	EOR	
Enid Fertilizer	US	Natural gas	1982	0.7	Industrial separation	225	EOR	
Shute Creek	US	Natural gas	1986	7.0	Pre-combustion	460	EOR	450-3,400
Sleipner	Nor	Natural gas	1996	0.85	Pre-combustion	-	Offshore aquifer	1,000
Great Plains	Can	Coal	2000	3	Pre-combustion	329	EOR	1,500
In Salah	Alg	Natural gas	2004	0	Pre-combustion	14	Onshore aquifer	1,900
Snøhvit	Nor	Natural gas	2008	0.7	Pre-combustion	153	Offshore aquifer	2,500
Century Plant	US	Natural gas	2010	8.4	Pre-combustion	>255	EOR	
Air Products	US	Natural gas	2013	1.0	Industrial separation	158	EOR	1700
Coffeyville	US	Petroleum coke	2013	1	Industrial separation	112	EOR	914
Lost Cabin	US	Natural gas	2013	0.9	Pre-combustion	374	EOR	1400
Petrobras	Bra	Natural gas	2013	0.7	Pre-combustion	-	EOR	5,000-7,000
Boundary Dam	Can	Coal	2014	1.0	Post-combustion	66	EOR	1,500 3,400
Quest	Can	Oil sands	2015	1	Industrial separation	64	Onshore aquifer	>2,000
Uthmaniyah	Saudi	Natural gas	2015	0.8	Pre-combustion	85	EOR	1,800-2,100
Abu Dhabi	UAE	Natural gas	2016	0.8	Industrial separation	43	EOR	
Illinois	US	Corn	2016	1.0	Industrial separation	1.6	Onshore aquifer	2,130
Kemper County	US	Coal	2016	3	Pre-combustion	98	EOR	
Petra Nova	US	Coal	2016	1.4	Post-combustion	132	EOR	1,640-2,066
Alberta	Can	Bitumen	2017	1.2 - 1.4	Industrial separation	240	EOR	1,800
Alberta	Can	Natural gas	2016-2017	0.3 - 0.6	Industrial separation	240	EOR	1,800
Gorgon	Australia	Natural gas	2017 (Institute estimate)	3.4 - 4.0	Pre-combustion	7	Onshore aquifer	2,300

Although there are currently several large-scale CO2 storage projects in operation around the world the deployment of large scale integrated CCS projects for the sole purpose of emission reduction has, to date, fallen short of the ambitions held for the technology by policy makers and industry (IEA, 2014). Sixteen of the twenty-two projects are enhanced oil recovery projects. To reach the climate change mitigation goals, the pace of CCS deployment would need to significantly increase over the coming decades. This can only be realized where governments demonstrate a clear, long-term commitment to CCS that is underpinned by detailed policy, legal and regulatory frameworks that provide predictability for investors. The largest emission reductions enabled by CCS would also need to be realized in developing countries. This is because cheaper and abundant fossil fuels will continue to provide a significant proportion of their energy needs (GCCSI, 2015).

3.4.2 Europe

The progress in EU has not lived up to the expectations held 5-10 years ago. At the time when CCS regulations entered into force in the EU there were aspirations for 12 CCS demonstration projects operating by 2015. Apart from the operating projects in Norway there are four projects in advanced planning in the EU, three in UK and one in the Netherlands. Recent cuts in government CCS funding in the UK has led to the abandonment of some of the UK projects.

The main reasons for the slow development in EU are a lack of specific CCS targets, a sharp fall in the carbon price and a lack of effective policy instruments. Most member states lack financial support for CCS deployment which would help to close the commercial gap. As a consequence, if EU intends to have CCS play a serious role in carbon mitigation, a much stronger policy drive will be necessary (GCCSI, 2015).

3.4.3 Research

Current projects have provided lessons for decreasing the cost of design, construction and operation of future carbon capture facilities. A lot of effort is still needed for research and development to further drive down costs. Several technologies targeting cost reductions are currently under development. Bench-scale efforts have been completed for a variety of next-generation technologies and small pilot-scale testing is underway for a number of promising approaches with the goal that they will be ready for demonstration-scale testing in the 2025 time frame (GCCSI, 2015).

The focus of capture technology development efforts has started to shift from bench-scale testing of emerging technologies and demonstration of existing technologies toward pilot-scale testing of technologies that can significantly reduce costs. There are several 2nd generation capture technologies that are currently being tested at pilot scale (or soon will be) worldwide. Pilot-scale testing of 2nd generation technologies using actual process gases could be a critical step in advancing more cost-effective capture technologies (GCCSI, 2015).

Transport of CO2 by pipelines, trucks, trains, and ships is already a reality, occurring daily in many parts of the world. Pipelines are – and are likely to continue to be – the most common method of transporting the large quantities of CO2 involved in CCS projects. Ongoing R&D activities are focused on reducing cost and further improving the safety of CO2 pipelines by developing and validating predictive models for CO2 pipeline design. A clear developing theme in the CCS conversation, especially in Europe, is concerned with the development of CCS hubs and clusters (GCCSI, 2015).

Geological CO2 storage has been successfully and securely demonstrated at a number of sites around the world over the last two decades, both in deep saline formations and associated with enhanced oil recovery (CO2-EOR) operations. This has built on the knowledge base already derived from over 40 years of CO2-EOR operations in North America, which have predominantly utilized CO2 extracted from natural geological reservoirs. Large-scale storage in depleted gas fields can also be considered as a mature storage option, given the industrial analogues offered by natural gas storage operations. Deployment of large-scale storage projects will improve the understanding and calibration of regional resource assessments – for example, in better understanding the effects of pressurization on resources in deep saline formations.

The most accurate method to predict storage resources involves the use of dynamic numerical simulations. These are computer-based modeling techniques which simulate CO2 injection into a reservoir, predicting the migration and ultimate fate of injected CO2 in response to various physical and chemical processes. These assessments are typically undertaken at the site scale, supported by a detailed knowledge of geology and related subsurface characteristics. Dynamic calculations have computational limits and with increasing spatial and temporal scales, uncertainty increases. However, sub-basin and even basin scale dynamic assessments have been undertaken and modelers are making large advances in this field. Regional assessments of deep saline formations typically use simplified, analytical (‘static’) calculations to determine storage resources. Direct comparison between regions should only be considered from a qualitative perspective, since the levels of characterization data available and methodologies employed across regions are not consistent. The level to which a country has undertaken regional resource assessments is categorized and shown in Figure 3-5 (GCCSI, 2015).

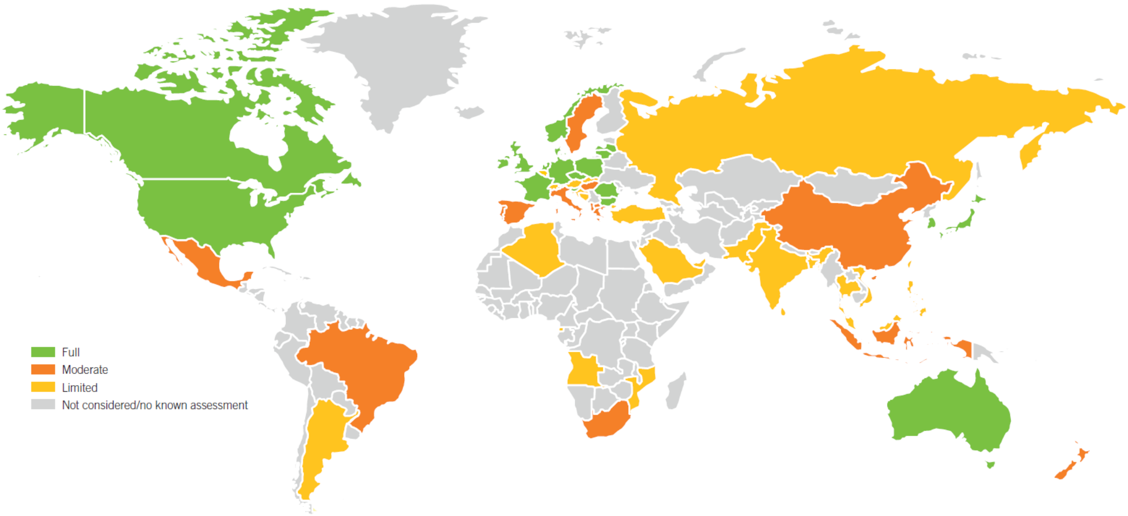

Figure 3-5. Geographical coverage of storage resources assessments (GCCSI, 2015).

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