THE GNCS FACTSHEETS

CCS – Carbon Storage

Carbon sequestration is the long-term isolation of carbon dioxide (CO_2) from the atmosphere through physical, chemical, biological or engineered processes. This will mostly involve transporting captured CO_2 to storage sites (see GNCS factsheets on air capture and CCS).

Storage Options

There are four main carbon storage options: in geological formations; through CO_2 enhanced oil, gas and coal-bed methane recovery; in the oceans; and by mineralization. Geological sequestration consists of injecting CO_2 in supercritical fluid form into geological formations (deep saline formations, depleted oil and gas fields and deep unmineable coal seams).[1] It is the most promising large-scale storage approach in the near term.[2] The oceans store 50 times as much carbon as the atmosphere, have taken up around half of all anthropogenic CO_2 emissions and have huge potential to absorb more. However, while scientific understanding is incomplete, increased ocean sequestration has potentially disastrous environmental impacts and is prohibited under the London Convention (sub-seabed geological storage is permitted).[3] The mineralization of CO_2 occurs naturally through a very slow reaction between CO_2 and some minerals (*e.g.* magnesium silicate) to form a mineral carbonate.[4] Experimental research is underway to increase the carbonation rate, *e.g.* in pilot trials to convert refining wastes like bauxite residue (red mud) chemically by combining them with CO_2.[5]

Storage Potential

Global storage potential can easily meet the IPCC and IEA goal of storing 145 billion tons (Gt) of CO_2 from emissions by 2050.[6] Estimates of geological basin-wide storage potential are between 8,000–15,000 $GtCO_2$.[7] Saline formations have the greatest potential among them, with conservative estimates starting at 2,000 $GtCO_2$ capacity,[8] and are broadly distributed.[9] Ten domestic projects to assess storage potential have been underway since 2008 in North America, Europe, Australia, China, India and South Africa, and there are a further 30 planned projects.[10] Most knowledge of storage prospects comes from oil and gas exploration data.[11] Only a few projects have estimated CO_2 storage potential for saline formations, whereas data on depleted oil and gas fields is more plentiful.[12] More targeted exploration is needed to locate suitable deep saline aquifers.[13] While most OECD countries have an idea of their potential storage capacity, there is still very little proven storage capacity ready to support commercial-scale project investment.[14] Given the 5–10 year timeframe required to move from initial screening to final storage site characterization, data gathering, capacity assessments, exploration, appraisal and injection testing should already be underway to deploy CCS in the next decade.[15]

Status of Carbon Storage

Geological storage projects have been operational worldwide for ten years. There are three commercial geological storage facilities in operation, all in deep saline aquifers (Sleipner in Norway, Snøhvit in the Barents Sea and In Salah in Algeria),[16] and an oil field project linked to

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1 Other, limited, experimental options include injection into basalt, oil shale, salt caverns, geothermal reservoirs, lignite seams, and methanogenesis in coal seams; CSLF. (2010). *CSLF Technology Roadmap*. Carbon Sequestration Leadership Forum. p. 15.
2 MIT (2007). *The Future of Coal – Options for a Carbon-Constrained World*. Massachusetts Institute of Technology. p. 43.
3 Ocean fertilization to increase the uptake of CO_2 is also prohibited, except for approved research activities. The London Convention was amended in 2006 to allow for sub-seabed CO_2 sequestration.
4 CSLF (2010), p. 15.
5 *Ibid.*
6 Global CCS Institute. (2010). *The Global Status of CCS 2010*. p. 10; IPCC. (2005). *Special Report on Carbon Capture and Storage*. Geneva: Intergovernmental Panel on Climate Change.
7 IEA. (2009). *Technology Roadmap: Carbon Capture & Storage*. Paris: International Energy Agency. p. 32; IEA. (2008). *CO_2 Capture and Storage: A Key Abatement Option*. IEA/OECD.
8 MIT (2007), p. 44; IEA (2009); IPCC (2005); Global CCS Institute (2010), p. 75;
9 IEA (2008), p. 106.
10 Global CCS Institute (2010), p. 11, 75 & 88.
11 IEA (2009), p. 9.
12 Global CCS Institute (2010), p. 75.
13 IEA (2009), p. 33.
14 Global CCS Institute (2010). p. 81-82.
15 *Ibid.*, p. 75.
16 McKinsey. (2008). *Carbon Capture & Storage: Assessing the Economics.* McKinsey & Co. p. 13.

enhanced oil recovery (EOR) in Weyburn in Canada.[17] Around 1 $MtCO_2$ is stored at Sleipner each year; up to 18 $MtCO_2$ will be injected in the Weyburn field over the lifetime of the project.[18] CO_2 has been reused for EOR for decades and is commercially viable (with benefits of EOR ranging from \$1–55/tCO_2).[19] Out of 32 large-scale EOR projects, most are located in North America.[20] Because of the financial incentives associated with its production, EOR provides early opportunities to study large-scale injection and long-term leakage risks.[21] Transition from CO_2 injection for EOR to permanent storage will require additional infrastructure and monitoring oversight.[22]

Measurement, monitoring and verification of stored CO_2 is required to identify leakage risk and surface escape, manage the CO_2 injection process, provide early warning of failure and verify storage or accounting and crediting.[23] Best practices guidelines are also needed for storage site selection, well construction, risk assessment, monitoring, remediation and site closure.[24]

Storage Costs

Moving from a desktop screening assessment to a fully assessed site that is ready for development is costly. Investment costs include site exploration, well drilling and completion, facilities (*e.g.* compressors, platforms), site closure and well plugging. Operating costs include monitoring, insurance and fuel. Overall costs for equipment, exploration and site set-up/closure costs are higher for offshore sites.[25] Capital costs range between \$0.6–4.5 per ton of CO_2 stored for a storage site receiving 5 $MtCO_2$ per year for 25 years.[26] Global investment needs range between \$0.8–5.6 billion in 2020 and \$88–650 billion in 2050.[27] Exploration and large-scale demonstration projects will enable us to refine these highly uncertain estimates.

Bottlenecks: Risk and Liability

There are two types of liability for geological sequestration: operational and post-injection. Operational liability includes the environmental, health and safety risks associated with CO_2 capture, transport, and injection, and can be managed within existing frameworks from the oil and gas industries. Post-injection liability issues include groundwater contamination, leaks to the atmosphere, risks to human health and contamination of mineral reserves.[28] These require new regulatory frameworks. Particular challenges include the conditions and timescale for transferring long-term liability for a 'closed' site from the operator to the competent authority, as well as setting the operator's financial obligations for long-term monitoring and stewardship.[29] Another challenge is public acceptance: several carbon storage projects have been delayed or abandoned as a result of public opposition to perceived risks.[30] While no CO_2 leaks have yet been observed, public confidence must be built through engagement and large-scale demonstration projects.[31]

Regulatory frameworks are being developed in North America, Europe and Australia. The 2009 EU "CCS Directive" requires EU member states to implement comprehensive national legislation on CO_2 transport and storage in 2011.[32] Notably, it recommends that the operator should only be able to transfer liability for a site at least 20 years after its closure (as in Australia). However, draft German legislation cites a minimum 30-year period, while the UK is likely to treat transfer decisions on a case by case basis.[33] Prior to national legislation, international agreements were amended to allow for CCS deployment (the London Protocol,[34] in 2006 and 2009, and the OSPAR Convention in 2007).[35]

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Further resources are available at **www.theGNCS.org**

[17] Interagency Task Force on Carbon Capture and Storage. (2010). *Executive Summary: Report of the Interagency Task Force on Carbon Capture and Storage.* US EPA & DOE. p. 3.
[18] Brown, K. *et al.* (2001). "Role of Enhanced Oil Recovery in Carbon Sequestration: The Weyburn Monitoring Project, a case study." p. 3.
[19] IEA. (2004). *Energy Technology Analysis: Prospects for CO_2 Capture and Storage.* International Energy Agency. p. 82.
[20] Global CCS Institute (2010), p. 89.
[21] MIT (2007), p. 53.
[22] At present, many EOR projects recycle much of the CO_2 used rather than storing it. Global CCS Institute (2010), p. 75.
[23] MIT (2007), p. 47.
[24] IEA (2009), p. 33.
[25] McKinsey (2008), p. 20.
[26] IEA (2009), p. 32.
[27] *Ibid*.
[28] MIT (2007), p. 57-58; Price, P. *et al.* (2007). *Carbon Sequestration Risks and Risk Management*. Lawrence Berkeley National Lab. p. 6.
[29] See 3rd IEA International CCS Regulatory Network Meeting (2011).
[30] Global CCS Institute (2010), p. 142.
[31] CSLF (2010), p. 14; IEA (2009), p. 9; IPCC (2005); MIT (2007), p. 53.
[32] See: http://www.ucl.ac.uk/cclp/ccsdedlegstorage.php.
[33] Rutland, D. (2010). *CCS Legal and Regulatory Developments in the UK*. London: UK Department of Energy and Climate Change.
[34] The amendments to the 1996 London Protocol allow, respectively, for offshore CO_2 storage and cross-border CO_2 transportation for storage.
[35] The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention) was also amended in 2007 to adopt similar provisions; Global CCS Institute (2010), p. 111.