CSLF Technology Roadmap Interim Report

Executive Summary and Conclusions

At the 5th CSLF Ministerial Conference, convened in 2013, Ministers stressed that the next seven years were critically important for creating the conditions for CCS to be ready for large-scale deployment by the end of the decade. The 2013 CSLF Technology Roadmap (TRM) established that the year 2020 was an achievable timeframe for demonstration of the 1st generation of CCS technologies and that by the year 2030, 2nd generation technologies should be moved through demonstration and into commercialization. However, now, two years later, barriers are still in place that inhibit the accomplishment of these goals.

Overall, except for a very few niche industrial sector applications, for the current generation technologies, *none* of the ten technology needs areas were generally perceived as progress being 'fast moving'. To the contrary, 'slow-to-moderate' progress was perceived as the norm for almost all of the ten areas, mainly because of policy and economic barriers that currently exist. The technical readiness of these technologies were perceived, in general, as ready for large-scale commercial deployment.

CCS is considered a key contributor in strategies for decreasing the impacts of climate change and global warming. The main takeaway from this interim report is that the next several years are a critical time period when not only technologies, but also regulatory policies and approaches toward project financing must become mature. In this context, the following recommendations are made to accelerate progress:

- Concerning economic barriers, governments should urgently consider methods to assist stakeholders to significantly drive down the cost of CCS deployment, since it is the stakeholders who will be making the majority of the financial investments.
- Concerning policy barriers, governments should review institutional regulatory policies to identify how these barriers to CCS deployment may be reduced.
- Concerning any remaining technology barriers, stakeholders should increase their mechanisms for sharing best practices, particularly regarding communications, regulation and cost reduction, and pledge to engage in public-private partnerships to encourage the development of additional demonstration projects and facilitate the development of CCS projects internationally.

Finally, Ministers should be champions of CCS, and should ensure that they understand how critical CCS is to reaching target goals for CO_2 emissions, and that CCS deployment will create and preserve jobs. Ministers should also recognize the contribution that CCS can provide in terms of energy security. These will all form part of the narrative that will help shape the future progress of CCS.

Introduction

The 2013 CSLF TRM was launched at the 5th CSLF Ministerial Meeting in November 2013 as the latest in a series of TRM documents that date back to 2004. The main objective of the 2013 TRM was to recommend to governments the technology priorities for successful implementation of carbon capture and storage (CCS) in the power and industrial sectors. In particular, the 2013 TRM was intended to answer three questions:

a) What is the current status of CCS technology and deployment, particularly in CSLF member countries?
b) Where should CCS be by 2020 and beyond?
c) What is needed to get from Point A to Point B, while also addressing the different circumstances of developed and developing countries?

The 2013 TRM contained several key recommendations for advancing carbon capture and storage (CCS) technologies toward the year 2020 and beyond:

Towards 2020 nations should work together to:

- Maintain and increase commitment to CCS as a viable greenhouse gas (GHG) mitigation option.
- Establish international networks, test centres and comprehensive RD&D programmes to verify, qualify and facilitate demonstration of CCS technologies.
- Gain experience with 1st generation CO_2 capture technologies and their integration into power plants.
- Encourage and support the first industrial demonstration plants for CO_2 capture.
- Develop sizeable pilot-scale projects for storage.
- Design large-scale, regional CO_2 transport networks and infrastructure.
- Agree on common standards, best practices and specifications for all parts of the CCS chain.
- Map regional opportunities for CO_2 utilization, addressing the different priorities, technical developments and needs of developed and developing countries.

Towards 2030 nations should work together to:

- Move 2nd generation CO_2 capture technologies for power generation and industrial applications through demonstration and commercialisation, with possible targets of 30% reduction of energy penalty, normalized capital cost, and normalized operational and maintenance (O&M) costs compared to 1st generation technologies.
- Implement large-scale national and international CO_2 transport networks and infrastructure.
- Demonstrate safe, large-scale CO_2 storage and monitoring.
- Qualify regional, and potentially cross-border, clusters of CO_2 storage reservoirs with sufficient capacity.
- Ensure sufficient resource capacity for a large-scale CCS industry.
- Scale-up and demonstrate non-enhanced oil recovery (EOR) CO_2 utilization options.

Towards 2050 nations should work together to:

- Develop and progress to commercialisation 3rd generation CO_2 capture technologies with energy penalties and avoidance costs well below that of 1st generation technologies. Possible targets for 3rd generation CO_2 capture technology for power generation and industrial applications are a 50% reduction from 1st generation levels of each of the following: the energy penalty, capital cost, and O&M costs (fixed and non-fuel variable costs) compared to 2013 1st generation technologies costs.

The 2013 TRM also identified ten distinct 'technology needs areas' that are vital for successful commercial implementation of large-scale CCS projects:

a) CO_2 capture in power generation
b) CO_2 capture in the industrial sector
c) CO_2 transport
d) Large-scale CO_2 storage
e) Monitoring stored CO_2
f) Mitigation / remediation procedures
g) Understanding storage reservoirs
h) Infrastructure and the integrated CCS chain (capture to storage)
i) CO_2 utilization, non-EOR
j) CO_2 utilization, EOR

Commencing in 2015, the CSLF Technical Group agreed to monitor progress in these areas at regular intervals and publish its findings. To that end, information was obtained (via a survey) from organizations in CSLF member countries that are working to develop, improve, demonstrate, or implement technologies relevant to CCS. Representatives of these organizations were requested to provide their evidence-based opinions, for each of the ten technology needs areas, on whether progress in these areas was occurring either 'very slowly', or at 'moderate pace', or 'fast moving'. They were also asked to indicate if there were economic, policy, and/or technological drivers that are affecting the relative amount of progress.

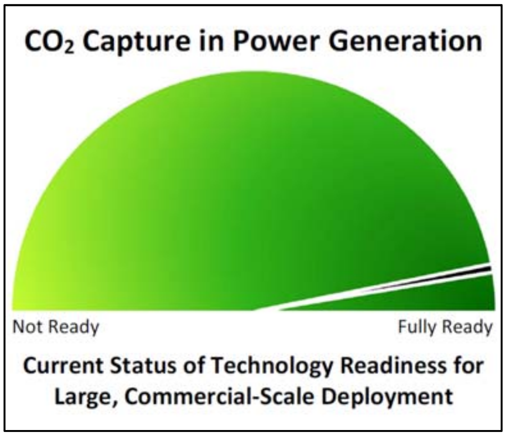
Information gathered in the survey has been used to chart progress in both application and adaption of 1st generation technologies that are now being used in commercial or demonstration-scale CCS projects; and also 2nd and 3rd generation technologies that are being tested in pilot-scale CCS projects (i.e., >1 MW and/or >1,000 tonnes of CO_2 injected per year). Although the 2013 TRM covers decadal timeframes towards the years 2020, 2030, and 2050, this survey was only concerned with progress towards the year 2020. The results of the survey are summarized in the following ten sections.

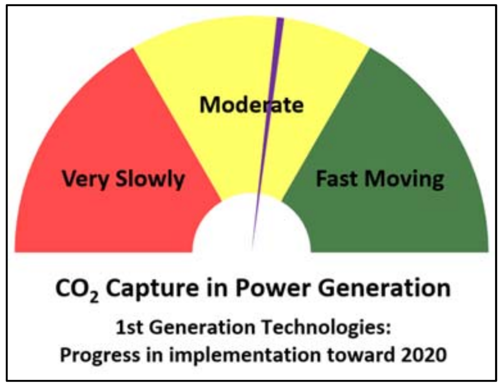
Global Trends in CO_2 Capture Technology from Power Industry

Technology Readiness

CCS experts from around the world consider CO_2 capture technology as fully ready for large scale demonstration, from a technology point of view. However, when taking barriers to implementation into account, the overall progress toward wide-scale use of CO_2 capture technology by the year 2020 has been only moderate.

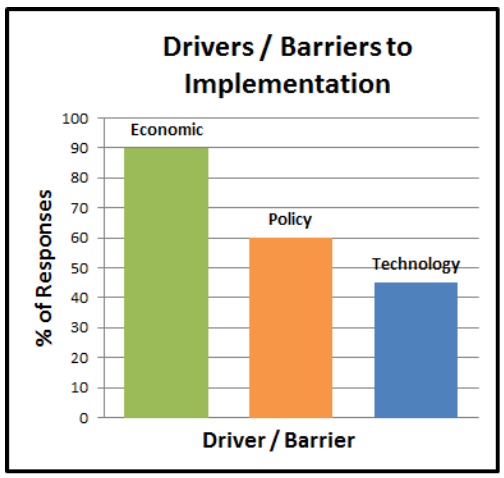
As of mid-2015, only one power station, Boundary Dam in Canada, is utilizing CO_2 capture technology in a large-scale project. Since 2013, more power production CCS projects have been cancelled than have been announced.





Barriers to Implementation

CCS experts have indicated that the most significant barriers to commercial-scale deployment of CO_2 capture technology are related to economics and policy. High cost, moderate public funding and limited regulations and incentives have been cited. The technical barriers are both minimal and manageable. Two potential technical challenges are: 1) Emissions from amine plants and that amine based absorption processes can lead to aerosol formation; and 2) Integration of the capture technology with the power plant. Both are being addressed by the international CCS community.



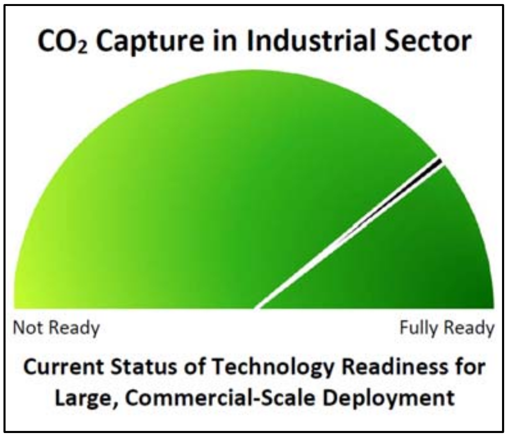
Next Generation Technologies

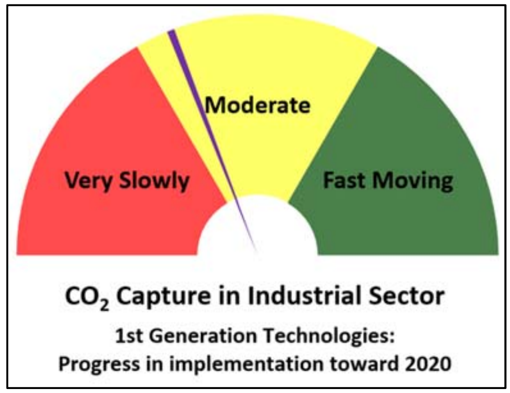
Development of next-generation technologies will reduce the cost of CO_2 capture. These next generation technologies are already being advanced at the R&D scale but they will need to be scaled up and field tested in pilot plants. However, the development of these new technologies is largely a function of economics and policy regarding adoption of CCS as a low emissions technology.

Global Trends in CO_2 Capture from Industrial Sector

Technology Readiness

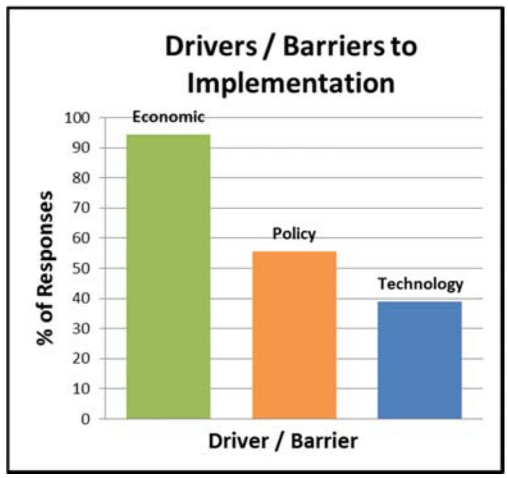
CCS experts from around the world rated the technical readiness of CO_2 capture technology differently depending on the industrial application. For liquified natural gas (LNG) processing, ethanol production and hydrogen production from reforming natural gas, CO_2 capture is an inherent part of the process and current technologies for doing so have progressed relatively rapidly. For the steel and cement industry, progress toward widescale use has been much slower. Overall, for most applications the technology is viewed as ready for large-scale demonstration but there is a need for more pilot projects.





Barriers to Implementation

CCS experts have indicated that the most significant barriers to commercial-scale deployment were the cost of the technology and the lack of policy in most countries for directing companies to pursue large-scale implementation of CCS. Some specific technical barriers also exist – operational challenges (e.g. contamination and intermittency) and integration issues – although the general view is that the technology for industrial applications is at a similar level of maturity as for application to power generation.



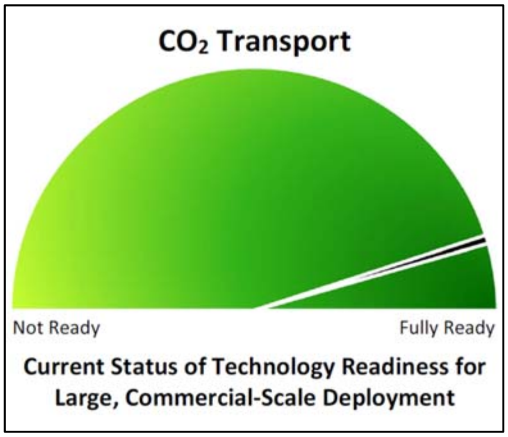
Next Generation Technologies

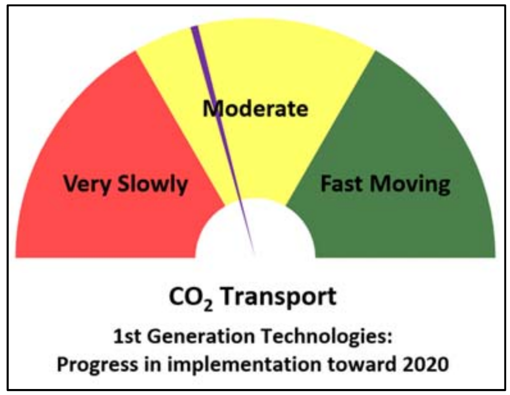
Development of next generation capture technologies has been very slow, although some applied R&D is taking place, in particular in the areas of bio-energy with CCS and in the cement industry. In some cases further R&D, focused on cost reduction and operational performance, is required before pilot-scale projects can happen. Development of these next generation technologies will be dependent on economics and policy regarding adoption of CCS as a low emissions technology.

Global Trends in CO_2 Transport

Technology Readiness

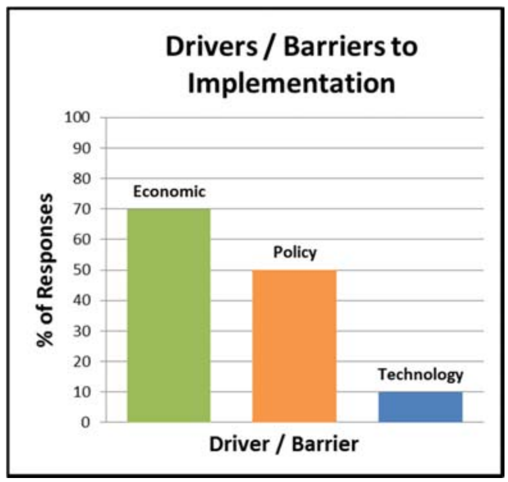
CCS experts consider the current generation of technologies for transporting CO_2 (by pipeline or by road/rail) are fully ready for large, commercial-scale deployment. However, non-technical barriers are inhibiting progress towards the 2020 goal of designing large-scale CO_2 transport networks and infrastructure. CO_2 for enhanced oil recovery (EOR) is being successfully transported in the United States, but the volumes are relatively small (approx. 60 million tonnes annually) and some of the pipelines are project-specific. Physical properties considerations for CO_2 (e.g., hydrate formation) and the purity of the captured CO_2 stream can complicate operational procedures and need to be considered, but there does not appear to be any insurmountable technical issues for onshore transport of CO_2.





Barriers to Implementation

CCS experts have confirmed that the most significant barriers to developing a CO_2 transportation infrastructure are related to economics and policy. CO_2 pipelines are very expensive to construct and there are currently insufficient policy drivers and incentives to bring about creation of a broadly-reaching CO_2 transport infrastructure. An additional challenge is that with the exception of current EOR operations, societal approval for routing of onshore CO_2 pipelines has proven to be extremely difficult to obtain – it was one of the factors that halted the Bełchatów CCS project in Poland.



Next Generation Technologies

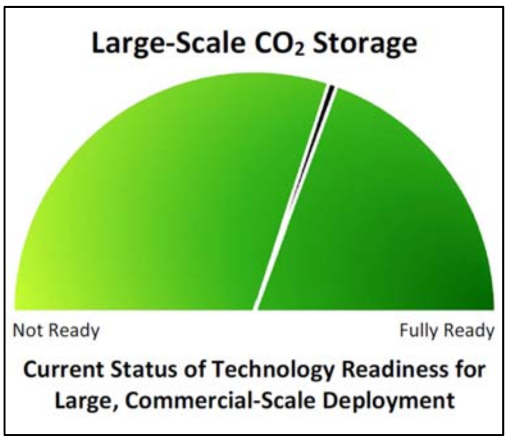
Next generation hybrid CO_2 transport systems are under evaluation which involve both pipeline and ship transport. Several countries are investigating the feasibility of shipping CO_2 from onshore sources to offshore terminals where the CO_2 would be injected into sub-seabed geologic reservoirs. As with the current generation of transport systems, there does not appear to be any insurmountable technical issues for this kind of CO_2 transport.

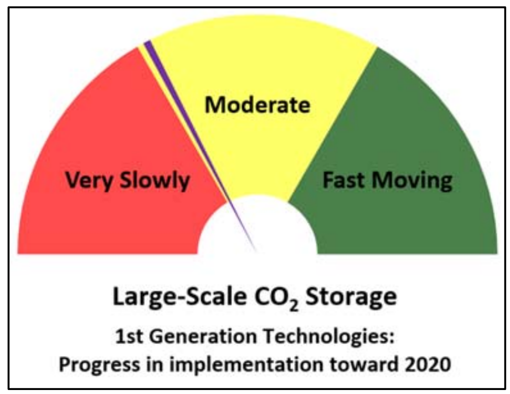
Global Trends in Large-Scale CO_2 Storage

Technology Readiness

CCS experts consider that technologies are reasonably developed to demonstrate large-scale CO_2 geologic storage. But when taking barriers to implementation into account, the overall progress toward large-scale storage has been slow. Whereas the International Energy Agency, for example, set a goal of 200 million tonnes (Mt) of CO_2 storage by 2020 in their CCS roadmap of 2013, the total capture capacity of the 14 operational large-scale CCS projects is limited to 28 Mt of CO_2.

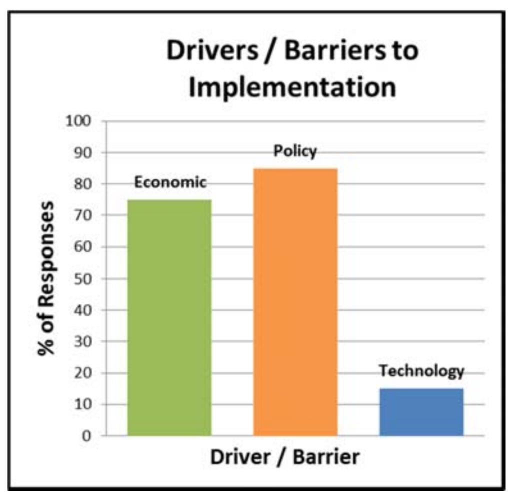
From a technology viewpoint, the remaining uncertainties involve the determination of storage capacities for individual geologic storage sites and the prediction of long-term CO_2 behavior in a reservoir. Both of these are site-specific and can be addressed by site characterization procedures, though these can take time and resources to accomplish. Each new storage project will add to the overall knowledge base such that uncertainties of this nature can be expected to lessen for each new storage project.





Barriers to Implementation

CCS experts have pointed to policy and economics barriers that are inhibiting implementation. These include uncertainties in long-term liability. And since CO_2 aquifer storage in general provides no revenue to compensate costs of CCS, policy-driven incentives are the only reason for undertaking a CCS project with non-EOR storage. Another critical barrier in some areas is public acceptance for onshore CO_2 storage.



Next Generation Technologies

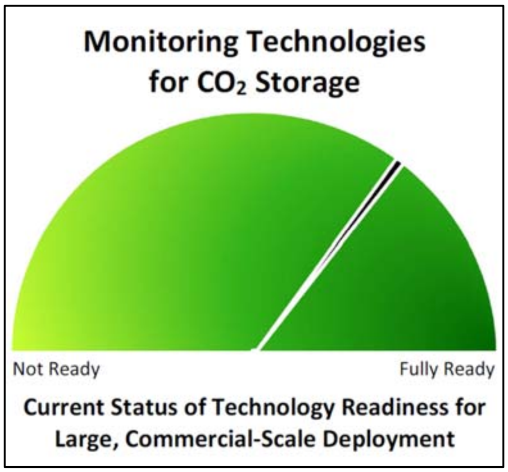
Large-scale CO_2 storage sites are geologically sedimentary in nature. There have been studies of the efficacy of large-scale CO_2 storage under basalt, but there are not yet any projects of this nature at a large scale.

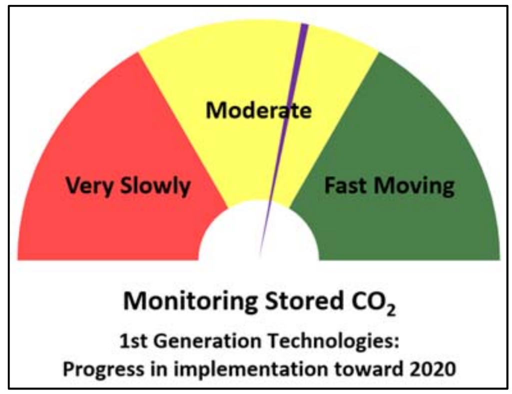
Global Trends in Monitoring Technologies for CO_2 Storage

Technology Readiness

CCS experts consider monitoring technologies for CO_2 storage as improving and progressing, and in general ready for large-scale demonstration. However, when taking barriers into account, the overall progress toward wide-scale use of these technologies is showing only moderate progress.

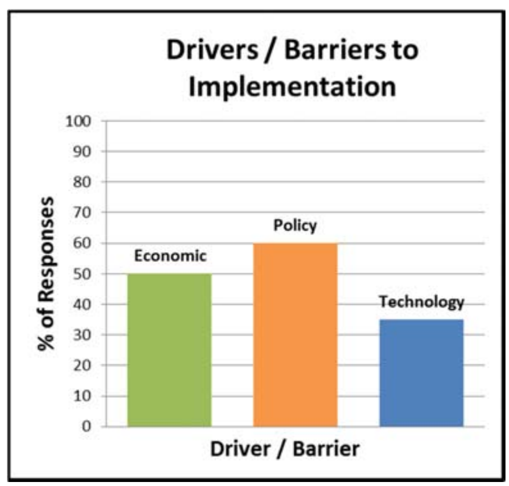
Technologies previously developed for the oil and gas industry are proving to be good techniques for monitoring storage of CO_2. The challenge has been gaining enough experience at large-scale field sites to prove reliability. EOR sites, Norway's offshore Sleipner project, and small-scale field tests have provided opportunities to broaden the knowledge base and contribute to scientific understanding.





Barriers to Implementation

CCS experts have indicated there are significant economic and policy barriers to commercial-scale deployment of CO_2 monitoring technologies. The lack of large-scale test sites and the fact that most technology development and field tests are government-funded are commonly cited issues. Monitoring technology itself was not necessarily considered a barrier as projects will use what technologies and tools are available. However, some of these technologies, such as seismic, are considered too costly or of low precision.



Next Generation Technologies

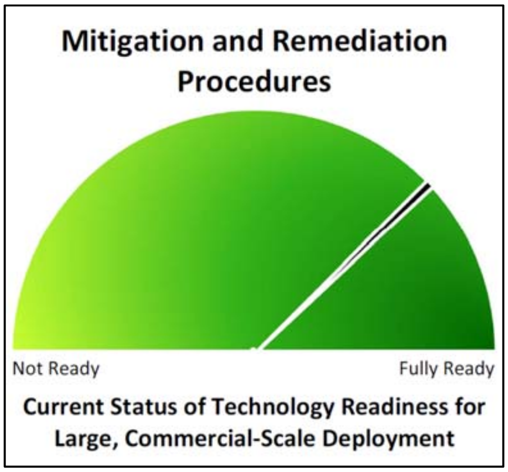
Current monitoring technologies are limited or have too much uncertainty regarding the exact CO_2 plume size and understanding complex geology and fluid flow. The contribution of government funding to progressing next generation technologies is recognized as a key contributor to advancing monitoring technologies, but large-scale sites are needed for technology validation.

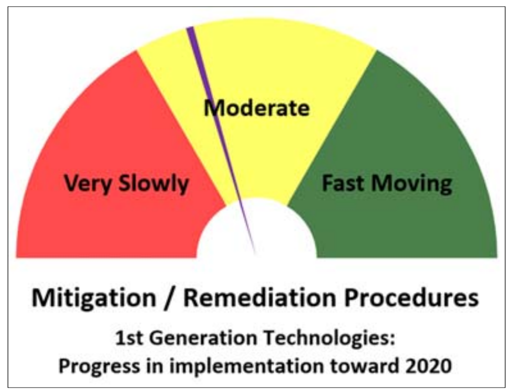
Global Trends in Mitigation and Remediation Procedures

Technology Readiness

CCS experts regard the mitigation and remediation procedures as being ready for large-scale demonstration, from a technology point of view, largely because they rely on methods that have been well-tested and deployed in oil and gas as well as ground water industries. The current solutions are, however, costly and challenging to deploy. The technology still needs demonstration for a variety of settings (geology, operational parameters, leak event type, etc.), and it needs research and development of (more) cost efficient methods.

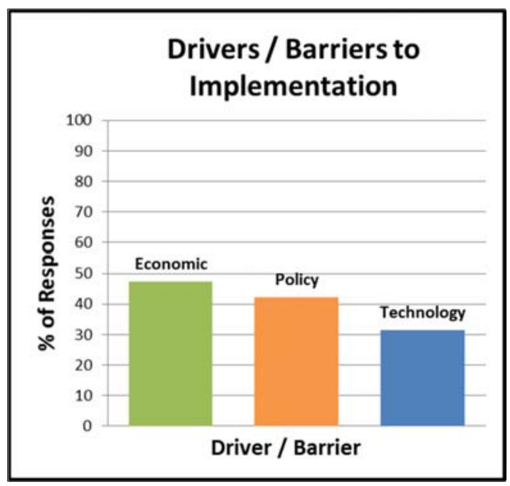
Overall, the commercial and environmental potential of these technologies and procedures has been recognized, and it is acknowledged that they should be in place before CCS can be deployed. But when taking barriers to implementation into account, actual progress toward their use has been slow to moderate.





Barriers to Implementation

CCS experts have indicated that there are still some economics and policy barriers that are inhibiting wide-scale use of these technologies and procedures. For example, there is no obvious consensus as to what constitutes a leakage and hence when a regulator might require remediation.

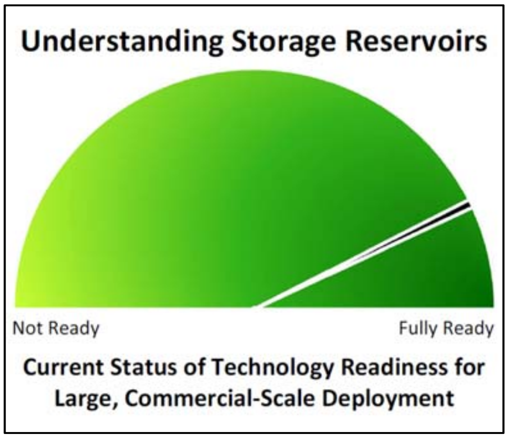


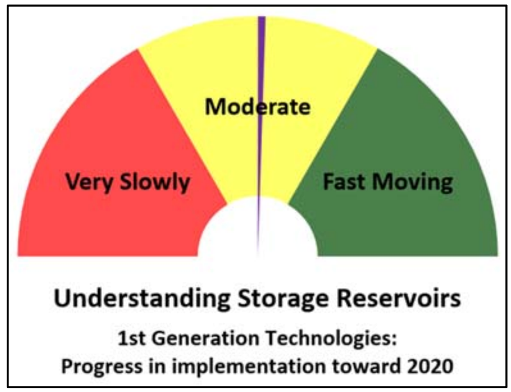
Technical barriers are also present. Mitigation and remediation, as "end of chain" technologies, have received much less attention than CO_2 capture, transport and storage. Some of these technologies and procedures are in a relatively early stage, and their development should be accelerated. Universities and research institutes carry out most of the research and desk studies, and this is expected to progress the technologies. As a follow-up, real-life field testing using controlled release, and involving industry, needs to be carried out for a variety of scenarios. However, an important regulatory barrier is the difficulty to obtain a permit for such experiments.

Global Trends in Understanding Storage Reservoirs

Technology Readiness

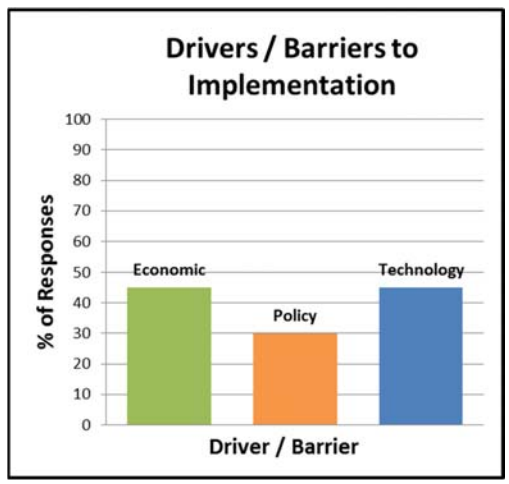
CCS experts regard the technologies involved in the understanding of storage reservoirs to be ready for wide-scale use but that barriers to implementation are reducing progress toward wide-scale use to only a moderate rate. Commercial CO_2 storage operations at existing large-scale CCS projects are providing an expanding source of experience and are of great value to future projects. These projects have generally adopted oil & gas industry best practices for CO_2-EOR and storage in deep saline formations, and their use has led to advancements.





Barriers to Implementation

CCS experts cite economic, technology, and policy barriers to commercial-scale use. Deploying conventional geological, geochemical and geophysical techniques at commercial scale is expensive, even though such approaches have provided detailed characterization of potential storage reservoirs. Other cost barriers exist, generally linked to the high cost of using oil & gas industry techniques in CCS applications. There are also still some technology-related barriers. The prediction of CO_2 plume behavior using modelling techniques is not straightforward and pressure management in reservoirs is a critical factor.



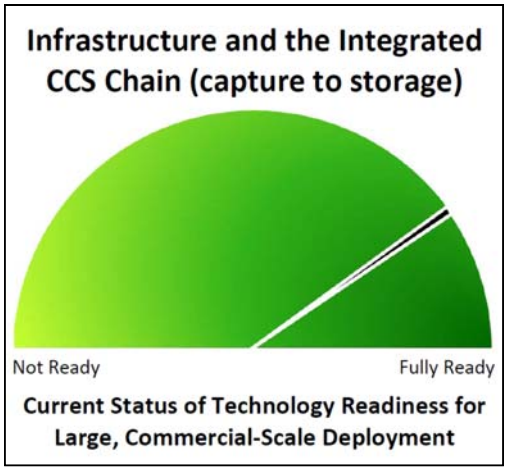
Next Generation Technologies

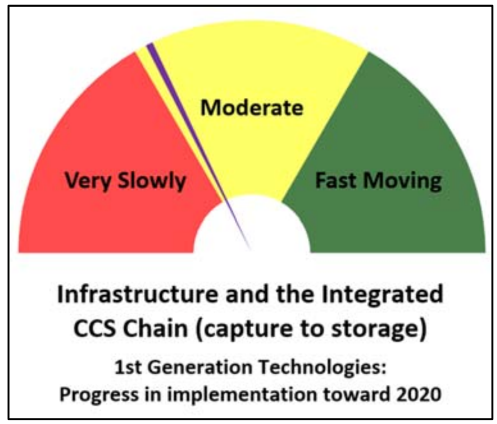
Understanding storage reservoirs for large-scale, commercial CCS operations has proved more difficult than first predicted. RD&D into advanced technologies and techniques that can further reduce residual subsurface uncertainties following site characterization using costly conventional approaches is needed. Cost-effectively reducing this uncertainty during site characterization will significantly reduce characterization time, development cost, operational risks and closure liability. Characterization and site selection link with regulatory requirements for site monitoring, and cost reduction in site monitoring is a key requirement.

Global Trends in Infrastructure and the Integrated CCS Chain (Capture to Storage)

Technology Readiness

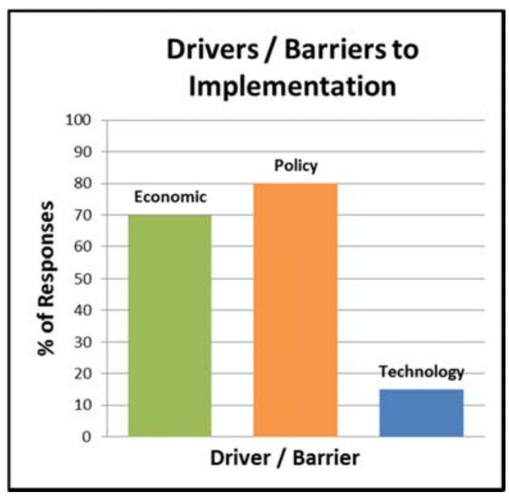
CCS experts consider infrastructure-related technologies involving the integrated CCS chain to be ready for large-scale demonstration. There are significant economic and policy-related barriers, however, that are inhibiting 'CCS hub' projects from happening. Projects such as the ROAD project in the Netherlands have helped develop an understanding of integration issues at the design phase, but significant additional experience will only be gained from the contruction and commissioning phases. Such infrastructure and integration activity is expensive and requires government support.





Barriers to Implementation

CCS experts have indicated that the most commonly cited barriers to commercial-scale deployment are the general lack of policy and difficult economics, including finance, ownership, business cases, risk allocation, etc. While technical issues are not generally considered to be barriers, CO_2 purity (especially where multiple sources are involved) could be a major issue. Also, plant and grid flexibility will need careful management.



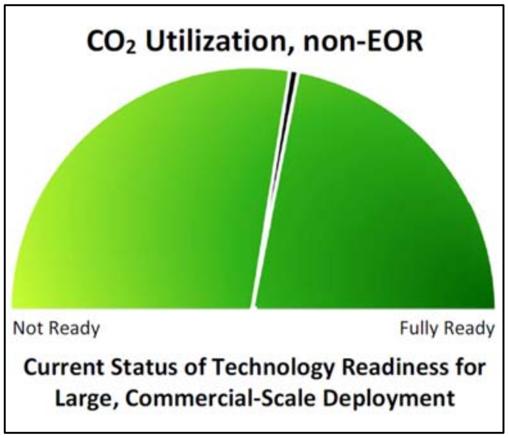
Next Generation Technologies

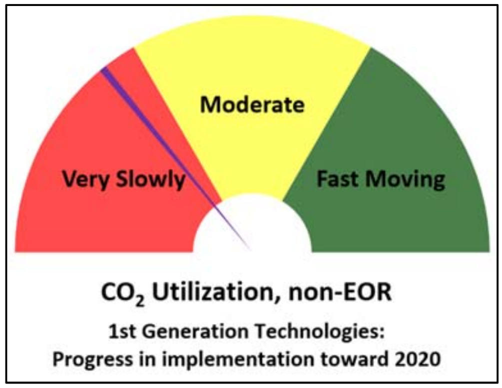
New technologies related to infrastructure and the integrated CCS chain may not actually be necessary, but there is a need to find better ways of adapting many of the existing technologies to industrial processes with CCS (e.g., chemicals plants, iron and steel, cement, etc.). Furthermore, multiple sources linked via 'hubs' to geologic storage sites will pose challenges that are not currently being addressed through R&D activities.

Global Trends in CO_2 Utilization, non-EOR

Technology Readiness

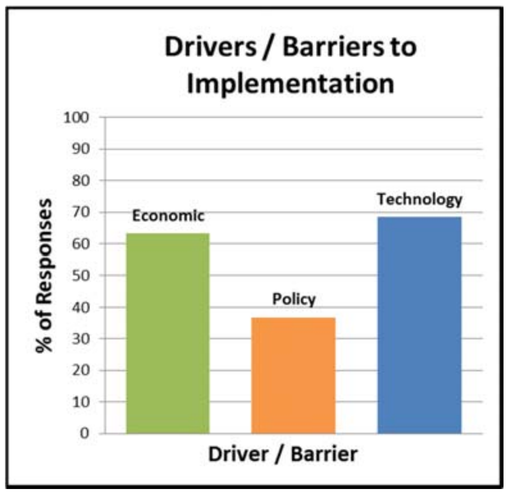
CCS experts consider the current generation of technologies for non-EOR CO_2 utilization at least somewhat ready for large-scale demonstration, though this determination is application specific. There may be some technologies which are ready for some niche applications but for most options, good business cases are lacking due to the high-cost and energy-intensive features for non-EOR CO_2 utilization. Overall progress toward wide-scale use of these technologies is in general very slow moving.





Barriers to Implementation

CCS experts have indicated that the most significant barriers to implementation of these technologies are related to economics and technology. In particular, the current generation of technologies can make use of only a relatively small volume of CO_2 compared to EOR, so a relatively small amount of attention is being paid to these technologies in the overall scheme of things. As a result, development of technologies for utilization of CO_2 have not been advancing as rapidly as for other aspects of CCS and the economic case for these new technologies is still a work in progress.



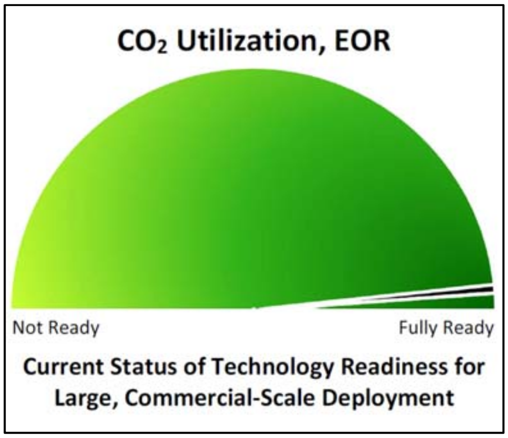
Next Generation Technologies

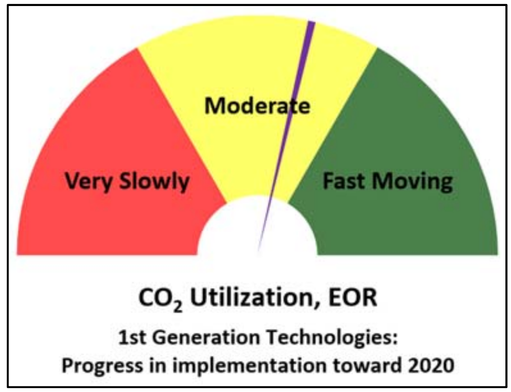
Development of next generation technologies for non-EOR CO_2 utilization is also moving very slowly, but there has been special attention from governments (especially in China) for promoting the development of new and advanced utilization technologies.

Global Trends in CO_2 Utilization, Enhanced Oil Recovery (EOR)

Technology Readiness

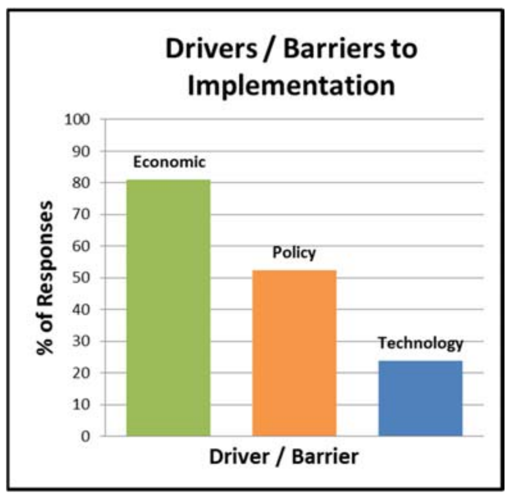
CCS experts consider CO_2-EOR as a deployed technology that is fully ready for large-scale demonstration but its widespread implementation around the world has been limited because of applicability, economics, or policy barriers. In the United States, CO_2-EOR has been in commercial use for more than 40 years. Outside of North America, however, this technology has not yet gained serious consideration. This is because of the abundant conventional resources that can be extracted naturally as is the case in the Middle East, the high cost of CO_2 from anthropogenic sources, and the lack of EOR prospects in places like Australia, Japan, and Korea.





Barriers to Implementation

CCS experts have indicated that the most significant barrier to wide-scale deployment of CO_2-EOR was economic, as EOR will signficantly increase the cost of extracting oil compared to waterflooding or tertiary recovery using natural gas and solvents, even though EOR is still considered economical (at current oil prices). Another economic barrier is the high cost of constructing additional infrastructure to move the CO_2 from large point sources to EOR locations; there are few places in the world where such infrastructure currently exists. Policy-related barriers also exist, where goverment support and incentives have been in general insufficient to enable wider-scale deployment.



Next Generation Technologies

Development of next generation CO_2-EOR has been slow moving, like its application in unconventional reservoirs and enhanced coal-bed methane (ECBM), and in extending its purpose to include CO_2 storage. Using CO_2-EOR for CO_2 storage requires new monitoring techniques to cover areas beyond the conventional monitored areas in EOR, to include a wider range of parameters, and to be extended for longer periods of time beyond the operational time of the oil field.