CARBON SEQUESTRATION LEADERSHIP FORUM

TECHNICAL GROUP

Ad Hoc Committee for Task Force Maximization and Knowledge Sharing Assessment

Monitoring Progress of the Technology Roadmap (TRM) 2017

Update on progress of Recommended Priority Actions to meet the TRM targets.

Period March – September 2020

September 2020

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1. Introduction

This note gives status as of September 2020 on monitoring recommendations in the CSLF Technology Roadmap (TRM). It represents an update of a report to the CSLF Technical Group presented at the April 2019 meeting in Champaign, Illinois, USA. The update was planned to be presented at the MRCH 2020 meeting of the CSLF Technival group but had to be postponed due to Covid-19.

The background is the decision made at the Venice meeting in April 2018:

According to the CSLF Technical Group (from the Follow-up plans of the 2017 TRM) the technical Group has an obligation to monitor progress on target and recommendations:

- The CSLF should
  - Monitor the progress in CCS in relation to the Recommended Priority Actions.
  - Report the findings at Ministerial meetings.
  - Suggest adjustments and updates of the TRM.

The targets set forth in the TRM are:

2025: Permanent storage of at least 400 megatonnes (Mt) CO_2 per year (or have permanently captured and stored 1,800 Mt CO_2)

2035: Permanent storage of at least 2,400 Mt CO_2 per year (or permanent capture and storage of in total 16,000 Mt CO_2)

The Recommended Priority Actions are:

1. Infrastructure, hubs and clusters

Facilitate CCS infrastructure development.

2. Large scale projects

Leverage existing large-scale projects to promote knowledge-exchange opportunities.

3. RD&D

Drive costs down along the whole CCS chain through RD&D

4. Business models

Facilitate innovative business models for CCS projects.

5. Utilisation (added at the Champaign meeting April 25-26, 2019)

Facilitate Implementation of CO_2 Utilisation

This update covers the period March 2019 – September 2020. Thus, Utilisation is new.

Ratings used below are as follows:

Good, the progress contributes to reaching the Target

Room for improvement, progress registered but insufficient to reach target unless new actions are initiated

Poor progress, target will not be reached. Strong actions required

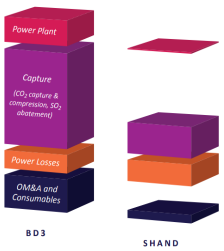
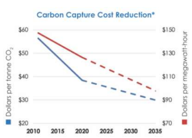
2. Results - Summary table

Progress towards 2025 target

Target	Rating	Conclusion
Long-term isolation from the atmosphere of at least 400 megatonnes (Mt) CO_2 per year by 2025 (or have permanently captured and stored of 1,800 Mt CO_2).	🔴	Need 10-fold increase in annual storage capacity next six years. Three plants have come online since March 2019, (the Gorgon project in Australia, and North West Sturgeon Refinery and Nutrien's Redwater Fertilizer Facility, both in Alberta, Canada, increasing capacity by 6 Mt CO_2/y). One facility was shut down (Petra Nova, Texas, USA), resulting in a net increase by ~5 Mt CO_2/y to 43 Mt CO_2/y. Two projects in construction in China may add 1+ Mt CO_2/y. Projects in advanced or early development will not add sufficient capacity by 2025, only 35 -40 Mt CO_2/y.

The table below indicates where the strongest efforts from the CSLF are needed:

Priority Recommendation (Strategic Action)	Rating	Conclusion
1. Facilitate CCS infrastructure development.	🟡	Positive developments are noted: • One project went online during spring 2020 (ACTL) • One project, The Norwegian Full-scale, has submitted FEED documents (FID expected late 2020/early 2021) and drilled an appraisal well • One other project, CarbonNet, has also drilled an appraisal well • One Project, Porthos, aims to apply for national funding from the Dutch SDE++ programme (Sustainable Energy Transition Scheme) in September 2020 • Several projects have received general funding or part funding (the Humber Region/Drax, Clean Gas Project/Teesside, Hynet, ACORN, Dunkirk, H21, Northern Lights) a. Of these, the Humber Region/Drax is new since March 2019 • Infrastructure for CO_2 transportation remains on the EU list of Projects of Common Interest (PCI)

		• New as well as continued interest in hubs, clusters and infrastructure is noted through new studies and workshops but all except on project are still in the late pre-FEED phase, at best. These developments should justify a change from red to yellow.
2. Leverage existing large-scale projects  		Active leveraging through CSLF and other meetings, as well as the International Knowledge-Sharing Centre. Reports by the Centre show that, for coal-fired power plants, capture cost on a per tonne basis can be reduced by more than 60% from the Boundary Dam 3 facility to the Shand 300MW single-unit power plant. Factors that contribute to the cost reductions include: • Scaling Up the CCUS Plant • Site layout and modularization, • Increasing capture capacity • Increased efficiency of the host power unit • Optimizing the CCUS operating envelope. • The ability of the capture facility to follow the variability of the thermal power plant • Development of a CCUS supply chain, including suitable competition and standardization • Reduce amine (solvent) degradation, water consumption and maintenance costs • Minimizing the impacts of the capture facility's energy requirements on the host power facility, including compression • Optimization of thermal energy required to operate the CO_2 capture process • Digitalisation • Reduce CO_2 transport and storage costs, e.g. through hubs, clusters and shared infrastructure
3. Drive costs down along the whole CCS chain through RD&D. 3.1. Capture  		Much good research that progresses CCUS technologies has been identified. However, no break-through technologies have been reported or identified that at TRL 6 or higher have strongly documented evidence of significant cost reductions. Positive developments include: • ITCN expanding • CCUS R&D community and private partners moving forward with commercial designs • Cost of avoided carbon reduced by 1/3 using NCCC results • NetPower has been demonstrating key components in the Allam Cycle in their 50 MW_{th} Demonstration Plant in La Porte, Texas • Oxyfuel: Callide project in Australia, has established a small demonstration project.

		• Carbon Engineering has received funds for demonstration and FEED work. • Funding is available for small projects, but not enough available for large scale. • Emirates Steel is considering additional industrial carbon capture projects to add CO_2 to their EOR project More efforts needed to increase possibilities for testing at the large pilot and demonstration scale
3.2. Storage		Storage sees progress in characterizing large-scale systems, data sharing, bringing down monitoring costs, and developing simulation tools. Much of the progress is happening through international cooperation.
4. Facilitate innovative business models for CCS projects		Initiative taken by China through CEM CCUS to map business models and incentive policies in member states. Preliminary results include information on four different business models, funding availability, initial investments, and inventive policies for the 37 projects in ten countries. Other activities and documents: 1. Consultation from UK BEIS on Business models for CCUS 2. Market based frameworks for CCUS in the power sector. Report by Cornwall Insight 3. Policy priorities to incentivise large scale deployment of CCS. Report from GCCSI
5. Facilitate Implementation of CO_2 Utilization		• Over 70 projects ranging from pilot to full-scale commercial operations. • Several of these projects have been completed while others are under construction. Further, these projects range in their scope of technologies from biological conversion of CO_2 (e.g., algae or other microorganisms) to mineralization and fuels and chemicals production via catalytic methods. • Some markets exist (e.g. EOR, fire suppression, urea). 45Q example of financial incentive. • Extensive interest from industry and governments.

3. Recommendations

<u>Recommendation1</u>

The Ad Hoc Committee for Task Force Maximization and Knowledge Sharing Assessment
changes name to
Technology Roadmap (TRM) Task Force

with mandate to

- Monitor the progress in CCUS in relation to the Recommended Priority Actions of the TRM
- Report the findings to CEM Ministers
- Evaluate the need for adjustments and updates of the TRM
- Update/revise the TRM if found necessary.

<u>Recommendation 2</u>

CSLF should, in cooperation with other key CCUS Groups (e.g. CEM CCUS Initiative and Mission Innovation (MI) CCUS Challenge), revise the Technical Roadmap (TRM). The present CSLF TRM is from 2017. Update is needed because

- The first milestone year, 2020, is passed, we may want to include additional years, e.g. 2030.
- The targets for 2025 and 2035, may have to be updated by results from recent studies and analyses on the role of CCUS. These studies include the IEA Energy Technology Perspectives planned for late this year, the IPCC 1.5°C report, updated National Climate Plans (NDC) from Paris Agreement signatories and other.
- The interest in CCUS for industry, CO_2 storage hubs, industrial cluster and infrastructure, hydrogen and CCUS (CO_2 utilization), direct air capture (DAC), and negative emission technologies has grown since the last TRM. While these topics are mentioned in the 2017 TRM, there has been growing global emphasis on all of them, including the wide-ranging applicability of CCUS for a number of applications.
- The role of organisations like CEM and MI has become important and a joint document with targets and recommendations will have an impact.

<u>Recommendation 3</u>

CSLF should take a more interactive approach between task force members and CSLF delegates/member countries, focusing on understanding:

- R&D (lab, bench, pilot-scale) interests and status within
- member countries
- Commercial development/industrial-scale activities; and
- Business development opportunities/mechanisms/incentives to facilitate utilization of anthropogenic CO_2 at commercial scale. To be cross-referenced with the Business Models Task Force.

4. Further work by TRM Task Force

- Prepare status of work to Policy Group/CEM CCUS Meeting in September 2020
- Prepare annual update and recommendations to the Policy Group/CEM CCUS for their spring meetings (late May/early June each year), with timeline starting from 2021:
  - Mid-February: Input from groups
  - Late February: Draft of discussion paper
  - Second week of March: Distribute to members: Discussion paper and draft letter to the Policy Group and the CEM CCUS
  - Late March: Annual update discussed at the CSLF TG spring meeting
- Prepare a 2021 version of the Technology Roadmap by fall 2021, jointly with other key CCUS groups, such as CEM CCUS and Mission Innovation CCUS.

ANNEX

A.0. Target

Long-term isolation from the atmosphere of at least 400 megatonnes (Mt) CO_2 per year by 2025 (or have permanently captured and stored of 1,800 Mt CO_2).

Progress recorded during period March 2019 – September 2020
Net increase in storage capacity during reporting period:
~ 5 Mt CO_2/year

Number of projects that came online in reporting period:
Three – 3.
The Gorgon project in western Australia and two as part of the ACTL, adding storage capacites of 4 Mt CO_2/y and 2 Mt CO_2/y.

Number of facilities in operation that closed down in reporting period:
One – 1.
Petra Nova, in Parish County, Texas, USA, operated by NRG Energy, closed down the CO_2 capture unit in May 2020. The capture rate had been on the average 1.2 Mt CO_2/y. The reason: Low oil prices and insufficient revenue for enhanced oil recovery (EOR) for receiver of the captured CO_2.

Number of projects added to large-scale list during reporting period (March 2019 – September 2020), projects under considerations:
A net increase of eight projects. 10 projects added (Abu Dhabi CCS Phase 2, UAE; Clean Gas Project, UK; Wabash, USA; Oxy and White Energy Ethanol, USA; Project Tundra, USA; Dry Fork, USA; CarbonSafe, US; Oxy and Carbon Engineering, USA; Integrated Mid-Continent, USA; ECO2S, USA). Two projects removed (in China and Korea).

Conclusion
The net increase in storage capacity during reporting period was ~ 5 Mt CO_2/year, bringing the total global capture rate to approximately 43 Mt CO_2/y.
A 10-fold increase in annual storage capacity is needed over the next six years. Only two projects are in construction, both in China, total capacity 1+ Mt CO_2/y. Even projects in advanced or early development will not add sufficient capacity by 2025, only 35 -40 Mt CO_2/y.

Status: Red

Recommended actions to speed up:
Increased efforts to get projects into planning, incentives must be put in place. International cooperation required.

Sources:
GCCSI:

- The Global Status of CCS, 2019. https://www.globalccsinstitute.com/resources/global-status-report/
- Presentation by Alex Townsend, GCCSI, at CSLF Technical group meeting, Chatou, France, November 4, 2019. https://www.cslforum.org/cslf/sites/default/files/documents/Chatou2019/Update-from-Global-CCS-Institute.pdf

Gorgon:
https://australia.chevron.com/news/2019/carbon-dioxide-injection

Alberta Carbon Trunk Line:
https://actl.ca/wp-content/uploads/2020/06/ACTL-Press-Release-REAL-FINAL.pdf

Petra Nova:
https://www.nrg.com/about/newsroom/2020/petra-nova-status-update.html

https://www.globenewswire.com/news-release/2020/08/18/2080295/0/en/International-CCS-Knowledge-Centre-Let-s-Be-Clear-Petra-Nova-s-Carbon-Capture-System-Works.html

Reported by:
CSLF Technical Group

A1. Infrastructure, hubs and clusters

Facilitate CCS infrastructure development.

TRM recommendations for infrastructure:

Towards 2020:

- Design and initiate large-scale CO_2 hubs that integrate capture, transport, and storage, including matching of sources and sinks.

Towards 2025:

- Implement the first large-scale (i.e., >10 Mt CO_2/year aggregate throughput) CCS chains in power, industrial, and bio-CCS. These should be focused in industrial regions that have the potential to share infrastructure, rather than focusing on individual projects.
- Implement initial shared infrastructure for a limited number of plants within industrial clusters. This should recognize that in the initial phases, volumes within these clusters may be less than one million tonnes per annum, but that expansion from this initial start will occur.

Towards 2035:

- Continue progressive rollout and expansion of full-scale CCS chains and clusters in power, industrial, and bio-CCS. This includes large-scale CO_2 transport networks that integrate CO_2 capture, transport, and storage, including matching of sources and sinks.

Progress recorded during period March 2019 – September 2020 to facilitate CCS infrastructure development

Infrastructure projects added in reporting period:

- Operational: 1
- In construction: 0
- Final Investment Decision (FID): 0

One project came online during 2020:

- Name: Alberta CO_2 Trunk Line (ACTL)
- CO_2 sources: Fertilizer plant; bitumen refinery
- Transportation means: Trunk-line with feeder lines
- Storage sites: Oil fields
- Business model: EOR

Other positive developments are:

- One project, The Norwegian Full-scale, has submitted FEED documents (FID expected late 2020/early 2021)
- Two projects, CarbonNet and Norwegian Full-scale (Northern Lights part), have drilled appraisal wells
- One Project, Porthos, aim to apply for national funding from the Dutch SDE++ programme (Sustainable Energy Transition Scheme) in September 2020
- Some projects have received general funding (the Humber Region/Drax, Clean Gas Project/Teesside, Hynet, ACORN)

   a. Of these, the Humber Region/Drax is new since march 2019
- Some projects have received funding for parts of the infrastructure chain, mainly to confirm feasibility of capture technology (Dunkirk, H21) or storage (Northern Lights)
- Infrastructure for CO_2 transportation remains on the EU list of Projects of Common Interest (PCI)
- New as well as continued interest in hubs, clusters and infrastructure is noted through new studies and workshops but all except on project are still in the late pre-FEED phase, at best.

Conclusions
Positive developments suggest a change from red to yellow.

The target to have at least one infrastructure project operational by 2025 has been reached (ACTL), with the possibility of at least two more coming on line by 2025 (the Norwegian full-scale project and/or PORTHOS), thus meeting the TRM recommendation for 2025 for infrastructure.

Despite the fact that progress on infrastructure development is lacking behind what is necessary to reach the overall TRM storage target for 2025, the traffic light colour for infrstructure should be changed from red to yellow.

Further change to green will considered after the decision on the Norwegian Full Scale Project in Fall 2020.

Recommendations
Strong action is required.

- Projects in advanced or early development may add up to 100 Mt CO_2/y by 2030 at best, but most likely less.

Corrective actions, if any, by CSLF to speed development and implementation of infrastructure projects:

- CCUS networks are important to reach the overall target. To this end, decision makers from in industry and governments should work together to
  - Bring infrastructure projects in advanced stage of development (FEED) to investment decision (FID)
  - Develop and implement business models
  - Accelerate planning of other infrastructure projects
- The Task Force continues to monitor the development of networks for CCUS, including clusters, hubs and infrastructure. The task Force updates this note on an annual basis.

Impact on TRM:
Depends on development towards next version

Reported by:
CSLF Technical Group

Sources
- CSLF Task Force on Clusters, Hubs, and Infrastructure and CCS (2020). Update 1, period March 2019 – March 2020. Report dated April 2020 (https://www.cslforum.org/cslf/sites/default/files/documents/Task-Force_CO2-Hubs-Clusters-Infrastructure-and-CCS_Annual-Report_2019-2020.pdf)

A.2. Large scale projects

Leverage existing large-scale projects to promote knowledge-exchange opportunities.

TRM recommendations for leveraging large-scale projects

Towards 2020:

- Establish a network for knowledge sharing among full-scale facilities (e.g., by expanding the existing International Test Centre Network to share knowledge and experiences and increase understanding of the scale-up challenge).
- Increase possibilities for testing at the large pilot and demonstration scale by facilitating planning and construction of more test facilities for technologies other than solvent-based technologies.

Towards 2035:

- Gain experience in the integration of power plants with CCS into electricity grids that utilize renewable energy sources, seeking to develop optimal hybrid concepts with zero or negative emissions.

Meetings added since April 2019 version:

November 30, 2018: Lessons learned workshop, CCUS. Organised by Emissions reduction Alberta. This workshop also covers Business Models and Utilization. http://www.gowebcasting.com/events/emissions-reduction-alberta/2018/11/30/lessons-learned-workshop/play

Important reports added since April 2019 version:

1. Shand 2nd Generation CCS Study available at https://ccsknowledge.com/resources/2nd-generation
2. The cost reduction potential for CCUS at coal-fired power plants. Report by the International CCS Knowledge Centre and the Coal Industry Advisory Board (CIAB) November 2019. https://ccsknowledge.com/pub/CIAB_Report_LessonsByDoing_CCUS_onCoal_Nov2019(1).pdf
3. Global Status of CCS 2019. Global CCS Institute (https://www.globalccsinstitute.com/resources/global-status-report/)

Progress recorded during period March 2019 – September 2020 to leverage knowledge and experience from large scale projects, based on references [1,2,3]

The progress reported is mainly based on lessons Learned from Boundary Dam Unit 3 (BD3) and Petra Nova CCS (closed down May 1, 2020, due to low oil prices) Projects, based on information received from the International CCS Knowledge Centre [1,2].

- Both BD3 and Petra Nova were first of a kind projects at a full commercial scale for each vendor. These capture projects had to work so each would have included contingencies in size of equipment, volume of installed packing or space allowing for modifications. Future projects may not need these contingencies.

- Construction cost savings may be identified only after the first units were designed or in the process of being built. Given that the design and construction process is sequential there are no opportunities to realize savings without costly rework.
- BD3 as an example was not able to take advantage of some opportunities but future projects would be able to apply these lessons. Mitsubishi heavy Industries (MHI) has indicated similar cost savings for future plants based on their experience at Petra Nova.

Below follows a summary of [2]:

- Scaling Up the CCUS Plant Economies of scale are fundamental drivers in the utility industry
- Site Layout and Modularization, employing this siting strategy enabled early design concepts to optimally place energy-intensive process units alongside the power plant
- Increasing Capture Capacity, the percentage of CO_2 capture at a CCUS facility is the amount of CO_2 that is separated or removed by the capture process from the total CO2 in the flue gas stream
- Optimizing the CCUS Operating Envelope. The requirements for reliability and capability of a thermal power plant's operating envelope are quite different from the requirements for its associated carbon capture plant
- The ability of the capture facility to follow the variability of the thermal power plant, while continuing to capture CO_2 at full capacity, is key to overall emission reductions
- Development of a CCUS Supply Chain. Well-developed supply chains increase competition, spur innovation and reduce technology costs, ultimately having a positive impact on capital costs.
- Supply of all equipment, such as packing, heat exchangers, compressors, and related raw materials that would be available within reasonable timeframes to meet demand
- Suitable competition between equipment suppliers that would exist to drive efficiency, innovation and ultimately to lower costs
- Standardization and significant volumes of supplier orders that would enable expansion by manufacturers toward efficient scales of production

Operating Cost Reduction CCUS-enabled coal-fired power plants generally operate at higher cost than conventional thermal power stations for several reasons:

1. Additional energy is required to operate the capture and compression systems which reduces the net energy output of the power plant in the case of a fully integrated design
2. Further operating expenses are incurred due to consumption of solvents, chemical reagents, catalysts and disposal of waste products
3. Additional staff is required to operate and maintain the capture facility

The first generation of CCUS plants has provided concrete understanding about real-world operations. Early challenges faced by these facilities have highlighted the areas where the biggest gains could be made to reduce operating costs:

1. Amine Degradation, the first commercial plant showed how vendor models and preliminary estimates of solvent performance did not match actual operations
2. Extensive piloting using identical flue gas and solvent combinations to quantify the risks of amine degradation
    a. Unfortunately, this risk mitigation strategy increases the cost of development and the timeframe for CCUS deployment. This procedure is necessary
    b. additional work must be undertaken by projects at industrial-scale facilities to ensure associated cost reductions

3. A deeper understanding of the impact of maintenance on the design and operating cost of the newer facilities has been developed, based on actual operations, along with effective strategies to optimize operating equipment.
    a. redundancy may be deployed at key pieces of equipment, such as key heat exchangers, to improve the operational reliability of the facility
4. Minimizing the impacts of the capture facility's energy requirements on the host power facility.
    a. Sourcing energy for capture from the power plant imposes a power production penalty or "parasitic load" that reduces plant's net power output
    b. If steam is extracted from the host thermal power plant, as in the case of BD3, the generation capacity of the unit decreases
    c. Portions of the steam turbine may be replaced to optimize the steam extraction pressure without imposing throttling losses to enable provision of peak efficiency at full load
    d. The quantity of steam available, although not linearly related, will generally follow the demand of the CO_2 capture facility
    e. In the case of Petra Nova, where an auxiliary, cogeneration, natural gas turbine supplies steam for CO_2 capture, it may be difficult to dispatch the two power units independently
    f. A guarantee to meet demand from the grid for the new gas turbine cannot be made without compromising efficiency as the coal-fired power plant reduces its load to respond to daily dispatch variations
5. Optimization of Thermal Energy required to operate the CO_2 capture process includes:
    a. Thermal energy for solvent regeneration to release CO_2
    b. Electrical energy for CO2 compression. A fully integrated capture facility draws its energy needs from the host power plant, as in the case of BD3. Alternatively, a purpose-built auxiliary power plant may be constructed to service the capture facility, which was deployed at Petra Nova
6. Water Consumption
    a. A CCUS system may be designed without the need for additional water to support the cooling requirements of the facility by sourcing it from flue gas condensation using a combination of dry and wet cooling
    b. This cost-saving opportunity is higher at power plants burning high-moisture fuels
7. Compression Efficiency
    a. Compression power at BD3 accounts for more than a third of the lost electricity output associated with the CCUS facility
    b. Compressor design improvements are required to maintain efficiency and operational flexibility to improve load following capability at the CCUS facility
8. Digitalization
    a. The potential impact and the associated barriers of these improvements varies considerably
    b. Savings could amount to 5% of the total annual power generation costs
    c. Improved planning by reducing outages through better monitoring and predictive maintenance and limiting downtime by rapidly identifying points of failure
    d. Improved efficiency of combustion in power plants that would lower loss rates in networks
    e. Improved project design across the overall power system
    f. Extend the operational lifetime of assets
    g. Increase the resilience and reliability of power supply
9. CO2 Transport and Storage Cost Reduction
    a. The UK CCS Cost Reduction Task Force has estimated that storage costs for CCUS-equipped power plants may be reduced from £25/MWh for early CCUS projects to

£5-10/MWh through investment in a CO_2 hub or common storage site with a capacity of up to 5 Mt of CO_2 per year. Should a storage cluster be developed to utilize several storage types and geologies, the reliability of CO2 storage would increase, thereby reducing development risk

b. Pipeline construction and installation costs increase at lower rates with increasing CO_2 transport capacity

c. The lowest cost transport network would:
    i. Transport large volumes of CO_2 in appropriately sized pipelines
    ii. Consider the sizing of trunk-line sections and feeder-line sections to ensure high utilization over the longest period of the asset lifetime
    iii. Minimize CO_2 transportation by accounting for terrain, shoreline crossings and planning constraints
    iv. Minimize the need for constructing additional pipelines that would incur significant planning costs

A specific example of cost reduction is shown in Figure A.2.1 [1,2]. Figure A.2.2 shows how these two projects fit into a larger picture [3].

Figure A.2.1. Cost reductions for Shand 2nd Generation CCS study relative to Boundary Dam Unit 3 Costs. Overall reduction of cost of capturing carbon on a per tonne basis is 67%, from [1,2].

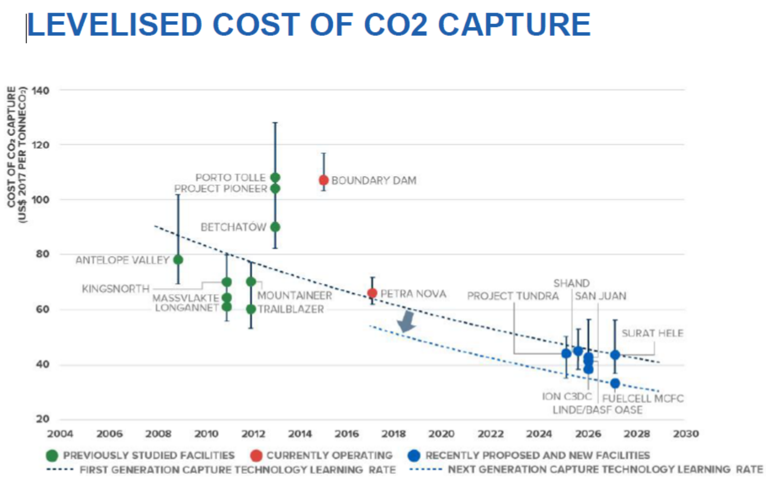


Figure A.2.2. Levelised cost of CO2 capture for large scale post-combustion facilities at coal fired power plants, from [3].

Conclusion
Overall reduction of cost of capturing carbon on a per tonne basis has been estimated to more than 60%.

The specific examples add to the conclusion from the April 2019 version that the recommendation "Leverage existing large-scale projects to promote knowledge-exchange opportunities" shows very good progress.

Status: green.

Identified bottlenecks for knowledge exchange:
No significant bottlenecks, but intellectually properties around capture technologies, detailed cost breakdown and negative experiences

Corrective actions, if any, by CSLF to facilitate exchange of experiences between large scale projects
No corrective actions required but CSLF should continue to engage large-scale projects and facilitate information and knowledge-sharing.

Impact on TRM:
Progress in this area to be reported in a possible update.

Reported by:
CSLF Technical Group

Sources
4. Input from The International CCS Knowledge Centre, Mike Monea
5. Shand 2nd Generation CCS Study available at https://ccsknowledge.com/resources/2nd-generation
6. Global Status of CCS 2019. Global CCS Institute (https://www.globalccsinstitute.com/resources/global-status-report/)

Note:
Storage and EOR not reported here, should include learnings from known projects such as Aquistore, Otway, Decatur projects.

A.3. RD&D

A.3.1 Capture

- Drive costs down along the whole CCS chain through RD&D

Progress recorded during period March 2019 – September 2020 for RD&D achievements/status/progress in relation to specific technical recommendations of TRM (Annex B of the TRM).

Specific RD&D recommendations from TRM towards 2020

1. Reduce the avoided carbon cost (or capture cost) in dollars per tonne of CO_2 ($/t$CO_2$) of currently available commercial CO_2 capture technologies for power and industry by at least 30%, while at the same time minimizing environmental impacts.

Status

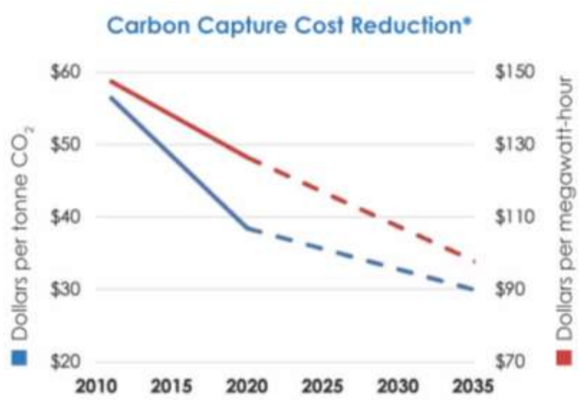


Figure A.3.1. Already reduced projected cost of carbon capture from fossil generation by 1/3 using results from the National Carbon Capture Center (NCCC), USA

Confidence that cost and performance improvements are real is growing from extensive testing at a scale under 10 MW [1]. Sharing results from large test facilities is needed.

2. Establish a network for knowledge sharing among full-scale facilities (e.g., by expanding the existing International Test Centre Network to share knowledge and experiences and increase understanding of the scale-up challenge).

Status

Using Open-access Technology is being proposed to increase knowledge sharing from the limited number of demo projects that will be funded in the short-term. A Memorandum of Understanding (MoU) will be signed summer 2019 among Guangdong CCUS Project, TCM, UK PACT Univ of Sheffield, SaskPower Knowledge Center and the US National Carbon Capture Center to support increased knowledge sharing from large-scale demos.

ITCN is establishing relationships with projects that are scaling up. – Norway, Middle East, China, India. Further, ITCN is establish relationship with organizations planning scale-up – CERC, NPC and other studies, Kemper final report through DOE.

Make best use of available scale-up information at sizes less than full-scale
Projects moving from NCCC to TCM with a 10X scale-up. Deep dive knowledge exchange

3. Resolve issues mentioned (in section 3.1.2 of TRM) regarding industrial CO_2 capture and bio-CCS and further develop technologies for applications and implementation in pilot plants and demonstrations.

Status

As described in Sec 3.1.2 of the CSLF Roadmap, many industrial projects capture CO_2, often without government subsidy, and serve as models for additional projects. Example projects include Quest, Air Products Port Arthur CCS project, Archer Daniels Midland Ethanol Plant, Emirates Steel, Tomakomai refinery, extensive application in the petrochemical industry in China, cement plant in Taiwan, concept studies on cement, waste incineration and fertilizer in Norway

The potential for CO_2 reductions from industrial process is high and often more cost-effective on individual projects than the larger point source of fossil power plants. A study performed for the former United Kingdom Department of Energy and Climate Change (DECC 2015; https://www.gov.uk/government/publications/industrial-decarbonisation-and-energy-efficiency-roadmaps-to-2050) indicated that as much as 36.5% of industrial CO_2 emissions in the United Kingdom may be reduced by directly employing CCS. In a roadmap towards zero emissions by 2050, the Norwegian process industries indicated that CCS can be responsible for 36% of the required cuts in CO_2 emissions, relative to a reference case with robust industrial growth (Norsk Industri 2016; https://www.norskindustri.no/siteassets/dokumenter/rapporter-og-brosjyrer/the-norwegian-process-industries-roadmap-summary.pdf).

The NCCC has developed collaboration for CCUS R&D in India with high-level support from both government and industry. India clearly only wants to discuss carbon capture as part as a complete commercial design, not CCUS R&D in isolated development. Indian colleagues are proposing several large commercial projects with the NCCC proposing options for carbon capture. FEED studies have been funded and commercial discussions are proceeding.

Emirates Steel is considering additional industrial carbon capture projects to add CO_2 to their EOR project. The NCCC and the ITCN have offered to share CCUS knowledge as Emirates Steel proceeds.

Even though these examples and the many more that are adding improved performance and cost information to cost-effective commercial design, addition projects are needed soon to raise confidence in a wide range of local process conditions.

Technology challenges related to the implementation of CCS in energy-intensive industries mentioned in the Roadmap:

- High costs – Response: Costs under specific industrial conditions are being reduced, but more large projects that will share knowledge are needed to reduce cost risk.
- Levels of uncertainty regarding investments – Response: Government-private partnerships are growing, but more, larger projects are needed soon.
- Environmental impacts as well as health and safety implications regarding waste products and toxicity – Response: The growing number of commercial and R&D projects each required environmental certification. This should be part of the knowledge sharing.
- Increased operational complexity and risks (integration, hidden costs of additional downtime, alternative product supplies, and technology lock-in; these will be site-specific) – Response: Each project, no matter how small that is operated under industrial conditions is important to understand the complexity of developing cost-effective, commercial products.
- New applications of existing technologies that are not yet proven at scale – Response: Most successful commercial projects adapt existing technologies to local process requirements. More large projects are needed soon.
- Understanding the impact of different compositions of the feed and/or flue gases compared to the power sector – Response: Any test facility will report that operating with real flue gas will very often lead to strong lessons learned for a design developed under lab conditions. More funding for testing needed to support large projects.

Conclusion**:** – Excellent, far-reaching improvements under development by CCUS R&D community and private partners moving forward with commercial designs, but more, larger projects needed to address climate change.

4. Increase possibilities for testing at the large pilot and demonstration scale by facilitating planning and construction of more test facilities for technologies other than solvent-based technologies.

Status 

More development in this area is needed. Funding is available for small projects, but not enough available for large scale. More large-scale projects are needed faster.

More cost-effective to test low TRL, non-solvent technologies at smaller scale first.

5. Fund and encourage RD&D activities for new and promising capture technologies. Increase activities on large-scale production of hydrogen with CCS, with the aim to develop this as a serious option in the 2025–2030 timeframe.

Status 

Growing optimism for R&D support for promising technologies. DOE continues to be generous in support of NCCC.

Progress reported on specific technologies and projects

Oxyfuel

- Some good reports from the Callide project in Australia, which was a small demonstration project. These reports do include recommendations for further work on oxyfuel.
- Not sure of current work on oxyfuel for coal or power but think cement industry is looking at oxyfuel.

Allam Cycle

- NetPower has been demonstrating key components in the Allam Cycle in their 50 MW_{th} Demonstration Plant in La Porte, Texas. Ii is believed that this demonstration still has relatively few operating hours, at least at the time of our visit to the site in June 2019.
- They had plans for a 300 MW commercial project, but some research is needed to see where that project is at.
- The 50 MW_{th} thermal demonstration was firing on gas though the cycle can be adapted to coal, and net Power or 8 Rivers Capital had been working with the Lignite Energy Council on this.

Direct Air Capture

- Carbon Engineering has received funds for demonstration and FEED work but once again there have been only smaller demonstrations of key portions of the technology.

In summary all three technologies would be good candidates for further R&D and Demonstration.

Identified common bottlenecks:
Commitment and funding.

Corrective actions, if any, by CSLF to speed development and implementation of infrastructure projects:

Impact on TRM:
Depends on development towards next version

Reported by:
CSLF Technical Group

The following recommendations **have not been properly evaluated.**
Towards 2025**:**

- Fund and facilitate cross-border RD&D cooperation to bring to demonstration CO_2 capture technologies for power generation and industrial applications that have avoided cost in \$/tCO_2 (or capture cost) at least 40% below that of 2016 commercial technologies, while at the same time minimizing environmental impacts.
- Fund promising technology ideas to be tested and verified at pilot scale (1–10 MW range) and/or separating 0.01–0.1 Mt CO_2/year.

Towards 2035:

- Encourage and facilitate cross-border RD&D cooperation to bring to demonstration CO_2 capture technologies for power generation and industrial applications that capture 100% (or very close to 100%) of the CO_2 and at the same time achieve 50% reduction of avoided carbon cost in \$/tCO_2 (or capture cost) compared to 2016 commercial technologies, while minimizing environmental impacts

Input by:

- The International CO_2 Test Center Network, Frank Morton
- The International CCS Knowledge Centre, Mike Monea

A.3. 2. Storage

Specific RD&D recommendations from TRM towards 2020

1. Identify, characterize, and qualify CO_2 storage sites for large-scale systems

Status

GeoCquest, a research consortium of Melbourne, Stanford and Cambridge universities, has developed an advanced modelling workflow to quantify CO2 flow and trapping by the different mechanisms over time and the influence of fine scale heterogeneities (mm-to metre scale), for improved prediction CO2 flow dynamics. Successful application of approaches like this have the ability to reduce uncertainty during commercial project decision making and help facilitate post-closure transfer; both of which if unaddressed impact significantly on a CCS project cost [1].

Several infrastructure projects have characterised large-scale storage systems.

2. Accelerate learning and technology development by sharing subsurface, well, and other relevant data and knowledge; for example, in initiatives such as the CO_2 Storage Data Consortium, an open, international network developing a common platform for sharing data sets from pioneering CO_2 storage projects.

Status:

On February 4 2020, CO_2 DataShare Consortium launched a web-based digital portal for sharing reference datasets from pioneering CO_2 storage projects (https://co2datashare.org). The new portal will enable researchers and engineers to improve their understanding, reduce costs and minimize uncertainties associated with CO_2 storage.

3. Fund activities that continue to drive down costs for existing monitoring technologies and techniques, and the development, demonstration, and validation of new measuring and monitoring techniques and sensors, onshore and offshore. This includes for leakage in terms of anomaly detection, attribution, and leakage quantification.

Status:

Several funding agencies and mechanisms, including ACT, have granted substantial funds for activities whose aims are to reduce costs for monitoring technologies.

The Australian Otway Stage 2C project (CO2CRC) has provided important findings into stored CO_2 monitoring. The research assessed detection thresholds for CO_2 in a storage reservoir (as little as 5,000 tonnes). The demonstration provides CCS stakeholders with confidence that CO_2 migration predictions can be verified with existing monitoring technologies. The success with the Otway Stage 2C project has paved the way for new, cost-effective, technology development in fibre optics sensing and subsurface monitoring. New seismic- and pressure-based monitoring technologies can provide data on-demand at significantly lower cost than current techniques (initial cost saving estimates of up to 75 %) [1].

4. Further advance and utilize simulation tools, with a focus on multiphase flow algorithms and coupling of fluid flow to geochemical and geomechanical models.

Status:

This is continuous work in progress. Several funding agencies and mechanisms, including ACT, fund activities towards this goal.

5. Develop and agree on consistent methods for determining CO_2 storage capacity (dynamic) reserves at various scales (as opposed to storage resources), at various levels of project maturity, and with a global distribution of this capacity.

Status:

The Society of Petroleum Engineers (SPE) has issued Petroleum Resources Management System (https://www.spe.org/en/industry/reserves/), which includes a section on capacity estimating.

CSLF has led a review of technologies to better utilise 'investment ready' and 'discovered' storage resources, to significantly improve the economics of CCS projects [2]. This CSLF task force investigated ways to improve pore space utilisation, including existing technologies developed in the hydrocarbon industry, maturing pressure management technology, and innovative emerging technologies, as well as general principles for storage operations.

The following recommendations have not been properly evaluated (but see also Target 3 above):

Towards 2025:

- Reduce M&V overall costs by 25% in average from 2016 levels.

Towards 2035:

- Reduce M&V overall costs by 40% in average from 2016 levels

Impact on TRM:
Depends on development towards next version

Reported by:
CSLF Technical Group

Sources:
[1] CO2CRC (Max Watson, personal communication)
[2] https://www.cslforum.org/cslf/sites/default/files/documents/Task-Force-on-Improved-Pore-Space-Utilisation_Final-Report.pdf.

A.4. Business models

- Facilitate innovative business models for CCS projects.

Progress recorded during period March 2019 – March 2020 for business models for CCS projects (no update received after march 2020)

Initiative taken by China through CEM CCUS to map business models and incentive policies in member states. Excel questionnaire distributed and preliminary results presented in [1].

Business models have been categorised in four alternatives:

1. Vertical integration model. All parts in the chain operated/owned by state-owned company
2. Joint venture between capture, transport and storage companies/operators
3. CO_2 transporter, in which a company provides the transporting service between source and sink, for a fee
4. CCS operator. One CCS operator receives CO_2 from capture sources and stores and/or sells it, e.g. for EOR or other utilisation purposes

37 large scale projects in ten countries were categorised. The vertical integration model dominates (57%), followed by the joint venture model (17%) and the rest being equally divided between the two last categories. The study includes information on funding availability, initial investments, and inventive policies for the 37 projects.

Other activities and documents since March 2019:

1. Consultation from UK BEIS on Business models for CCUS [2]
2. Market based frameworks for CCUS in the power sector. Report by Cornwall Insight [3]
3. Policy priorities to incentivise large scale deployment of CCS. Report from GCCSI [4]

Status: Yellow

Identified common bottlenecks:
Challenge in collecting information from projects and countries

Corrective actions, if any, by CSLF to speed development and implementation of business models and incentive policies

1. A presentation from China at Annual TG meeting in Saudi Arabia September 26-29, 2020
2. Support China in obtaining necessary information.

Impact on TRM:
Depends on development towards next version

References

[1] Zhang, Xian. CCS financing and business model. Presentation at CEM CCUS meeting in Abu Dhabi, UAE, January 14, 2020

[2]
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/819648/ccus-business-models-consultation.pdf
[3]
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/819348/Cornwall_Insight_WSP_-_Market_based_frameworks_power_CCUS.pdf
[4] https://www.globalccsinstitute.com/resources/publications-reports-research/policy-priorities-to-incentivise-large-scale-deployment-of-ccs/

Reported by:
CSLF Technical Group

A.4. Utilization

- **Facilitate Implementation of CO_2 Utilization**

TRM recommendations for CO_2 utilization

Towards 2020:
Governments and industry should work together to:

- Resolve regulatory and technical challenges for the transition from CO_2-EOR operations to CO_2 storage operations. There may be value in experiences from reporting requirements for CO_2 operations that are claiming credits under the 45Q tax credit in the United States. [1]
- Research, evaluate, and demonstrate carbonation approaches, in particular for mining residue carbonation and concrete curing, but also other carbonate mineralization that may lead to useful products (e.g., secondary construction materials), including environmental barriers such as the consequences of large mining operations and the disposal of carbonates.
- Support research and development pathways for the development of novel catalysts using abundant materials and advanced manufacturing techniques to produce nanocatalysts to bring down costs.
- Support RD&D on subsea separation and improved mobility control.
- Map opportunities, conduct technology readiness assessments, and resolve main barriers for the implementation of the CO_2 utilization family of technologies, including benchmarked life cycle assessments and CO_2 and energy balances.
- Increase the understanding of CO_2 energy balances for each potential CO_2 reuse pathway and the energy requirement of each technology using technological modelling.

Towards 2025
Governments and industry should work together to:

- Promote more offshore CO_2-EOR pilot projects as part of deployment of large-scale CO_2 storage, as CO_2 becomes available in amounts and during time windows relevant for EOR.

Progress recorded during period March 2019 – March 2020 to facilitate implementation of CO_2 utilization (no updates received after March 2020).

Status: yellow

Projects
An initial overview assessment has shown that there are over 70 projects ranging from pilot to full-scale commercial operations. Several of these projects have been completed while others are under construction. Further, these projects range in their scope of technologies from biological conversion of CO_2 (e.g., algae or other microorganisms) to mineralization and fuels and chemicals production via catalytic methods. Table 1 below is a listing of some of these projects, their location, and the scale and status.

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[1] This refers to § 45Q of the US Internal Revenue Code, which allows for tax credits of $20 per metric tonne of qualified carbon dioxide stored and $10 per metric tonne used for EOR, captured by the taxpayer at a qualified facility. As of September 2017, there were proposals in the US Congress to increase these credits.

Table 1: Summary of Global CO_2 Utilization Projects (pilot to commercial)
*(*Not all inclusive*)*

Project/Company Name	Country	State/Province	City	Status
Mineral Carbonation International	Australia	New South Wales	Newcastle	Pilot
Aurora Algae, Algae Tec	Australia	Puertollano		Commercial
LanzaTech	Belgium	East Flanders	Ghent	Construction
Carbon Upcycling Technologies	Canada	Alberta	Calgary	Pilot
Ingenuity Lab	Canada	Alberta	Edmonton	Pilot
CERT	Canada	Ontario	Toronto	Pilot
CVMR Corporation	Canada	Ontario	Toronto	Pilot
Pond Technologies	Canada	Ontario	Markham	Pilot
Tandem Technical	Canada	Ontario	Ottawa	Pilot
Carbicrete	Canada	Quebec	Montreal	Pilot
CarbonCure Technologies	Canada	Nova Scotia	Dartmouth	Commercial
CleanO_2 Carbon Capture Technologies	Canada	Alberta	Calgary	Commercial
CO2 Solutions	Canada	Quebec	Quebec City	Pilot
C2CNT	Canada	Alberta	Edmonton	Pilot
LanzaTech	China	Beijing	Beijing	Operational
C4X	China	Jiangsu Province	Suzhou	Pilot
LanzaTech	China	Jiangsu Province	Shougang	Completed
LanzaTech	China	Shanghai	Shanghai	Completed
Global Bioenergies	France	Ile-de-France	Evry	Pilot
Covestro	Germany	North Rhine-Westphalia	Leverkusen	Operational
Carbon Recycling International	Iceland	Höfuthborgarsvaethi	Svartsengi	Operational
LanzaTech	India	Haryana	Gurgaon	Operational
Breathe	India	Karnataka	Bangalore	Pilot
Tuticorin – Use	India	Kerala	Tuticorin	Operational
New Energy and Industrial Technology Development Organization (NEDO) 9 projects	Japan	Victoria		Commercial
OCAP Network	Netherlands	Bacchus		Pilot
LanzaTech	New Zealand	Auckland	Glenbrook	Completed
SABIC	Saudi Arabia		Jubail City	Operational
LanzaTech	South Africa	Mpumalanga	Nelspruit	Construction
Aljadix	Switzerland	Basel-Stadt	Basel	Pilot
LanzaTech	Taiwan	Taipei	Taipei	Completed
Carbon8 Avonmouth	United Kingdom	England	Avonmouth	Operational
Carbon8 Brandon	United Kingdom	England	Brandon	Operational
Carbon8 Leeds	United Kingdom	England	Leeds	Operational
Carbon Capture Machine	United Kingdom	Scotland	Aberdeen	Pilot
IronKast	United States	Arizona	Tucson	Pilot

Accelergy Corp	United States	California	Palo Alto	Operational
Blue Planet	United States	California	Los Gatos	Pilot
Calera	United States	California	Moss Landing	Pilot
Carbon Upcycling UCLA	United States	California	Los Angeles	Pilot
Hago Energetics	United States	California	Ventura	Pilot
Kiverdi	United States	California	Hayward	Pilot
LanzaTech	United States	California	Modesto	Construction
Oakbio	United States	California	Sunnyvale	Pilot
Opus12	United States	California	Berkeley	Pilot
Saratoga Energy	United States	California	San Francisco	Pilot
Living Ink	United States	Colorado	Boulder	Operational
Innovator Energy	United States	Connecticut	New Haven	Pilot
Algenol Biofuels	United States	Florida	Fort Myers	Pilot
Dioxide Materials	United States	Florida	Boca Raton	Pilot
MicroBio Enginnering and Orlando Utilities Commission	United States	Florida	Orlando	Pilot
Global Algae Innovations	United States	Hawaii	Lihue	Operational
LanzaTech	United States	Illinois	Skokie	Completed
Bio-Thermal-Energy Inc.	United States	Iowa	Cedar Rapids	Pilot
BioProcess Algae	United States	Iowa	Shenandoah	Operational
EE-AGG	United States	Iowa	Boone	Pilot
University of Kentucky Center for Applied Energy Research	United States	Kentucky	Rabbit Hash	Pilot
Catalyst	United States	Massachusetts	Fall River	Pilot
Novomer	United States	Massachusetts	Boston	Pilot
TerraCOH	United States	Minnesota	Excelsior	Pilot
Liquid Light	United States	New Jersey	Monmouth Junction	Pilot
Solidia	United States	New Jersey	Piscataway	Operational
Dimensional Energy	United States	New York	Ithaca	Pilot
Novomer	United States	New York	Rochester	Pilot
The Center for the Capture and Conversion of CO2	United States	Rhode Island	Providence	Pilot
Proton Power	United States	Tennessee	Lenoir City	Pilot
Carbon Free Chemicals	United States	Texas	San Antonio	Operational
C2CNT	United States	Virginia	Ashburn	Pilot
Low-Energy-Consumption CO2 Capture and Conversion	United States	Wyoming	Laramie	Pilot
Wyoming Integrated Test Center	United States	Wyoming	Gillette	Operational

Reports

While there are numerous reports on the subject of CO_2 Utilization, several key reports have been published in the past two years, or will soon be published:

- UK report (May 2017) by Imperial College and ECOFYS: *Assessing the Potential of CO_2*
- *Utilisation in the UK*
- Mission Innovation report (September 2017) on CCUS: *Accelerating Breakthrough Innovation in Carbon Capture, Utilization, and Storage*

- US National Academy of Sciences – October 2018 – *Developing a Research Agenda for Utilization of Gaseous Carbon Waste Streams*
- OGCI (2018) *The Potential Value of CCUS to the UK Economy. Oil and gas Climate Initiative November 2018*.
- US National Petroleum Council report on CCUS – due 2019
- International Energy Agency: *Putting CO_2 to Use: Creating value from emissions; September 2019.*
- US National Petroleum Council report on CCUS: *Meeting the Dual Challenge: A Roadmap to At-Scale Deployment of Carbon Capture, Use, and Storage in the United States, December 2019.*

These reports are in addition to the previously published reports by CSLF, and partner organizations such as the IEAGHG and GCCSI.

Meetings, Conferences and Workshops
There are numerous meetings, conferences, and workshops on the subject of CO_2 Utilization that are held throughout world. Table 2 below is a summary of several of these events (note: not an endorsement or all-inclusive list):

Table 2: Summary of Major CO_2 Utilization Events

Title	Location	Dates	Participants
International Conference on Carbon Dioxide Utilization	Rio de Janeiro, Brazil (16^{th}) Aachen, Germany (17^{th})	August 27-30, 2018 June 23-27, 2019	Mostly Academia
Carbon Dioxide Utilization Summit	Manchester, UK (11^{th}) Houston, Texas (12^{th})	September 26-27, 2018 February 27-28, 2018	Industry focused
International Overview of CO_2 Utilization	Paris, France	July 2, 2018	Industry, government, research institutions
7^{th} Conference on Carbon Dioxide as Feedstock for Fuels, Chemistry, and Polymers	Cologne, Germany	March 20-21, 2019	Industry, associations, government
CO_2 Reuse Summit	Zurich, Switzerland Berlin, Germany	May 16-17, 2018 May 8-9, 2019	Industry, research institutions, university, academia
Some Major Conferences with carbon/CO_2 utilization sessions: GHGT series (global, varying locations), Carbon Management Technology Conference (US), Annual CCUS Conference (US).			

In addition, there are numerous events that occur for specific CO2 utilization technologies such as algae, etc.

Market mechanisms:
CO_2 is utilized in various industries today, such as:
- Enhanced oil recovery (EOR) has facilitated CO_2 utilization in North America for several decades.
- Additionally, there are smaller scale CO_2 utilization mechanisms that exist – fire suppression, urea production, etc.

To facilitate wider-scale deployment of CO_2 utilization options will require both technological development and market pull. One recent example of providing market pull is the 45Q tax credit in the United States which provides a $35/tonne credit for projects that utilize CO_2, provided they meet certain requirements (https://www.catf.us/wp-content/uploads/2017/12/CATF_FactSheet_45QCarbonCaptureIncentives.pdf).

Corrective actions, if any, by CSLF to facilitate CO_2 Utilization:

- CSLF should continue to engage members through the CO_2 Non-Enhanced Hydrocarbon Recovery Utilization Task Force. This engagement should take a more interactive approach between task force members and CSLF delegates/member countries, focusing on understanding:
  - R&D (lab, bench, pilot-scale) interests and status within member countries (Note: coordinate with other efforts on TRM Progress Reporting?);
  - Commercial development/industrial-scale activities within each member country; and
  - Business development opportunities/mechanisms/incentives to facilitate utilization of anthropogenic CO_2 at commercial scale. Efforts should be cross-referenced with the Business Models Task Force.

Through these efforts, utilize the Task Force to facilitate ideas, strategies and opportunities for collaboration.

Identified bottlenecks:

- Bottlenecks will vary, depending upon the utilization technology and the products that it produces. For example, is the technology "commercially ready", i.e., can it deploy? What are the specific market/regulatory/financial barriers for deployment, and are there mechanisms that exist to facilitate deployment?

Sources:

- Sources for the information include the CSLF and its Technical Group members; various reports noted above.

Impact on TRM:
Measures progress in this area. Can potentially provide input into next version/updates of the TRM.

Reported by:
CSLF Technical Group