Carbon Sequestration leadership Forum
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CARBON SEQUESTRATION LEADERSHIP FORUM

TECHNICAL GROUP

Ad hoc Committee on

Monitoring Progress of the Technical Roadmap 2017

Results and Recommendations from "Phase 0"

April 2019

This note is a follow-up of the discussions in the CSLF Technical Group that were initiated in Venice in April 2018, and followed up in Melbourne in October 2018. It is based on discussions in the *ad hoc* group and a note from Norway 07 December 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 recommendatins:

- Through its Projects Interaction and Review Team (PIRT), 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.

In a teleconference of the *ad hoc* group 22 January 2019 it was decided to start the monitoring work by having group members rank the progress of five technical priority recommendations in the 2017 TRM using a traffic light approach. This will give indications of the efforts required and secure some results for the April TG meeting. The more extensive approach can then be presented to the whole group for discussions.

1. 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).

The Priority Recommendations 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.

Results - Summary table

Progress towards 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. Only one plant came online in 2018 (CNCP Jilin, China), increasing capacity by 1 Mt CO_2/y to 38 Mt CO_2/y. Projects in construction may add 7+ Mt CO_2/y in 2019. Projects in advanced or early development will not add sufficient capacity by 2025, only 35 -40 Mt CO_2/y.**

Progress of priority recommendations (strategic actions) necessary to reach target.

Each action is in itself not sufficient but in practice necessary, or at least a strong enabler, for the target to be reached. Thus the target may still be red even though none of the priority recommendations are. There are other recommendations that also need to be met. The table below indicates where the strongest efforts from the Technical group are needed.

Priority Recommendation (Strategic Action)	Rating	Conclusion
1. Facilitate CCS infrastructure development.		**Many good plans and studies but no infrastructure/network projects on line the last years; no project passed the Final Investment Decision (FID) gate in 2018**
2. Leverage existing large-scale projects		**Active leveraging through CSLF meetings, International Knowledge-Sharing Center , conferences, and reports. Not known which projects have used experience/knowledge from other projects.**
3. Drive costs down along the whole CCS chain through RD&D.		**Much good research going on that progress CCUS technologies but no break-through technologies reported or identified that at TRL 6 or higher have convincing evidence of significant cost reductions**
4. Facilitate innovative business models for CCS projects		**Many good plans and studies but progress on development of business models have not been implemented, in many cases due to lack of policy and regulatory environment relevant for CCUS projects.**

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

ANNEX

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).**

Increase in storage capacity last year:
~ 1 Mt CO_2/year

Number of projects that came on line last year:
One – 1.

Conclusion
Need 10-fold increase in annual storage capacity next six years. Only one plant came online in 2018 (CNCP Jilin, China), increasing capacity by 1 Mt CO_2/y to 38 Mt CO_2/y. Gorgon and ACTL are delayed but may add 6 Mt CO_2/y in 2019. Only two other 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.

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, 2017
The Global Status of CCS, 2018

Reported by:
Lars Ingolf Eide

PRIORITY ACTION/STRATEGIC ACTIONS

1. Infrastructure, hubs and clusters

- **Facilitate CCS infrastructure development.**

Infrastructure projects, operational or in construction, at end writing TRM 2017:

- **Operational:** Three - 3
  - **Name:** The Denver City (from 1985), Gulf Coast (from 1999), and Rocky Mountain hubs **(**from 1986**)**
  - **CO_2 sources:** Natural CO2 deposits; natural gas cleaning; hydrogen production from natural gas
  - **Transportation means:** Trunk-lines with feeder lines
  - **Storage sites:** Oil fields
  - **Business model:** EOR

- **In construction:** One - 1
  - **Name:** Alberta CO_2 Trunk Line
  - **CO_2 sources:** Fertilizer plant; bitumen refinery
  - **Transportation means:** Trunk-line with feeder lines
  - **Storage sites:** Oil fields
  - **Business model:** EOR

- **Infrastructure projects added in reporting period (2018):**
  - **Operational:** 0
  - **In construction:** 0
  - **Final Investment Decision (FID):** 0

- **Expected contribution from infrastructure projects to the target**
  - The one infrastructure project in construction (ACTL) may add a capacity of 2 Mt CO_2/year
  - Projects in advanced or early development are unlikely to amore than 35 -40 Mt CO_2/y by 2025.

- **General progress on other projects:**
  - One project in Norway received funds for FEED, aiming at FID in 2020
  - Two projects received funding from EU as Projects of Common Interest (PCI):
    - Port of Rotterdam, Netherlands
    - CO_2Sapling (UK lead European project)

- **Other progress:**
  - Increased focus on importance of clusters, hubs and infrastructure in Europe (EU Set-plan with CO_2 transport systems as PCI; projects like Teesside, HyNet, Align, H21 North of England, Humberside, Merseyside, Scotland, South Wales), Australia CarboNet, Southwest Hub), USA (workshop report on siting and regulation CCUS infrastructure), Korea (infrastructure into CCS Master Action Plan), IEAGHG (report addressing business models for infrastructure**),** numerous reports in the UK.

Conclusions

Progress on infrastructure development is lacking far behind what is necessary to reach the storage target. Strong action is required.

Despite many good plans and studies the conclusion is justified by:

1. No infrastructure/network projects have come on line the last years
2. Only one is in construction, with anticipated start up in 2019, increasing capacity by 6 Mt CO_2/y
3. No project passed the Final Investment Decision (FID) gate in 2018
4. Projects in advanced or early development will only add 35 -40 Mt CO_2/y by 2025, at best.

When seen in light of a statement by the UK CCUS Cost Challenge Taskforce Report July 2018: ”CCUS infrastructure is key to unlocking huge clean growth potential in the UK and can contribute to a cost-effective pathway for reducing UK CO_2 emissions” it is clear that progress must be accelerated.

Identified common bottlenecks:
Commitment and funding beyond studies, lack of business models

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

- **Make decision makers**
  - Aware of the importance of hubs and infrastructure
  - Allocate funds for investments (beyond studies and plans)
  - Co-operate across businesses and nations

  Workshops in cooperation with GCCSI, IEAGHG, International CCS Knowledge Centre, CO2GeoNet, MI, others could be a contribution to this

Sources include:

- Norwegian State Budget 2019 (continued support to Norwegian Full-Scale Project
- European Commission SET-PLAN TWG9 CCS and CCU Implementation Plan (PCIs)
- Carbon Capture Journal Jan 27, 2019 (Port of Rotterdam and CO_2Sapling funded as PCIs))
- Presentations at CSLF TG meeting Melbourne Oct 2018 (Southwest Hub, CarboNet)
- Delivering Clean Growth: UK CCUS Challenge Task Force (UK clusters)
- Element Energy: Deployment of an industrial CCS cluster in Europe: A funding pathway
- IEAGHG Technical Report 2015-03 (Clusters).
- IEAGHG Technical report 2018-01 (Business models for infrastructure)
- Reports to UK BEIS by Pale Blue Dot and Element Energy in 2018
- UK Government (2018). Clean Growth. The UKCarbon Capture Usage and Storage deployment pathway. An Action Plan. https://www.gov.uk/government/publications/the-uk-carbon-capture-usage-and-storage-ccus-deployment-pathway-an-action-plan (Accessed 15 march 2019)
- Align CCUS Project, website and webinar Feb. 2019
- Presentations of H21 North of England by Northern Gas and Equinor (Brussels and Edinburgh Nov. 2019)
- The Global Status of CCS, 2017
- The Global Status of CCS, 2018

Impact on TRM:
Depends on development towards next version

Reported by:
CSLF Technical Group

2. Large scale projects

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

Actions during reporting period to leverage knowledge and experience from large scale projects

- The CSLF Technical Group is active in leveraging knowledge and experience from large-scale projects. From the past 5 years alone, CSLF Technical Group meetings or workshops have included the following activities to leverage knowledge and experience from large-scale projects:
    - April 2019 TG Meeting: Presentations from Project Tundra, ADM; Additionally, CSLF members are invited to attend the MGSC Annual Meeting, which includes discussion of the ADM project, including other activities such as CarbonSAFE projects in the region.
    - October 2018 CSLF Meeting in Melbourne, Australia: Gorgon, CarbonNET, Southwest Hub. Policy meeting also included an update on the Hydrogen Energy Supply Chain Project between Australia and Japan.
    - April 2018 CSLF Meeting in Venice, Italy: Update on MHI's CDR process and commercial experience; Update on Fort Nelson Project; Norcem Carbon Capture Project
    - December 2017 meeting in Abu Dhabi, UAE: Update on ROAD Project, Uthmaniyah project, Emirates Steel Project
    - May 2017 CSLF meeting in Abu Dhabi, UAE: Emirates Steel Project, Uthmaniyah, ADM; Workshop in conjunction with that meeting: Emirates Steel, Shell Quest, Petra Nova, Boundary Dam; SABIC; Discussion of Full-scale CCUS activities in Norway.
    - October 2016 in Tokyo, Japan: More focused on large pilot/demo projects such as Tomakamai and NetPower
    - June 2016 meeting in London, UK: Policy Group – International Collaboration on Large-scale Saline injection; Bellona – CO2 Market Makers for Strategic EU Hubs and Clusters
    - November 2015 meeting in Riyadh, KSA: SABIC; Ministerial Meeting – Panel on large-scale CCUS projects: ADM, ROAD, Uthmaniyah, Occidental Petroleum's CO2-EOR business case.
    - June 2015 meeting in Regina, Saskatchewan: Workshop on Lessons Learned from Large-scale projects: Presentations were from ROAD, ADM, Kemper, Quest; PCOR Bell Creek Project; Equinor (Statoil at that time); Boundary Dam (SaskPower); Dakota Gasification
    - Highlight workshops from CSLF that had large-scale project engagement
- In addition to the CSLF, there are numerous other activities that focus on leveraging knowledge and experience from large-scale CCUS projects.
    - International Knowledge-Sharing Center (SaskPower/Canada). Their entire mission is to support new global CCS projects with business development, operations, and technological improvements to advance the deployment of CCS facilities around the world.
    - CLIMIT Summit: Includes significant number or presentations on Norwegian projects such as Sleipner, Snohvit, and the full-scale CCS projects. Also includes broader global participation, which touches upon large-scale projects.
    - IEAGHG/GHGT Conferences. The GHGT-14 conference in Melbourne, Australia included the following sessions: Session 1C: Large-scale Integrated Projects Experience; Session 2C: Regional Projects (this session included Boundary Dam and also a previous US project: AEP's Mountaineer Power Plant – Stratigraphic Test Well to Site Closure)' Session 5C: Panel Discussion 3: From Projects to Infinity: Large-scale project experiences to be shared; Session 6C: Panel discussion 4: The status and potential of the Norwegian-

EU CCS Project; There were also numerous other sessions that included results from large-scale projects, some very technical.
    - DOE's RCSPs typically conduct annual meetings which are open to the public or research community. For example, MGSC Annual Meeting: http://sequestration.org/resources/reports.html.
    - CO2GeoNet: The 13th Open Forum included presentations from several large-scale projects that captured lessons learned or described techniques used in their storage projects. It also included a post-Open Forum workshop that brought together Norwegian and American experts to discuss a number of topics on large-scale CCUS applications. Additionally, the 12th and 11th Open Forums also included additional presentations, panels, and workshops on knowledge sharing from large-scale or integrated projects. For example, the 11th Open Forum included a workshop focused on dealing with liability: final closure, liability and transfer of responsibility of the storage site.
    - DOE's Annual CCUS Meetings have included updates on large-scale CCUS projects:
- Reports (Peterhead/Goldeneye, Boundary Dam, Air Products, Sleipner, In Salah)
    - Peterhead/Goldeneye: GHGT-13 included a paper on experience in developing the Goldeneye Storage Permit Application. There is also a paper published on the Summary Report for the Full CCS Chain for the Peterhead project: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/531394/11.133_-_FEED_Summary_Report_for_Full_CCS_Chain.pdf
    - Boundary Dam: IEAGHG report: https://ieaghg.org/docs/General_Docs/Reports/2015-06.pdf
    - Air Products project: IEAGHG Report: http://documents.ieaghg.org/index.php/s/YKm6B7zikUpPgGA?path=%2F2018%2FTechnical%20Reports
    - Equinor and partners have provided/shared information from the Sleipner and Snohvit projects. For example, Equinor has made datasets available via the IEAGHG: https://ieaghg.org/terms-of-use?id=248:sleipner-benchmark-model
    - In Salah Project: There is significant information available on this project as well. Has been presented on numerous occasions: https://www.spe-uk.org/aberdeen/knowledgefiles/In%20Salah%20Gas%20CO2%20Project%20Overview%20SPE%20June%202013pdf.pdf; http://www.cgseurope.net/UserFiles/file/Ankara%20workshop_june%202012/presentations/Allan%20Matheison.pdf
    - Weyburn-Midale, extensive number of publications and literature on this project: https://ptrc.ca/projects/weyburn-midale
    - IEAGHG and GCCSI: Numerous reports from both organizations that leverage key learnings from large-scale projects. Additionally, some of their reports are also further reaching and can influence decisions on new large-scale projects such as finance and regulatory aspects.
    - DOE Best Practice Manuals: https://www.netl.doe.gov/coal/carbon-storage/strategic-program-support/best-practices-manuals
- Other workshops/meetings:
    - TCM and SINTEF workshop: http://www.tcmda.com/en/Press-center/News/2016/TCM-shares-crucial-CCS-lessons-learned-with-Road/
    - 1st, 2nd, and 3rd workshops on offshore carbon storage
    - IEAGHG network meetings include numerous lessons learned from large-scale projects.
    - IEAGHG conferences other than GHGT series, such as Post-Combustion Carbon Capture Conference.
    - Numerous others, have not captured a fully comprehensive list.

Projects that have used the experience:

- It is unknown which projects, i.e., those being proposed now or previously, have used experience/knowledge from other projects. It may also be difficult to track this particular information.

Conclusion
Numerous examples of active leveraging through CSLF meetings, International Knowledge-Sharing Center , conferences, and reports.

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..

Sources:
Sources for the information include the CSLF and its Technical Group members; CO2GeoNet website; U.S. Department of Energy and National Energy Technology laboratory websites, Other sites referenced in the body of the report.

Impact on TRM: Measures progress in this area.
Reported by: CSLF Technical Group

Template reporting progress, Phase 0

3. RD&D

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

RD&D achievements/status/progress in relation to specific technical recommendations of TRM (Annex B).

General
Progress is being made (e.g. papers presented at GHGT14). Globally, significant R&D investments are occurring (Respondents to CSLF Maximization and Knowledge Sharing survey mostly indicated stable RD&D budgets for CCUS; many national and regional programmes). There is good progress and sustained efforts at the lab- and bench-scale.

Mission Innovation CCUS Challenge holds promise of concerted international efforts, increased bi- or multilateral co-operations in CCUS RD&D emerging.

Examples of international cooperation at the regional are the cooperative programmes the European Carbon Dioxide Capture and Storage Laboratory Infrastructure (ECCSEL) and Accelerating CCS Technologies (ACT). ECCSEL is a permanent pan-European distributed research infrastructure, ERIC (European Research Infrastructure Consortium). Within the initial 5 European founding Member countries (France, Italy, the Netherlands, UK and Norway (Operations Centre)), 15 service providers offer open access to more than 55 world class CCS research facilities across Europe. The whole CCS chain is included.

ACT is an international initiative to facilitate RD&D and innovation within CO_2 capture, utilisation and storage (CCUS). Ten European countries and USA, who joined ACT in 2018, are working together in ACT with the ambition to fund world class RD&D innovation that can lead to safe and cost effective CCUS technology.
The ambition of ACT is to facilitate the emergence of CCUS via transnational funding aimed at accelerating and maturing CCUS technology through targeted innovation and research activities.

Capture
Globally, there are many test facilities for smaller scale capture pilots that have been in operation for many years, and several capture technologies have moved from small pilots to large pilots. This has partly been due to cooperation between test facilities with encouraging results. The National Carbon Capture Centre (NCCC) in USA and the Technology Centre Mongstad (TCM) in Norway, where particularly mentioned by respondents to the CSLF Maximization and Knowledge Sharing survey. The International Test Centre Network (ITCN) is an important factor in bringing capture technologies up the TRL ladder.

Respondents to the CSLF Maximization and Knowledge Sharing survey indicated particular progress in modular design of capture systems and Pd membranes. One respondent indicated that an extremely cost effective capture technology had been developed but gave no further evidence or reference.

Storage
For pilot-scale projects and field tests, storage lags behind capture. However, respondents to the CSLF Maximization and Knowledge Sharing survey said that valuable experience and knowledge have been gained for RD&D projects, Otway and Tomakomai were particularly mentioned. Progress on fiber optic sensing for monitoring storage sites was also reported.

For storage, it is probably somewhat more challenging to identify progress than for capture, due to challenges like the level of characterization required and the acquisition of CO_2 for injection.

Utilisation
Much work is reported in the literature, but appears to be related to applications rather than technologies as such.

In the CSLF Maximization and Knowledge Sharing survey the majority of respondents (10 of 16) indicated incentives are being used for Utilization technologies

Conclusion
Much good research going on that progress CCUS technologies but no break-through technologies reported or identified that at TRL 6 or higher have convincing evidence of significant cost reductions

Identified bottelnecks for RD&D:

Corrective actions, if any, by CSLF to facilitate exchange of RD&D results

Need sustained, continued R&D investment beyond the lab- and bench-scale. Need to start moving promising technologies to the pilot-scale. Also, incremental advancements from R&D are important and should be considered for investment along with transformative technologies. While there has been good progress on CO2 injection pilots, need to re-visit what has been learned and focus of the next set of pilot projects.

Sources:

Impact on TRM:
Depends on development towards next version.

Reported by:
CSLF Technical Group

4. Business models

- **Facilitate innovative business models for CCS projects**

Summary of business models implemented or suggested business models during reporting period.

Business models implemented:
EOR has been a market driver for decades in the United States

The US, the 45Q tax credit (E.G. **https://www.catf.us/wp-content/uploads/2017/12/CATF_FactSheet_45QCarbonCaptureIncentives.pdf**) and low-carbon and renewable fuel standards, which also place a value on carbon have the potential to spur investment.

Other progress:
Business models exist to varying degrees in different regions. For example, public-private models are under consideration/development in, amongst others, Norway and UK.

IEAGHG, IPIECA, Pale Blue Dot, Pöyry/Teesside Collective and UK BEIS reports/presentations on topic. Heightened awareness of importance. Globally, other efforts, whether incentives, taxes or direct government investment, have been utilized or considered.

Increasing focus on utilisation of CO_2 as part of a business concept for CCUS.

An ACT event**:** Framework for CCS risk sharing and business model selection, workshop in Brussles Wednesday, March 13-15, 2019. The aim of the workshop will be to present and discuss the methodology developed to understand the main components of a CCS business model and a business case at system and sector level (**http://www.act-ccs.eu/events/2019/3/13/framework-for-ccs-risk-sharing-and-business-model-selection**).

In the CSLF Maximization and Knowledge Sharing survey ~50% indicated CCS incentives have been used to implement CCS since January 2018, including:
- In USA, the 45Q Tax credit, the renewable fuel standard and the low-carbon fuel standard
- In Australia, ANLEC R&D has developed a portfolio of research shaped by the priorities for reducing investment risk for these three proponents.
- In the United Kingdom, government funded studies that include business models
- In Norway, a business model for the full-scale project has been outlined.

Many conferences and workshops on CCUS include sessions on business models or related topics (e.g.. GHT14 2018; CLIMIT SUMMIT 2019).

Conclusions

Despite many good plans and studies the conclusion on the development and implementation of business models for CCUS is:

Progress on development of bussiness models have not been implemented, perhaps due to lack of policy and regulatory environment relevant for CCUS projects. Progress is behind what is necessary to support the development of CO_2 hubs, clusters and infrastructure, which will be needed to reach the storage target. Action is required.

Identified common bottlenecks:

Commitment and funding beyond studies for projects on the drawing board.

Corrective actions, if any, by CSLF to facilitate innovative business models

Business models must be in place before infrastructure projects will make an investment decision. There is a need in many cases to develop guidance or rules for actual implementation so project developers and financiers have the ability to make sound investment decisions. Need to ensure a sound technological and scientific basis is available to ensure appropriate business models are developed. Models need to be tailored to specific regions/countries to meet their needs/market conditions**.**

Sources:

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Impact on TRM
Depends on development towards next version

Reported by:
CSLF Technical Group