CSLF Joint Task Force on the Development of 2^{nd} and 3^{rd} Generation CO_2 Capture Technologies

A status report

Lars Ingolf Eide, Norway

Regina, Canada

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History

- The following topics of great interest to CSLF that should be moved forward in Task Forces (CSLF Ministerial Meeting in Washington DC in November 2013):
  1. Communications
  2. Global collaboration on large-scale CCS project(s)
  3. Financing for CCS projects
  4. Supporting development of 2nd and 3rd generation CCS technologies
  5. Transitioning from CO_2-EOR to CCS.

Our mission

- The fourth Task:
  - ”Efforts should be taken to better understand the role of 2^{nd} and 3^{rd} generation technologies for CCS deployment, and policies and approaches identified among individual CSLF member countries that can stimulate 2^{nd} and 3^{rd} generation CCS project proposals to improve the outlook for successful Large Scale Integrated Project deployment in the 2020 to 2030 timeframe. Development of these technologies will benefit from the CCS Pilot Scale Testing Network, which is in the process of being stood up. ”

What to do

- Technical Group
  - Map/Identify 2nd and 3rd generation
    - mature in the 2020 –2030 timeframe,
    - development plans to scale from current readiness
    - major challenges facing technology development.
  - Use existing networks to map potential for testing 2nd and 3rd generation technologies at existing test facilities
- Policy Group
  - Map initiatives and funding mechanisms for 2nd and 3rd generation technologies in CSLF member countries.
  - Prepare a Policy document on how to achieve an accelerated implementation of 2nd and 3rd generation CO_2 capture technologies

Approach Technical Group

- ***Summarise several review papers, NOT an original work (quasi-metastudy).***
  - ***SINTEF (2013), DOE/NETL (2013) and IEAGHG (2014) ZEP (2013), CSLF (2013a) and GCCSI (2014).***
  - ***References to these documents usually not given in the general descriptions, nor to papers and articles used by the mentioned references*****.**

Organization of report

- Post-combustion
  - Solvents
  - Sorbents
  - Menbranes
  - Other (Cryogenic, hydrates, CO_2 enrichment, algae, supersonic pressurized)
- Pre-combustion
  - Solvents
  - Sorbents
  - Membranes
  - Other (cryogenic, fuel cell concepts, not requiring capture facilities)

Organization of report

- Oxy-combustion
  - Chemical Looping Combustion (CLC)
  - Oxygen Transporting Membranes (OTM)
  - Other (incl. air separation, turbines and boilers, high pressure, CO_2 processing and clean-up
- Other new emergig technologies with limited info today
- Test facilities and capabilities
  - CCS Test Centre Network
  - ECCSEL
  - Other (China, Japan, Korea, Europe, etc)

Example of technology summary

Enzymes

The enzyme carbonic anhydrase (CA) is known to accelerate the hydration of neutral aqueous CO_2 molecules to ionic bicarbonate species. CA is amongst the most well-known enzymes, since it operates in most living organisms, including human beings. By adding a soluble enzyme to an energy efficient solvent one may be able to achieve a lower cost process for carbon capture and mimicking nature's own process. Increasing the kinetic rates of the hydration of CO_2 and dehydration, as CA does, results in enhanced absorption and desorption of CO_2 into and out of a CO_2 solvent and/or in various membrane processes with immobilized CA. Novozymes applies ultrasonic energy to increase the overall driving force of the solvent re-generation reaction.

Maturity: 3rd generation; TRL 1 - 2 (Bench scale testing with real flue gas)
Challenges: Understanding the level of enzyme activation; increasing the chemical and physical stability of the enzymes (mainly thermal stability); advancing the limited cyclic capacity (for carbonates)
Some players: CO_2 Solutions, Novozymes, Carbozymes, Akermin
Pathway to technology qualification: Further basic research to understand the level of enzyme activation and to increase the chemical and physical stability of the enzymes (mainly thermal stability). In addition, the limited cyclic capacity (for carbonates) needs further advancements. Scale-up to lab and small pilot.
Infrastructure required: The concept can utilize the existing infrastructure for post-combustion as found at many larger test facilities, such as access to real flue gas, water, electricity and other utilities. Some modifications may be required, depending on the need for recycling enzymes to avoid high temperature exposure.
Environmental impact: Potentially low impact. If inorganic carbonates are use as main component and there are no other activators than the enzyme, there should be no emissions.
Applications: Power industry, cement industry, steel industry

TCN member facilities and capacities

Facility	Owner(s)	Country	Technology approach (post-, pre- or oxy-combustion) that may be tested	Flue gas	Capacity		Available infrastructure	Comment
				Type, amount	Carbon dioxide, t CO_2/y	Power (real or equivalent)		
National Carbon Capture Center	DOE, operated by Southern Company	USA	Post and pre	Coal power:14 % CO_2; Post: Slip stream ~ 17 000 kg/hr. Possibiity to dilute with air to 3% Pre: Syngas 750 kg/hr		Post: 0.5 – 4.3 MW_e Pre:	Real flue gas, water, electricity	
CO2 Test Center Mongstad	Gassnova, Statoil, Shell and Sasol	Norway	Post	Refinery FCC: 12 – 14%, 22 – 50 000 Sm^3/hr CHP gas turbines: 3.5-9%; 28 – 56 000 Sm^3/hr	FCC : 80 000 CHP: 25 000	Coal: 10 - 12 MW Gas: ~ 7.5 MW	Real flue gas, water, electricity	
Shand	SaskPower	Canada	Post, may evolve into other types after 1 – 2 years	Coal power	45 000	5 – 6 MW	Real flue gas, water, electricity	Presently operated by Mitsubishi-Hitachi, may be open to others from 2017
PACT	UKCCSRC	UK	Post, pre and oxy	Coal, gas, biomass From stand-alone units (not from plant)	1	Two 330kW Gas Turbines; 1,5 MW_{th} gas turbine burner rig One 250kW air/oxyfuel combustion plant	Flue gas from stand-alone burner or turbine; water, electricity; gas mixing facility with trace gas injection capability	

Example of summary presentation

Capture approach (Post-, pre- or oxy-combustion	Technology group	Tecchnology Readiness Level (TRL)	Generation	Application (power and industry)	Potential testing facilities for demo-scale w/capacity
Post-, solvents	Amine-based solvents	Commercially available from several vendors (Fluor, MHI, Aker to mention a few)			
	Precipitating solvents	4 – 5	2nd - 3rd	Power, cement, steel	
	Two phase liquid system	3 - 4	2nd - 3rd	Power, cement, steel	
	Enzymes	1 – 2	3rd	Power, cement, steel	
	Ionic fluids	1 – 4	2nd - 3rd	Power, cement, steel	
	Novel systems - Encapsulated solvent - Electrochemical (EMAR)	1 – 2	3rd	Power, cement; EMAR also steel & aluminum	
Post-, sorbents	Calcium looping system	5 – 6	2nd	Power, cement, steel	
	Other sorbent looping systems	1 – 6	2nd - 3rd	Power, cement,steel	
	Vacuum Pressure Swing	2 – 3	3rd	Power, cement	
	Temperature swing	1 – 2	3rd	Power, cement	

Identified emerging (2nd and 3rd generation) CO_2 capture technologies and the possibilities to use existing testing facilities. Note that the spread in TRL for some groups reflects variations of individual technologies within the group.

Green=Commercial

Yellow=2nd generation

Red=3rd generation

Next steps TG

- Quality check of 2nd and 3rd generation report
- Complete information gathering on test facilities
- Finalize summary table and conclusions
- Coordinate with PG

All in good time for a room document at the Ministerial in Riyadh in November

Definitions (DOE/NETL)

- 2nd generation technologies—currently in R&D, will be validated and ready for demonstration in the 2020–2025 timeframe
- 3rd generation technologies (“Transformational” technologies) —in the early stage of development or conceptual. The development and scale-up to occur in the 2016–2030 timeframe, demonstration in the 2030–2035 time period.

Use of TRL

carbon sequestration leadership forum

TRL definitions according to IEAGHG (2014)

Maturity	TRL	Definition
Demonstration	9	Normal commercial service
	8	Commercial demonstration, full scale deployment in final form
	7	Sub-scale demonstration, fully functional prototype
Development	6	Fully integrated pilot tested in a relevant environment
	5	Sub-system validation in a relevant environment
	4	System validation in a laboratory environment
Research	3	Proof-of-concept tests, component level
	2	Formulation of the application
	1	Basic principles, observed, initial concept

TRL definitions according to GCCSI (2014)

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Maturity	TRL	Definition
Demonstration	9 8	The process is implemented at full or reduced scale but is representative of a commercial plant in performance and complexity. The process is engineered in the same manner as a commercial project and fully integrated with the flue gas source process. Flue gas is derived from a source representative of the commercial application. The plant operates over the full range of operating conditions.
Pilot/demonstration	7	The overlap between pilot and demonstration
Pilot	6	The main parts are integrated and tested in a complete process to conduct performance tests and sensitivity analyses. First engineering design takes place. Real flue gas e.g. derived from a new or existing source, conditioned to meet actual characteristics if necessary (e.g. dedicated burner).
Lab/bench/pilot	5	The overlap between lab/bench and pilot
Lab/bench	4 3	The core process components are tested in a lab facility or at bench-scale to demonstrate the working principle on single components or limited integration (main parts of the process). Flue gas is artificial.
Concept/lab-bench	2	The overlap between concept and lab/bench
Concept	1	The idea is demonstrated using theoretical calculations and/ or observation of basic principles in laboratory.

Maturity and pilots vs. demo

- Reviewers/vendors differs in assessment of maturity
  - E.g., Temperature Swing Adsorption (TSA) and Pressure Swing Adsorption (PSA) are classified by GCCSI (2014) at TRL 5-7, whereas IEAGHG (2014) classify them as, respectively, TRL 1 and 3
  - Reviewers often indicate a range of TRLs for a technology
- The boundary between “pilot” and “demonstration” is floating and un-precise, in terms of quantities as well as units. Examples:
  - SINTEF (2012) may be interpreted to include technologies with CO_2 capture rates of a few kg/hour to several tons/hour as pilot
  - GCCSI (2014) mentions both technologies with 1 – 2 MW_{th} and 35 MW_{th} as pilots.

Our use of TRL

- We have classified technologies according to estimated TRL, basically using the IEAGHG (2014. We have strived to find a balance when there are different views among the referenced sources, realizing that some of our classifications may be open for dispute.

- NOTE: The TRL grading is based on technical status, not on feasibility or whether this approach is CCS or CCUS

Maturity definitions in relation to emerging (2nd and 3rd) generation capture technologies

The terms 2nd and 3rd generation technologies are generally not used in the reviewed documents

Classification used in this report, generation	SINTEF (2013)	DOE/NETL (2013)	IEAGHG (2014)	GCCSI (2014)
2nd	Pilot scale testing	Pilot scale testing (real and simulated gases)	Development (TRL 4 – 6)	Pilot (TRL 5-7)
3rd	Proof of concept/lab scale testing; Idea/theoretical investigations only	Proof of concept/lab scale testing; Idea/theoretical investigations only (real and simulated gases)	Research (TRL 1 – 3)	Concept and lab/bench (TRL 1 – 5)

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Comments?

Thank you!