ZEP Advisory Council 52

13th September 2017

Agenda Item 9: Network Technology

9.a. Network Technology Update

Appended to this paper is an update for the ZEP Network Technology.

9.b. ZEP recommendations to Mission Innovation

Appended to this paper are recommendations for the Mission Innovation workshop in September.

The AC is invited to approve the ZEP Mission Innovation narrative and table of recommended topics for discussion at the Mission Innovation workshop in September.

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ZEP Advisory Council 52

13th September 2017

Agenda Item 9.a: Network Technology update

NWT co-chairs: Filip Neele (TNO), Arthur Heberle (Mitsubishi Hitachi Power Systems)

Work programmes for three of the Temporary Working Groups (TWGs) under Network Technology (NWT) have now come to an end, with reports by Future CCS Technologies and Clean Hydrogen approved at the AC49 meeting in December, and a report by the TWG Fast Track Transport and Storage approved at the AC50 meeting in March.

The next NWT meeting will be held on 19th October in Brussels (venue to be confirmed). The focus of the meeting will be developing a new work programme for the Network, building on the priorities identified at the ACEC Away Day. These include:

- SET Plan TWG9 CCS and CCU - delivering on gaps identified in process
- New TWG Mission Innovation
- Regional modelling of CCS alongside other technologies, including Rotterdam, North France, Poland/ Germany/ Czech Republic border
- CCU
- Managing CO_2 from different emitters
- Energy storage
- Flexible operation of CCS plant and possible links with CCU
- Supporting IEA and IPCC on 2 degree/below 2 degree scenario & Bio CCS
- 100% capture (challenge posed by IEA below 2 degree scenario)
- Negative Emissions technologies
- Input into SET- Plan FP9

TWG Mission Innovation

Co-chairs: Filip Neele (TNO), Nils Røkke (Sintef)

A new TWG Mission Innovation has been established as a way for ZEP to provide input to the international Mission Innovation Carbon Capture Innovation Challenge (IC–3), co-led by the United States and Saudi Arabia. Terms of reference for the TWG were approved at the AC51 meeting in June. The TWG co-chairs circulated an invitation to NWT and NWPE members to suggest topics to be discussed during panels at the Mission Innovation Workshop on 25-29th September 2017 in Houston Texas, under the main focus areas of capture, storage, and utilisation. Input received from members was discussed at a teleconference held on 30th August, and a paper drafted by the co-chairs, providing a list of recommended topics to be discussed at each panel. This paper and accompanying narrative are appended to this paper as pre-read 10.b.

The AC is invited to approve the ZEP Mission Innovation narrative and table of recommended topics for discussion at the Mission Innovation workshop in September.

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Agenda item 9.b. ZEP input to Mission Innovation

Introduction

The objective agreed in Paris to keep global warming to well below 2 °C and pursue efforts to limit the increase to 1.5 °C has generated a renewed momentum for carbon capture and storage (CCS) to be a part of the portfolio of technologies that can deliver low carbon emissions across a number of sectors. All low carbon technologies available will be needed to achieve this objective (1).

CCS together with carbon capture and utilisation (CCU) are important technologies for the global decarbonisation of the power generation and energy intensive industries in a cost-effective manner, leading to the delivery of low-carbon products, produce clean hydrogen which can be used to decarbonise heating and transport, and play a key role in the transition to a net zero emissions power sector (2). Delaying the deployment of CCS significantly increases the cost of reaching climate goals (3). The key to delivering CCS lies in the development of CO_2 transport and storage infrastructure. The early establishment of CCS infrastructure in key European industrial regions creates a strategic asset for Europe and is the catalyst that will enable a low carbon emissions future for industry, heat, power and transport (4).

A promising area for further emissions reductions is carbon capture and utilisation (CCU), which enables the use of CO_2 as a feedstock for products such as chemicals, building materials and substitute fuels. In addition to cutting emissions, CCU technologies can bring multiple economic benefits. They can support the EU's industrial revival and the development of a circular economy. They can contribute to our energy security, to the decarbonisation of the transport sector and to the deployment of wind and solar electricity by providing energy storage. Moreover, innovation in CCU will also support the further development of carbon capture and storage, as it helps advance capture technologies and create demand for the CO_2 captured. Mutual benefits could be drawn by developing hubs and clusters for CO_2 capture, transport, storage and utilisation around sites with emissions-intensive industries (5).

Many of Europe's industrial and power emitters are located in regional clusters, which should be able to connect to regional CO_2 hubs via national and cross-border CO_2 transport and storage infrastructure (6). This allows such clusters to reconcile continued growth with cutting carbon emissions, transforming into drivers of sustainable economic zones and

generating new jobs across the economy. The development of regional CO_2 hubs also opens up other opportunities such as Carbon Capture and Utilisation (CCU), Enhanced Oil Recovery, and links to heat and hydrogen networks (4).

There are currently 21 large-scale CCS projects in operation or under construction globally, with many more smaller-scale pilot and demonstration projects (7). This proves that CCS technology is ready for deployment and the long term business case has been made, but more needs to be done. Technological developments are needed to drive down cost (8). A policy framework is needed that incentivises the capture and storage of CO_2 and facilitates an environment in which follow-on projects and investments can develop; above all, investment and financing models are needed to realise the cross-border transport and storage infrastructure that facilitate future hubs (4, 9).

Mission Innovation

Following the Paris COP21, the Mission Innovation (MI) inititative was set up to drive innovation in the energy sector. A number of challenges were defined, one of which is CCS. Focusing on the lower technology readiness levels (TRL), MI aims to define the R&D agenda for the coming period and stimulate international cooperation. The signatories of the MI have committed to increase the R&D investment in clean R&D research and innovation from 2015 to 2021. This document puts forward research directions to be considered for international R&D co-operation, from the EU point of view. Key elements include increasing the flexibility of CCS chain elements, clustering both capture and storage.

Current status in the EU

EU and national funding instruments have limited success in delivering CCS demonstration projects. Currently two CCS projects are ongoing in Europe, both located in Norway. There clearly is a need for coordinated action to initiate CCS by providing effective and stable policy and support schemes.

Currently EU Member States are in the process of formulating an Implementation Plan for CCS, which describes actions to realise the ambitious goals by 2020, as well as actions to meet 2030 targets. The targets for CCS and CCU in the EU have been laid down in the SET-Plan. The actions include closing gaps in national and European funding instruments, putting in place a suitable regulatory framework for cross-boundary CCS projects, actively supporting the development of demonstration projects in power and industry, and setting up projects in CCU, transport and storage. National energy and climate plans will be delivered by 2020, in which the role of CCS will be clarified.

The activities defined in the Implementation Plan address current barriers to the roll-out of CCS. Demonstration projects in power and industry will test not only technology, but also incentive systems and the regulatory environment. Active support of regional industrial clusters will drive the development of industrial reform and regional CO_2 hubs, with parallel efforts to assess, test and permit storage capacity.

Gaps and barriers

The most important developments needed in Europe are linked to developing efficient policy and support mechanisms for CCS (4, 9). At the same time, CCS demonstration projects are required to test and demonstrate the technology on a wide range of emission sources and to drive technological development. Work is to be undertaken now to meet 2030 deadlines, such as the development of CCS clusters and the preparation of large-scale storage (4).

Development of new capture technologies is needed to reduce cost and to provide dedicated solutions for all relevant sectors. Operational CCS projects will provide test beds for current first-generation technologies, forming the essential driver for subsequent emerging technologies (8).

For the power sector, the increasing share of renewable energy will lead to fossil-based plants being deployed in a load-following mode (2). This requires the development of highly flexible, yet low-cost separation technology.

While the utilisation of CO_2 is considered currently as more a possible complementary alternative to contribute to climate mitigation goals, with EOR as the most compatible with CCS, it is expected to act as a driver for the development of capture projects and, subsequently, of transport and storage infrastructure. CCU is a pathway to new industrial opportunities. CO_2 can be used as a carbon source for the synthesis of products such as chemicals, fuels or materials. There are several differences between CCS and CCU. The main differences are the capture technologies and CO_2 volume involved. To use CO_2 as a raw material, we need to improve CO_2 capture technologies for small CO_2 emitters with two main constrains: the small space available for the capture equipment and the low cost. This is why there is the development of CO_2 applications with flue gases or a low level of CO_2 concentration - to decrease the cost of CCU. Moreover, the volume of CO_2 is not the same for CCS and CCU. In most of the cases, CCU projects address a diversity of products for different markets, and they cover both niche and mass applications with volumes of CO_2 from thousands to tens or hundreds of thousands of tonnes. So the volume of CO_2 use will always be less than the volume of CO_2 stored where the amount is typically of the order of 1 million tonnes of CO_2 per plant per year. One proposition is to develop a CCU project with CCS when it is possible. This synergy could make it possible to decrease costs if some of the CO_2 captured is used in CO_2 conversion to produce a high value product (5). Additionally CCU has the capacity to use CO_2 emissions in stranded locations, where there is no opportunity for geological storage. It will be important to understand and quantify the potential of CCU technologies as a CO_2 mitigation option; LCA guidelines should be developed for comparing and reporting (10).

With many industrial and power emitters located in clusters, there is scope for integrating industrial processes and networks. There will be opportunities for cost reduction through process combination and optimisation, with carbon capture as an essential element. This may require a broader scope to systems analysis and optimisation and could, e.g., lead to shared capture installations, with the flexibility to accept variations in load level and amounts of impurities.

Combining and restructuring industrial processes and networks, such as those for hydrogen, heat and CCU, is expected to both reduce overall cost and increase benefits (from utilisation of CO_2).

Transport and storage cost can be reduced through the development of integrated networks. Transport and storage of CO_2 largely builds on existing knowledge and technology. Key gaps and barriers are found in the area of regulations, liability and cross-border issues. Stable frameworks are needed to support investments by potential CO_2 providers, transport operators and storage providers.

A key barrier to the development of CCS in Europe is the lack of permitted storage; the long lead time of storage appraisal, testing and permitting is an issue that needs to be addressed. Setting up an up-to-date storage atlas will support potential storage operators.

Input into Mission Innovation

The high-level gaps and barriers described above derive from the required future role for CCS as a climate mitigation technology. A more detailed analysis of R&D needs has been made that directly feeds into the Mission Innovation R&D agenda (8, 9, 10).

A significant part of the recommendations for the R&D agenda falls into the category of cross-cutting issues. While technology development is valuable and will be fuelled by a continuous drive to reduce cost and increase efficiency, the development of large-scale CCS systems requires setting up the appropriate regulatory environment. This includes such issues as the London Protocol and the sharing of liability in a multi-player CCS network.

The tables below list recommendations for R&D topics for each of the headings ('panels') under the four focus areas: capture, utilization, storage and cross-cutting. The specific topics must be further elaborated to fit within the remit of MI for co-operative efforts among the MI countries and the specific interest/vehicles available to progress such work.

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4) ZEP, 2015. An Executable Plan for Enabling CCS in Europe. Belgium (http://www.zeroemissionsplatform.eu/library/publication/255-executableplan.html)

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7) GCCSI, 2016. The Global Status of CCS: 2016. Summary Report. Australia

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9) ZEP, 2017. Fast Track CO_2 Transport and Storage for Europe. Belgium (http://www.zeroemissionsplatform.eu/library/publication/275-fasttracktas.html)

10) ZEP, 2016. Carbon Capture and Utilisation. Belgium (http://www.zeroemissionsplatform.eu/library/publication/272-cleanhydrogen.html)

Focus area: Capture		
Panel	*EU / ZEP input*	*Relevance*
Solvents	Improve flexibility of capture system; increase integration of capture plant in power plant or industry facility; decrease energy penalty; decrease equipment volume; improve robustness (presence of impurities); improve on material degradation; improve sorption / desorption kinetics; decrease of desorption energy by using phase-changing solvents (2nd formed phase to be separated mechanically instead of thermal separation, less water content for further thermal treatment); improved capture efficiency by adding enzymes	• Lower emissions due to solvent entrainment (need for highly efficient droplet/aerosol /fine particle separation) • Technologies to enrich CO_2 concentration in the flue gas stream (higher CO_2 concentration decreases costs) • Economic CO_2 capture also in smaller-scale plants leads to higher application flexibility • Higher capture efficiency (process intensification): smaller area needed for capture plants • Decrease cost (both CAPEX and OPEX), widen the range of emission sources for which a capture solution is available, improve flexibility • Biological capture to produce biomass based CCU products
Sorbents and Looping Systems	Develop standardized test procedures of new materials; decrease cost by minimizing cycle time and productivity; increase robustness in presence of impurities. Scale up fluidised bed systems; improve stability of CLC materials; develop methods to minimise heat requirements; proof of concept of advanced looping concepts; improvement of mechanical stability of solid sorbents (especially in looping systems)	
Membranes	Enhance permeance and selectivity (CO_2, air, depending on application), improve sealing, enhance stability (Pd-based membranes), improve mechanical/chemical/thermal stability and resilience (stress, impurities, fouling); membrane with separation and chemical synthesis capabilities for CCU; separation of CO_2 from flue gas or separation of flue gas from CO_2; decrease of pressure drops; cheap membrane materials	
Combustion and Other Technologies	Improve fuel and operational flexibility Enable near 100% hydrogen fuelled/NH_3 fuelled high-efficient power cycles using ICE and/or turbomachinery components. Improve robustness (presence of impurities), improve on	

	solvent degradation, improve sorption / desorption kinetics; biological capture i.e. CO_2 capture by any type of biomass like trees, algae etc. but very low capture kinetics as critical issue leading to high area need	

Focus area: Utilization		
Panel	*EU / ZEP input*	*Relevance*
	Quantify the value of CCU technologies as climate mitigation option and renewable energy storage Develop LCA guidelines for comparing CCU technologies and for reporting Explore options for combining CCS and CCU Design tailor-made incentive schemes to kick-start early projects Recommendations regulatory framework for CO2 based based chemicals, fuels	Clarify the role that CCU can play in climate mitigation plans Support the development of CCS through CCU CCU as one tool among others for coupling of different sectors (industrial symbiosis), opportunities of sharing infrastructure for conventional-made products/fossil products leading to cost-effective system; complementarity of CCS with CCU (location, CO2 purity, CO2 volumes, …)

Focus area: Storage		
Panel	*EU / ZEP input*	*Relevance*
Injectivity and capacity	Injectivity stimulation: improve modelling capability of well and near-well coupled chemical-mechanical effects of injection; improve predictive capability of injectivity processes and potential problems related to chemical clogging or scaling, both within the injection tubing as well as the reservoir formation, or mechanical reduction of reservoir permeability. CO_2-EOR / CO_2-EGR: optimize CO_2 EOR/EGR for CO_2 storage. Storage site availability: how to efficiently grow single storage sites into clusters; produce an international storage database (or atlas) indicating the availability of (potential) storage sites; improve capacity and injectivity prediction calculations and synchronize the methodology for storage capacity. Pressure management (through water production) when injecting in saline aquifers: modelling / monitoring breakthrough of CO_2 at production wells, treatment and discharge of water, develop autonomous (self-powered) production wells.	Reservoir specific optimization of the injectivity scheme and suitable remediation techniques will lower the costs for storage by preventing or reducing down-time or complete shutdown which can result from injectivity issues and subsequent pressure build-up. Injectivity schemes need to consider the variations in CO_2 supply, delivery conditions and quality based on the organization of CO_2 sources in clusters as well as economic constraints. This way the optimized injection schemes will support the development of CCS clusters and lower storage costs. Simulations show that changing the injection scheme can lead to significant CO_2 storage, while HC recovery is not affected. This could reduce the cost and speed up large scale CCS. Optimization schemes will depend on regulatory and economic environment; this dependency can be used to study incentive schemes. This will support efficient, cluster based CCS, as well as the development of a storage atlas
Monitoring, verification and performance metrics	Develop methodologies and systems to quantify the performance of the storage system; define the value of monitoring information by combining monitoring data, include uncertainty analysis, develop a suitable (chemical) CO_2 tracer, which would allow us to monitor	De-risking storage development supports potential storage operators. Issues include quantifiable metrics for storage site performance, cost-efficient and CO_2-specific well abandonment techniques.

	the breakthrough and migration of CO_2 to logging tools to measure µ-annuli. De-risk site handover: develop monitoring methods, which support storage site hand-over; develop CO_2-specific abandonment methods, develop post-abandon monitoring techniques – autonomous, long-life, well-based sensors Improve understanding of migration into and through overburden	Monitoring should cause minimum disturbance, (unlike seismics) – so long-life autonomous sources and sensors are required.
Induced seismicity	Develop coupled modelling of pressure effects / fracture initiation and propagation and link with monitoring. Inclusion of seismicity modelling in injection strategy optimization	A better understanding of induced seismicity supports both operator and regulator in assessing the performance of a storage site.
Well diagnostics	Development of low-cost, high-quality well measurement tools. Re-using existing oil gas wells, reservoirs and infrastructure for CCS: develop a transparent and harmonized (EU, global) well safety and well integrity assessment methodology; develop dedicated inspection technologies addressing CCS specific requirements; develop CCS well integrity and well safety forecasting models and scenario methods to preclude potential degradation risks, increase safety. Develop methods to asses P&A wells and to seal them when necessary.	Development of automated tools allows cost reduction in monitoring / performance assessment. Huge costs (multibillion) are required to properly abandon wells of depleted oil and gas reservoirs. Re-use for CCS should be addressed. Develop natural mechanisms (e.g., microbes, clays) that provide in-situ sealing when needed.

Focus area: Cross-cutting		
Panel	*EU / ZEP input*	*Relevance*
Framework conditions and network development	Network development: behavior of a transport and storage network with multiple suppliers and storage sites; complementarity of CO_2 storage and CO_2-EOR projects	How to operate a multi-supplier and multi-store network? Transient phenomena – shut-in, start-up – must be taken care of so as to not depressurize (part of) the system. How to operate multiple wells from a single platform or site? What happens when wells or a pipeline are shut in? When operating multiple depleted reservoirs in a network, how to handle the flows? How to avoid low temperatures in a depleted reservoir?
Effects of varying CO_2 quality and supply	CO_2 quality: resolve specifications / design standards for the CO_2 transported through the network. Intermittency: understand the impact of non-baseload CO_2-delivery.	Quality specifications are a key issue when connecting additional suppliers. Impurities impact on the dynamics of CO_2 in the system – this impact is yet incompletely understood and experimentally / theoretically validated for mixtures of CO_2, H_2 and impurities/components for the off-gas or solvent system. Impurities arise from the capture system (e.g., degradation products and), as carry-over, or from reservoir. Issues include interaction between CO_2 and the reservoir, corrosion or degradation of transport system materials, mixing of CO_2 from multiple suppliers. The topic of intermittency includes the impact on the transport and storage systems, transient phenomena, line-pack, shut-in an start-up of injection wells (relevant for depleted pressure fields),

		effects of intermittent injection on well integrity, resilience of the CCS chain to variations in CO_2 quality / pressure / flow, fiscal / legal hurdles for buffers to match supply and demand.
Integrating and optimizing processes	CCS as part of integrated industrial processes: integrating CCUS into industrial processes to achieve emission cuts, cross-sector benefits; research into integrating industrial processes and products (heat, power, other) to reduce energy demand; use CCUS to achieve emission cuts. Carbon-negative technologies: develop carbon-negative technologies. Optimize existing technologies for bio-CCS; life-cycle analysis; cost/benefit allocation analysis in multi-actor chains.	Smartly combining different activities in densely populated industrial regions has major potential. E.g. investigate benefits of coupling CO_2 usage / storage with other sectors, such as geothermal energy production. Carbon-negative technology is generally accepted as inevitable if we wish to achieve the climate objectives (not only for the 1.5 °C scenario, but also for the 2.0 °C scenario).