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6th December 2017

Agenda Item 8: Review of Network 2018 Work Programmes

8.a. Network Policy and Economics

Appended to this paper are the following pre-reads:

8.a.I. Network Policy and Economics update

8.a.II. Draft terms of reference TWG Innovation Fund

The AC are invited to approve the draft TOR

8.a.III. ZEP input to the detailed design of the ETS Innovation Fund: Recommendations for the Delegated Act governing the Innovation Fund

The AC are invited to approve the draft paper

8.a.IV. Draft terms of reference TWG PCIs: CO_2 PCI development

The AC are invited to approve the draft TOR

8.a.V. Insights on the funding opportunities and gaps for CCS in Europe

8.b. Network Technology

Appended to this paper are the following pre-reads:

8.b.I. Network Technology update

8.b.II. October meeting minutes

8.b.III. Draft forward work programme for 2018

The AC are invited to approve the draft TOR

8.b.IV. Mission Innovation report to the Commission

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Agenda item 8.a.I. Network Policy and Economics update

Co-chairs: Lamberto Eldering (Statoil), Angus Gillespie (Shell), Jonas Helseth (Bellona)

Network Policy and Economics co- chairs held a call on 2nd November to discuss the future work programme in light of recent developments including the outcome of recent engagement in Brussels by Graeme Sweeney.

It was agreed that the invitation to ZEP from Artur Runge-Metzger at DG CLIMA to come up with a proposal on how to fund a "market maker" through the Innovation Fund should be the immediate priority for NWPE. Given that work on the design of the Innovation Fund is likely to progress quickly after trilogue negotiations have come to an end, there is a short amount of time to put this together to have maximum impact. It was agreed that the members of TWG Transport and Storage, which was previously led by Owain Tucker at Shell and Keith Whiriskey from Bellona, would be the correct group to take on this piece of work. As Owain Tucker is not available Sarah Kempe has agreed to input from Shell. A new Temporary Working Group Innovation Fund has been formed to undertake this work.

The Secretariat has sent a formal invitation letter to Nico Van Dooren inviting him to co- chair TWG Policy and Finance.

The next NWPE meeting will take place on Monday 5 February 2018.

Temporary Working Group Policy and Funding

- Element Energy report on smart funding pathways

The ACEC has approved on behalf of the AC ZEP's summary of the i24c report on funding pathways for industrial CCS. The summary is attached for information.

Temporary Working Group PCIs

The co-chairs have agreed that instead of wrapping up the TWG as previously planned, there will be a future role for the group in supporting the PCI projects in overcoming barriers to deployment. This would include, but not be limited to, regulatory issues such as ratification of the London Protocol. An updated Terms of Reference is attached for approval.

Temporary Working Group Innovation Fund

Attached for approval are:

a) draft Terms of Reference and membership of the Temporary Working Group
b) draft recommendation on funding a market maker through the Innovation Fund

Temporary Working Group ME5

TWG ME5 will continue to publicise its report, and undertake further modelling on a regional/ country basis on request. For example it was recently agreed that ZEP could assist North Rhine-Westphalia with regional modelling.

Energy Intensive Industries and CCU Policy

Chair: Rob van der Meer (HeidelbergCement)

It was agreed at the ACEC Away Day that the TWG should remain active after the publication of the "Climate Solutions" report to undertake further work on policy drivers for CCS and CCU.

The TWG will build on the conclusions from Network Technology on Life Cycle Analysis of CCU products to produce policy recommendations on CCUS.

2017 review

TWG Policy and Finance

Short papers on the Renewable Energy Directive, Governance on the Energy Union and Emission Performance Standards have been produced and distributed to Commission and Parliamentary stakeholders.

The TWG suggested an amendment to the RED II to enable biomass with CCS to be included alongside CHP biomass for support; this was included in the Council's revised text.

The TWG produced a response to the European Court of Auditors consultation on European funding mechanisms for CCS and RES, which will be reported on in 2018.

The "funding modalities" paper produced in 2016 was used to inform ZEP's input into design of the Innovation Fund, through an expert workshop in May, and a response to the Commission's Impact Assessment.

The TWG input recommendations to the Commission on reuse of NER 300 funds.

TWG PCIs

In 2017 the working group has submitted a supporting document to the consultation on the four PCI applications for CO_2 transport, which were approved in November.

The TWG also input into a Commission consultation on the TEN- E regulation with the aim of making the process more accessible for CO_2 projects.

TWG Energy Intensive Industries and CCU

Published report "Climate solutions for EU industry." The report has been shared with Commission and Parliamentary stakeholders and was presented at COP 23.

TWG ME5

The TWG produced ZEP's 5th Annual Market Economics report. The report has been presented externally at a European Parliament hearing on CCS; The Eighth International Conference on Clean Coal Technologies; COP 23. The report has been shared with the Commission, Parliamentary and Member State stakeholders.

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Agenda Item 8.a.II: TWG Innovation Fund draft TOR – for approval

1. The Temporary Working Group (TWG) will be convened to provide input to the European Commission on the detailed design of the ETS Innovation Fund and the associated Delegated Act.
2. The TWG will produce a written report on how the Innovation Fund Delegated Act could be designed to enable the Fund to support CCS 'Market Makers'. The report will also include ZEP recommendations for the wider implementation of the Innovation Fund, including project selection criteria.
3. The TWG will be co-chaired by Sarah Kempe (Shell) and Keith Whiriskey (Bellona) and will be populated by ZEP members. Where possible, the TWG will also seek feedback from the ZEP Government Group.
4. The TWG will complete its draft report no later than 29th November 2017 so that it can be presented for approval to the ZEP Advisory Council on 6th December.

ZEP input to the detailed design of the ETS Innovation Fund: Recommendations for the Delegated Act governing the Innovation Fund

Introduction

In March 2016 ZEP provided detailed recommendations for the design of the Innovation Fund Delegated Act, based on lessons learnt by CCS projects from across Europe including previous NER 300 projects. These recommendations can be found appended to this document and remain ZEP's core input to the Commission on the design of the Innovation Fund.

This updated paper provides input to the Commission on how the Innovation Fund Delegated Act can specifically support the development of CCS "Market Makers". The Market Maker concept was developed by ZEP in its earlier work on developing a business case for CO_2 Transport and Storage and in its "Executable Plan" for CCS.

This new work has been undertaken following a request from DG Climate Action Director, Mr. Artur Runge-Metzger.

Why 'Market Makers'?

Multiple studies have demonstrated that a key barrier to widespread CCS deployment is the lack of business case for private sector investment in early CO_2 transport and storage (T&S) projects[1]. ZEP's work has shown that there are three main reasons for this:

1. **Requirement for timely investment in storage appraisal.** In some cases, this may need to take place up to 10 years before an emitter can deliver CO_2 for storage. There is no rational case for private sector investment in storage appraisal absent of a firm commitment to CCS deployment.

2. **Cross-chain risk between different actors in the CCS chain.** For CCS projects involving different entities managing the capture, transport and storage of CO_2, the commercial model needs to deliver predictable revenue streams to actors at each stage of the chain, with protection against cross-chain default. As an example, if CO_2 is not delivered as expected to a storage site then this can undermine investment in the project as a whole. This creates a big risk for developers/operators that is priced into the overall cost of a project, raising costs or simply making the project uninvestable.

3. **Liabilities associated with CO_2 storage resulting from the CCS Directive.** The requirement on storage operators to monitor and address CO_2 leakage from storage translate into unbounded liabilities due to the long time horizon associated with permanent storage and unknown future CO_2 emissions penalties if a leak were to occur.

[1] Ref: ZEP Business Case for Storage; CCSA Lessons Learned; IEA 20 years of CCS; Crown Estate: CCS – Balancing the carbon cycle, 2016

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In order to unlock early investments in CCS, ZEP has advocated for an approach whereby investments in T&S Infrastructure are underpinned by the public sector through direct investment and/or appropriately structured regulation. Publicly backed T&S Infrastructure can help to mitigate investment risks for the private sector, stimulate CCS by creating an investment model, and enable emissions intensive industries to address future increases in the cost of emitting CO_2 by providing access to the infrastructure they need to decarbonise.

ZEP has put forward an approach to T&S infrastructure based on Market Makers. Market Makers will compensate for a lack of market for CO_2-storage, by developing CCS infrastructure and then contracting with industrial emitters for the delivery of CO_2. Emitters will be required to pay a T&S fee that covers the costs of CO_2 T&S and a small element of capital repayment, which is then used to refinance the Market Maker. Over time the Market Maker can be privatised or disbanded as a commercial market for CO_2 storage develops.

ZEP has previously proposed that EU funds should be made available to support the development and capitalisation of strategic CO_2 Market Makers. The Innovation Fund can play a key role in supporting the development and deployment of CCS[2]. ZEP welcomes the provisional agreement on the overarching framework for the new Fund and believes that the legislative basis creates a framework in which CCS 'Market Makers' can be supported, subject to appropriate criteria.

Recommendations

1. Principles
   - Explicitly reference the value of CCS Market Makers in supporting the development and deployment of CCS.

   - Ensure that Innovation Funds are compatible with other sources of EU funding and are not deducted from other sources of funding (as was the case with the EEPR funding). The requirement for co-funding by Member States is encouraged but not mandated to allow for the eligibility of other sources of funding.

2. Eligibility criteria
   - ZEP strongly advises against the categorization of CCS projects and technologies as established under the NER300 as these proved unduly restrictive. Projects should instead align with the targets set out in the SET- Plan Implementation Plan for CCUS as these have been endorsed as strategic priorities by the Commission, Member States and stakeholders.

   - ZEP recommends specific inclusion of Market Makers within eligibility criteria, as Market Makers will be essential to enabling a wide range of industrial CCS projects.

   - Projects should be able to demonstrate long term value to EU decarbonisation. Projects should be compatible either with Member State 2050 decarbonisation roadmaps, or with longer-term EU objectives, including net zero emissions during the second half of the century.

[2] Element Energy report

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3. Selection procedure
   - Projects should not be assessed on the cost of avoided emissions alone. Instead, a more-rounded approach to project assessment should be taken in line with the revised ETS Directive, which requires projects to "*have the potential for widespread application or for significantly lowering the costs of transitioning towards a low-carbon economy".* Market Makers could meet these criteria in a number of ways:
     - Supporting emissions reduction across multiple sectors
     - Transboundary projects, e.g. where CCS T&S infrastructure can support emissions reductions in multiple countries or regions, including but not limited to Projects of Common Interest for CO_2 transport.
     - Providing backbone infrastructure that can enable continued decarbonisation over many years, as new streams of CO_2 are added.
   - Market Maker projects should not be required to estimate the total amount of CO_2 stored, rather the total capacity of the CCS infrastructure that will be made available to industrial emitters. This enables the addition of further CO_2 streams over time, up to the capacity of the transport and storage facility.
   - ZEP welcomes the recommendation set out in the Commission's summary report that projects should be selected based on project viability and robustness of business model. The inclusion of a market maker can demonstrate how the separate parts of the CCS chain will be managed including cross-chain risk.

4. Disbursement of revenues
   - Market Makers require early funding to enable CO_2 storage appraisal and investment in infrastructure ahead of any industrial investment in CO_2 capture. Therefore ZEP welcomes the inclusion of milestone payments within the revised Directive. Milestone funding that is not linked to verified avoided emissions can usefully be assigned for storage appraisal and development of infrastructure.
   - The funding rate should be established with sufficient flexibility to enable a range of different CO_2 emitters to access the T&S infrastructure developed by Market Makers at different times, i.e. if 100% capacity of the pipeline isn't achieved until year 20 of operation then no penalty should be applied to the Market Maker/T&S operator.

4. Post-award conditions
   - Under NER300 projects were required to enter into operation within four years or lose their funding, which created a significant risk. Instead projects should establish realistic deployment pathways with milestones and appropriate incentives to ensure timely delivery.

5. Transitional Arrangements

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- It is important that clarity is provided in the Delegated Act on the utilisation of the bridging fund between NER300 and the EU Innovation Fund and that any supporting EC decision or EIB internal regulation is in place to allow immediate utilization of the Innovation Fund in 2021.

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Agenda Item 8.a.IV: TWG PCIs: CO_2 PCI development draft TOR – for approval

ZEP TWG PCI: 27th November 2017, Version 1.6 – for circulation to the AC for comment and approval

At the latest meeting of ZEP Network Policy and Economics WPE a need for a dedicated CO2 PCI TWG was indicated with a TOR:
"Provide support to the CO_2 cross border PCI projects in the next steps of maturation"

Background

- ZEP has supported all CO_2 cross border proposals for the 2017 PCI list.
- The updated PCI list now has 4 CO_2 cross border transport projects.
- The PCI status is a prerequisite to be eligible to apply for Connecting Europe Facility (CEF) funding. A next round of application expected soon.
- Apart from funding PCI projects will receive priority in case of regulation barriers that may arise from discrepancies between neighbouring jurisdictions.
- Financial support is the focus for many of the CO_2 cross border PCI projects; the projects will be required to apply for the CEF funding themselves. However, other barriers that are specific for cross border transport of CO_2 may require assistance of external parties.
- The relevant Member States have supported the PCI projects. As it is the first time CO_2 transport projects are on the list, many uncertainties remain.
- The biggest legal barrier for CO_2 cross border transport is the slow pace of ratification of the amendment of Article 6 of the London Protocol. Although not an EU specific barrier, having the 4 CO_2 cross border PCI projects on the list means more engagement within the EU should be demanded.

Deliverables

- Internal deliverable: Topic list of PCI specific challenges. Action plan on meeting challenges
- External deliverable: provide informed support that contributes to understanding of CO2 PCI specific challenges.

Actions for the ZEP and TWG PCI

The ZEP ETIP sees that it can add value to the EC by bringing an industry perspective on the barriers that CO2 cross border PCI projects face in the next steps of maturation. The TWG-PCI will:

- Seek ZEP GG input to create an understanding of the challenges of the integration of the CO_2 PCI with wider CCS strategies noting that the benefit from a CO_2 PCI project is completely dependent on the Member State CCS policies.
- Seek input from the selected PCI projects on barriers where external engagement from ZEP would benefit early removal.
- Develop this input into an action plan to engage with relevant stakeholders.

Administration

- The TWG will be supported by the ZEP Secretariat.
- The TWG currently has the following volunteers: Lamberto Eldering, Statoil
- A call for volunteers to join the working group will soon be launched on approval of this paper.

Insights on the funding opportunities and gaps for CCS in Europe

CCS is critical to retaining high-skilled jobs in sectors such as steel and cement in Europe. The development of CCS infrastructure will enable these essential industries to decarbonise in line with the EU's climate change commitments, ensuring their long term survival while creating new opportunities for inward investment. ZEP's previous analysis has shown that the value of CCS to the EU could total €1trillion by 2050.

As small industrial plants lack the expertise or resource to develop their own CO_2 transport and storage, industrial CCS can be developed most effectively at a regional level with "clusters" of energy intensive industries sharing transport and storage infrastructure. Today there are regional bodies working to develop industrial CCS clusters in strategically important locations such as Teesside in the UK and Rotterdam in the Netherlands; for these proposals to progress into concrete projects, access to funding at both an EU and Member State level will be vital.

A recent report commissioned by Industrial Innovation for Competitiveness (i24c) and authored by Element Energy used the case study of a hypothetical industrial cluster in the Port of Rotterdam to assess the current and future funding likely to be available for industrial CCS projects, with the aim of developing a funding pathway to 2030. This short paper aims to highlight the key findings of this work.

The i24c report looks at funding for one industrial cluster in Europe, however, for all Member States with a need for CCS to have access to infrastructure will require multiple clusters. There are five industrial clusters identified for development in the SET-Plan Implementation Plan for CCUS under the Horizon 2020 programme. It is with this in mind that ZEP has assessed the findings of the report.

<u>The key findings from the report include:</u>

- **In the case of Rotterdam, €160m may be enough to fund a low cost first "phase" of an industrial CCS cluster**, which would involve capturing existing waste streams of CO_2 and transporting them via new onshore and offshore pipelines to an existing offshore platform for storage. This would decrease risk and capital cost for "phase two", which would bring in captured CO_2 from more industrial sites, including new pipelines for transport with the aim of increasing to 3 million tonnes of CO_2 a year captured and stored. "Phase two" would cost around €720 million.

- **The infrastructure from these initial phases of development can be extended to enable access to multiple Member States which might not have access to CO_2 storage**. For example in Rotterdam, pipelines could be extended to allow the German Ruhr region access to offshore CO_2 storage. The strategic importance of this has been recognised in the Commission's Trans-European Networks for Energy (TEN-E) initiative which for the first time has introduced a category for Projects of Common Interest (PCIs) for cross- border CO_2 transport.

- **A coordinating body will be needed to develop a CCS cluster.** A CCS cluster would provide a decarbonisation solution to a wide range of industrial emitters. These organisations would be responsible only for the capture part of the CCS chain; transport and storage would need to be developed separately. ZEP has previously outlined how a "market maker" can take responsibility for transport and storage and store the CO_2 captured by emitters on a commercial contract basis.

- **There is currently a significant shortfall in funding is for storage appraisal.** The report recommends a dedicated fund is set up for storage exploration and appraisal in Europe. This would support the action within the SET-Plan Implementation Plan for CCUS to develop a storage atlas for Europe. Access to data on storage potential will have strategic significance for planning CCS deployment in Europe in support of 2050 decarbonisation targets.

- **There is a short term funding gap in EU funds to 2021**. There are currently four main European funding mechanisms that an industrial CCS cluster could draw from; the EU ETS Innovation Fund; Horizon 2020; the Connecting Europe Facility; and EU Structural Funds. Of

these, only Horizon 2020 is available before 2021, meaning there is a short term funding gap which will need to be filled by either Member State or private funds.

- **Access to funding from the ETS Innovation Fund and EU Structural Funds will be crucial.** Horizon 2020 funding is targeted at improving capture technologies, and a limited amount of funding for CO_2 storage appraisal. Funds from the Connecting Europe Facility are reserved for PCIs which in the case of CCS relate to cross-border transport of CO_2. These activities are valuable but will not in themselves enable the development of a CCS cluster. Therefore access to EU Structural Funds and the Innovation Fund will be key to a funding pathway.

- The Innovation Fund will be open to a range of technologies including CCS, CCU and renewables. The fund has the potential to cover 60% of costs of phase 1&2 of a single CCS cluster. However, as funds will be shared between different projects it is not a given that a CCS cluster would receive funding to the level needed. **ZEP supports the recommendation that the Innovation Fund supports a limited number of larger projects which will provide the greatest impact for industrial decarbonisation.**

- **Based on the availability of EU funds, Member State support will be crucial to developing CCS clusters in the 2020s.** In the case of a Rotterdam cluster this could equate to €220m in grant funding pre-construction and €50m/annum operational costs. As it could be possible for multiple Member States to access CO_2 storage through a single cluster, this funding could come from multiple sources. For Member States to plan the CCS deployment required to safeguard their at- risk sectors there needs to be a strong governance framework through the Directive on Governance of the Energy Union that focuses not just on 2030 but 2050 decarbonisation targets.

- **Currently activities related to Annex II of the ETS are excluded from accessing Structural Funds.** This would make a CCS cluster ineligible for funding. However, Member States may be able to apply for funding for these activities as R&I under their Smart Specialisation plans. It is clear that without access to these funds there is a significant gap in the funding pathway laid out, especially if the ambition is to develop more than one CCS cluster in Europe in the 2020s.

- **The EU ETS currently does not provide the price certainty needed to include ETS revenues in financial models**. A government guarantee to top up the ETS price to the EU projected price would overcome this barrier, leading to value of around €1bn in avoided emissions by 2035.

<u>Based on these findings, ZEP recommends the following actions be taken:</u>

1) EU Commission to investigate the value of setting up a dedicated fund for storage appraisal. This is a key enabling action for the strategic planning of CCS clusters in Europe.

2) The ETS Innovation Fund is designed in a way that ensures maximum impact for industrial decarbonisation to 2050, including the ability to fund critical infrastructure projects. In the case of CCS this could be funding for a “market maker” to develop shared CO_2 transport and storage infrastructure as a public good.

3) The Commission reviews the eligibility criteria for the EU Structural Funds, in particular the European Regional Development Fund which supports investments in the low carbon economy. Developing CCS infrastructure for industry is key to long term sustainable development in regions and needs to be seen in this context.

4) A strong Governance framework is put in place to enable Member States to support the development of CCS clusters. As ZEP has noted previously[1] for CCS deployment pathways to be implemented Member States need to have a focus on not just 2030 targets but 2050 targets for decarbonisation. When looking at 2050 it becomes clear CCS is a necessity to meet the Paris Agreement. The 2050 view contained in the proposed Governance Directive is vital to allow for effective planning for decarbonisation.

[1] ZEP Governance paper

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Agenda Item 8.b.I: Network Technology update

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

The Network Technology met on Thursday 19th October in Brussels. The minutes from this meeting are appended as pre-read 8.b.II. The next NWT meeting is expected to take place in February 2018.

The focus of this meeting was on developing a new 2018 work programme for the Network, building on the priorities identified at the ACEC Away Day and AC52 meetings. From these discussions three new TWGs are proposed, with draft terms of reference for two included in the draft forward work programme for 2018 appended as pre-read 8.b.III.

TWG Mission Innovation

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

The Mission Innovation workshop took place on 25 to 29th September 2017 in Houston Texas, with Nils Røkke and Filip Neele representing ZEP and the European Commission on capture and storage, respectively. Ahead of the workshop a narrative and list of recommended topics for panels was submitted, following approval at the AC52 meeting in September. The TWG co-chairs have proposed that the forthcoming Mission Innovation report should contain 2 caveats from the ZEP/European Commission, these are that:

- The emphasis on low TRL work should not lead to the conclusion that CCS is not ready for deployment. The topics proposed in the report are meant to support large-scale CCS, in the timeframe of about 5-10 years.

- The heavy emphasis on utilisation requires a remark that utilisation alone is unlikely to result in CO_2 removal or emission reduction on a scale that is significant for climate mitigation. Opportunities for cross-fertilisation between CCS and CCU should be pursued where possible, as CCU can deliver the support for developing CCS infrastructure.

In October the TWG co-chairs with Wim van der Strict (Arcelor Mittal) presented the Commission with a workshop report (appended as pre-read 8.b.IV), recommending Priority Research Directions for the final Mission Innovation report.

Overview of 2017 activities

Future CCS Technologies

The Future CCS Technologies report was published in January and used as input for SET-Plan Implementation Plan for CCS and CCU and Mission Innovation.

Commercial Scale Feasibility of Clean Hydrogen

The Commercial Scale Feasibility of Clean Hydrogen report was published in April. Conclusions from the report were presented at 9th Trondheim Conference on CO_2 Capture, Transport and Storage in June and the CCSA Technical Working Group meeting in June. Key messages from the report were also presented at the ZEP Clean Hydrogen Workshop, which took place in November at the Commission.

Fast Track CO_2 Transport and Storage for Europe

The Fast Track CO_2 Transport and Storage for Europe report was published in June and has been used as input for SET-Plan Implementation Plan for CCS and CCU and to the H2020 draft work programme. The report conclusions were also presented at the IEA CO_2 transport and storage infrastructure workshop in May.

Input to Horizon 2020 2018/19 draft Work Programme

In January Network Technology co-chairs worked with the Secretariat to develop proposals under the H2020 2018-2020 R&D programme, in a joint submission with EERA, which was sent to DG Research and has been used as input to the SET-Plan TWG 9 draft Implementation Plan. Further input was then provided as the proposals developed.

Input to SET-Plan TWG9 CCS and CCU

Network Technology members attended meetings of the TWG9 and provided input to the Implementation Plan, which was adopted in October.

Input to Mission Innovation Carbon Capture Challenge

A new ZEP TWG Mission Innovation was established to provide input to the Mission Innovation process. Filip Neele and Nils Røkke attended workshops in April, May in Brussels, and September in Houston Texas, representing the European Commission and ZEP.

Meetings

A Network Technology meeting was held on the 19th October at the European Commission in Brussels, which focussed on developing the forward work programme for 2018.

ZEP Network Technology

Minutes: Network Technology meeting 19th October 2017

Attendance

Filip Neele, TNO (NWT co-chair)
Arthur Heberle, Mitsubishi Hitachi Power Systems (NWT co-chair)
Isabelle Czernichowski, BRGM
Kristin Jordal, Sintef
Owain Tucker, Shell (by teleconference)
Eric de Connick, Arcelor Mittal
Rob van der Meer, Heidelberg Cement
Niels Peter Christensen, Gassnova
Marko Maver, Bellona
Ernest Groensmit, LM Consultancies
Wilfried Maas, Shell
Gareth Johnson, SCCS
Peter Zweigel, Statoil
Claude Heller, Air Liquide
Keith Whiriskey, Bellona
Harriet Howe, ZEP Secretariat
Vassilios Kougionas, European Commission

Item 1: Introduction and issues update

Filip Neele (FN) introduced the meeting and provided a short update on Network Technology activities since the last meeting in November 2016. The meeting agenda was adopted unanimously.

There was an invitation for national CCS updates, these included:

The Netherlands- FN updated the meeting on the recent Dutch Government announcements on CCS, noting that this was a clear statement that despite the cancellation of the ROAD project there was still cause for optimism.

The UK- Gareth Johnson (GJ) noted that the UK had also reaffirmed a commitment to CCS in the Clean Growth Strategy, which had been published the previous week and allocates £100 million of funding for CCS R&D.

Norway- Niels Peter Christensen (NPC) provided an update on the recent Norwegian state budget proposals for 2018, which include significant cuts to capture projects, adding that a pitch to reinstate funds in the budget would take place ~May next year.

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Germany- Arthur Heberle (AH) informed the meeting that following the recent German election there was still no stance on CCS. Rob van der Meer (RvdM) provided information on plans for stakeholders from the industrial sector to write to the German Government underling the important value of CCS and CCU for the German energy intensive industry. It was noted that in Germany the focus is orientated towards CCU rather than storage, for which there is strong public resistance due to the perceived environmental and safety risks.

European Commission update- later in the meeting Vassilios Kougionas provided an update on recent DG RTD activities, including a meeting the previous day between ZEP and Patrick Child (Deputy-Director General, DG RTD). At the meeting Patrick Child had communicated that he had been pleased with ZEP's around Mission Innovation and added that there was much interest in the Commission for the planned Clean Hydrogen Workshop. The importance of future FP9 funding for CCS projects was discussed, with initial discussions expected to take place around June 2018.

Item 2: ZEP update

FN provided an update on the Mission Innovation Workshop held in Houston in September, a summary of the workshop was circulated prior to the meeting in the pre-reads.

Owain Tucker (OT) asked whether well bore leakage had been added to the list of Priority Research Directions (PDRs). FN responded that the well integrity panel had produced a PDR covering leakage and that this would be covered further in the report due later this year.

FN reiterated the importance of getting 2 European Commission/ZEP caveats into the report; that actions must be considered in the climate context, and that higher TRL activities are also needed. NPC noted that European Commission/ZEP Mission Innovation activities could be better coordinated with those of EERA, particularly around TRL level recommendations, and offered to put FN in touch with his colleague leading on this work. It was agreed that in a focus on the scale up challenges would be important.

Harriet Howe (HH) provided an update on the SET-Plan TWG9 CCS and CCU, included that the final draft of the Implementation Plan, which had been amended following the announcement on the ROAD project, had been adopted by the European Commission at the end of September. The Implementation Plan will now be presented at the SET-Plan conference at the end of November in Bratislava. A recommendation of the TWG9 was for a Standing Working Group to be established, which could implement actions and monitor progress. The first meeting of the Standing Working Group is scheduled for 30th January 2018, with the plan to meeting twice a year.

HH informed the meeting of the upcoming ZEP Clean Hydrogen Workshop, to be held on the 8th November in Brussels. An invitation to the workshop was extended to NWT members.

Item 3: Enabling onshore CO_2 storage in Europe – H2020 ENOS Project

Isabelle Czernichowski (IC) presented an overview of the ENOS project and the planned work programmes. The focus of much of the discussion was around the public perception aspects of the project. AH asked whether there had been any initial feedback from local people around the

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project, such as through a survey, to analyse public acceptance before and after public involvement (e.g. by public eduction). IC responded that there was experience of open dialogue for projects in Spain and the Netherlands and future work would build on this. It was agreed that there would be value in sharing the feedback on this public research. Wilfried Mass (WM) pointed to activities in Alberta as an example, with the possibility to connect the two local communities virtually.

IC invited NWT members to provide feedback on best practise through the end user team and also to attend the CO_2GeoNet Open Forum taking place next year. HH agreed to circulate this invite alongside the minutes.

It was suggested to consider a positive wording when talking about CCS/CCU: Wordings like “clean industry”, “clean hydrogen”, “clean jobs” might be favourable to be used in future communication.

Item 4: ZEP Energy Intensive Industry and CCU Policy report

RvdM presented an overview of the recently published ZEP report: *Climate solutions for EU industry: interaction between electrification, CO_2 use and CO_2 storage*, including an introduction to the ‘sink factor’ analysis used in the report. RvdM noted that whilst CCU would be important part of the solution for industrial decarbonisation it would only achieve 20% of CO_2 and that there was a risk that attention could be diverted from the need to permanently store CO_2.

There was an in-depth discussion of the sink factor metric used in the report, the figures cited and the boundaries adopted for the analysis, with RvdM adding that further work could be done to refine the boundary conditions with input from the Commission. EdC stated that the report had already created some very serious negative political consequences for CCU (caused severe damage to CCU), especially because of the application of a “sink factor” in the report and that a separate analysis on some of the figures in the report was being planned with 2 academic institutions. EdC stated that the sink factor is wrong and completely misleading because it has questioned the LCA methology and the already published emission default values by JRC. It was shown that a CO2 reduction by a CCU fuel up to more than 60% is possible compared to a conventional process and that in such a case the sink factor of the avoided CO2 emissions is 100%.

Later discussions focused on next steps for the CCU work, particularly around the sink factor. It was agreed that there was a need to categorise some of the different CCU pathways, in addition to CCS and EOR, finding examples of technologies where LCA analysis has already been done. The sink factor analysis could then be attached to best practice ‘test cases’ to illustrate how it works.

EdC added that Arthur Runge Metzer from the Commission has already consulted academics on this issue, with expectation that a piece of work will be published in the spring. This was confirmed by Vassilios Kougionas. It was agreed that the Network should contact the Commission and academics working on this project to determine their objectives for this piece of work. It was also agreed that a terms of reference for a new TWG focusing on the sink factor analysis, which could

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then be presented at the AC53 meeting in December and circulated for NWT members for expressions of interest.

Item 5: Feedback from ACEC Away Day

RvdM provided a short update on actions from the ACEC away day, which took place in July and were summarised in the pre-reads circulated ahead of the meeting. There was agreement with the recommendation that the Network adopt a stronger focus on regions and Member States, rather than just Brussels. An action was taken to invite the newly announced ERA-NET Act projects and the OGCI to present at the next NWT meeting.

Item 4: Network Technology forward work programme

Proposals for the 2018 NWT work programme were circulated ahead of the meeting and were discussed in detail at the meeting. These included the topics:

Working leading on the CCU Policy report

As already outlined under *item 4* of the minutes; an action was taken to produce a terms of reference for this working group to present at the AC53 meeting in December.

Liability in the CCS chain

FN presented slides based on a summary of the background and approach of the proposed TWG. A key question identified was how CO_2 storage liabilities could be effectively managed by developers where 20 year monitoring timescales were required. This should include how business models could be structured in order to reduce commercial party risk and that this piece of work should be developed with input from the Commission and Member States.

Niels Peter Christensen presented additional slides outlining some observations and considerations on the technical aspects of CCS liability (e.g. apparently little impacts on parts within the CCS chain can cause big impacts on the whole CCS chain (e.g. concentration of impurities causes conflicts of interests), different permit authorities are responsible for transportation and for storage, different storage development risk elements like e.g. poor reservoir quality, operator of storage site etc.)

It was suggested that the 2012 ClimateWise report on storage had overstated the level of risk involved. OT noted that progress had been made with the Peterhead project in this area by developing a comprehensive technical understanding of the risk. It was suggested that obtaining the data needed to make detailed calculations or modelling or liabilities would be challenging, however, assessments could be made on orders of magnitude as a starting point. It was agreed that a greater technical underpinning was needed, which could then be translated into language suitable for communicating to investors and insurers.

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It was suggested to discuss risk sharing between a CCS operator and a “Clean H2” applicant, which has nothing to do with CCS.

From these discussions it was agreed that a work item on this topic presented two related but distinct issues: the options available for sharing or allocating risk and liability with a legal and contractual focus, and also a more technical assessment of the storage risks. It was agreed that to cover the former NWT should seek input from members of the NWPE, particularly with regards to legal elements of work planned. It was also suggested to link this topic to ERA-NET projects.
An action was taken to present an updated terms of reference for a new TWG to the AC53 meeting in December.

Options for industrialised regions: CCS/CCU, process reform, linking networks

FN introduced the discussion by suggestion that this topic would partly build on the CCU report discussed earlier. EG added that this would also link to the previous discussions on liability, which would be particularly relevant for the Rotterdam region.

There was a discussion of the role of CCS proposed in the recent IEA ETP report for a below 2 ˚C, as well as the upcoming IPCC report expected to be published in Q1/Q2 2018, the former of which shows a substantial shift in the role of CCS.

It was agreed that a briefing note could be produced to communicate the ZEP position on the level of ambition in these reports. GJ added that this should include an assessment of the realistic timeframe needed to achieve the scale of CCS required to meet targets and what the corresponding CO_2 penalty would be if this was not within the 2050 timeframe outlined in the IEA and IPCC reports. This could then lead to a discussion around what measures needed to address this time lag, for example by adding more BECCS. PZ noted that work had already been done with the IEA on build out rates for CCS for a 2 ˚C scenario, showing that this would be achievable with sufficient incentives in place. Further analysis could be done on the build out rates needed in a below 2 ˚C scenario.

WM noted that this work would add urgency to ZEP messaging and strengthen the existing narrative, with KJ adding that the focus of communications should be on clean industry and urgently delivering the infrastructure needed to achieve this, rather than a simple focus on delivering CCS. An action was taken to present an updated terms of reference for a new TWG to the AC53 meeting in December.

Item 5: NWT next steps

It was agreed that the next meeting would take place in February 2018 to initiate new work programmes approved at the AC53 meeting in December.

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Actions

Action		Owner
1	NPC to send colleagues details to FN for Mission Innovation	NPC & FN
2	HH to circulate invite to ENOS project end user group	HH
3	Invitation to new ERA-NET Act projects and OGCI to present at next NWT meeting	FN/AH/HH
4	Updated terms of reference to be drafted for 3 new TWGs covering CCU, liability in the CCS chain, and the role of CCS in a below 2 degree scenario	FN/AH/HH & NWT members

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ZEP Advisory Council 53

6th December 2017

Agenda Item 8.b.III: NWT draft forward work programme for 2018

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

Draft terms of reference for two of the three TWGs proposed at the NWT meeting in October are presented to the AC53 here for approval, after which they will be circulated to NWT members for expressions of interest before the next NWT meeting, planned for February 2018.

TWG Collaboration across the CCS chain – draft TOR for approval

The push for meeting the emission reduction targets set at the Paris COP in 2016 is gaining momentum, with increasing emphasis being placed on addressing the more difficult sectors of the economy. Lowering the carbon footprint of industrial processes and activities comprising distributed emission sources, such as transportation and domestic and commercial heating, requires substantial new infrastructure, whether it be through CO_2 removal, electrification or new energy carriers (e.g. hydrogen and synthetic fuels). CCS can deliver a cost-effective solution servicing multiple sectors at large scale and is tentatively now being re-examined in European energy policy portfolios.

To make an impact, large-scale deployment of CCS will need to be occurring in Europe by 2030; the countries around the North Sea report plans to store tens of megatonnes annually. These volumes require transport and storage infrastructure that connects multiple sources of CO_2 (capture systems) to multiple injection sites located offshore.

Agreements will be needed to define allocation of liability, performance responsibilities and ownership of the CO_2 between the operators of network elements, i.e., operators of capture facilities, transport providers, and storage operators. While these agreements will have similar characteristics to those in other gas supply and transportation networks, the leakage liability of the storage operator is specific to CCS. Under the EU CCS Directive, which has been transposed into national law in all Member States, the cancellation of EU ETS allowances for permanently stored CO_2 means that a storage operator becomes liable for leakage out of the storage complex against the future price of CO_2 allowances. Commercial and regulatory handling of this unquantifiable and effectively uncapped liability is one of the key issues that need to be resolved for successful deployment of CCS. If it is not, at worst it will prevent the private sector investing and participating in CO_2 storage.

Long-term contingent liabilities arising from market, technological and natural uncertainties are difficult or impossible for the private sector to insure against or to underwrite from balance sheets. Sharing of liabilities between the public and private sector is therefore a model that has arisen in many infrastructure sectors to enable private sector capital to be deployed and organisations to operate facilities for the public good.

Exposure to liabilities in CO_2 storage arises from the natural geological uncertainties of subsurface containment and the technological solutions to manage these uncertainties. Risk is generated from the combination of likelihood and impact of an event arising from these uncertainties. Hence a liability sharing model between public and private entities for CO_2 storage requires an understanding and quantification of uncertainty and risk as well as commercial and policy mechanisms to enable workable contracts between storage operators and various counterparties, including government.

Objectives:

This working group will have two parallel objectives that will be brought together by mid-2018 in a way that is beneficial to the Norwegian full chain CCS project, the Rotterdam Platform, and the two ERA-NET ACT projects, ELEGANCY and ALIGN-CCUS, with their case studies.

The first objective is to understand and estimate the likelihood and impact of a range of events that are specific to CO_2 storage operations. Databases of such events exist in the US, which could provide a starting point. There is little specific experience in Europe related directly to these types of storage events, apart from Sleipner and Snøhvit. However, substantial North Sea petroleum industry experience does exist from which analogues and extrapolations can be used to create expert best estimates. Implications on the level and cost of appropriate monitoring will be formulated where possible, potentially leading to recommendations for updating monitoring requirements.

The second objective is to provide industry and expert support to the two ERA-NET ACT projects ELEGANCY and ALIGN-CCUS. Both these projects are looking into legal and commercial aspects of CCS chains: one with hydrogen production and one with CO_2 utilisation. Of particular note is that the ELEGANCY project will deliver a report on policy-issues, business risks and de-risking instruments by mid-2108. ELEGANCY includes work on how to select different business model options to address public-private risk sharing and a workshop is planned for CCS stakeholders in September 2018 to test identified business models, commercial structures, and cost effective risk mitigation options, including insurance. Case studies in both these projects include the UK industrial clusters, Rotterdam, and Norwegian full chain projects.

Both objectives will lead to outlining the options available for sharing or allocating risk and liability in different organisational models for CCS networks comprising multiple sources and multiple storage sites. It is expected that in due course national CCS infrastructure will be connected across borders; commercial models used in early CCS projects should therefore not impede later expansion and interconnection.

Approach:

- Data collection from North America, Canada, North Sea, and expert assessment for uncertainty and risk quantification;
- The working group membership for Objective 1 should include petroleum operators and other parties with substantial experience of risk quantification for oil and gas, and storage operations;

- The TWG is to liaise with, and advise, two ERA-NET ACT projects: ALIGN-CCUS and ELEGANCY, which will review current ideas about the organisation of CCS in various Member States (relevant countries include UK, Norway and The Netherlands), as well as develop commercial aspects of H_2-CCS and CCUS networked infrastructure (including cross-border);
- The working group membership for Objective 2 will overlap with, and complement, the ERA-NET ACT project consortia.

Membership:

- Potential CCS operators.
- Representatives from the ALIGN-CCUS and ELEGANCY projects.
- Representatives from regional clusters: e.g., Tees Valley, Rotterdam, Norwegian CCS initiative.
- The group will seek a diversity of expertise in addition to the two ERA-NET consortia, including geoscience, reservoir engineering, legal (covering cross-border issues) and commercial (including finance and insurance) experts.

Interested Parties:

- TAQA (Chris Gittins)
- Shell (Owain Tucker, Wilfried Maas)
- Queen Mary University London (Raphael Heffron – Professor of Law)
- Bellona (Marko Maver)

The AC are invited to approve the draft terms of reference

TWG Role of CCS in a below 2 ˚C scenarios – draft TOR for approval

The contribution of CCS in integrated assessment models to future deeper climate change mitigation and the economic value of CCS from comparison of models with and without CCS have not resonated such that CCS deployment build out is supported by a wide group of stakeholders.

It is suggested that recognition of the broader value of CCS (long-term employment, energy access and security, investment in energy intensive industries, hydrogen as alternative low carbon energy carrier etc.) may contribute to a wider support for CCS. Furthermore, the role of CCS proposed in the recent IEA ETP 2017 report for a below 2 ˚C, as well as the upcoming IPCC 1.5 deg C report - expected to be published in Q1/Q2 2018 - show a substantial shift in the role and value of CCS, amongst other reflecting recent Energy Transition developments.

Objectives

- The TWG will produce a briefing note communicating the ZEP position on the changing role of CCS for deeper and earlier decarbonisation scenarios, the development requirements of

CCS to contribute to these pathways and a broader description and potential quantification of value of CCS beyond economics only.

- This should lead on from previous work on the build out scenarios needed to achieve 2 ˚C targets.

Approach

- Inventory and description of the changing role of CCS with specific focus to the EU
- Assessment of urgency of early CCS deployment (in the EU) to realise the CCS build out rate requirements of below 2 deg C scenarios, specifically for BECCS
- Broader articulation of value of CCS, where possible with quantification of jobs, energy access, balance of trade, carbon imports upon retirement of energy intensive industries, etc.
- Communicate the ZEP position on the level of CCS ambition in the IEA ETP report
- Incorporate the key recommendations into ZEP messaging

Membership:

- To deliver The ZEP interim task force needs to build on contributions from NetWork technology, Market Economics and Communications workgroups. Specifically contributions from the European Commission and Member States and Regional stakeholders (like the Port of Rotterdam) will support credible outcomes. Contact with IPCC contributors/lead authors is needed for relevant up to date information (see below)
- The TWG can collaborate with ongoing “Role of CCS in Scenarios” and “Value of CCS” activities in IEAGHG and OGCI and can consider a joint publication or focus on a EU (countries) specific ZEP study which can take inputs from these activities.

Access to IPCC 1.5 deg C:

- A complication for the TWG will be the access of CCS information in the IPCC 1.5 deg C report as this has been shared with reviewers on a “do not distribute” basis and is expected to develop with upcoming drafts.

CCS and Sustainable development goals exclusion:

- The Paris accord highlights in Article 6 the aspiration “to promote the mitigation of greenhouse gas emissions while fostering sustainable development” . As such the contributions of CCS to and possible tensions with the 17 Sustainable Development Goals have attracted attention (amongst others in the IPCC 1.5deg C report). Though relevant, it is proposed not to include this in the proposed TWG where it could be a focus of future ZEP studies

Proposed TWG: CCU and Sink Factor Methodology – for discussion

Building on the work of the ZEP report: Climate solutions for EU industry: interaction between electrification, CO_2 use and CO_2 storage the proposed TWG will focus on clarifying the sink factor

Approach:

- Refinement of the sink factor analysis presented in the ZEP CCU report, linking sink factor with LCA
- Categorisation of different CCU pathways, as well as CCS and EOR
- Analysis of existing test cases for the different CCU pathways, and an assessment of the sink factor and CO_2 emissions avoided compared to conventional processes with consideration of proper boundaries

Membership:

- Energy intensive industries and organisations who can contribute to 'test cases' to illustrate the sink factor methodology presented
- Liaise with academics and European Commission already conducting related work

Draft terms of reference for the proposed TWG will be submitted for approval at the AC54 meeting in March.

Mission Innovation workshop

Houston TX, Sep 26-28, 2017

Filip Neele (TNO), Nils Røkke (SINTEF), Wim van der Stricht (ArcelorMittal)
Workshop report, Oct 30, 2017

1. Mission Innovation

Mission Innovation[1] (MI) is a global initiative of 23 signatories (22 countries, and the European Commission) to stimulate energy innovation. MI was announced at the Paris climate summit (COP21), in November 2015. In the area of energy innovation 7 challenges[2] were defined that cover areas such as smart grids and sustainable biofuels. The MI steering group is now chaired by the European Commission. Challenge 3, the carbon capture innovation challenge, has the objective "to enable near-zero CO_2 emissions from power plants and carbon intensive industries". The goal of the Carbon Capture Innovation Challenge is twofold: first, to identify and prioritize breakthrough technologies; and second, to recommend research, development, and demonstration (RD&D) pathways and collaboration mechanisms. The challenge on carbon capture will define an R&D agenda for the next five or ten years for MI through a number of Priority Research Direction (PRDs). The challenge is led by the USA and Saudi Arabia.

Breakthrough technologies were formulated in a workshop held in Houston, Texas, in September 2017. The CCUS challenge was divided into focus areas: capture, utilisation, storage and cross-cutting topics. For the focus areas of capture, utilization and storage four panels were defined that each formulated two priority research directions. The cross-cutting area chose to use a different partition and produced three priority research directions. These are all discussed below. A formal MI report describing and explaining these research directions will be available early 2018.

MI targets at low technological readiness levels (TRL), levels 1-3 or 4, with the aim to improve carbon capture, utilisation and storage technologies. MI is to complement global organisations that support higher TRL developments, such as CSLF[3]. Towards the end of the workshop, the focus on low TRL was somewhat relaxed and it was agreed that higher TRL work should be included in future international cooperation that is to come out of MI.

2. EU position

Large-scale CCS projects have not yet developed in Europe beyond the two mature storage projects (Sleipner and Snøhvit) in Norway. This is in spite of a number of funding mechanisms that have been available with varying complexity. As a result, there is a clear and continuing need for CCS projects that demonstrate the feasibility of CCS, that help bring down the cost of CCS and that initiate CCS infrastructure. CCUS is indispensable to reach climate targets for Europe and the world, to decarbonise our industry, power, to provide sustainable hydrogen and climate positive solutions[4]. Further support of ongoing and new CCU demonstration projects is also needed to further be a driver for CCS development. Recent new H2020 funding opportunities are aimed at TRLs in the range 4-7.

[1] http://mission-innovation.net/
[2] http://mission-innovation.net/our-work/innovation-challenges/
[3] https://www.cslforum.org/cslf/
[4] Also called carbon negative solutions- like bioccs

The focus on pilots, demonstration and commercial-scale projects is clearly reflected in the SET-PLAN TWG9 CCS and CCU Implementation Plan, which lists ten high-priority targets, most of which aim at developing pilots and demonstrations of capture, transport and storage.

It is to be noted that the focus on high-TRL activities in Europe does not rule out the funding of low-TRL work. The development of pilots or demonstration projects will require developments also at low TRL, because some methodologies or technologies are being developed or deployed for the first time and to continue the efforts to bring down costs and increase efficiency.

3. MI workshop and preliminary results

The result of the workshop is the list of priority research directions (PRDs) that were formulated for each of the panels in each focus area.

3.1 Capture

The table below list the capture PRDs. The capture area was divided into four panels which is reflected in the table. Most of these topics have been covered or are covered in past and present framework programme calls. However, this does not mean that they are topics which are exhausted, significant improvements can still be made. Solvents and sorbents are the most mature technologies – there seems to be a consensus on how to gradually make these better. Membranes are so diverse that there is still good scope for new breakthroughs depending on the application. The combustion and other technologies are less covered in EU programmes. The focus on supercritical oxy-fuel cycles and what actually happens within these cycles has great interest as they promise efficiencies comparable to unabated NGCC plants. Thus, there is scope for definition of low TRL research in the pre-competitive area which can be suited for international collaboration. Zero emission hydrogen production with CCS has hitherto not been covered in any R&D programmes we know about.

Capture panel	**Priority Research Directions**	**Comment**
Panel C1 - Solvents	- Designing High Performing Solvents for CO_2 Capture - Creating Environmentally Friendly Solvent Processes for CO_2 Capture	Topic of many EU funded projects in FP6, 7 and H2020. Also, partially covered in some projects in ACT
Panel C2- Sorbents and Looping systems	- Designing Tailor-made Sorbent Materials - Integrating Sorbent Materials and Processes	Also a topic at higher TRL in past and ongoing EU projects.
Panel C3- Membranes	- Understanding of transport phenomena in membrane materials - Architecturing membrane systems enabling cost-effective novel process designs	Same comments as above. Maturity very dependent on membrane type and application.
Panel C4 – Combustion and other technologies	- Catapulting Combustion Into The Future - Developing alternative lower-cost technologies for hydrogen production from fossil fuels with CO_2 capture through effective combinations of combined reforming and combustion	At present less focused in EU programmes, Dynamis looked into this in FP6, ENCAP and Decarbit also FP7. ACT covers system approach to H_2/CCS.

3.2 Utilisation

The table below lists the utilisation-related PRDs. The research directives proposed in the PRD's were fairly well aligned with the SET-PLAN TWG9 CCS and CCU Implementation Plan, in particular with R&I Activity 7: CCU Action. The following topics have been addressed in the respective PRD's:

- Enabling competitive CO_2 valorisation (PRD U4.1, U1.1, U2.1, U2.2)
- Carbonation of industrial wastes with CO2 (PRD U3.1, U3.2)
- Transformation of CO_2 and renewable energy into chemicals and fuels (power-to-chemicals and fuels via syngas) (PRD U4.1, U1.1, U2.1)
- Production of polymers from CO2 (PRD U2.2)
- Advanced solar chemicals and fuels from CO_2: direct utilisation or solar energy for CO_2 valorisation (PRD U1.1, U4.1)

The 'Biological Conversion of CO_2' panel discussion was focussed on research of microorganisms that can convert carbon dioxide with the power of the sun or with chemical reducing power from waste or renewable resources. There were two thematic groups of researchers represented in the panel:

- Photosynthetic (algae) section: Algae – biomass utilization research using photosynthetic energy (large group)
- Chemolithotrophic: conversion of CO_2 using micro-organisms (bacteria) with renewable power

The targeted TRL levels are lower compared to the SET-PLAN, but in general the topics are relevant in the European context since they are being studied in ongoing CCU initiatives already and can be an extension/diversification of added value.

Utilisation panel	**Priority Research Directions**	**Comment**
Thermochemical conversion	-Valorizing CO_2 by breakthrough catalytic transformation into fuels and chemicals - Creating new routes to carbon-based functional materials from CO_2	Partially addressed by H2020 projects
Electrochemical and photochemical CO_2 conversion	- designing and controlling molecular-scale interactions for electrochemical and photochemical CO_2 conversion - Harnessing multiscale phenomena for high performance electrochemical end photochemical transformation of CO_2	Partially addressed by H2020 projects
CO_2 conversion to solid carbonates	- Unlocking carbon mineralization – opportunities from complexity -tailoring carbon mineralization – locking carbon products	
Biological conversion of CO_2	- Accelerating biological activation for feeds, fuels and chemicals	Partially addressed by H2020 projects

3.3 Storage

The table below lists the storage-related PRDs. While available storage technology allows the development of large-scale storage projects, proven by the ongoing projects in Norway as well as by the ready-to-go but cancelled projects in the UK and The Netherlands, the storage PRDs address areas that are highly relevant for the first CCS projects. Taking up topics such as pressure limit definition, conformance monitoring and well integrity during the development of operational projects will support future storage operators.

All of the PRDs in the table below are relevant for Europe. As indicated in the table, some of the topics are already being taken up in ongoing projects, proving that low-TRL topics are also relevant in the European context. Until the start of operations of first CCS pilots or demonstration projects, R&D projects can take up the PRDs and provide guidance, methodologies or techniques to be used by the first storage operator or operators.

Storage panel	**Priority Research Directions**	**Comment**
Capacity and injectivity	- Advancing multi-physics and multi-scale fluid flow to achieve gigatonne capacity - Improved definition of dynamic pressure limits - Optimal injectivity of CO_2 by control of near-well environment	Partly addressed by ERA-NET ACT projects
Monitoring, verification and performance metrics	- Smart conformance monitoring - Advanced techniques to locate and evaluate anomalies	Partly addressed by ERA-NET ACT projects
Induced seismicity	- Enhanced characterisation of fault and fracture systems - Next generation seismic risk forecasting	
Well integrity	- Locating, evaluating and remediating existing and abandoned wells - Establishing, demonstrating and forecasting well integrity	

3.4 Cross-cutting topics

Modelling tools including multiscale analysis, as well as enhanced use of data analytics and machine learning, can accelerate development of new materials, and identification and rapid deployment of advantaged, integrated, or intensified process systems. Use of systems, techno-economic, and life-cycle as well as social systems analyses to select best options for development is a key role for guidance of CCUS research efforts, yet requires funding and support in order to improve metrics, benchmarks, and the tools themselves. Basic research in fundamentals of CO_2 properties, separation, transport and reaction as well as development of advanced sensors and spectroscopic or other in situ analytical tools for characterization, are essential for rapid advancement of the science which underpins CCUS opportunities. Integrated or intensified systems which optimize capture together with utilization or storage are also considered under crosscutting themes.

This area was not covered by the EU delegates but there were people circulating from the cross-cutting area in all the panels – thus some feedback was provided. The following table shows the various areas covered. A separate report will be finished for each of the PRDs. Many of the topics addressed have been subject to R&D in Europe as well – but the social dimension to CCUS is not that well covered. In the search for topics that could be suited for low-TRL pre-competitive research there is ample space in thermo-physical properties of CO_2 – impurities mixes, AI and CCS, modelling and platforms for modelling and consistent LCA tools/frameworks.

Cross cutting panel	Priority Research Directions	Comment
Addressing cross-domain basic science and engineering R&D needs for intensified carbon capture, purification, transport, utilization, and storage	- Integrating Experiments, Simulation, and Machine Learning across Multiple Length Scales to Guide Materials Discovery and Process Development in CCUS - Developing tools to integrate life-cycle techno-economic, environmental and social considerations to guide Technology Portfolio Optimization - Incorporating Social Aspects into Decision-Making - Addressing cross-domain basic science and engineering R&D needs for intensified carbon capture, purification, transport, utilization, and storage	The cross-cutting report is somewhat different to the other reports and has a granulation higher than the PRDs by discussing challenges.

4. Way forward

The MI report that is being developed is likely to play an important role in the definition of low-TRL activities in the coming period. The relevance for the EU of the PRDs formulated during the MI workshop is highlighted above, for each of the MI focus areas.

Two comments are made here. Firstly, there was a strong delegation representing the utilisation community at the workshop, as an illustration of the growing importance of CCU in the discussions around CO_2 capture. While CCU can be a driver for CO_2 capture activities, its limited role in climate mitigation must be clearly understood. Utilisation is unlikely to result in (permanent or semi-permanent) CO_2 removal or emission reduction on a large scale for climate mitigation. MI was initiated prior to the Paris COP, with the goal to support reaching emission reduction targets. Opportunities for cross-fertilisation between CCS and CCU should be pursued where possible, as CCU can deliver the support for developing CCS infrastructure or complement it in cases were CCS is not feasible (remote locations, small CO_2 emission volumes, etc.).

Secondly, the focus on low TRL should not distract from the need for pilots, demonstrations and commercial-scale projects in Europe. In other words, the emphasis on low TRL work should not lead to the conclusion that CCS is not ready for deployment. The topics proposed in the report are meant to support large-scale CCS by decreasing cost and increasing efficiency, in the timeframe of about 5-10 years. Support for CCS to emerge from the current valley of death remains top priority.

During the MI workshop, discussions revolved around setting up international cooperation that address one or more of the MI PRDs. The current ERA-NET ACT framework could be used, building out from its current set-up to include more countries and perhaps a wider set of topics. It is clear that MI challenge #3 needs an implementation plan and that a fast track needs to be identified to be able to leverage funding in the area to be a global initiative.

As mentioned above, during the period of developing pilots or demonstration projects, R&D projects are likely to address some of the PRDs.

It is key that MI takes on board the recommendations and the guidance on PRDs into an implementation plan as the placeholder for achieving a doubling of the R&D effort in clean energy already by 2021. For Europe this will have to be linked to the CCUS implementation plan of the SET Plan and the vehicles at hand in European and MS/AC funding mechanisms. The lower TRL scale means

that there could be space for pre-competitive and more basic research collaboration among the MI countries. One possibility could be to shortlist topics of that nature and then match that with existing or fast implementation R&I mechanisms. In H2020 there is at present the possibility to pursue some of the items listed in the tables above. In general all calls should be open for MI collaboration within CCUS (NZE calls); presently only some calls mention MI explicitly.