ZEP Advisory Council 50

22nd March 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. TWG Fast Track Transport and Storage report

A final draft version of the report; Fast Track CO_2 Transport and Storage for Europe is appended to this paper.

Members of the Advisory Council are invited to approve the report.

9.c.i ZEP/EERA input to the Horizon 2020 Energy Work Programme 2018/2019

Appended to this paper is the joint ZEP/EERA input to the Future of the Horizon 2020 Energy Work Programme from January 2017.

9.c.ii Horizon 2020 draft Energy Work Programme 2018/2019- Comparison with the ZEP/EERA input

Appended to this paper is an overview of differences between the ZEP/EERA input the Horizon 2020 Work Programme and draft proposals.

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ZEP Advisory Council 50

22nd March 2017

Agenda Item 9.a: Network Technology update

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

The last meeting of the ZEP Network Technology (NWT) took place on Friday 4th November in Brussels and the agenda for this meeting is available on the ZEP website[1].

At the previous meeting of the Advisory Council (AC) in December, reports by the Temporary Working Groups (TWGs); Future CCS Technologies and Clean Hydrogen were approved. Also approved at the December AC meeting were the key conclusions from the report by the TWG Fast Track Transport and Storage. The TWG have now completed a final draft version of this report (appended as pre-read 9.b), which the AC are invited to approved.

In January Network Technology co-chairs worked with the Secretariat to develop proposals under the Horizon 2020 Energy Work Programme for 2018/19, in a joint submission with EERA (appended here as pre-read 9.c.i). This was sent to DG Research and has been used as input to the SET-Plan TWG9 CCUS draft Implementation Plan. The Commission has now provided the Secretariat with a set of draft activities being considered for Horizon 2020. In its current iteration there are a number of discrepancies between activities under the draft Work Programme and those proposed by ZEP and EERA (summarised in pre-read 9.c.ii). Graeme Sweeney and Marie Bysveen have written to the Commission providing feedback on these proposals (see pre-read 1.c.ii), and with Network co-chairs and the Secretariat will provide further input to the Commission before the final work programme is published later in 2017.

The next Network Technology meeting will be held in early May in Brussels, with the date and venue to be confirmed in due course. The focus of discussions at this meeting will be the development of a forward work plan, building on the recommendations of the March Advisory Council meeting, in addition to how the Network can support the work of the newly established TWG Energy Intensive Industries / CCU Policy, and continue to provide input to the SET-Plan TWG 9 on CCUS, as part of ZEP's input to this process.

Temporary Working Group – Future CCS Technologies

Co-chairs: Markus Wolf (GE), Zoe Kapetaki (GCCSI), Ton Wildenborg (TNO)

A final draft version of the TWG report: *Future CCS Technologies* was presented at the December meeting of the AC, where it was approved.

[1] http://www.zeroemissionsplatform.eu/technology.html

Dissemination and related engagement activities for the report are ongoing, in line with proposals outlined by Weber Shandwick and the ZEP External Relations Group (ERG). The report was published in mid-January on the ZEP website, and promoted through the ZEP newsletter and Twitter platform. Key conclusions from report have also been used as input for the joint ZEP/EERA submission to the future Horizon 2020 programme and SET-Plan TWG9 on CCUS. Further engagement activities are be planned with the specific objective of providing input to Member States and research councils.

Temporary Working Group – Fast Track T&S

Co-chairs: Chris Gittins (TAQA), Ward Goldthorpe (Crown Estate)

The TWG have now completed a final draft of the report; *Fast Track CO_2 Transport and Storage for Europe* (appended to this document as pre-read 9.b), which the AC are invited to approve. The report sets out a framework, by which readiness for CCS may be assessed against 8 key criteria; open access to information, appraisal activity, strategic planning, market structure, regulation, incentives, politics, and communication, and technology.

An executive summary of the report, outlining its key recommendations, was presented and approved at the December AC meeting, and have already been used as input for the SET-Plan TWG9.

Members of the Advisory Council are invited to approve the report Fast Track CO_2 Transport and Storage for Europe.

Temporary Working Group – Clean Hydrogen

Chair: Claude Heller (Air Liquide)

A final draft version of the TWG report: *Commercial Scale Feasibility of Clean Hydrogen* was presented at the December AC meeting, where it was approved. For final publication it was recommended that a number of the images within the report be amended to improve clarity, which has now been completed.

Further feedback from this meeting involved the use of the term ‘green hydrogen’, referring to hydrogen produced through electrolysis with renewable energy. There was some concern that this term implied a preferred method for producing hydrogen. Following discussions with the TWG chair and ERG it was decided that the term ‘green hydrogen’ would be replaced with ‘hydrogen produced from electrolysis using renewable electricity’. The report has now been amended with these recommendations and publication of the report is planned for Q2 2017. At this time the ERG currently expects to hold a number of briefings with key journalists. In addition, the report will be promoted on social media, and the TWG may look to organise a technical workshop on CCS and hydrogen.

A number of the report’s conclusions have already been used as input for the joint ZEP/EERA submission to the future Horizon 2020 programme. An abstract outlining the report’s key

conclusions has also been submitted for presentation at the 9th Trondheim Conference on CO_2 Capture, Transport and Storage shortly, which will take place on 12-14th June.

Zep
Zero emissions platform

Fast Track CO_2 Transport and Storage for Europe

(Draft report, February 2017)

Executive Summary

CO_2 transport networks and permanent CO_2 storage will be required in Europe to deeply decarbonise industry, produce low cost hydrogen, to remove CO_2 from the atmosphere, and decarbonise any remaining fossil electricity generation. All of these activities will be needed to reach the 'well-below' 2 °C target of COP21. Indeed, reaching the 1.5 °C and 2 °C warming targets requires deep decarbonisation at all possible sources as rapidly as possible, in addition to the need to remove CO_2 from the atmosphere. A potentially disastrous 4 °C warming will be the result of current INDCs utilising solely efficiency, process changes, renewable energy, and electro-mobility.

The UN's Intergovernmental Panel on Climate Change (IPCC) stated in its 2014 synthesis report that, in the absence of CCS, the global cost of the mitigation measures necessary to keep atmospheric CO_2 concentration levels by 2100 to 450ppm will increase by 138%. It continued: *"Many models cannot reach 450ppm CO_2-equivalent concentration by 2100 in the absence of carbon capture and storage (CCS)"*.

Carbon Capture and Storage (CCS), a key climate change mitigation technology, is one of the ten actions of the European Strategic Energy Technology Plan (SET-Plan). The potential for CCS to significantly reduce the cost of decarbonisation is widely recognised in several markets. It requires major investment in infrastructure and confidence that a reward for decarbonisation will be forthcoming. Building a completely new network based service industry to maturity will take time, investment, commitment from all stakeholders, and clear direction from Governments. Ensuring the delivery of a public/private success story for CCS will require consistent government action, committed industry cooperation, shared best practise and active support of NGO's on behalf of a responsible society.

This report underlines the urgency for coordinated action now. The process from identification of an eligible geological storage site to first CO_2 injection involves a range of timeframes, always including several investment years prior to injection operations. A well-characterised pressure-depleted gas field is expected to take less time to appraise, permit, design and construct, than the same process for a deep saline aquifer, which could take ten years or more. However, there are underground structures that could be permitted and converted to CO_2 injection in less than ten years – e.g. already appraised aquifers, and a number of depleted oil and gas fields. A snowballing effect should take place where the permitting and developing of one store makes permitting neighbouring stores much easier. Timelines will shorten further once the initial enabling infrastructure is in place, with the process of connecting storage sites and extending infrastructure back to multiple sources and regions becoming a 'production line'. There will still be storage sites and infrastructure elements that will take longer to appraise and develop than others, but the system will become mature enough to cope with a range of delivery times.

The most immediate need is to identify the first few enabling pieces of infrastructure that can quickly be expanded and extended. This has already been done over the last ten years for a number of prospective projects (Rotterdam/P18, White Rose/Endurance, Grangemouth/Goldeneye, and in Norway) but delivery has not been forthcoming. The EU and its Member States have also invested innovation funding and research time over many years, and now have the collective capability to act to deliver this infrastructure.

These projects must be kick started urgently through substantial public funding by governments. These will be flagship projects for Europe and funds must be committed, without risk of removal, such as happened with the cancellation of the UK CCS Commercialisation Programme in 2015. Clear communication and the establishment of long-term policy frameworks by Member State Governments will help to underpin investor confidence, facilitating the establishment of public/private partnerships. Furthermore, the communication from Governments to the general public will help to answer questions on how and why CCS is needed in the context of National and EU mandated climate change targets, as well as communicating the accompanying socio-economic benefits, such as job creation.

An open information flow should allow every Member State to play a role and benefit from the information generated at various stages of each project and shared on a non-discriminatory basis. Organisations and information sharing platforms already exist to enable this, with information covering technology, materials, manpower, expertise, data and analysis, permitting process, commissioning, operations and maintenance. If properly leveraged this information sharing may enable time saving short cuts particularly for first expansions and extensions.

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Terms and Abbreviations

C	Capture
T	Transport
S	Storage
EC	European Commission
MS	Member States
Market Makers	As defined in the ZEP Executable Plan[1]
PCI	Project of Common Interest
ETS	Emissions Trading Scheme
FID	Final Investment Decision
E&P	Exploration and Production
DMO	Data Management Organisation
EOR	Enhanced Oil Recovery
NDO	National Development Organisation
RDO	Regional Development Organisation
FEED	Front End Engineering and Design

[1] ZEP Executable Plan for CCS in Europe (Zero Emissions Platform, 2015)

8 key activities and kick-start actions:

This report identifies 8 key activities, requiring consistent and concurrent progress, including a number of immediate actions for 2017. This will require the European Commission and 'first mover' Member States (MSs) to establish a co-ordination, governance and delivery framework to deploy the "bow wave" of early projects and enabling infrastructure utilising public/private partnerships and organisations that can undertake market making functions. This report identifies 8 key activities, requiring consistent and concurrent progress, including a number of immediate actions for 2017.

1. **Open access to information**: All high potential permanent storage locations in first mover MSs need to be identified. EC and these MSs to ensure processes/regulations for access to relevant data. MSs to establish or mandate responsible national organisations to gather and analyse licence-holder data in full cooperation with license-holders in order to evaluate and rank all storage structures. Respect confidentiality of data to a practical and reasonable extent. Regularly and systematically evaluating CO_2 storage potential will become an obligation for all licence-holders.

2. **Storage appraisal**: High ranking structures need full evaluation and certification. Evaluation is conducted by licence-holder in partnership with mandated existing or new national organisation using EC standards and methods (to be defined). Licence-holders declare intent to store or waive their rights. Combination of certification and intent to store wins mothballing support where necessary.

3. **Strategic planning:** EC establish a coalition of CCS first mover Member States. Formalise complementary planning responsibilities at regional, national, interregional and EC levels aligned with 2050 decarbonisation targets and aggregated national roadmaps. Use these to support PCI (Projects of Common Interest) applications for example.

4. **Market Structure:** National organisations need to be mandated to execute the plans and to fulfil CO_2 transport, hub and storage duties from the delivery points at sites capturing CO_2 up to and including the storage locations as market makers. In 2017 a working group is required comprising EC, first mover MSs and the finance sector (e.g. EIB) to deliver regulation, financial support and governance mechanisms to underpin these entities.

5. **Regulation:** Build on recent reviews of the CCS and ETS Directives to identify existing policy barriers to the delivery of CCS infrastructure. Update policy and law to accelerate development of CCS and any complementary technologies and initiatives. These legal and policy updates should enshrine the actions identified here under the activities: Market Structure, Strategic Planning, Storage Appraisal, and Incentives.

6. **Incentives:** Member States to substantially fund the first flagship projects to meet the 'first injection by 2020' date (initially planned for 2015). Establish a working group comprising EC and first mover MSs to establish or adapt existing funding mechanisms for: pre-FID storage appraisal, transport and PCI feasibility, and industrial cluster development. Continue to review

and evaluate EU financial support mechanisms which may facilitate the delivery of CCS infrastructure.

7. **Politics and communication:** EC and MSs to communicate a single clear message, supported by industry and public authorities regarding the imperative and unavoidable role of CCS in achieving National and International climate obligations, including the Paris Agreement. The message underpins policy and justifies targets and expectations for fuel burning power generation, industries, households and transport and confirms the role of CCS alongside renewables.

8. **Technology:** Capture, transport, injection and storage technologies must be shared and optimised. EC and MSs set up information and technology sharing platforms and acceleration initiatives. By sharing human, physical, and IT resources the costs of CCS infrastructure may be reduced by introducing 'economies of scale'.

This report will examine each of these activities, identify actions, and propose a framework of responsibility by identifying opportunities for removing barriers to progress. It builds on the ongoing work of the TWG Transport & Storage and the TWG Policy and Financing, in addition to the work of the UK Cost Reduction Task Force[2], and current ZEP work on hubs and clusters.

Delay in immediately progressing the development of CO_2 storage will have long reaching effects on the speed, cost and viability of economy wide deep decarbonisation in line with the 2°C goal of the Paris agreement. CO_2 storage and the transport networks that connect emitters cannot be realised overnight. CO_2 storage development takes time, with exploration, characterisation and development all required to provide safe permanent CO_2 stores. A steady build out rate is necessary to build up the skills and services sectors necessary to construct and maintain the required number CO_2 storage sites. Delay will leave insufficient time for not only the required CO_2 storage development but also CO_2 transport networks to connect distant CO_2 sources – endangering continued industrial production and employment or restricting decarbonisation ambition.

Delay and the resulting limited access to CO_2 transport and storage will have direct and long term implications, such as reduced decarbonisation optionality and increased risk of non-delivery of decarbonisation. Strategic industries such as steel manufacture and their employees may be left without feasible decarbonisation avenues, undermining national and European political support for climate ambition. The results being a global warming beyond the 2°C target or an even greater reliance on atmospheric CO_2 removal, a process that also relies on CO_2 transport and storage as Bio-CCS or aircapture-CCS is expected to be the major negative emissions contributor.

Action now on CO_2 storage development allows for a steady build out pace of CO_2 storage sites and CO_2 transport and CO_2 capture, lowering costs and increasing success rates for infrastructure planning and public engagement. Immediate deployment gives a significant upside of "*rapid decarbonisation insurance potential*" – in the case of increasingly adverse climate change, CO_2 capture deployment can be accelerated more rapidly as infrastructure is established.

[2] The potential for reducing the costs of CCS in the UK (UK Government, 2013)

First movers will become the foundations of a CO_2 network, benefiting from inward investment, technology, and service development along with the creation of a new export sector. The operation of a CO_2 storage industry in a country or offshore territory would be a potential export sector, taking CO_2 from emitting sectors lacking local CO_2 storage capacity. Access to CO_2 storage will increase certainty for investment and redevelopment in local carbon intensive industries, retaining the social licence for these sectors in a deeply decarbonised future. The presence of accessible CO_2 transport and storage will be a requirement in attracting emerging low carbon investments such as decarbonised hydrogen production.

Regions with aging and declining hydrocarbon extraction industries can redevelop with a new CO2 storage economy, retaining high skilled jobs and services sectors by building on existing infrastructure and industries. Early movers in planning and development of CO_2 storage will benefit from the preservation and reusing existing fossil infrastructure, such as gas pipelines. As CO_2 storage will be required to grow into a global industry. The IEA estimates that by 2050, ≈70% of CO2 will be captured and stored in non-OECD countries. The development of CO2 storage technologies in the Europe will give local companies access to a new global market.

1 Open Access to Information (S)

All potential storage sites need to be evaluated and ranked, with oil and gas Licence-holders best placed to conduct initial evaluations, including the screening and ranking of all structures lying within their exploitation and production (E&P) license responsibilities. Where licence-holders decline or lack the expertise to conduct the evaluations a national Data Management Organisation (DMO) or a nominated qualified organisation working for the DMO can complete these preliminary tasks. This same body can also conduct preliminary screening of structures lying outside licensed areas. The obligation to assess CO_2 storage potential in every structure will become part of a licence-holder's submissions for licenses, development plans, production plans and decommissioning plans, and will also cover all non-producing, undeveloped and non-hydrocarbon bearing structures within licenses.

Some of the data owned by licence-holders is confidential and has commercial value, some is shared with existing authorities, and in some countries much of the data is already in the public domain. Confidential status must be respected, but practical solutions to provide adequate access to relevant data must be adopted in order to allow the storage market to develop. Much of the data originates from commercial hydrocarbon E&P activity, and thus has commercial value requiring protection. Therefore, the extent of 'open access' needs clarification; whether this will include the general public, approved project developers only, or access through a staged access regime dependant on defined user categories. Full assessment (see Activity 2 - Storage Appraisal) of high ranking structures requires access to more data. For confidential data with commercial value special arrangements are needed to regulate disclosure, with a consistent format for data and platform access and sharing (see Activity 5- Regulation). As structures approach the end of their producing life, or as licenses approach expiry dates the level of commercial value, and hence inherent confidentiality of the associated data is likely to decline. Here, licence-holders could be required to provide increasing amounts of confidential data a few years before production or use of the structure is scheduled to cease, or before a CO_2-EOR activity in the license area is due to start.

Country by country, the establishment or recognition of a DMO is a priority decision, including its form and evolution, or merger into an eventual national or interregional CCS infrastructure development organisation (NDO or RDO). National bodies already exist, responsible for managing subsurface geological and hydrocarbon production data, and for making this publicly available. The function of providing open access or staged access could thus be integrated with already existing functions for the hydrocarbon sector (and emissions registration). Alternatively, new organisations could be launched with a dedicated data and information management function, producing data and reports to be used by an NDO/RDO, project developers, investors and governments for developing and monitoring emission reduction policies and instruments. Rules are needed to establish best practise on a country by country basis with consistency achieved through adoption of standard data collection, evaluation, storage and access practices. Funding of DMOs should be of public or mixed public-private origin. These national bodies are accountable to the national governmental authorities and are advised by an industrial end user group.

MSs are to develop living T&S plans or roadmaps, including lists of high-ranking potential storage sites, based on initial, high-level, standardised risk assessments ('high-ranking' here refers to the capacity, complexity, reliability and estimated risk. Aspects like location or proximity to CO_2 sources are not part of the initial evaluation by licence-holders or the coordinating body. It is up to MSs in

their plans and roadmaps, and subsequently T&S developers to consider such issues to decide which sites in the list are the best to develop first). The screening and ranking of storage prospects at various levels of confidence (see Activity 2- Storage Appraisal for advanced evaluation) is to be executed at a national level by the DMO with standardized screening and ranking methods. The UK has demonstrated this approach with storage portfolios developed by the British Geological Survey for The Crown Estate and by Pale Blue Dot for the (then) Department of Energy and Climate Change. A summary of the actions required under Activity 1 are listed in Table 1.

Table 1, Open Access to Information (S): Proposed actions under Activity 1

Action	Owner	Timetable	Requirements
1.1 Establish an organisational model for data management and organisation and regulate access to E&P company data.	1.1 Implementation by MS (or inter-regional bodies with more than one MS, North Sea for example) with coordination from the EC.	1.1 Before end 2017, in advance of 1st CCS implementation, in line with national CCS roadmaps (**see Activity 3**)	1.1 Consider use of existing similar bodies at national level. Determine model requirements with regard to public access of information.
1.2 Identify an existing, or create a new public or public-private body to collect and coordinate data – a DMO.	1.2 MS (+industry?)	1.2 Mid 2018	1.2 Separate DMO or merged with NDO/RDO in the future. The functions of the DMO, financed by the government, are to: • Provide public access to information on storage and transport infrastructure, emissions, environmental baseline etc • Gather and store information. • Provide procedures, templates, formats and standards. • Update the national ranking of potential storage locations and publish annual reviews.
1.3 Implement data management functions in existing/new DMO. Launch DMO and active management of the National Storage Atlas with facilitation of client queries	1.3 MS (+industry?)	1.3 Mid 2018	1.3 Maintain a national storage atlas and CCS relevant database. Different timing for individual MS dependent on timing national CCS implementation plan/roadmap. Starting in 2019 undertake annual reviews of data management functions.

2 Storage Appraisal (S)

Appraisal will involve access to data to a much more complete level, hence the licence-holders themselves are best placed to conduct standardised evaluations leading to certification where such a system can be adopted. However, it is possible that the holders of the highest ranking storage sites might not be motivated to perform full appraisal of the sites. In this case all data must be accessible to a public national body that can accelerate the evaluation. A DMO would not be empowered to perform this task; an NDO or RDO would be more suitable, funded by the Government(s) in question. At EC level, or through some other recognised body such as the Society of Petroleum Engineers (SPE), the standard to which such appraisals are conducted needs to be established so that a common approach can be taken.

Several countries, including most countries around the North Sea, have transposed the CCS Directive into law, which means a common approach to permitting storage sites is already established, and expected to become more standardised with experience. Consideration is needed on how national permitting authorities may allocate licenses in the event that a competitive industry evolves. Licence-holders and perhaps their partners will consider that they have first rights where they have taken the investment risks to obtain exploration or production licenses, and invested to explore or produce hydrocarbons. Some countries may declare that these companies always have first rights. In the event that an licence-holder should wish to waive such rights there will need to be a system of auction or reallocation developed, preferably on a consistent basis (across the North Sea for example). It is possible that some large storage structures will span two or more countries requiring common and consistent rules. There should be open season on open unlicensed areas with aquifer storage potential.

Unless a more active approach is adopted, the reluctance of some licence-holders to progress CO_2 storage risks good sites laying fallow. License holders should periodically declare their intent to store or not to store in each and every structure identified either by them or in the national atlas, especially those that rank high. The rights to structures that licence-holders declare no intent to store should be offered up to the market on an auction basis, or returned to a relevant national organisation. This does not imply that any abandonment obligation gets transferred away from the licence-holder and partners, with that procedure addressed in the eventual permitting procedure and storage license award. Eventually all E&P and O&G transport facilities will need to be decommissioned and removed, excluding those with potential for use in the CO_2 storage industry. However, there is no incentive for licence-holders to maintain facilities, platforms, wells or pipelines once production has ceased. An incentive is required to ensure that the most important and most useful facilities are mothballed (with a regular review process). The highest ranking storage sites should qualify first, where capacity is high compared to mothballing cost. Evolution of a CO_2 ship transport industry may one day alter this prioritisation. This might encourage licence-holders to declare intent to store rather than release to market.

It is likely that few, or no, players will emerge as either transport or storage developers in some or even in all countries. It must be made clear that in such cases MS will take charge through a nominated NDO (National Development Organisation, for transport and/or storage). The principle of a Market Maker acting in some combination of capacities, from emissions sources to storage sites, has been proposed by ZEP and adopted as a realistic alternative in other studies. Licence-holders

could remain in charge of their original facilities but subcontracted to the NDO, with further consideration of possible public/private combinations at various stages of evolution and maturity. Outsourcing and franchising models can be developed, but oversight remains with the NDO. Where more efficient, a regional equivalent (RDO), which may even combine the functions of several NDOs, could be considered. The residual obligations of responsibility and liability for decommissioning owned by the last licence-holder, and in some countries the original licence-holder, must be incorporated into this model. A summary of the actions required under Activity 2 are listed in Table 2.

Table 2, Appraisal (S): Proposed actions under Activity 2

Action	Owner	Timetable	Requirements
2.1 Decide on scope of appraisal (initial vs full), responsible body and related (public) data.	2.1 EC with MS (and industry)	2.1 End 2017	2.1 Model must be flexible to fit with variations in governance practice among MS.
2.2 Decide on standards of appraisal including determination of storage capacity and risk assessment. MS to examine regional Storage Atlases and declare areas of CO2 storage importance.	2.2 MS	2.2 End 2017	2.2 Storage and development lead time 5-10 years. Utilise existing organisations, identified in **Activity 1** for low cost early appraisal.
2.3 Determine rules for handover of existing E&P infrastructure • Assign priority to sites planned for decommissioning. • Licence-holders to provide relevant data and information for appraisal well before license termination and on the status of asset before possible handover to NDO. • Avoid early decommissioning of high potential infrastructure, through planning, reporting, and transparency.	2.3 EC with MS (and industry)	2.3 End 2017 Intent to store/not store in structures identified by licence-holders. To be repeated on a 2 to 3 year basis.	2.3 EC develop mothballing scheme enacted by MS. • Decide whether site is to be suspended (and handed over to T&S developer/licence-holder/NDO) or abandoned. Licence-holders to suspend and handover, rather than abandon, key sites. • When potential storage sites are decommissioned (in the case of hydrocarbon fields), the licence-holder is to hand over all data and models, to be included in the database.
2.4 Decide on financing model for site appraisal • Confirm who pays for in depth evaluation; national bodies or E&P licence-holders.	2.4 MS & industry	2.4 End 2017	2.4 During the early phase of T&S development, the study (from evaluation to permitting) of the first storage sites should be fully funded, either directly or through a system of subsidies.
2. 5 Establish an organisation for the appraisal, development and management of T&S infrastructure (NDO/RDO). • In-depth appraisal including pre-FID detailed risk assessment, storage permit application, FEED studies and due-diligence review.	2.5 MS (and industry)	2.5 Mid 2018, with the establishment of regional planning coalitions by the end of 2017 (See **Activity 3).**	2.5 Until a T&S licence-holder/s are identified and relevant public-private business models implemented the development of permitted storage sites and transport links to those sites is a public task de-coupled from the development of capture projects.
2.6 Develop 1st suite of storage prospects and commence high ranked pre-FID appraisal activities (NDO/RDO).	2.6 MS	2.6 End 2018	2.6 MS review and update decommissioning guidelines in context of accessing high ranked storage prospects. Beyond the existing decommissioning regulations, tax breaks may be considered to help co-fund this process.

3 Strategic Planning (T&S)

Strategic European CCS and T&S infrastructure planning is required at three levels (regional, national, and sub-national) within a coordinated pan-European framework, consistent with 2050 decarbonisation targets and aggregated national roadmaps.

A **pan-European plan** could be managed by the EC, utilising a committee approach made up of representatives from the regional coalitions described below. Here the specific mandate would be to create the targets and actions for T&S that are realistically deliverable on the basis of best available technology, deployment rates and supply chain capacity. This will need to take account of the twin issues of inability of the private sector to deliver T&S ahead of demand and the pace of deployment of infrastructure to prevent residual emissions in the industrial sector/regions. This plan must address the increasing urgency to commence deployment of cross-border infrastructure to prevent residual emissions in multiple economic sectors including industry, domestic heating and transport. The private sector cannot plan, invest in, and deliver T&S infrastructure ahead of demand so government intervention is required. The plans will therefore need to include funding estimates for progressing storage characterisation and development, as well as transport planning including aggregation networks and pipeline corridors, and potential inland and seaward shipping routes.

Inter-regional plans with active inter-governmental coalitions are required to create and manage the strategic and delivery plans for T&S infrastructure that will service the decarbonisation needs of more than one country. The cross-border characteristic of this infrastructure and the geographical spread of storage resources mean that a combination of national, multi-national and EU joint funding arrangements will be required, in addition to EU funding available through competitive bidding processes. It is worth noting that the North Sea Basin Taskforce is not an example of a mandated regional coalition. An active coalition will need to comprise representatives from national bodies that have government authority to deliver on the design and active management of regional plans. Coalitions of this nature will be needed in areas such as Northern Europe/North Sea Basin, Eastern Europe/Baltic Sea, South Eastern Europe/Adriatic and the Iberian Peninsula.

Countries that are members of a regional coalition will need their own **national delivery plans** that are executed within national budgets, governance processes and public-private financing schemes. These plans will include the physical infrastructure requirements and from national sources to sinks, their interfaces with cross-border sources and sinks, and the deployment schedules necessary to meet the regional and pan-European plans. An example is the UK Infrastructure and Project Authority (IPA), charged with prioritising and delivering national projects in public-private financing initiatives. Such an organisation could provide the representative to a regional coalition, ensuring that regional and national plans are consistent. In other countries alternative institutions can be used but they should not be research councils or innovation funders, and should have responsibility for delivering projects using public and private financing. For cross-border projects of common interest collaboration of national authorities should be either under bi-lateral arrangements or within the remit of the regional coalition.

Sub-national/local plans involving stakeholders in industrial cities and regions where CCS is key to sustainable economic activity should make a major contribution to the development of national plans. Local business and sub-national authorities have the best data and knowledge to undertake

bottom-up estimates of emissions reduction targets, investment needs, low carbon industrial activity, job retention and creation, and synergistic infrastructure projects such as hydrogen and CO_2 T&S, as well as the level of policy and financial support required to deliver their low carbon future. Local planning should incorporate the development of CO_2 cluster aggregation networks and identify storage options in collaboration with other local areas where storage activities may take place (either onshore or offshore) and which consequently have the potential for new economic activity. A summary of the actions required under Activity 3 are listed in Table 3.

Table 3, Strategic planning (T & S): Proposed actions under Activity 3

Action	Owner	Timetable	Requirements
3.1 Develop and manage a coordinated pan-European framework and action plan that is consistent with 2050 decarbonisation targets and aggregated national roadmaps.	3.1 Managed by the EC (DG ENER, DG CLIMA, DG REGIO) utilising a committee approach made up of representatives from regional coalitions (see 3.2)	**3.1** Establish Committee by end 2017 and first plan by mid 2018	• Refreshed every 2 years to ensure compatibility with evolving UNFCCC commitments, national progress towards targets, capacity building and economic activity. • Customers are the EC and initially EEA member states. • Budgets and resource allocation from EC and national authorities to establish effective data gathering, plan development and oversight.
3.2 Review ToR and governance of interregional bodies such as NSBTF to establish whether they can form the basis of an active mandated coalition. **3.3 Develop and manage interregional T&S plans designed to be consistent with the pan-European framework (3.1) and include targets, policies and coordinating actions.**	**3.2** National authorities already participating in interregional bodies. **3.3** Mandated active interregional coalition made up of representatives from relevant national authorities.	**3.2** Establish interregional coalitions, budgets and governance by end 2017. **3.3** First "5 year plans" by mid 2018.	• Refreshed every 2 years in line with pan-European plan and covering a 5 year horizon. • Plans to include public funding estimates for progressing storage appraisal (**See Activity 2**), as well as transport planning including aggregation networks and pipeline corridors, and potential inland and seaward shipping routes. • Plans to include national timetable for legislation and institutional capacity building for market making functions and delivery (**See Activity 4**) • Initial coalitions to include N. Europe/North Sea Basin, E. Europe/Baltic Sea, SE Europe/Adriatic, Iberian Peninsula
3.4 Develop and manage delivery plans that include the physical T&S infrastructure requirements from national sources to sinks, the interfaces with cross-border sources and sinks, the deployment schedules necessary to meet the interregional and pan-European plans, and the institutional market making model to be adopted (see Activity 2).	**3.4** National authorities including government departments and public bodies mandated to manage delivery of public good infrastructure and emissions reduction targets (for example the UK Department for Business, Energy and Industrial Strategy (BEIS) and the Infrastructure and Projects Authority (IPA)).	**3.4** Initial national "5 year" delivery plans by mid 2018.	• Delivery plans to be refreshed on an annual basis to ensure contributions for funding at both the national and regional level are coordinated for inclusion in annual budgets. • Budget pledges required from EC and national authorities • Resourcing dedicated to national plan development and implementation as well as contributing to regional coalitions • Existing national authorities own these actions and targets as forerunners to dedicated NDOs and RDOs
3.5 Undertake bottom-up estimates of	**3.5** National authorities described	**3.5** Sub-national	• Customers are national authorities active in the interregional coalitions

emissions reduction targets, investment needs, low carbon industrial activity, job retention and creation, and synergistic infrastructure projects such as hydrogen and CO_2 T&S	above to identify and catalyse first mover regions, local business communities and sub-national authorities. Existing examples include Port of Antwerp, RCI, Leeds City Gate H21, Tees Valley Unlimited.	groups to be in place by end 2017 with data provided for national 5 years plans during first half of 2018.	and EC committee. • Assessment of policy and financial support required to deliver their low carbon future. • Funding support from national and regional authorities. • Data to feed in to updating national 2030 and 2050 roadmaps.

4 Market Structure (T&S)

Under current regulatory and policy frameworks across Europe, significant market barriers and failures exist which discourage and prevent investment in common CO_2 T&S infrastructure and hubs. Key reasons for this have been identified as:

- The missing market for the services (because of the lack of capture facilities and clear visibility of a revenue stream) so that any investment has to occur ahead of market demand;
- The associated coordination barrier, resulting from the need for storage certainty to take a Final Investment Decision (FID) for building a capture facility, and the need for CO_2 supply certainty to take FID for building a storage facility;
- Exposure of one part of the CCS chain to failures/underperformance elsewhere in the chain;
- Potential uncapped liabilities for key storage performance characteristics and for certain categories of leakage.

These investment barriers must be addressed in an enduring policy framework that stays in place for a period of 15+ years, or until such time as carbon markets provide an appropriate price incentive to cover both investment and performance risk. Unlike for renewable technologies, subsidies and capital grants alone are not sufficient to make CCS part chain projects investable. Even if there was an existing carbon price incentive, the risks, delivery time, scale and planning of the infrastructure needed just to decarbonise Europe's industrial regions mean additional intervention mechanisms are required to create the right investment conditions.

Ensuring investment in, and stability of income and returns from T&S assets where no market exists requires a sustained robust joint regulatory and contractual framework that can adapt to changes in circumstances, but which operates at both pan-European and national levels in order to mitigate change of law risk. Hence this framework needs to be constructed so that EU based regulation and financial support mechanisms provide a back-stop to various options for national implementation approaches. Without socialised cost and liability sharing a market transition for CCS from FOAK to a viable infrastructure service is highly unlikely. Recognising that T&S deployment must occur aligned with strategic plans focussed on 2050 climate targets, the delivery framework has to create a basis for allocation of transport and storage specific risks and liabilities between the public and private sectors while taking account of a no regrets level of capacity for the infrastructure. This framework needs to be implemented through a combination of institutions responsible for "making" the market and mechanisms that enable a "transition" from T&S being non-investable to being investable.

Governments need to establish the statutes of Market Makers. These sit between CO_2 sources and CO_2 sinks, planning and investing in infrastructure, coordinating flow, taking title to and risk in CO_2. They could be 'National Champions', formed by amalgamation of existing players, franchised by Governments, funded centrally, performing against a national plan and budget, regulated both nationally and from Brussels. Effectively, monopolies that require regulating, but over time leading to franchised or sub-contracted entities. At the national level, governments have a spectrum of business models for T&S delivery and operation that can be used, ranging from a 100% state owned entity through a number of public-private partnership structures, including a regulated private entity with appropriate risk sharing and liability underwriting. National delivery models should be

supported by the above EU level mechanisms. A summary of the actions required under Activity 4 are listed in Table 4.

Table 4, Market Structure (T & S): Proposed actions under Activity 4 (see also Table 3, Strategic Planning).

Action	Owner	Timetable	Requirements
European and Regional Actions: **4.1 Establish EU based regulation and financial support mechanisms that provide a back-stop to 'Market Making' functions, including various options for national level joint public/private investment.** **4.2 Ensure joined up delivery organisations and market making functions within regional coalitions (incorporating new RDOs or NDOs in partnership)**	• EC (DG ENER, DG CLIMA, DG REGIO) in conjunction with first mover MS authorities, EIB and relevant national banks/treasuries such as the UK Green Investment Bank (GIB). • EC and MS within high priority regional coalitions	• Establish working group/taskforce by mid-2017 to develop support mechanisms and governance • Put in place resources and institutional processes by mid 2018 • High priority RDOs or NDO partnerships in place by mid 2018 (**See Activity 2**)	• Agree a set of general rules for a regulated asset base model applicable to T&S infrastructure investment. • Agree a pooled fund for a storage risk and intra-chain performance risk insurance/underwriting mechanism. • Revise rules for CEF, modernisation and regional development funds in a carve-out for CO_2 T&S. The alternative is to create a new special purpose co-investment fund. • Establish a quantum of loan guarantees with the EIB and national banks such as GIB for use with CO_2 T&S projects; • Establish a pooled fund for storage characterisation and appraisal grants. • Establish new RDOs in parallel with, or in place of, NDOs in high priority coalitions to ensure rapid implementation of delivery structure.
National Actions: **4.3 Develop national legislative and financial framework** **4.4 Implement market making functions either through use of existing public sector institutions or creation of new Markets Makers (incorporating NDOs)** **4.5 Select preferred national model for public and private sector investment and operation**	• First mover countries in high ranked regional coalitions • National authorities responsible for relevant regulation and permitting, carbon markets, infrastructure delivery, and public sector financing or investment	• National frameworks completed by mid 2017 • Relevant Legislation enacted by end 2017 • National delivery institutions (NDOs), mandates, budgets and resourcing in place by mid 2018	These actions take place in parallel with those of Activity 3. Governments have 2 courses of action: Variant 1 – leverage existing public sector institutions with delivery from private sector: • Government treasury and investment authorities – involved in specific PPP finance model • Market regulator – involved in coordination and regulated business model • Subsidy and tariff counterparty authority – can be involved with performance risk underwriting and T&S licence-holder remuneration • ETS/EUA authority – can be involved in allowance underwriting • Oil and gas regulator – involved with permitting, operational regulation, infrastructure planning • Health, safety and environment authorities – same function • Pipeline System licence-holders – same function Variant 2 – create new Market Makers at national or sub-national level (NDOs) that combine some or all of the above functions: • Strategic planning function • Mandated and financed to deliver pre-FID storage appraisal • Operate to a business model with risk underwritten by government.

5 Regulation (C, T&S)

Consultations regarding the CCS and ETS Directives have been completed, with amendments to be made. These Directives have a purpose, to provide a framework within which to achieve reduced emissions of CO_2. Directives can either stimulate and accelerate, or hinder and frustrate.

They need to be implemented in each member state, and there needs to be careful monitoring to ensure that progress is being made towards achieving targets. Many of the actions listed here will be repeated in other sections, but this section specifically tasks the regulators and policy developers. A summary of the actions required under Activity 5 are listed in Table 5.

Table 5, Regulation (C, T & S): Proposed actions under Activity 5 (see also Table 4, Market Structure).

Action	Owner	Timetable	Requirements
5.1 Continuous review of regulation to monitor effectiveness, identify best practice, and support knowledge transfer between MS. Potential further review of CCS Directive if not amended. **5.2 Ensure EU regulation can support market structures and market making functions at national level. (see Action 4.1)** **5.3 EC to provide clarity on the effectiveness of BECCS to generate negative emissions, and facilitate clear policy to support if demonstrated beneficial.** **5.4 Coordinate and maintain EU Energy Roadmap comprised of National Roadmaps, recognising the contribution of fully integrating a meaningful level of CCS.**	• EC & First Mover MS. • DG CLIMA to analyse and feedback to MS from aggregate reviews of CCS Directive.	• Undertake review of EU policy/regulation portfolio every 2 years (in conjunction with **Activity 3** review cycle). • Annual review of EU and first mover MS policy and regulation harmonisation. • Annual knowledge transfer events with MS outside first mover coalitions • Implement policies and regulations to facilitate complementary technologies and investments by end 2018 with requirement to be transposed to MS by end 2019	• Policy portfolio needs to include an agreed set of general rules for a regulated asset base model applicable to transport and storage infrastructure investment and financial mechanisms to underwrite key market failures in the T&S business models; • Create incentives for MS to comply with planning or regulatory requirements consistent with delivery of plans and market structures (see Activity 6). • EC to ensure that CO_2 EOR projects allow emitters to qualify for EU ETS allowances. • Allocate ETS funds to support T&S in a complementary way to PCI support (additive and gap-filling). • Adopt facilitating policies and regulations for complementary technologies such as BECCS, hydrogen from SMR with CCS for heat and transport, CCU in industrial clusters etc. • Ensure transition mechanisms are developed for trade exposed energy intensive industries.
5.5 As part of Article 33 of the EU CCS Directive; establish escalating levels of capture ready compliance for new power stations, as well as energy intensive industries, such as cement, chemical, refining, and steel, encouraging regular reporting of capture readiness status. **5.6 Implement legislation following best practice and utilising knowledge sharing resources from other MSs.**	• European Commission (DG ENER, DG CLIMA) and Member States. • Every 3 years MS report on status of implementation of CCS Directive.	• Harmonise with pan-European and regional plans with first reports by mid 2018. • EII sector requirements and regulations to be harmonised with first 5 year plans in mid 2018 and enabling/support regulations by mid 2019.	• Power plant developers required to submit regular (e.g. every 5 years) updates on capture readiness level, with incorporation into regional and national 5 year delivery plans. • Cost and efficiency impacts of retrofitting capture capability included as part of the assessment for funding and approval.

5.7 Develop or improve national legislation and regulatory portfolio to ensure market making is enabled and delivery barriers are removed. **5.8 Implement, review and harmonise national and regional CCR, third party access and H&S regulations.**	• First mover MSs • MS responsible for relevant regulation and permitting, carbon markets, infrastructure delivery, and public sector financing or investment	• Enabling legislation and regulations in place by mid 2018 (see **Activity 4 market structures**) • Formal reporting on regulatory status to the EC every 2 years in conjunction with planning cycle for pan-European action plan and regional delivery plans.	• Enabling regulatory frameworks need to be effective across borders • National regulatory frameworks need to facilitate cross-sector synergies (power, industry, heat and transport). • First mover MS and EU to hold annual knowledge sharing conferences to compare regulatory experience and practical issues.

6 Incentives (C, T&S)

At present the ETS is not working as an incentive to store CO_2, with a coordinated, pro-development system of subsidies and investment mechanisms required. This may be supported (and positively distorted) by specific national tax breaks for participating players. Local integrated energy network plans may generate synergy, e.g. Port of Rotterdam and local greenhouse CO_2 networks, but important questions remain. How do we stop early decommissioning by E&P licence-holders not keen to store in depleted oil and gas fields? How do we incentivise E&P licence-holders to preserve valuable infrastructure? How do we incentivise CO2 storage in deep saline aquifers? This is a dynamic 30 year juggling exercise that needs to be conducted through an open forum with constant review of what is working and what is not, by bodies empowered to adjust the carrots and sticks.

The city of Duisburg is the heart of German steel production and Europe's largest steel production site, with an annual production of more than 15 million tonnes of crude steel in an industry employing some 18,000 people. In a 2016 study[3] Ecofys estimated that the European steel industry as a whole may face net ETS (carbon permits) costs of €27.1bn from 2021 to 2030. This is based on a carbon cost of €20.1bn in 2021, rising to €40.7bn in 2030, and includes continued free allocation. Using this study as an illustrative guide; the net carbon cost for Integriertes Hüttenwerk Duisburg from 2021 to 2030 would be approximately €1.9bn. This assumes steel production and CO_2 emissions remain constant through the period. Carbon prices are anticipated to rise post 2030 in line with deep decarbonisation goals and a reduction in free allocations, resulting in a growing CO_2 cost for the Ruhr steel industry. The steel industry and primary steel production of the Ruhr therefore clearly requires an accessible decarbonisation pathway. Access to CO_2 transport and storage infrastructure will be needed to decarbonise the blast furnaces of the Ruhr. A failure in the provision of a CO_2 network for this industry will result in unavoidable and increasing CO_2 cost to steel producers, as few technological means to significantly reduce CO_2 emissions from primary steel production will be available. Partnership between the local steel industry, regional government and federal government should at minimum aim to have revenues from the ETS reinvested to enable the deep decarbonisation of steel sector at the lowest cost. These investments could be in the creation and expansion of shared CO_2 transport networks, increasing CO_2 usage in the region, and in the development of offshore CO_2 storage. This would give confidence to steel producers that the infrastructure to enable them to decarbonise would be available in a timely manner, aiding continued investment in the region and employment.

Industrial contribution could take many forms. One approach, if the appetite can be fostered, would be to replicate the advantages of the Danish energy efficiency scheme that saw industrial users pooling resources to a common fund. A similar concept may allow to a lesser or greater extent for the rational investment and expansion of no regrets regional, strategic CO_2 infrastructure, to the benefit to the industrial cluster as a whole. Such an approach could serve as a way to continue and/or supplement an initially publicly capitalised CCS value chain licence-holder (i.e. the regional 'market maker').

[3] Carbon cost for the steel sector in Europe post-2020 (Ecofys, 2016)

There is as yet no agreement among industrial players on what they want and even less on how to get it. Border carbon adjustments could be good for some, bad for others. Industry might be persuaded to support an infrastructure first story because:

- It reduces obligation in the near future
- It provides some certainty on the decarbonisation strategy and obligations
- It safe guards investments and can encourage continued investment in existing plants
- It can be attractive for the host regions as it offers a cooperative strategy to decarbonise and can address the conflicts emerging between employment, competitiveness and decarbonisation

Clearly, a combination of sector, region, national, and European funding is required to incentivise the further development and initial deployment of CCS. Access to various funds such as e.g. European Regional Development Fund (ERDF), Modernisation Fund, Innovation Fund (NER400) should be made possible, and synergies between them should be created.

Regional Policy, the EU's main investment policy, is now key to be called upon. Through three main funds, the European Regional Development Fund (ERDF), the Cohesion Fund (CF) and the European Social Fund (ESF), Regional Policy investments help to deliver many EU policy objectives and complement EU policies such as those dealing with education, employment, energy, the environment, the single market, research and innovation. After more than twenty years of DG RTD support for CCS research and development, regions should be now encouraged to consider including CCS in their Strategies for Smart Specialisation, which is a prerequisite to benefit from ERDF funding in order to boost innovation. This ERDF funding could then be accessed either through regional operational programmes or through interregional programmes called Interreg.

European Territorial Cooperation, better known as Interreg, is one of the two goals of cohesion policy and provides a framework for the implementation of joint actions and policy exchanges between national, regional and local actors from different Member States. Over the years, Interreg has become the key instrument of the European Union to support cooperation between partners across borders. The aim: to tackle common challenges together and find shared solutions - whether in the field of health, research and education, transport or sustainable energy. Therefore this instrument is key for helping CCS development at interregional and pan-European levels.

Regions that seek to grow into CO2 transport hubs can access upcoming EU funds to aid development of base infrastructure. It is important that the first industrial CCS projects lay the foundational infrastructure. Regional planners need to work with and encourage local CCS project developers to see that CO_2 infrastructure and storage is prioritised, has capacity to grow, and aids the development for a logical CO2 hub. Active regional and national support for strategic industrial CCS projects increases the likelihood of success. Developing project proposals takes time; regions and project developers need to begin now in order to access upcoming funding schemes, or lose the opportunity.

The forthcoming EU Innovation Fund is the most evident route for laying the first enabling CO_2 infrastructure. Regional CO_2 infrastructure development plans need to propose and support first mover projects that fit the scale of expected Innovation Fund funding. Regions and national governments should work with the European Commission and Parliament to make the modalities of

the Innovation Fund compatible with CO_2 infrastructure and CO_2 storage led deployment. To be eligible for Innovation Funding industrial regions must act quickly to develop regional plans and priorities.

Industrial sectors and industrial regions that will benefit from the presence and expansion of CO_2 networks could be persuaded to establish pooled funds aiding the capitalisation of a market maker. Contributions from national treasuries and/or European Union could be used to bring all actors together.

Projects of Common Interest (PCIs) can potentially be sought to develop CO2 transport infrastructure. However, the CEF is not structured to incentivise pre-feasibility and feasibility studies. CO2 transport and storage strategic delivery plans and oversight of a regional CO2 Market Maker will increase the potential for successful access PCI funding. A summary of the actions required under Activity 6 are listed in Table 6.

Table 6, Incentives (C, T & S): Proposed actions under Activity 6 (see also Table 3, Strategic Planning and Table 4, Market Structure).

Action	Owner	Timetable	Requirements
6.1 Establish an EU pre-FID storage site appraisal pooled fund and grant scheme to enable the private sector to undertake storage characterisation outside a government sponsored full chain CCS project. **6.2 Establish a new pooled fund and grant scheme, or new rules/a carve-out within the CEF to incentivise pre-FID CO_2 transport solutions within regional strategic plans, feasibility studies, route mapping, design etc without an existing market** **6.3 Review and modify all existing and proposed EU funds to ensure fit-for purpose rules and sufficient funding scale to support real CCS projects**	6.1 European Commission (DG ENER, DG CLIMA, DG REGIO) in conjunction with first mover Member State authorities 6.2 European Commission (DG ENER, DG CLIMA, DG REGIO) in conjunction with first mover countries in high ranked regional coalitions National Treasuries or infrastructure delivery authorities 6.3 European Commission (DG ENER, DG CLIMA, DG REGIO) in conjunction with first mover countries in high ranked regional coalitions	6.1 Establish working group/taskforce by mid-2017 to develop requirements, rules and establish governance, resources, and funding by mid-2018. 6.2 Include with storage taskforce above or create different working group by mid-2017 and establish fund/new rules by mid-2018. Put in place governance, resources and institutional processes by end 2018. 6.3 Complete review and modify funds by mid 2018	• Grant scheme needs to support and harmonise with strategic plan delivery (**See Activity 3 Strategic Planning**) • Ensure an EU portfolio of appraisal prospects to be funded (see **Activity 2**) • Potentially create carve-out for CO_2 storage appraisal in Innovation Fund and/or include in Regional Development Fund etc • Grant scheme needs to support and harmonise with strategic plan delivery (See **Activity 3 Strategic Planning**) • Ensure an EU portfolio of first mover transport solutions/PCIs and CEF – effective rules for CO2 T&S infrastructure ahead of market demand, economic utilisation etc. • Include Regional Development Fund, Modernisation Fund, Innovation Fund (NER400). Make these funds flexible, additive, gap-filling, encourage oversizing (right sizing), and rewarding negative emissions.
6.4 Pool ETS obligations within sectors or regions, and reuse of ETS revenues for CO_2 infrastructure charged to industries **6.5 Encourage industrial sectors and regions to establish pooled funds (e.g. through levies with co-contribution from national treasuries and/or EC)** **6.6 Incentivise E&P licence-holders to promote and**	6.4 European Commission (DG ENER, DG CLIMA, DG REGIO) in conjunction with first mover countries in high ranked regional coalitions 6.5 Peak industry bodies and regional development authorities 6.6 EC and MS	6.4 Start dialogue by mid-2017 Mechanism for distribution of ETS revenues by end 2018 6.5 EC to encourage sector and national actions by end 2017 and first funds established by mid 2018 to coincide with first 5 year delivery plans	• Note combination of sector, region, national, pan European funding required • Note need for a pan-European industrial decarbonisation policy portfolio • At present industry feels that ETS and carbon pricing is just a tax and will (rationally) fight it all the way. If we can show they get something of value (CO_2 transport & storage) they *may* be more willing to engage.

preserve valuable infrastructure		6.6 Incentive schemes in place by end 2017 (see **Activity 2**)	
6.7 Review incentive structure, and continually adjust beyond 2018	• EC & MS & industry	• First review end 2019 to check the effectiveness of activities and industry participation	• Development of upfront enabling infrastructure (oversized transport and storage) beyond 2020.

7 Politics and Communication (C, T&S)

The European Commission, the European Parliament, Member States and the Committee of the Regions (an EU advisory body composed of locally and regionally elected representatives coming from all 28 Member States) must cooperate to produce and share:

- Strategies, roadmaps and action plans for enabling the further development and deployment of CCS in Europe;
- A coherent, single message on the imperative and unavoidable role of CCS in achieving National and International climate obligations, such as those set out in the Paris Agreement ratified in 2016.

This will provide support and justification for investment in CCS pilot and demonstration projects, alongside the development of renewables. In order to achieve this local, national, regional and European bodies need to provide clear answers to the following questions on CCS:

- What are we trying to do?
- Why are we trying to do it?
- How are we doing, looking back and forecasting based on current commitments?
- What do we need to do next (once policy is in place), always looking forward?

A summary of the actions required under Activity 7 are listed in Table 7.

Table 7, Politics and Communication (C, T & S): Proposed actions under Activity 7 (see also Table 3, Strategic Planning).

Action	Owner	Timetable	Requirements
7.1 Publish fact based history of GHG emissions and climate impact, climate scenarios, the development of commitments made so far, and progress against these commitments, including the impact of measures taken since 1990 country **7.2 Energy/Climate/Social Policy, clearly articulated, Direction Statements, Targets, Target Dates, Review Dates, Responsible Party, Budget** **7.3 Climate action and responsibilities clearly allocated to govt dept, website with background, reason for urgent action, tracking mechanism to measure and report progress.** **7.4 Publish financial cost of climate change mitigation without CCS.** a. Govt budget detailing resources allocated to climate action including CCS, forecast spend for 5-25 years, annual review b. Govt plan to deliver T&S or export (for non-storing countries). How Govt will make sure the players play their part. c. Govt role to define and establish Market Makers and other players **7.5 Public out-reach programmes to be funded by NDO/RDO to educate general public on need for CCS to decarbonise across industry.**	• Joint owned and published by climate depts., climate associations, economic and political groups of Nations, UN, UNEP, EU, ASEAN, AEEP, USAN • NDO/RDO	• 2017. UNEP proposes platform and responsible body, e.g. IPCC, and sets out framework of data to track, scenarios to maintain, actions available and calculated impacts.	• Identify/create sponsor, platform, and framework to act as a central source of data and analysis • Publish policy, plans, targets, measurement method, progress and eventually success. Associated media campaign required to ensure it reaches the general public. • Analysis of social-economic benefits to the supply chain and local economy for each T&S cluster to be funded by NDO/RDO with input from local/regional governments in areas of likely clusters. Outcomes, including job creation, should then be communicated to communities. Policies could be introduced by regional governments to provide financial benefits (e.g. lower council taxes) for communities where T&S is located.
7.6 EU to mandate that MS energy policies consider CCS as equal with renewables, given need for CCS to decarbonise sectors other than electricity. Subsidies for one low carbon technology should be applicable to others, given need for all energy sources going forward.	• EU & MS	2017	

8 Technology (C, T&S)

90% of the technology required for CCS is already well used or demonstrated, however, some elements need scaling up. The Demo projects, now on hold, are designed to generate confidence and track record by underpinning knowledge and theory. For this to be achieved, coordination and information sharing between research associations and industry needs to take place, embedding the right attitude towards sharing technology from the beginning.

Elements of the technology for capture, transport and storage of CO_2 as part of a CCS industry are already widely in use in individual process chains, or are being demonstrated at scale at various projects around the world[4]. However, there are elements of the technology that require further scale-up in order to generate knowledge, and thereby enhance confidence in Capture, Transport & Storage technology, increase performance and provide cost reductions.

It is important to ensure that knowledge gained from centrally-funded CCS projects/research is shared with the wider CCS community. We have multiple research institutions, universities and industries all competing for limited funds. The coordinating body both allocates the right funds, at the right time to the most qualified and advanced research facility, as well as players competing to pull funds towards them. Both must coexist for a dynamic, evolving research infrastructure, with the objectives; to spend wisely, avoid repetition of work, and avoid irrelevant work through transparent communication and coordination.

The openness of a wiki is an example of how knowledge could be shared to accelerate development and demonstration of technology. Each research organisation could categorise its capabilities using one wiki page for each research team, department, and facility. Such pages can summarise past research, ongoing research based on research questions, progress (or failure) to address the research questions, links to the follow on questions spawning a new wiki page per research question. The EU could sponsor a wiki covering Europe, coordinated by a nominated body. Each wiki page can have links to published papers, links to associated research sites and links to other wiki pages covering complementary research. Industries, companies, individuals can enhance the wiki by providing context, reporting what happened when the research was tried out, and suggesting further research questions to close down residual unknowns. A summary of the actions required under Activity 8 are listed in Table 8.

[4] Future CCS Technologies (Zero Emissions Technology and Innovation Platform, January 2017).

Table 8, Technology (C, T & S): Proposed actions under Activity 8 (see also Table 3, Strategic Planning and Table 4, Market Structure).

Action	Owner	Timetable	Requirements
8.1 Member State ministries to provide tax relief for service companies on CCS technology development work.	• MS	• End 2017	• National Energy Policy in place that provides certainty to industry that the government requires and drives a CCS sector.
8.2 Mandate that all gov. funded research results are to be provided to the DMO. **8.3 Require centrally-funded R&D projects to be between multiple academia and industry organisations to facilitate knowledge-sharing** **8.4 RDO to collate MMV /containment learnings on costs and benefits of technologies, to ensure that they are SMART and efficient. As above, MMV plans to be made available to the RDO, and subsequently to potential licence-holders. Technical experts within/members of RDO to review and rank technologies, with results provided on RDO platform for access to future licence-holders.**	• DMO and relevant Member State ministries.	• 2017	• Potential change in grant payments e.g. 20 % (or similar) of research grant to be paid by research council only once data is provided to RDO by the research organisation. • Clima can aggregate links to procedures and timelines to obtain all sources of EC funds, and links to MS government sites that categorise national and local sources of funds. By aggregating links to all sources of funds, an extra level of transparency is achieved.
8.5 RDO to support ongoing storage appraisal work, by providing funding where required, and/or technical expertise. Results to be shared nationally (and in turn with the RDO) via sharing platforms.	• RDO	• From end 2018	• Platform for sharing data is required. • May require enabling legislation at EU level to define areas of CO_2 storage importance.
8.6 Member State ministries to create call for funding (via EU/National Research Councils) to collate baseline data. Data to be added to Member State national database e.g. CDA in UK, and shared with RDO.	• RDO to facilitate regional baseline studies, and provide platform for	• 2017	• Platform for sharing data is required.

Summary and timeframe for key actions

This report recommends that each of the 8 listed activities proceed in parallel. However, a number of the actions outlined in Chapters 1-8 must be completed in sequence. Table 9 illustrates 3 key stages (shaded from dark to light) with the corresponding actions needed to deliver full-chain CCS projects.

Table 9: Summary of actions	Stage 1 (2017)		Stage 2		Stage 3
1. Open access to information	Database model and responsible body for management indentified/created.	Database model implemented and management organisation launched.	Database made available centrally to regulator.	Database available to E&P licence-holders (for fee) and populated.	Database becomes open access.
2. Storage Appraisal	Prospect appraisal plan defined.	High ranking structures identified (as per activity 1) and storage play types mapped.	Licence-holders declare intent to store/waive rights.	Certification/mothballing support awarded.	
3. Strategic planning	'First-mover' MS identified and coalition established.	Formalise planning responsibilities at European, interregional, national, and sub-national levels.	'First-mover' MS to produce European, regional, national, and sub-national plans.	Plans used to support PCIs And support 'off-plan' proposals from private companies.	
4. Market Structure	MS establish 'Market Makers' - public/private partnerships - to deliver early projects and facilitate infrastructure development.	MS develop legislative and financial framework to support Market Makers.	Market makers manage development of pilot projects and primary CCS infrastructure on behalf of National Governments.	Capture decoupled from transport/storage.	Market scale allows private companies to develop pipelines, hubs and storage sites with specific government direction.
5. Regulation	Identify existing regulatory barriers to project delivery.	Continuous review of regulation (e.g. ETS and CCS Directives).	Regulate to avoid the creation of monopolies by Market Makers.	Light-touch regulation to maintain strategic direction and support private companies.	
6. Incentives	Establish a working group comprising EC and MS to identify and review funding mechanisms for FOAK projects.	Implement incentive mechanisms, supporting FOAK projects as a balance between State support and managed competition. Regulation developed on a case-by-case basis.	Implement incentive mechanisms creating viable business opportunities for CCS (e.g. carbon price, low-carbon power premium, or incentive to store).		
7. Politics and Communication	National Governments recognise and acknowledge benefits of CCS.	National Governments provide a supportive policy environment for CCS pilot projects.	National Governments support CCS 'Market Makers' and CCS pilot projects.	MS encourage private industry to develop CCS projects through relative policy support.	
8. Technology	EU-wide information and technology sharing platforms established (as per activity 1).	FOAK application of existing technologies transferred from analogue industries.	Scaled up application of transferred technology Development of CCS specific technologies.	Market scale drives technological advancement.	

Contributors

To be added

30th January 2017

Joint Input to the Future of the Horizon 2020 Work Programme from the European Zero Emission Technology and Innovation Platform (ZEP) and the European Energy Research Alliance Joint Programme for CCS (EERA JP CCS)

This joint paper outlines the views of both the European Zero Emission Technology and Innovation Platform (ZEP) and the European Energy Research Alliance for CCS (CCS EERA) in relation to the development of the 2018/19 Horizon 2020 Work Programme and specific calls relating to CCUS.

The Paris Agreement and new goal to limit global warming to 'well below 2 degrees' have brought a new sense of urgency to discussions around CCS in Europe. Whilst other regions around the world have begun to make tangible progress towards commercial deployment of CCS, Europe now lags behind.

The EU has the research capability, the skills, the infrastructure, and the political commitment to tackling climate change, necessary to take full advantage of the environmental and economic opportunities that CCS offers. Horizon 2020 and the SET Plan can provide the platform for coordinating EU and Member State action on CCS, focusing international cooperation and delivering meaningful progress towards its commercial deployment between now and 2020 and beyond. This will support European technological leadership in future CCS markets.

Summary of recommendations

ZEP and the CCS EERA submit the following recommendations for key research, deployment and innovation actions that should be supported through the Horizon 2020 programme.

1. **Cost-efficient clean hydrogen and hydrogen infrastructure**
    a. Large-scale clean hydrogen production with CO_2 capture at a reduced cost
    b. Integration of clean hydrogen production and consumption in a flexible, low carbon energy system

2. **Improved technologies for CO_2 capture**
    a. CO2 capture processes with high operational flexibility
    b. Lower cost CO_2 capture technologies and processes, including greater than 90% capture rates,

3. **Unlocking shared CO_2 transport and storage infrastructure**
    a. Support for the characterization, assessment, and management of storage capacity
    b. Technologies for increasing the efficiency of CO_2 storage resource utilization

c. Methodologies for assessing and costing CO_2 storage liabilities
d. Methodologies and tools for quick-starting CO_2 transport and storage across Europe
e. Support for the development and deployment of European CO_2 transport and storage infrastructure to support full-scale CCS demonstration projects
f. solutions for CO_2 transportation, including integrated solutions for CO_2 shipping
g. Integrating power, industrial and other single point emitters into CCS clusters

4. **Support for the development and operation of demonstration or pre-commercial CCS projects**
   a. CCS Development Fund (ERA-NET) for achieving the specific targets for CCUS under the SET Plan Action 9

5. **Bioenergy and CCS (BECCS) and Bioenergy and CCU (BECCU) for energy sector decarbonisation and negative GHG emissions**
   a. Pilot and demonstrate concepts of Bio-carbon capture, re-use and storage (Bio-CCUS) in relevant industrial sectors
   b. Energy system optimization and feasibility of carbon negative and system balancing concepts
   c. Systemic approach of realistic potential with business insight and sustainable impact of Bio-CCUS in different sectors

6. **Support to the stakeholder coordination of CCUS in Europe**

Detailed recommendations

1. Cost-efficient clean hydrogen and hydrogen infrastructure

a. Large-scale clean hydrogen with CO_2 capture production at a reduced cost

Technologies already exist for H_2 production with CO_2 capture from natural gas and coal, and there are multiple projects already removing (i.e. capturing and releasing) CO_2 during hydrogen production. Cost for such technologies is presently significantly lower than for H_2 production with electrolysis. There are also several high-potential technologies under development (e.g. chemical looping reforming, membrane reactors, sorption-enhanced reactors) that have the potential for even cheaper and/or more energy efficient hydrogen production with CCS.

In order to accelerate the hydrogen economy, research and demonstration should be pursued for most promising technologies. The expected impact of such high-potential technologies is further cost reduction, and even more efficient use of resources for hydrogen production from both natural gas and residual industrial gases.

Technology RD&I projects for hydrogen production with CO_2 capture should aim to leverage technologies and systems from TRL 3 and 4, with the demonstration of technologies at TRL 6 and 7.

b. Integration of clean hydrogen production and consumption in a flexible, low carbon energy system

There is a need for better understanding of the techno-economic aspects of hydrogen production integrated into a European energy infrastructure, which includes CCS. Cases studies/value chain

analyses are required to clarify under what conditions, and in what regions, hydrogen production with CCS can be an early driver for accelerating CCS deployment and reducing CO_2 emissions in a range of sectors.

Hydrogen production with CO_2 capture, in addition to that from electrolysers using renewable energy (or nuclear power), must be evaluated within a common framework. Hydrogen production plants with CO_2 capture can be expected to be operated to match seasonal variation in demand for hydrogen and are likely to be used on conjuction with hydrogen storage facilities, variable electricity production and industrial uses for hydrogen (e.g. ammonia production)

Mixing of CO_2 from hydrogen production and from other sources (e.g. post-combustion capture from power and industry) must be investigated in order to understand limits for possible impurities, including potential impacts on the storage reservoir, and therewith enable CO_2 transport and injection design for a future pan-European CCS infrastructure, without unnecessary additional costs due to excessive design margins. Hydrogen can also be used for transport and (partially or completely) replace natural gas in the gas grid to decarbonise domestic heating. These are promising options to reduce the domestic CO_2 emissions of a number of Member States.

2. *Improved technologies for CO_2 capture*

a. CO_2 capture processes with high operational flexibility

Support for the final development of capture technologies that facilitate efficient and low-cost operational flexibility should be pursued. This could include, for example, polymeric membranes, the development of solids-based flexible processes, as well as combinations of different capture techniques.

Pilots and demonstration projects should be developed, reflecting the various TRL levels for the different technologies. In order to reduce emissions quickly and cost-effectively, there is a need for faster scaling-up of promising technologies, to speed up feedback from real applications outside the laboratory.

Operational flexibility is increasingly becoming an issue in European industrial sectors (including power and some energy intensive industries), in part due to the increasing share of intermittent renewables in the electricity system. Most capture technologies support base load operation but further research is needed to improve operational flexibility, not only of the capture technologies themselves but also their integration into shared CO_2 transport and storage infrastructure schemes.

b. Lower cost and higher efficiency CO_2 capture technologies and processes at greater than 90% capture rates,

Integrated Assessment Models for achieving 'well below 2 degrees' objectives established by the Paris Agreement typically demonstrate the need for negative emissions technologies and increased CO_2 capture rates above the common baseline of 85-90%. Indeed, these issues are currently being considered by both the International Energy Agency (IEA) and the IPCC, ahead of its Special Report on 1.5 degrees expected in 2018.

A variety of CO_2 capture technologies are capable of achieving higher CO_2 capture rates from industrial emissions sources but often the cost-benefit of achieving a higher capture rate is marginal or uneconomic. Targeted R&D is there needed to lower the cost of achieving higher capture rates and improve the efficiency of capture processes to reduce associated energy consumption.

In some cases, co-firing of fossil fuels with biomass and CCS may offer an alternative means for achieving 'net zero' emissions using existing infrastructure from a particular industrial process In addition to the low initial investment, the annual fuel costs are often lower in co-fired plants resulting in short payback periods. However, the economy-environment trade-offs are difficult to resolve, especially for poorer countries that have pressing near-term needs for low-cost power, and may benefit from further R&D activities to lower costs and improve efficiencies.

3. Unlocking shared CO_2 transport and storage infrastructure

a. Support for the characterization, assessment, and management of storage capacity

The availability of proven storage capacity is a key enabler for power or industry to start the development of capture operations. However, due to its long lead time, early development of storage sites will be needed prior to investments in CO_2 capture projects.

Storage capacity should be made available to store CO_2 from likely first-mover capture projects. Research is required to improve the status of large-scale potential storage reservoirs; an assessment of the effort to obtain a storage license for potential storage reservoirs would provide clarity about storage cost and development time line.

Clustered storage reservoirs potentially reduce storage costs and should be prioritised. Improved strategies for assessment and management of a portfolio of individual co-located storage targets could lead to significant cost and risk reductions. This requires a number of actions:

i. Consistent reporting of storage resources and reserves with special focus on connected and/or co-located pore volumes and an assessment of efforts required to develop each storage resource.
ii. Provision of sufficient assured (strategic, bankable) storage capacity for expanding CO_2 capture markets.
iii. Reduce costs of storage appraisal, especially for large saline aquifers which can cover 100s square kilometres.
iv. Strategic spatial planning,
v. Societal information and engagement.

The work should be based on real sites across Europe offering good perspectives for further implementation of the first demonstration or pre-commercial CCS projects in Europe, and on a significant contribution of social sciences.

b. Technologies for increasing the efficiency of CO_2 storage resource utilisation

These should be tested and validated on real data from (targeted) new/existing pilot, demonstration or industrial sites:

i. Pore-space optimisation methods including pressure management technologies and improving trap efficiency will be necessary to ensure lowest cost storage in both saline aquifers and in depleted hydrocarbon fields.
ii. Technologies for maintaining injectivity could benefit from a better understanding of aquifer behaviour and diagenetic and other geological controls on injectivity.
iii. Optimised strategies for maximising CO_2 storage during and following enhanced hydrocarbon recovery (both oil and gas)
iv. Strategies to optimise CO_2 storage injection across connected and/or co-located pore volumes (such as stacked formations), especially in large saline aquifers to reduce costs

through economies of scale. This would also include ways to manage these in a regulatory sense.

v. Improved understanding of CO_2 storage infrastructure and injectivity responses to variable supply rates is needed to maintain operational availability at the store. This includes understanding the impact of intermittent injection on well materials.

c. Methodologies for assessing and costing potential CO_2 storage liabilities

A robust method for assessing and costing long-term liabilities for leakage and ground movement are needed to support investment in transport and storage infrastructure and commercialisation. For storage operations, liability is closely related to the initial risk assessment of the storage complex, as well as with monitoring of site conformance during storage operations. Upon site handover to the competent authorities, a good knowledge of site conformance will be the basis for an assessment of long-term residual risk and liability. With a transition to a large scale CCS, increasing quantities of CO_2 will need to be injected into storage aquifers in the coming decades. Large injection rates could bring significant geomechanical effects, and the ability to detect, understand and manage these impacts is a challenge that needs to be addressed.

The following topics need further development:

- Reliable methods for pre-FID analysis of long-term storage liabilities
- A quantitative methodology for site conformance assessment and, hence, risk and liability assessment of storage sites should be developed, to support both potential operators and competent authorities.

d. Support to the development and deployment of European CO_2 transport and storage infrastructure to support full-scale CCS demonstration projects (strategic infrastructure planning)

The long lead times in the development of storage reservoirs causes significant uncertainty regarding the capacity and location of transport and storage infrastructure. In the absence of firm commitments of CO_2 infrastructure operators, there is no incentive for the industry to develop transport infrastructure.

Coordination is required between European Member States, regions, industrial stakeholders and the European Commission to identify and investigate potential CO_2 transport infrastructures, and to support further activity towards the development of CO_2 transport Project(s) of Common Interest (PCI). Early storage pilots of greater than 100,000 tCO_2 per annum would also help to reduce barriers to commercial scale storage operations by demonstrating feasibility and security of storage in a European context.

ZEP has previously published reports on an Executable Plan for CCS in Europe and identified the potential for CCS Market Makers. A H2020 call could facilitate and enable early discussions around strategic CO_2 infrastructure planning, helping to address the early stage commercial barriers and fund necessary strategic and technical support.

e. Optimized solutions for CO_2 transportation, including integrated solutions for CO_2 shipping

Support should be provided for optimised, integrated solutions for ship transport of CO_2, including off-shore loading and unloading, transient behaviour, and downhole injection/management with typical CO_2 qualities. R&I activities should also support the integration of ship transport of CO_2 in CCS clusters and pipeline-based transport infrastructures. Project results should be supported by pilot scale development and deployment.

There is currently no common agreement the acceptable CO_2 stream compositions that can be safely transported and injected from a corrosion point of view. There is a need to develop CO_2 specifications that are safe but not overly restrictive in order to increase the flexibility and reduce the cost of the whole CO_2 chain.

f. Integrating power, industrial and other single point emitters into CCS clusters

There is a need for additional support for semi-mature (TRL 5-6) technologies in industrial CCS pilots and demonstration projects to enhance scaling-up and resolution of first-of-a-kind issues.

It will be important to consider linking future power-industry clusters, where syngas from power can be transformed into chemicals or fuels including hydrogen or electricity (co-generation), thus reforming and re-structuring both power and industry.

4. Support for the development and operation of demonstration or pre-commercial CCS projects

a. CCS Development Fund (ERA-NET) for achieving the specific targets for CCUS under the SET Plan Action 9

Member States recently adopted 10 specific targets for CCUS under Action 9 of the Strategic Energy Technologies Plan and work is underway to assess current actions that could contribute towards delivery of the targets. In a number of cases there are likely to be gaps between the actions already being undertaken and the actions needed to deliver on the 10 specific targets.

There exists a timely opportunity to repurpose a proportion of the unspent funds from the second call of the NER300 programme to support delivery of the specific targets for CCUS under the SET Plan. In order to best-leverage Member State and European Commission funding, the unspent NER300 funds awarded to the White Rose project could be disbursed through a new CCS ERA-NET to support delivery of the SET-Plan targets and kick-start commercial deployment of CCS projects across Europe.

In the present economic and regulatory climate, there are no economic incentives for CCS projects. To prevent delays in the start of CCS and to avoid unnecessary high future decarbonisation costs, continued support is to be given to first-wave demonstration or pre-commercial CCS projects, incorporating risk and cost-sharing approaches for CCS chains.

Over time frameworks for incentives/regulations/business models should evolve as CCS technologies develop and there may be a need to develop new models with sufficient flexibility to support effective and timely wide-spread CCS deployment and ensure appropriate cost and risk sharing across the whole CCS chain.

CCS is most cost effective where deployed on a cluster basis, and where transport and storage infrastructure may be shared. It is also important to ensure that frameworks are developed that allow large emitters that are not located within clusters to implement CCS as deployment levels increase up to and beyond 2030.

5. *Bioenergy and CCS (BECCS) and Bioenergy and CCU (BECCU) for energy sector decarbonisation and negative GHG emissions*

a. Pilot and demonstrate concepts of Bio-carbon capture, re-use and storage (Bio-CCUS) in relevant industrial sectors

Fulfilling the Paris agreement target of 1.5 to 2 deg C warming will require the use of carbon negative solutions. Biomass based carbon (CO_2) capture, storage and re-use (Bio-CCUS) is the only viable solution for achieving this at scale and with an estimable cost, with bioenergy RES-hybrids providing pathway to negative CO_2 emissions and integrating larger shares of variable and intermittent renewable energy in all scales of applications, from residential scale to large systems.

R&D activities will be required to adapt and optimize current pre- and post-combustion capture technologies to achieve negative emissions both in domestic and industrial use. E.g. in biogas upgrading, biomass gasification and treatment of biofuel exhaust streams.

CCU (Carbon capture and utilization) is referred to as a family of technology concepts utilizing captured CO_2 as a feedstock for other processes, to produce materials, transportation fuels or to be utilized as a process medium, e.g. carbon chemistry products, liquid biofuels, other products or enhanced oil or gas recovery. These technologies can potentially provide a cost effective pathway for deployment of CCS technologies, contribute to climate mitigation, resource efficiency and cascading use of raw material, provided that additional renewable electricity is available.

b. Energy system optimisation and feasibility of carbon negative and system balancing concepts

c. Systemic approach of the realistic potential of BECCUS to supporting European decarbonisation across different sectors

There is a need to substantiate the volumes of biomass needed in Europe, including which sources and which technologies should be used, and whether unconventional biomass sources could be pursued. Medium and long term market and technical solutions and cost level comparison of these climate change mitigation solutions should be the driver for directing demonstration actions. Both pilots and models should be developed to progress BECCS and BECCU and to define the future role of the technologies in Europe.

6. *Support to the stakeholder co-ordination of CCUS in Europe*

Over the last decade a secretariat has provided integral support to ETP and, subsequently ETIP, ZEP. At present the ZEP secretariat also provides support to the TWG9 on CCUS under the SET-Plan. Support for the current secretariat is funded through Horizon 2020 to the end of 2017 and ZEP would recommend that this funding support for a secretariat is continued into the 2018/19 Work Programme.

Leveraging MS's initiatives and gaining momentum at a European scale will be greatly enhanced by the development of integrated research and innovation projects (IRP's) in CCUS. This should be focused at topics in TRL 3-5, reflect the strategies of the European countries involved and be complimentary to already committed funding in the field.

20th January 2017

Joint Input to the Future of the Horizon 2020 Work Programme from the European Zero Emission Technology and Innovation Platform (ZEP) and the European Energy Research Alliance for CCS (EERA CCS)

Summary of recommendations

Modelling by the IPCC, IEA, European Commission and national governments has highlighted the importance of CCS deployment to decarbonising power, industrial, heat and transport sectors at least cost for many European nations. In order to increase the speed and scale of CCS deployment in Europe, ZEP and the CCS EERA make the following recommendations for key research, deployment and innovation actions that should be supported through the Horizon 2020 programme.

1. Cost-efficient clean hydrogen and hydrogen infrastructure
    a. Clean hydrogen production with CO_2 capture at a reduced cost
    This could be covered by NZE5, but depends on final wording
    b. Integration of clean hydrogen production and consumption in a flexible, low carbon energy system
    This could be NZE5
    Could fall under ' Additional activities' (p. 77)

2. Improved technologies for CO_2 capture
    NZE1 – but final wording should capture the details below
    a. CO2 capture processes with high operational flexibility
    b. Lower cost CO_2 capture technologies and processes, including greater than 90% capture rates, energy system balancing and optimization, and feasibility of carbon negative emissions.

3. Unlocking shared CO_2 transport and storage infrastructure
    NZE2 covers most of this
    a. Support for the characterization, assessment, and management of storage capacity
    b. Technologies for increasing the efficiency of CO_2 storage resource utilization
    c. Methodologies for assessing and costing CO_2 storage liabilities
    d. Development and deployment of European CO_2 transport and storage infrastructure to support full-scale CCS demonstration projects
    e. solutions for CO_2 transportation, including integrated solutions for CO_2 shipping
    f. Integrating power and industrial emitters into CCS clusters

4. Support for the development and operation of demonstration or pre-commercial CCS projects

NZE4 – this should be the ERA-NET ROAD

a. CCS Development Fund (ERA-NET) for achieving the specific targets for CCUS under the SET Plan Action 9

5. Bioenergy and CCS (BECCS) and Bioenergy and CCU (BECCU) for energy sector decarbonisation and negative GHG emissions
   No mention of BioCCS or of negative emissions in the NZEs
   Could be included in NZE5, depending on final wording
   a. Pilot and demonstrate concepts of Bio-carbon capture, re-use and storage (Bio-CCUS) in relevant industrial sectors
   b. Energy system optimization and feasibility of carbon negative and system balancing concepts
   c. Systemic approach of realistic potential with business insight and sustainable impact of Bio-CCUS in different sectors

6. Support to the stakeholders of the European Zero Emission Technology and Innovation Platform (ETIP ZEP)
   CC5 does not include CCS