Novel carbon capture and utilisation (CCU) technologies: research and climate aspects

Scientific Expert Workshop
Brussels, 25 January 2018

SAPEA

Science Advice for Policy by European Academies

Workshop Report No 1

This Workshop Report has been produced under the auspices of the SAPEA Consortium under Grant Agreement Nr 737432 "Science Advice for Policy by European Academies" (SAPEA) that was signed by the Consortium and the European Commission on 22 November 2016.

PUBLISHER

SAPEA
c/o acatech
Pariser Platz 4a
10117 Berlin | Germany

CONTACT

SAPEA Communications Office
13 Rue d'Egmont
Brussels 1000 | Belgium

contact@sapea.info

SAPEA
Science Advice for Policy by European Academies

Novel carbon capture and utilisation (CCU) technologies: research and climate aspects

Brussels, 25 January 2018

Workshop Report 1

About SAPEA

Spanning the disciplines of engineering, humanities, medicine, natural sciences and social sciences, SAPEA (Science Advice for Policy by European Academies) brings together outstanding knowledge and expertise from over 100 academies, young academies and learned societies in over 40 countries across Europe.

Working closely with the European Commission Group of Chief Scientific Advisors, SAPEA provides timely, independent and evidence-based scientific expertise for the highest policy level in Europe and for the wider public.

SAPEA is part of the European Commission Scientific Advice Mechanism (SAM) which provides independent scientific advice to the College of European Commissioners to support their decision making.

The project is funded through a grant from the European Union Horizon 2020 programme running from November 2016-October 2020.

SAPEA comprises the European Academy Networks: Academia Europaea, ALLEA, EASAC, Euro-CASE and FEAM.

For further information about SAPEA visit: www.sapea.info

1. Introduction

The purpose of the workshop was to review and discuss the draft of the SAPEA Evidence Review Report, *Novel carbon capture and utilisation technologies: research and climate aspects*, which examines CCU's mitigating potential on climate change and future research needs.

It took place on 25 January 2018 at the *Palais des technologies* in Brussels, attended by 27 European experts, eight Working Group members, and 22 observers from the European Commission. Its aim was to collect feedback from the scientific community regarding CCU's impact on the following issues:

1. Climate change mitigation
2. Society and related services
3. The energy system as a whole, its sub-systems, and their boundaries
4. The introduction of new technologies
5. New opportunities and challenges, and
6. Future research needs.

The findings of the Evidence Review Report, the Expert Workshop and from a later Stakeholder Hearing will feed into the European Commission Group of Chief Scientific Advisors' Scientific Opinion on the potential of CCU technologies, to be published in spring 2018.

2. Organisation of the Workshop

Following a plenary introduction, three parallel rotating breakout sessions were organised on the following three sub-topics:

1. Societal services impacted by CCU and system boundaries/analysis,
2. Technology overview and a simplified system analysis of services delivery (carbon-energy balance, scale, costs),
3. Opportunities, incentives, challenges, gaps and research scenarios.

3. Outcome

As an emerging topic, there were dynamic discussions on issues around the use of renewable energy; the cost of replacing significant parts of the present energy infrastructure; the share of biomass, hydro, nuclear, etc. in the future energy system and what should be included/excluded in a full-cycle CCU system. Part of the discussion focused on whether to give more space to chemical products from the conversion of CO_2. However, there was general

consensus that in the long-term (a horizon of 2050), CCU would make a decisive contribution to climate change mitigation provided that

- available energy be 100% renewable,
- CCU be a component of a wider systemic approach to energy production, with a cyclic concept of carbon management, implying services other than only mitigating climate
- technologies have been demonstrated.

It would pull the economy out of fossil fuel utilisation, though in the short-term, this effect would be negligible and in the medium-term (at the horizon of 2035) it would still be relatively small.

4. The main points raised during the discussion:

i. Format and Principles of the Report

- In this context the report points to issues going beyond climate change mitigation sensu stricto.
- CCU is treated as a service for the defossilisation of energy production and use in various sectors and systems, including energy, products, and mobility. However, clear boundaries should be drawn between the different systems: on one side the CO_2 sources such as the cement and steel industries, fossil fuel-fired power plants, waste incinerators and the atmosphere, and on the other CO_2 utilisation such as for synthetic fuels for mobility and energy, for chemicals and mineral materials, and for biomass. The concepts of "negative" and "avoided" emissions are not always clearly defined and lend themselves to confusion. CCS (Carbon Capture and Storage) should have its place in the report.
- Full-fledged CCU for defossilising the economy through the substitution of fossil fuels by synthetic ones requires a high percentage of "renewable" electricity generation.
- Requirements for research should be addressed sector-by-sector, domain-by-domain, technology-by-technology, and the potential benefits identified.

ii. Climate Change Mitigation Potential

- Measuring the climate change mitigation efficiency or potential of CCU is extremely difficult as long as CCU is not implemented on a large scale. The scientific relevance of data in this area is not evident. Therefore, estimates are and will remain approximate for some time to come and this should be clearly stated. The experts avoided giving numbers that are not well established.

iii. Cost and infrastructure

- Do we have data on the impact of CCU on electricity prices and infrastructure investment that can be referenced? Is Syngas really the preferred option as energy carrier in a fully-fledged CCU system (transport in existing pipelines)?
- As PV (Photovoltaics) costs are coming down and wind energy is following a similar trend, is there still a need for CCU or is this development a precondition for "total" CCU? Although this might be difficult to achieve (lack of experience), CCU as a service should be benchmarked against other defossilisation services, such as CCS.
- The report considers CO_2 avoidance as a cost item without taking into account that CO_2 emissions should not come free of charge (ETS being ineffective), putting it at a disadvantage compared to CCS.

iv. Life Cycle Analysis (LCA), competing systems, and time horizon

- The report addresses mainly the long-term and advocates CCU within a new energy system with different energy efficiencies. Participating experts indicated that the short- and medium-terms with its various existing energy mixes as well as competing systems such as e-mobility, CCS, biomass, nuclear, methane from waste management, etc. should, however, also be adequately addressed and Life Cycle Analysis (LCA) applied. The working group experts argued that Life Cycle is not relevant in a cyclic carbon approach.

v. Mobility

- Fuel will remain the main mobility vector for aviation and long-distance maritime and road transport. Here, CO_2 emissions are unavoidable and for recovering that CO_2, direct air capture (DAC) will be necessary. This issue is addressed in the report.

vi. Process industries and chemical products

- In the cement industry fly-ash can be used for carbonation with long or indefinite retention times. However, quantitatively, this amounts to nothing of significance. While recently progress on less energy-intensive conversion of Mg silicates to carbonates has been achieved in the lab, it is not yet clear whether a pilot plant would achieve similar results.
- A small number of chemicals using hundreds of thousands to millions of tons of CO_2 as feedstock are already routinely produced and LCA, including CO_2 retention times, should be addressed. Furthermore, the production of technical gases should not be neglected.

vii. Sources of CO_2

- When most industrial point sources in the vicinity of REN (renewable energies) and conversion facilities are tapped, where will CO_2 for chemical products and synfuel come from? A discussion developed on whether the transport of CO_2 from point sources to conversion facilities would be a viable solution or whether direct air capture could become competitive. Some CO_2 producing process industry, such as fermentation, biogas, etc., will always remain and an attempt to estimate the generated quantities should be made.

viii. H_2 production

- Large scale CCU will not work without massive "green" generation of H_2 via electrolysis. Could this lead to water stress? While in theory splitting methane molecules could be cheaper, industrial pilot plants have not given encouraging results so far. This should be stated. On the other hand, new technologies bringing down energy needs and costs for electrolysis can be expected (e.g. photoelectrolysis).

ix. Energy/electricity storage and energy independence

- The huge need for energy storage when going beyond 30% REN raises the question whether CCU with Power to Gas (P2G) is the only option. This depends on the energy mix as well as on the availability of distributed storage in advanced batteries. Data on how much storage capacity is ultimately needed should be provided.
- European energy independence in conjunction with CCU is a very strong argument!

x. Incentives and business model

- Incentives to go for full-fledged CCU will be needed at various levels whether CO_2 is taken from point sources, including fossil fuel fired power stations, cement and steel industries, and waste incineration, or directly from the air. As an example, if the conversion of CO_2 from cement kilns were eligible for subsidies, other industries could follow. Should we aim at incentives for CCU comparable for example with those for biomass production? Are there better examples? In any case, we should aim at competitive costs for synthetic fuels from CO_2 compared with biofuels.
- Should the report at least try to look at "business models" (e.g. business for products), where results could be achieved much more quickly than in the energy domain, even though at relatively modest scales? What sort of subsidies do we need for promoting CCU for products?

xi. Alternative scenarios

1. A fully biomass-based scenario, including methane from waste management, even if it cannot assure "negative emissions".
2. An "ammonia economy". Ammonia is also an energy vector (however, less efficient per volume than synfuel).
3. High-temperature solar reactors for syngas from water and CO_2.
4. A methanol economy (Synthetic methanol from CO_2).
5. Full-fledged CCS.

5. CONCLUSIONS

The Workshop has been a very useful element in the preparation of the final version of the report on Carbon Capture and Utilisation. The participants discussed the long-term potential of Carbon Capture and Utilisation technologies as described in the report and on most of the basic assumptions while providing several constructive comments on elements where further information might be needed, such as on the methodology employed in the study, on the medium term impact, how in practice and to what extent CCU might contribute to climate change mitigation in different scenarios, the role of new technologies for H_2 electrolysis, cost-related data on new infrastructure and equipment. Last but not least, a business model for CCU might be a good idea, but the Working Group experts argued that there are too many uncertainties and it is therefore too early.

The organisers thank all participants for their valuable contributions.

Scientific Expert Workshop on "Carbon Capture and Utilisation"

(Palais des académies, Brussels, 25 January 2018)

Agenda

SAPEA
Science Advice for Policy by European Academies

Room Rubens:

09:00 – 09:05	Welcome, *Prof. Joos Vandewalle,* President KVAB
09:05 – 09:15	Introduction to SAM and SAPEA, *Prof. Elvira Fortunato*, Member of the Group of Chief Scientific Advisors and *Yves Caristan*, Secretary General Euro-CASE and SAPEA board representative
09:15 – 09:25	Introduction to the topic and task, *Prof. Robert Schlögl*, Chairman
09:25 – 09:50	Introduction of participants, using one PowerPoint slide each
09:50 – 10:00	Workshop structure – agenda and rules
10:00 – 13:15	Break-out sessions – 3 parallel rotating sessions

Round 1:

10:15 – 11:15	**Room Stevin:** *Societal services impacted by CCU and system boundaries/system analysis* – Leader: Carlos Abanades
10:15 – 11:15	**Room Marie-Thérèse:** *Technology overview and simplified system analysis of services delivery (carbon+energy balance, scale, costs)* – Leader: Marco Mazzotti
10:15 – 11:15	**Room Albert I:** *Opportunities, incentives, challenges, gaps and research scenarios* – Leader: Gabriele Centi

Round 2:

11:15 – 12:15	Break-out sessions same as Round 1

Round 3:

12:15 – 13:15	Break-out sessions same as Round 1 and 2

13:15 – 14:00 Lunch (Throne room)

Room Rubens:

14:00 – 15:30	Reporting from Break-out sessions – Session Chairs (30 min each, including discussion)
15:30 – 17:00	Presentation of report's final part on "Assessment of potential & conclusions" and discussion in the plenum – Robert Schlögl and Marco Mazzotti
17:00 – 17:30	Final discussion, conclusions/wrap-up, Robert Schlögl.
17:30	End of Meeting

Session descriptions

There will be three parallel but rotating sessions, each lasting one hour. In each of the sessions there will be roughly an equal number of participants. After one hour all participants (except the discussion leaders) will leave their current rooms and move to the next parallel session with a different topic, where they will again remain one hour and then move to the last session. After three hours each participant will thus have had an opportunity to cover the whole range of issues. It should be noted here that the study proposes options rather than making recommendations.

Session: Societal services and system boundaries

Objective of the session:

Understanding how Carbon Capture and Utilisation can fulfil the aim of reducing CO_2 emissions and ultimately even reducing the present level of atmospheric CO_2 in the context of a service system whereby CCU ultimately becomes the lever enabling continuous recycling of CO_2 into synthetic fuels and other products without the need for introducing any fresh fossil carbon (coal, oil, natural gas) into the cycle.

Background:

CCU is not, at this time, included in any EU scheme allowing derogation from ETS or even active promotion, there being only the CCS directive addressing the issue of carbon economy. The session will provide an opportunity to explain the system boundaries, including direct air capture (Capture of CO_2 not only from point sources such as coal-fired power stations, steel mills, cement factories, etc., but directly from ambient air) and biomass utilisation. Much emphasis will be placed on renewable energy sources, providing the energy that is needed in order to extract and concentrate CO_2 and break the O=C=O bonds and produce H_2 from water. While economically speaking CCU does not comply with any law of return of investment in the short term, in the long term it makes good sense as a social service, preserving a liveable and sustainable environment.

Key questions:

- How should we look at CCU as a service? What is the service that it provides, including environmental aspects and energy independence? Is this a realistic option; and if yes, under which circumstances?
- Can industrial innovation and competitiveness be supported through the circular economy, recycling CO_2 in synthetic fuels and products?
- Is CCU a realistic alternative to CCS?

Session: Technology overview and simplified system analysis of services delivery

Objective of the session:

Understanding: the technology behind CCU and its constraints in particular with respect to the carbon and energy balance (input and output); the role of CO_2 recycling through synthetic fuels versus fixation of CO_2 in products and the respective share in CO_2 sequestration; the role of scale (an industrial plant will not necessarily reproduce the results obtained in the lab); the economic fundamentals.

Background:

At present, the energy system is fuelled largely by fossil fuels such as coal, oil and natural gas. Liquid fuels have the highest energy density while natural gas has the lowest CO_2 emission per energy content, with coal having the highest. In addition, nuclear, hydro, wind, solar and biomass provide also sizeable proportions of energy, some more, some less flexible with respect to demand.

All fossil-powered energy systems provide relatively cheap energy, with coal being the cheapest. Changing this system into one where renewable energy is used to recycle CO_2 into energy carriers and chemical products does not come free of charge. Again, it does make sense when looking at it as a service (e.g. transport, electricity, industry, etc.)

Key questions:

- To which extent can climate change objectives be supported by replacing crude oil and gas in chemicals and fuels (and through fixation of the CO_2 in materials)?
- Is the use of peak renewable energy for CCU a viable and desirable option?
- Would we prefer using electricity from renewable sources directly, such as for electric cars?
- Do we have an idea of the full costs involved?

Session: Opportunities, incentives, challenges, gaps and research scenarios

Objective of the session:

Understanding: beyond the remaining substantial technological issues there are vast opportunities for industry and smaller enterprises in bringing the CCU system up to speed; to what extent financial (and non-financial) incentives can accelerate the transition to a full CCU system; what is still missing to make CCU a realistic option (the gaps) and what research might be needed to bridge these gaps.

Background:

The present energy system is the result of heavy investment in capital intensive machinery, transmission infrastructure, and buildings, etc. In order to get the transition towards a carbon neutral or even carbon negative system up and running, we need to see the opportunities that come with such a transition but also put in place financial and non-financial incentives. Such incentives are already in place for bio-fuel. Can we apply similar incentives to synthetic fuels and other CO_2-based products? Evidently, creating a system mainly (or totally) based on renewable energy sources is a huge challenge. In particular storing intermittent energy poses a huge problem. Is Power-to-gas a viable storage solution, H_2 becoming the vector? It becomes quickly evident that there are still large gaps in technology availability and knowledge to fill and only research can fill them.

Key questions:

- Can we identify the opportunities offered by the transition to a full CCU system?
- What incentives would be needed to make the opportunities attractive?
- Which solutions for storage of energy are available (power to gas, flow batteries, lithium batteries)
- How realistic are these solutions?
- How much efficiency increase can be expected in the various scenarios of CO_2 capture and conversion and in energy conversion and storage?
- Where should we invest in R&D to make the system more efficient?

After Lunch:

The rest of the day will be spent on reporting and discussion of session outcomes and a presentation of what will be the "Assessment of potential and conclusions" of the CCU Report and its discussion in the plenum. As already mentioned in the introductory paragraph, the discussion of options rather than the formulation of recommendations is to be considered a core outcome of the study. A scientific opinion on the challenges and opportunities of novel CCU technologies in particular with respect to their climate mitigation potential will be drafted by the European Commission Group of Chief Scientific Advisors.

List of participants

Carbon Capture and Utilisation Expert Workshop, 25 January 2018, Brussels			
Invited Experts			
Bardow	André	Energy Systems, RWTH	Germany
Bowker	Michael	Cardiff Catalysis Institute	UK
Breyer	Christian	Lappeenranta University of Technology	Finland
Carus	Michael	nova-Institut GmbH	Germany
Chadwick	David	Imperial College of London	UK
Chorkendorff	Ib	V-SUSTAIN	Denmark
Ciais	Philippe	Laboratoire des Sciences du Climat et de l'Environnement	France
Dibenedetto	Angela	International Conference on Carbon Dioxide Utilization	Italy
Faaij	Andre	University of Groningen	The Netherlands
Filippi	Ermanno	Casale SA	Switzerland
Gazzani	Matteo	Utrecht University	The Netherlands
Hoppe	Helmut	ECRA	Germany
Iaquaniello	Gaetano	Kinetics Technology	Italy
Kakaras	Emmanouil	Mitsubishi Hitachi Power Systems Europe GmbH	Germany
Loréa	Loréa	CEMBUREAU	Belgium
Mac Dowell	Niall	Imperial College of London	UK
Markowz	Georg	Carbon CEEnergy	Germany
Millini	Roberto	Eni S.p.A.	Italy
Perathoner	Siglinda	University of Messina	Italy
Quadrelli	Alessandra	CPE Lyon	France
Pant	Deepak	VITO	Belgium

Ramirez Ramirez	Andrea	TU Delft	The Netherlands
Røkke	Nils	SINTEF, EERA, SET-Plan	Norway
Smit	Berend	EPFL	Switzerland
Strömberg	Lars och Birgitta	Vasa Värme	Sweden
Vainikka	Pasi	VTT	Finland
Working Group members			
Schlögl (Chair)	Robert	Fritz-Haber-Institute	Germany
Abanades	Carlos	Spanish Research Council	Spain
Aresta	Michele	CIRCC, University of Bari	Italy
Cantat	Thibault	CEA	France
Centi	Gabriele	University of Messina	Italy
El Khamlichi	Aïcha	ADEME	France
Mazzotti	Marco	ETH Zürich	Switzerland
Mikulcic	Hrvoje	University of Zagreb	Croatia
Olsbye	Unni	University of Oslo	Norway
KVAB			
Vandewalle	Joos	President	Belgium
Scientific Advice Mechanism (SAM)			
Fortunato	Elvira	European Commission Group of Chief Scientific Advisors	
Heuer	Rolf-Dieter	European Commission Group of Chief Scientific Advisors	
Klumpers	Johannes	DG RTD – SAM Unit	
Carvalho	Maria da Graça	DG RTD – SAM Unit	
Boavida	Dulce	DG RTD – SAM Unit	
Caristan	Yves	SAPEA	France
Gehrisch	Wolf	SAPEA	France
Verraes	Jacques	DG RTD – SAM Unit	
Salvi	Maurizio	DG RTD – SAM Unit	

Cotta	Jose	DG RTD – Advanced Energy Production	
Kougionas	Vassilios	DG RTD – Advanced Energy Production	
Tiedje	Jurgen	DG RTD – Advanced Manufacturing Systems and Biotechnologies	
Bowadt	Soren	DG RTD – Advanced Materials and Nanotechnology	
Tilche	Andrea	DG RTD – Climate Change and natural hazards	
Joliff-Botrel	Gwennael	DG RTD – Energy Strategy	
Velkova	Maria	DG CLIMA – DG for Climate Action	
Gumbert	Andreas	DG CLIMA – Road Transport	
Sakellaris	Konstantinos	DG CLIMA – Strategy and Economic Assessment	
Maniatis	Kyriakos	DG ENER – DG Energy	
Schally	Hugo-Maria	DG ENV – DG for Environment	
Handley	Peter	DG Grow – DG Internal Market, Industry, Entrepreneurship and SMEs	
Peteves	Estathios	DG JRC – Joint Research Centre	
Tzimas	Evangelos	DG JRC – Joint Research Centre	
Klimke	Torsten	DG MOVE – DG for Mobility and Transport	

Spanning the disciplines of engineering, humanities, medicine, natural sciences and social sciences, SAPEA brings together the outstanding knowledge and expertise from over 100 academies, young academies and learned societies in over 40 countries across Europe.

SAPEA comprises the European Academy Networks: Academia Europaea, ALLEA, EASAC, Euro-CASE and FEAM.

SAPEA is part of the European Scientific Advice Mechanism (SAM) which provides independent, interdisciplinary and evidence-based scientific advice on policy issues to the European Commission. SAPEA works closely with the European Commission Group of Chief Scientific Advisors.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 737432

www.sapea.info
@SAPEAnews