Club CO_2

International Overview on CCU

Symposium

July 2nd 2018
PARIS







Acknowledgements

Club CO_2 thanks all the speakers and the members of ISO/TC265 who accepted to participate in the symposium.

A big thank you to IPGP as well for hosting the event. Club CO_2 is especially thankful for the help of Benedicte Menez and Irène Pesty.

The workshop on LCA and standardization was very fruitful thanks to the participants.

Executive Summary

The **"International Overview on CCU Symposium"** is associated to the ISO TC/265 Plenary Meeting: the entire week, there will be discussions on the extension of the TC's scope from CCS to CCUS. One first discussion will be to **develop LCA guidelines for CCU** and we hope that today's discussion will generate input for this work.

CO_2 utilization is a subject for many countries, linked to climate policies. It has a clear role to play at different time scales. Hence, most of them plan to **support research and demonstration projects** in order to encourage new technologies and to improve their performances. Supporting countries' strategies, transnational actions pave the way for the deployment of CCU:

- **ERANET ACT CCUS** is an international initiative aiming to facilitate innovation,
- **Initiative Phoenix** is linking national and European RD&I activities on CCU,
- **ECCSEL** network gathers world-class research infrastructure in Europe for developing CCUS technologies,
- **Mission Innovation Carbon Capture Challenge** targets to enable near-zero CO_2 emissions from power plants and carbon intensive industries.

Strongly involved in climate actions, DG-RTD presented H2020 outcomes, the new Programme Horizon Europe and the report on the climate mitigation potential of CCU technologies by SAM. CCU decarbonization potential is still debated and DG-RTD considers that a **harmonized Life Cycle Assessment** is a key tool to assess this potential.

According to Global CO_2 Initiative, **from a business point of view, insights are promising**: by 2030, there exist a potential to use over 6 Gt CO_2 per year and to generate **1 trillion US$ /year**. However significant progress towards scalable technologies is needed. Building materials, chemical intermediaries, fuels and polymers represent the biggest markets.

The International Energy Agency reminded us the **important place of CCUS in achieving global climate targets**. The portfolio of technology should represent 15% of cumulative reduction in 2060 (about 100 Gt) to comply with a 2°C-scenario and up to 32% (close to 200 Gt CO_2) to be below 2°C. IEA identified mineralization technologies as promising.

During the workshop session, AFNOR highlighted how standardization could support the assessment of CCU and its deployment. Existing methodologies of LCA are not precise enough and work should be continued in order to define **harmonized guidelines**: three different methodologies have been presented:

- EU-Methodology for quantifying GHG for fuels from CCU (JRC)
- US Department of Energy's LCA guidance and tools for CO_2 Utilization
- Global CO_2 Initiative' LCA & TEA guidelines

From discussions with the attendance, **nine recommendations have been produced** to improve the assessment of CCU technologies:

Reco #1	**Improve the definition of the "Goal and Scope"** (System boundaries, function, functional unit). **Application and local market should be identified in a first step to serve as basis for LCA.**
Reco #2	**Use LCA for screening and optimizing new CCU technologies at an early stage (even at lab scale).** It should not be the final analysis to perform after technology development at TRL9.
Reco #3	**Consider two different references for the reference scenario** (to be compared with the CCU-scenario): 1. The current, most available process/technology, 2. An environmentally competitive solution even if it's currently not economically viable.
Reco #4	**Make available more specific & reliable data**, eg CO_2 captured, data of CO_2 utilization processes, hydrogen,…
Reco #5	**A LCA is a multicriteria analysis to identify environmental burden transfer. Therefore, the global warming potential (GWP) should not be the only environmental impact assessed.** **The most relevant environmental impacts should also be assessed (eg: land use, human toxicity, resource depletion, etc.). This assessment will be communicated to the scientific community.** Specifically regarding CO_2, there is a need to figure out: 1. The amount of CO_2 utilized into the process 2. The amount of CO_2 avoided into the process 3. The GWP (considering upstream).
Reco #6	If it is decided to **aggregate the impacts:** - An **aggregation method of impacts should be agreed upon** - Or, at least, **a list of methodologies of aggregation should be clearly presented and defined** This assessment will be used by **policy makers to decide between technologies**
Reco #7	**If system expansion is not considered, allocation of impacts should be done over the whole value chain from the CO_2 emitter to the actor using CO_2:** there is a need to define economic value creation/penalty and environmental benefits/burdens, and to share these values. **Make integrated assessments (economic and environmental) even for low-TRL technologies.**
Reco #8	**Make ISO technical prescriptions** of processes, properties and performances of products.
Reco #9	**Harmonized LCA guidelines for CCU processes through ISO standard should be define to address the main pitfalls (eg definition of FU, goal and scope,…). Technical prescriptions and standards may help to create a label for CO_2-based products/services.**

Norway:
- FUTUREFEED: conversion of CO_2 into methanol, chemicals, polymerisation
- Finnfjord / UiTprotect (bioconversion)
- CO_2 BIO/Univ. of Bergen (high added-value chem.)

Germany:
CO_2 Plus
Kopernikus
Carbon2Chem

United Kingdom:
BEIS's programme on CCUS (2016-2021)

Canada:
ACCTC
Valorisation Carbone Quebec

France:
- VALORCO (chemicals)
- JUPITER1000 (methane)
- CRYOCAP (CO_2 capture)

Mexico:
Carbon Capture Pilot Project (CCPP) on poza Rica NGCC plant

Germany:
- Compensation stone (mineralization)
- Captured CO_2 to boost biomethanol production

- Bioconversion: Xin'Ao Group CO_2 Fixed by Algae into Bioenergy Demonstration Project
- Mineralization: Sichuan Univ.-Sinopec Joint Carbon Utilization Project
- Chemicals: Lu'An Group CO_2 Reforming of Methane
- Fuels: Large project of Carbon Recycling International

- Carbon Conversion Flagship
- Carbon Mineralization Flagship

Mineral Carbonation International PTy Ltd

Mineral carbonation, chemicals, bioconversion projects

Contents

Plenary Session

1. Welcome

Valérie Czop, President of French Mirror Committee ISO/TC265, EDF

In June 2012, France hosted the kick-off meeting of **ISO TC265**. Six years later, a lot of work has been done, thanks to the experts coming from 18 member countries and 11 observer countries, involved in 6 working groups.

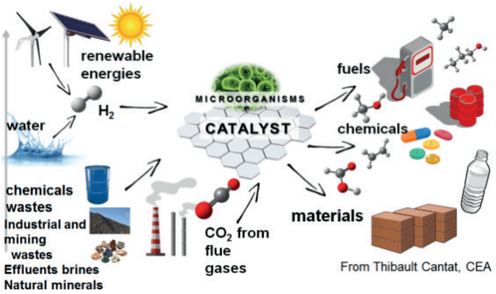
On July 3rd 2018, TC265 is back in France for its eleventh plenary meeting. Two new issues at least are now considered: **CCS in other industries than power** (eg cement sector) and CO_2 Utilization. We all know that **CO_2 utilization** doesn't address to large CO_2 emitters (as power plants) but we are convinced that it must be taken into account as one of the solutions against global earth warming.

The French Mirror Commission chaired by Valérie Czop is strongly supported by Club CO_2 (which endorses this TC meeting as well) and relies a lot on the Club CO_2's collective expertise. Plus Club CO_2 has been working on CO_2 utilization for several years. Therefore, it seemed obvious that we could take advantage of the opportunity of having worldwide experts coming to France for the ISO meetings to organize a working day on CO_2 utilization.

2. Opening Address

D. Bonijoly, President of Club CO_2

The ADEME (French Environment and Energy Management Agency) founded Club CO_2 in 2002 with the support of the IFP Energies Nouvelles (IFPEN – formerly French Petroleum Institute) and (BRGM (Bureau of Geological and Mineral Research).



On March 19th, 2016, Club CO_2 became a non-profit association registered under French law with the BRGM as Chairman and EDF and IFPEn as administrators.

The Club unites together **24 actors of the industrial world and of research**. Club CO_2 is pursuing its involvement in the promotion of CO_2 utilization (CCU) as a means of reducing the carbon footprint of the economy.

3. European context and regulatory framework: implications for research and innovation

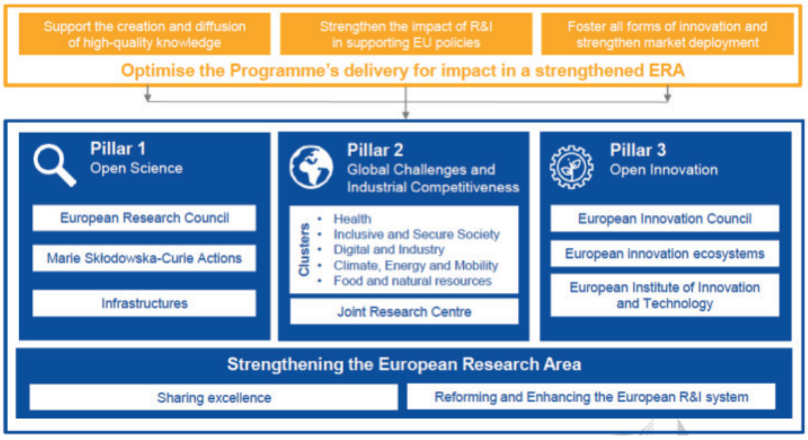
Jurgen Tiedje, EC-DG RTD

Horizon 2020 is providing major support to activities in CO_2 utilization. A study published in February 2018 by DG RTD[1] found at least **61 projects related to CO_2 utilization, from FP7 and mainly Horizon 2020** for a total EU contribution in excess of **240 M€**. Within H2020, the **SPIRE** initiative (Sustainable Process Industry through Resource and Energy Efficiency) has the following objectives:

- A reduction in fossil energy intensity of up to 30% by 2020
- Efficiency improvement of CO_2-equivalent footprints of up to 40%
- Major integration of industrial processes through Industrial Symbiosis
- A reduction in non-renewable, primary raw material intensity of up to 20%

1- https://ec.europa.eu/info/research-and-innovation/strategy/support-policy-making/scientific-support-eu-policies/p4p_en#p4p_sustainable

Horizon Europe is the Commission proposal for a **100 billion € research and innovation funding** programme for **2021-2027**. There's a 35% budgetary target for tackling climate change.



Commissioner Cañete requested to SAM (EC Scientific Advisory Mechanism) to provide scientific advice based on existing research on the **climate mitigation potential of CCU technologies** to inform future policy decisions. The SAM Report has been published[2] : **CCU can play a role in decarbonizing the economy and reach EU climate targets**.

- It can enable the shift to RES (ie provide chemical energy storage and grid services).
- Critical Requirements: Abundant and cheap low carbon energy
- **Develop a methodology to assess the climate mitigation potential of CCU technologies** (starting point: Clean Development Mechanism-UNFCC). **Harmonized LCA practices for CCU** to constitute an integral part of such methodology.
- Develop a cross-sectoral, systemic regulatory and investment framework for CCU.
- Strategic aspects related to CO_2 as alternative feedstock for industry and business implications has not been thoroughly analyzed.

Questions raised: Should CCU be eligible for ETS system? Does CCU have added-value in a circular economy?

Conclusions:

- Debate between CCU decarbonization potential and circular economy opportunities is ongoing, business opportunities are to be considered as well.
- GAPS: There is a need for streamlined methodologies to assess CCU investments, harmonized LCA methodologies for CCU as a critical building block.
- GAPS: The market deployment, penetration and the sustainability of CO_2 utilization technologies is intrinsically linked to the deployment of RES.
- Strong momentum is possible, but strong commitment from industry and society is highly needed.

2- http://ec.europa.eu/research/sam/pdf/sam_ccu_report.pdf#view=fit&pagemode=none

4. Potential global market of CCU

Volker Sick, Global CO_2 Initiative

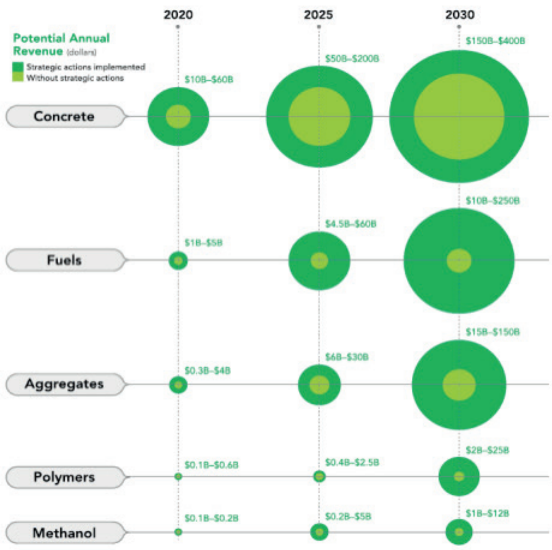
Existing industry needs to adopt a CO_2 emissions reduction program but the timeline is short. More than strong policy, incentives are required to develop and to accelerate the deployment of CCU technologies.

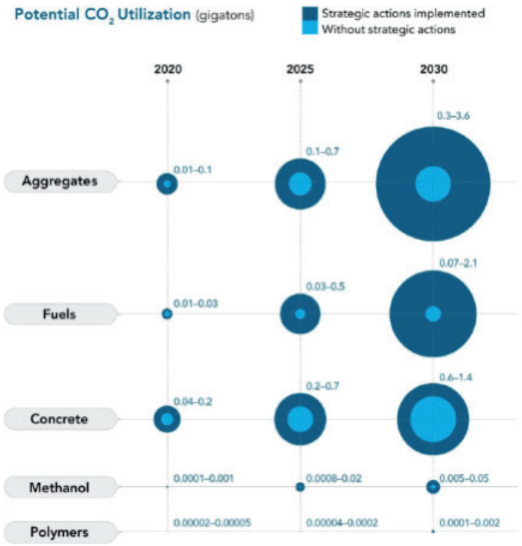
Barriers of CCU deployment:

Technology	Lack of coherent funding strategy Need to improve CO_2 capture and H_2 production from reduction or electrolysis
Market	Lack of access to feedstocks; address the need for access of inexpensive and large scale quantities of CO_2 Lack of competitiveness of CO_2-based products. CO_2-based products have to compete with conventional and bio-based feedstocks. These options are often lower in cost.
Policy	Lack of long-term policy framework: need to explore both incentives and credits as well as a carbon price. Governments need to fund R&D research

GCI used the following methodology for the development of the **Roadmap for CO_2-based Products:** Technology Landscaping ; Preliminary market assessment; Accelerating deployment of CO_2-based products.

Annual market size could reach $800 billion - $1.2 trillion with annual CO_2 consumption from 3 to 6 Gt/yr. Top 4 markets in terms of environmental impact and commercial opportunity are **building materials, chemical intermediates, fuels and polymers**.





Key strategic actions to accelerate implementation:

- Increase the cost of polluting competition
- Decrease cost of utilization of CO_2
- Scaling-up production
- Steady supply of CO_2: Governments should incentivize development of a CO_2 infrastructure to anticipate growth in CO_2 demand
- Maximize high potential long shots: target applications that have the highest CO_2 abatement potential.

We need a **common model to assess potential of CO_2-based products** and to answer the question: are they carbon-negative and profitable? Guidelines have been developed and a toolkit v1 for LCA and TEA will be released in October 2018.

Conclusions:

- CO_2-based products offer a significant opportunity to mitigate CO_2 emissions driven by market returns.
- By 2030 potential to utilize over 6 billion metric tons of CO_2 per year / 1 trillion US$/year.
- Significant progress towards scalable technologies is needed.
- Building materials, chemical intermediaries, fuels and polymers represent the biggest markets.
- Funding, incentives and prompt strategic action are necessary to move the CO_2-based products industry towards full-scale capacity. The path to a 2°C future depends on it.
- A public release of LCA-TEA toolkit and market study will come soon.

5. Session 1: International overview on CCU

5.1 Australia

Michael Malavazos, Director Engineering Operations, Energy Resources Division, Premier and Cabinet

National Policy background

- Commonwealth (federal) and state legislation in existence since early 2000's to permit and regulate CCS and CCUS projects
- Renewable Energy Target (RET): dominating factor in Australian Emission Reduction Policy scheme over the last decade
- Moving to an Emissions Reduction Target (ERT)-type Scheme through recent National Energy Guarantee (NEG) Initiative

Key actor in CCU

Mineral Carbonation International Pty Ltd (MCi), a joint venture between the Greenmag Group, Newcastle University and Orica, develops and optimizes a promising method of utilizing CO_2.

The Mineral Carbonation process mimics and accelerates the Earth's own carbon sink mechanism process, whereby CO_2 is captured in mineral deposits and then stored in rocks. These solid products can be used in various applications including building materials. Currently the research team has built and commissioned a batch plant and a semi continuous plant at the University of Newcastle.

The aims of the project are to:

1) decrease the cost for storing CO_2 by mineral carbonation by 40%;
2) decrease the energy intensity by 40%;
3) develop new, and improve the existing, unit operations to optimize the process and test these unit operations in the demonstration plant;
4) identify and optimize the production of offsets (eg pavers and bricks) or metal ores
5) identify suitable locations in New South Wales for sourcing feedstock for the demonstration plant

Australia is also involved in four CCS projects and a CO_2-EOR project is under preparation in Cooper Basin.

5.2 South Korea

Sangsik Yim, Korea Gas Safety Corp.

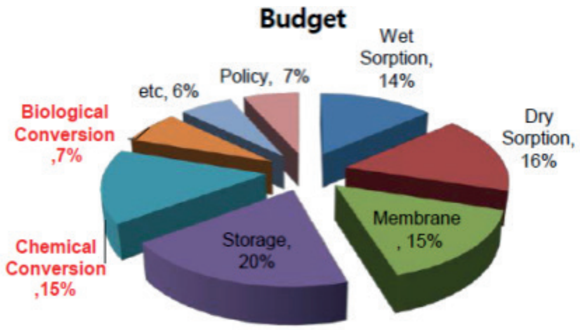
National Policy background

- Framework Act on Low Carbon, Green Growth (April 14th, 2010)
- 1st Framework Action on Climate Change reported from Governmental Department (Dec. 2016)

Key actors in CCU

CCUS is supported by ministries through demonstration and research funding by the Ministry of Science and ICT as well as the Ministry of Trade, Industry and Energy). Korea Agency for Technology and Standards (KATS) supports the standardization of all industrial technologies. Korea Gas Safety Corporation (KGS) supports the standardization of CCUS.

Outstanding projects



1. **Korea CCUS program (2011-2020)** funded **51 projects** for **151M. US$.**

22% of the budget is allocated to CCU (chemical and biological conversion).

2. **National Strategic Project for Carbonization** (2017-2022, 42 million US$):

- **Carbon Conversion Flagship:** Technology for separating and utilizing the C1 gas of industrial by-product gas to produce useful raw material (23M US$)
- **Carbon Mineralization Flagship:** Technology to produce abandoned mine fillings by directly utilizing low-concentration CO_2 emitted from a power plant (19M US$)

Miscellaneous

CCU is one value chain for reducing emissions of CO_2. Technologies of utilization and storage must be performed in parallel.

Economic and environmental questions should be addressed simultaneously:

- To reduce costs of CCU (purity of CO_2, catalyst improvements,...)
- To assess the potential of CO_2 reduction (which must be quantified and verified)
- To assess the storage time of CO_2

5.3 China

Bo Peng, China University of Petroleum (Beijing)

Policy background

CO_2 Emission Reduction is correlated to Chinese Energy Structure. Coal will still be the main energy source and **CCUS should play an important role**. A new energy structure is required to remove the need for coal entirely. Low carbon policies are driven at national level (NDRC, MOST, Environmental) and regional level (local governments). The carbon market started in December 2017.

The Main Purpose of CO_2 Utilization is Emission Reduction. Two major documents pave the way:

- "Assessment Report of Carbon Dioxide Utilization Technology in China" (2015)
- CCUS roadmap is being updated and will be published in 2018

Key projects

Bio-conversion	Project: Xin'Ao Group CO_2 Fixed by Algae into Bioenergy Demonstration Project Products: Biodiesel, feed ,etc. CO_2 utilization: ~20,000 t/yr
Mineralization	Project: Sichuan Univ.-Sinopec Joint Carbon Utilization Project Scale: 1 000 t/yr
Chemicals	Project : Lu 'An Group CO_2 Reforming of Methane
Fuels	Large project of Carbon Recycling International

Among other uses:

- Enhanced Oil Recovery: CNPC, SINOPEC, Yangchang
- Enhanced Coal Bed Methane(ECBM)

Miscellaneous

Question of the **assessment of CO2 utilization technologies is raised**. There's a need of **technology development, Economic and business models, Policy, QV** and **LCA**.

5.4 India

S. K. Sharma, Professor Emeritus (presentation by videoconference)

Policy

India's Intended Nationally Determined Contributions (INDC) for the period 2020-30 are aimed at reducing emission intensity of its GDP by 33-35% by 2030 compared to the levels in 2005.

The country intends to create carbon sinks of 2.5-3 billion tons of CO_2 equivalent by increasing forest cover and by using chemical, biological and mineral processes.

National Programme on CO_2 Sequestration Research (NPCSR) is being coordinated by DST, Gov. of India for promoting research on development of Technologies for CCUS. More than **110 projects** have been funded. Projects undertaken include:

1. Carbon capture process development
2. Catalytic conversion of CO_2
3. Materials for CO_2 capture
4. Membrane separation of CO_2
5. Effective carbon-dioxide use
6. Sorbents/absorbent
7. Chemical mineralization
8. Development of nanomaterials for CO_2 sequestration
9. Carbon dynamics in different land use sectors in the long term context of carbon sequestration; crop land, forest land, grass land, wet land and agro-ecosystem
10. Biological carbon sequestration: including terrestrial, fresh water and marine form,

Some examples of pilot/commercial CCU/CCS plants:

- 60 kt/yr CO_2 converted into soda ash in Tutikoran
- Capture of CO_2 by amine absorption at:
    - the Aonlaurea plant of Indian Farmers Fertiliser Cooperative with Chemical Production of 450 t/d at Jagdishpur, India
    - the Urea plant of Indo Gulf Corporation Ltd has a production capacity of 150 t/d urea plant of Indian Farmers Fertiliser Phulpur, India
- CCU project for production of alcohol from refinery gases initiated at Panipat Refinery
- Set-up of an algae-based process for capturing CO_2 from National Aluminium Company (NALCO) coal-fired plant at Angul, Orissa

Miscellaneous

Key questions on CCU:

- Technology: Energy penalty, energy recovery, carbon capture efficiency,
- Economics: cost of avoided CO_2, retrofit cost, optimal scale of operation
- Environmental: net carbon emission reduction

5.5 Germany

Dr. Cyriac Massué, Max-Planck-Institute for Chemical Energy Conversion, Germany

Policy

Germany has an ambitious target for CO_2 emissions reduction, by 80% to 95% by 2050 (compared to 1990 with emissions of 1 200 Mt CO_2 eq).

Key programmes and projects

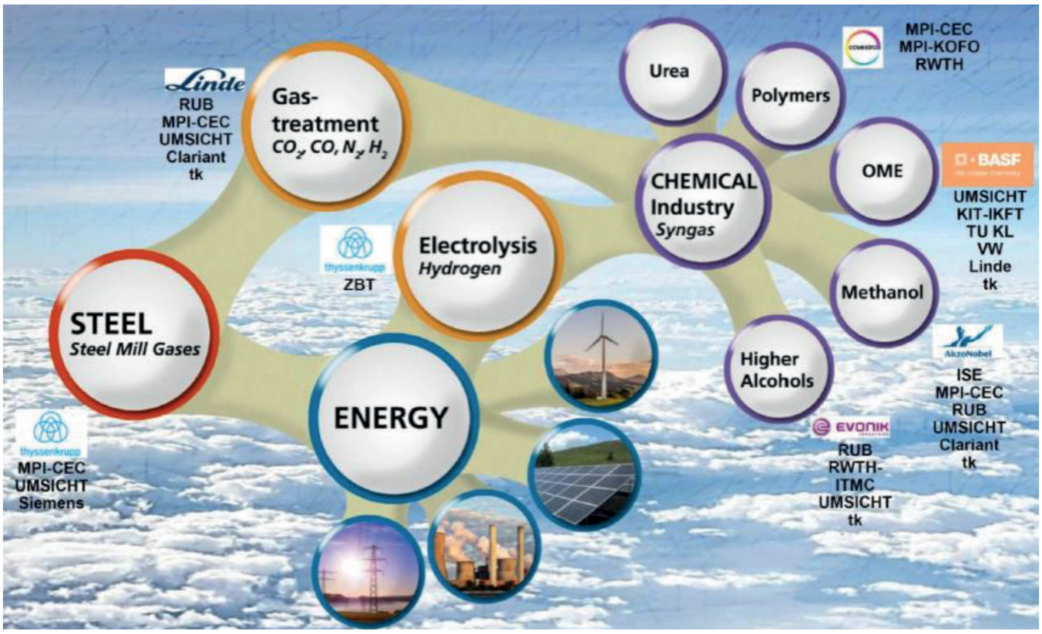
How to close C-loops? 3 major programmes have been carried out:

- CO_2 Plus[3] (2016-2019): 15M€
- Kopernikus[4] P2X (2016-2019): 32 M€
- Carbon2Chem[5] (2016-2020): 60 M€

Carbon2Chem intends to close the C-cycle for the steel industry via power-to-X. The pilot built consists in:

- A gas cleaning unit (Capacity: 100 Nm^3/h coke oven gas; 70 Nm^3/h basic oxygen furnace gas; completed in April 2018)
- Renewable H2 generation by water electrolysis (Capacity: 440 Nm^3/h H2-production rate; completed in April 2018)
- CO_2 conversion plant in chemicals with Covestro, BASF, Evonik, ...

3- http://www.chemieundco2.de/en/co2plus/
4- https://www.kopernikus-projekte.de/en/projects/power2x
5- https://www.thyssenkrupp.com/en/carbon2chem/



By 2020, **industrial partners pledge 1 G€ for real scale construction**.

5.6 Netherlands

Bart van den Berg, Netherlands Enterprise Agency

Policy

By 2030, the new climate law targets 49% CO_2 reduction in electricity, industry, transport, consruction and agriculture. **CCU offers opportunities alongside CCS**.

Government supports CCUS through research and demonstration funding:

- 2017/2018: CCUS tender in 'Top Sector Energy' programme
- 2018: CCUS Pilots and CCUS Feasibility studies
- 2018: Fiscal measures to support capture, transport, re-use of CO_2
- 2018/2019: ACT call
- Future: "Broaden renewable energy premium" (Coalition Agreement)

Projects and initiatives

Today, there is an **active CO_2 market for greenhouse applications** in The Netherlands: greenhouses use 500 kt/year of industrial CO_2 (OCAP grid).

Among CCUS projects:

- CO_2 capture pilot at Waste Incinerator of Twence (2 kt/yr)
- "Compensation stone" of DRBG, with 250 kg/m³ CO_2 (mineralization)
- "Groen gas Almere" and Kloosterman and various other biofermenters deliver Bio-CO_2 to industrial gas companies
- Bio-MCN uses captured CO_2 to boost bio-methanol production
- Example of R&D: Electrochemical conversion (development at low TRL scale)

New initiatives between industry and research are emerging rapidly:

- MWIs aim to capture CO_2 for utilization
- AVR announced plans for CO_2 capture in Duiven
- Green Deal CO_2 delivery North Holland
- BioCCS is already in place on biogas production plant through several Dutch technology providers
- Dow Chemicals Terneuzen and Arcelor Mittal to collaborate

6. Session 2: International overview on CCU

6.1 Norway

Gaëlle Cauchois, Carbon Limits

Policy

There is no clear, strategic push for CCU at a national level, even if some initiatives are receiving support. Norwegian authorities and its funding agencies have mainly focused on CCS. **CCU is not seen as a long-term storage option and there is no real industry in Norway that can convert large amounts of CO_2** (for example for CO_2-to-methanol or fuels). The Research Council funds CCU projects, but these projects have to be part of other strategic initiatives (energy, nanomaterials).

Actors

Among key actors: Equinor, Sintef, CO_2BIO, Finnfjord, Norner, UniResearch, Nordic Blue Crude (Sunfire technology), University of Bergen, University of Oslo, University of Southeast Norway, University of Tromso.

Projects

Futurefeed	Activities on: 1. materials for the reduction of CO_2 to CO 2. the conversion of CO_2 to methanol 3. the conversion of CO_2 to chemicals 4. the polymerization of CO_2 and epoxides to aliphatic (polycarbonates) They have also looked at the conversion of CO_2 into the useful chemicals propylene carbonate, acrylic acid, phenyl carbamates.
Finnfjord/ UiTproject	Project of algae production (world's largest closed photo-bioreactor 300 m3) National Centre for CCU funded by the Norwegian government Looking for potential participants for an interdisciplinary and inter-sectorial CCU consortium
CO_2BIO/Univ. of Bergen	The aim of the pilot is to establish a manufacturing facility that can produce omega-3 and other high-value products from algal biomass, using pure CO_2 captured at TCM and residual heat from the TCM plant.

Miscellaneous

ERANET ACT CCUS[6] is an international initiative to facilitate RD&D and innovation within CO_2 capture, utilization and storage. From 2018, ACT is open for countries all over the world with interest in CCUS. Eleven countries participate in ACT: France, Germany, Greece, the Netherlands, Norway (ACT coordinator), Romania, Spain, Switzerland, Turkey, the UK, and the USA.

6- www.act-ccs.eu

6.2 France

Paul Bonnetblanc, French Energy and Environment ministry

National background

Target 4: 75% CO_2 emissions in 2050. New goal, after the Paris agreement, is carbon neutrality.

1) Energy Transition Law for Green Growth
2) Circular Economy Roadmap

Key actors

- **Club CO_2**, with a dedicated Working Group on CO_2 Utilization since 2013.
- **DGEC**: French Energy & Environment ministry : member of Mission Innovation
- **MESR**: French Research ministry via participation to new call of **ERANET ACT** (CCS and CCU), Initiative Phoenix on CCU (Germany, the Netherlands, France and Spain): main goal of PHOENIX is to link national and European RD&I activities with respect to CO_2 utilization to ensure an optimal use of public funding and private investment.
- **National agencies: ANR** (French Research Agency), and **ADEME** (Environment and Energy Management Agency) fund CCU projects via specific R&D programs or generic programs (energy or circular economy)

Projects

At demo scale:

VALORCO	CO_2 conversion technologies with direct flue gases or CO_2 captured from steelmaking
JUPITER 1000	Demonstration of massive renewable energy storage into the transmission gas grid via production of gas via electrolysis of H2O and an industrial source of CO_2
CRYOCAP	Unique capture process (cryogenic) on a Steam Methane Reformer

At pilot scale: several CCU projects including industry symbiosis (VASCO2,...)

Miscellaneous

France is a founding member of the **ECCSEL ERIC**, together with Norway (host), Italy, the Netherlands and the UK. It represents a world-class research infrastructure in Europe for developing CCS technologies. It gives access to 56 distributed research facilities, open to all interested researchers, engineers and students based on selection of the applications according to specific, transparent criteria.

6.3 UK

Solma Parsa, UK Government's Department for Business, Energy and Industrial Strategy

National background

Clean Growth Grand Challenge intends to make clean technologies cost less than high carbon alternatives, and for UK businesses to take the lead in supplying them to global markets.

Key actors

Pale Blue Dot, Wood, University of Sheffield, Kiwa, Progressive Energy, ARUP, University of Manchester, Jacobs, The Royal Society, Department for Business, Energy and Industrial Strategy.

Projects and programmes

The aim of the 2016-2021 505 M£ BEIS energy innovation programme is to accelerate the commercialization of innovative, clean, cheap and reliable energy technologies by the mid-2020s.

Three core routes support decarbonization:

- Energy Efficiency through Industrial Energy Efficiency Accelerator (9.2M£)
- Fuel Switching: Industrial Fuel Switching and Hydrogen (40M£)
- **CCUS: 20M£ for Demo-scale projects, 15M£ for open call UK, 4.4 M£+6.5 M£ for ERANET Call 1 & 2**

6.4 Mexico

Benjamin Heras, SEMARNAT

Among other actions, Mexico initiated in 2015 a **National Strategy and Inventory of CO_2 sources, utilization and storage sites.** In 2018, the Department of Energy launched the **Mexican CCUS Centre**. It will support:

- Carbon Capture Pilot Project (CCPP) on Poza Rica NGCC plant
- CO_2-EOR Storage Project (CESP) operated by PEMEX (Brillante field).

Projects are funded by the World Bank and supported by CSLF, Canada and UC Berkeley.

Mexico is a member of ISO TC/265. The country underlines the importance to have official standards on CCS.

6.5 Canada

Richard Surprenant, CO_2Solutions Inc.

National background

Canada's action on climate change[7]

1. Actions to reduce emissions
2. Pricing carbon pollution
3. Adaptation and climate resilience
4. Funding for reducing emissions
5. Modeling and reporting

7- https://www.canada.ca/en/services/environment/weather/climatechange/climate-action.html

Agenda for pricing carbon pollution:

- Jan 2018: draft legislation
- Jan 2019: Federal backstop of up to C$50/tonne by 2022

Key actors

Governments: Natural Resources Canada, Alberta, Quebec, Saskatchewan, BC, Ontario

Agencies: Sustainable Development Technology Canada, Green Ontario Fund, Fonds vert, Emissions Reduction Alberta, PTRC, Alberta Innovates

9+ Universities; 17+ Companies among them solutions providers (CO_2 solutions, Inventys, Carbon cure)

Projects

QUEST	CO_2 sequestration project; 3 Mt injected since 2015
Weyburn-Midale	CO_2-EOR operated with CO_2 from USA
Boundary Dam	CO_2 Capture: • Sequestration « Aquistore » • EOR Weyburn-Midale In operation since 2014
ACCTC	• Located at Enmax Shepard power station in Calgary • 5 bays of 25,000 ft to demonstrate conversion technologies • Will host Xprize round 3 demonstration until February 2020 • Capacity: 5 tons of CO_2 per day and per bay
Valorisation Carbone Quebec	• Located at Chimie Parachem site in Montreal-East • $28.5M funding from government of Quebec and industry • Project led by CO_2 Solutions • Opportunity for industry participation -Total is first VCQ Industrial Partner • 120+ technologies screened by a scientific committee • Project goal: to accelerate the development and demonstration of large-scale CCU technologies, starting in the fall of 2018

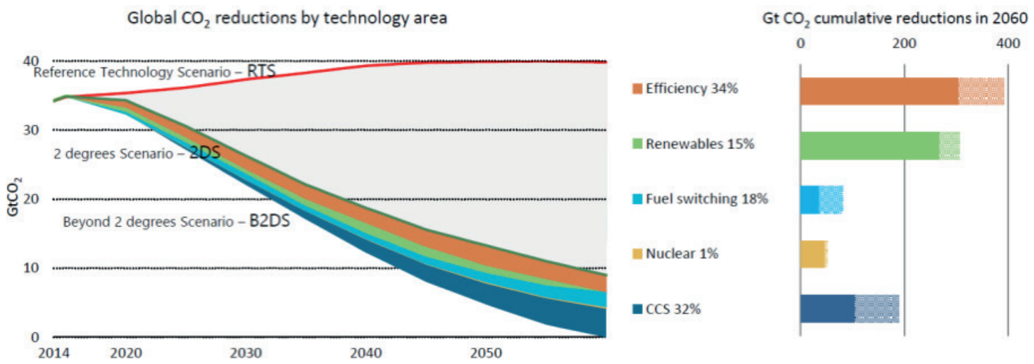
Miscellaneous

Conversion of CO_2 could work well in Quebec or BC (more than 90% renewable power and cheap). On the other side, it will be a challenge in Alberta (less than15% renewable power and deregulated/ expensive).

7. Conclusions

Niels Berghout, IEA

CCUS plays a key role in achieving global climate targets: 15% to achieve 2°C, 32% to be below 2°C:



CCS is a cost-effective way to control CO_2 emissions from ongoing fossil fuel use but could represent a family of options. **The amount of CO_2 utilized and geologically stored (145 Mt/yr) is dwarfed by global anthropogenic CO_2 emissions (40 000 Mt/yr).**

A framework[8] was developed to evaluate whether a CO_2 utilization option is likely to have an emissions reduction benefit. Three criteria have been proposed:

1. **Reduces anthropogenic CO_2 emissions** in comparison to other options
2. **Potential revenue** can cover the cost of feedstock CO_2 and help finance CO_2 capture/avoidance, reducing investors' dependence on climate policy alone
3. **Both demand for resulting products and supply of necessary raw materials are scalable** to a level that is meaningful in climate change mitigation terms

Calculating and accounting emissions benefits is complex for two reasons:

1. **The products from CO_2 utilization often do not lock up the CO_2** (a fuel made from CO_2 releases its carbon as CO_2 during end-use, whereas mineralization may be treated as permanent)
2. **CO_2 utilization may generate products that change market equilibrium**, resulting in increased demand while also displacing production via other routes, potentially in sectors that are completely unrelated to the CO_2 source (market perturbation)

A report on CO_2 utilization is due by the end of 2018. It will include projections on the potential of CCU up till 2030.

Summary

- No CO_2 utilization options are available today that meet the 3 criteria: unless all energy inputs are (practically) zero carbon, climate benefits are likely to be small
- Ideal candidates for CO_2 utilization would:
  - Be fully self-financing (not reliant on government climate policy or subsidies)
  - Be large scale (construction products?)
  - Have minimal downstream emissions (mineralization)
  - Need no separate CO_2 capture step (use direct flue gas as an input instead of CO_2)
  - Use biogenic CO_2 and renewable electricity (if they cannot be used directly)
- CO_2 utilization addresses political and public acceptance drawbacks of CCS. This makes it attractive, but it should be promoted according to its overall merits.


1 Goal and Scope
2 Inventory
3 Impact assessment
4 Interpretation

Workshop session

Which tools to enhance CCU?

LCA & STANDARDIZATION as tools for the deployment of CCU

Workshop session : LCA & standardization

8. EU-Methodology for quantifying GHG for fuels from CCU

Robert Edwards, JRC

8.1 Suggestion for a rationale methodology (JRC's draft method)

Preamble

The method for quantifying GHG in RED1 for biofuels does not work for CCUs. **The Commission has to propose a methodology for accounting for GHG emissions savings from CCUs in RED2**. An earlier version of this methodology was proposed for calculations under Fuel Quality Directive.

A method was designed for two types of CCU-fuels:

1. **Power-to-fuels (electrofuels)** that borrow CO_2 (released again at the tail pipe); use only renewable electricity (RE) as an energy source. There is no fundamental difference with RE-hydrogen in vehicles
2. **Industrial exhaust-streams to fuels** (eg blast furnace gas) for which some of the energy in the fuel can come from industrial gas streams

General provisions

For simplification, the emissions for construction are not counted but are considered CO_2, CH_4 and N_2O emissions arising from:

- Supplying and processing the feedstocks
- Process emissions
- Transport and distribution

To find the percentage of savings, the total emissions per MJ of CCU road transport fuel are compared to the "fossil fuel comparator" (94 g CO_2 eq/MJ in RED2).

GHG intensity of feedstocks

It doesn't matter what the feedstock is (product, waste, residue, by-product, co-product, etc.) but wheter the source is elastic or rigid. Considering renewable electricity, it is:

- **Rigid** if it is already counted towards renewable electricity (RE) targets (it is just being diverted from other users). Its GHG intensity is that of the extra grid electricity that replaces the diverted RE.
- **Elastic** if it is **additional** to what would have been consumed anyway: e.g. from peak-shaving, or not grid connected, or **maybe an improved guarantees-of-origin scheme** that deals also with grid stabilization issues. Its GHG intensity is that of the renewable source.

Electricity as a feedstock

Average grid-electricity emissions are calculated and used for grid electricity or "renewable electricity" that is **not additional**.

For RED2, JRC calculated the average GHG intensity of electricity consumed in each EU member state. It includes:

- Power-station emissions (IEA 2018 data)
- Upstream emissions for supplying the fuel
- Transmission losses
- Accounting for power station's own-use and heat export
- Accounting for trade between states

Regarding **additional** renewable electricity:

- For simplicity, RED gives zero emissions to PV and wind
- Latest draft of RED2 includes various additionality rules (coming up later)
- But grid-connected CCU can be used for grid stabilization (eg when there is more than a given % of renewable electricity in the grid mix).

Accounting for CO_2 capture

There are two ways to account for CO_2 capture:

1. Don't count the vehicle combustion CO_2, because without CCU it would be in the air anyway.
2. **Count the vehicle combustion CO_2 but give a credit for the CO_2 captured in the production process. It's the preferred option of JRC**.

Does the CO_2 capture have to come from the air? Not in the short term, because industrial CO_2 is always captured from sources that would otherwise emit it. Much more concentrated-CO_2 is available than the market can use. So an increase in industrial CO_2 demand will result in more capture. Additionally, theoretical energy for air capture is 5x higher than for typical flue gas. So **at the moment, air-capture for CCU is just a waste of energy and emissions**.

Allocation to multiple products

Two strategies exist:

The **Substitution** (= "system expansion") means giving a credit to one product for the emissions saved by its co-products.

The **Allocation** allocates the plant and upstream emissions to co-products proportional to various properties whose choice will depend on the process and nature of co-products:

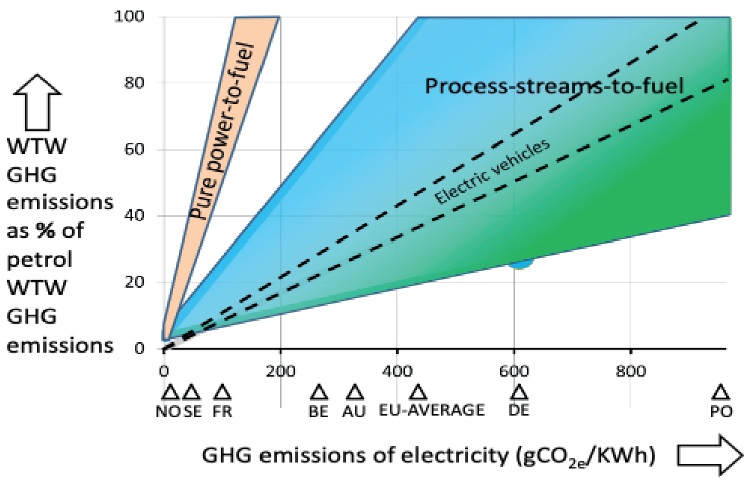
- For process-heat and electricity, the only workable method is exergy-allocation (used in RED),
- For products with a clear market price, carbon intensity is best allocated by economic value.

Therefore for CCU, JRC proposes:

- First allocate between heat, electricity and material/fuel products by exergy
- Then allocate between the material/fuel products by economic value (av. 10 yrs)

Unlike fuels, CCU-materials may sequester their carbon for long periods of time. However, if the materials directly replace fossil materials with the same lifespan, the fossil materials would sequester carbon for that amount time. So the carbon sequestration of the CCU-materials is described completely by the CO_2 captured during production. So, **there is no need for time-dependent carbon accounting here and the method also works also for CCU-materials**.

X to fuels: range of results calculated from JRC draft method:



Pure electrofuels save less GHG than electric cars using the same electricity. Using energy in exhaust gases can save more GHG than EVsthough that does depend on the alternative use of the gas.

Remarks:

- WTW emissions: battery production emissions are not included
- Approximate EV/gasoline comparison based on similar vehicles
- National emissions are for **consumed** electricity, but need to be updated.

But electrofuels have other advantages:

- They can **export renewable fuels** from regions with non-exportable excess renewable electricity,
- They can **stabilize the grid** over longer periods than electric cars, (by part-time electrolysis + hydrogen storage),
- Electric aeroplanes are unlikely.

8.2 RED2 (Yet to be approved)

Two types of CCU fuels are reported in RED2 draft:

1. **Renewable liquid and gaseous transport fuels of non-biological origin (ReNoBiO):** energy content comes from renewable energy sources other than biomass;
    - Excludes bio-electricity or biogas for electrofuels
    - Includes H_2 and electrofuels from wind or solar electricity + CO_2
    - Minimum 70% GHG saving set by RED2 draft

2. **"Recycled carbon fuels" (RCFs)** can incorporate energy from industrial exhaust streams, i.e. liquid and gaseous fuels that are produced from liquid or solid waste streams of non-renewable origin.

If continuous grid electricity is used, the percentage of ReFuNoBio is equal to the percentage of national renewable electricity.

CCU plant (producing ReFuNoBios) can be grid-connected with supply-contract with RE producer but:

- It must have an "element of **additionality**"
- It must have a "**temporal and geographical correlation**" i.e. can only make fuel when the RE is being produced
- It should **not add to grid congestion**
- "The renewable properties of this electricity are **claimed only once** and only in one end-use sector."

The European Commission will decide on LCA methods for both CCU types and the GHG thresholds for recycled carbon fuels. These thresholds shall be set by the Commission latest by 1 January 2021 by the means of a delegated act following consultations.

9. US-LCA Guidelines for CCU

Timothy Skone (webex/video), Senior Environmental Engineer, U.S. DOE, NETL

Background:

LCA team at the National Energy Technology Laboratory at the U.S. DOE, in collaboration with other researchers and Office of Fossil Energy at the DOE made **CO2U Guidance**, developed **tools** (based on open LCA and Excel template) and generated **NETL data** (eg Upstream CO_2 data). This has been carried out:

- To provide technical support to U.S. federal funding recipients
- To influence the development of consistent, robust analyses for policy decisions
- To provide value to the LCA community

In 2016, a Funding Opportunity Announcement for CO2U projects sets forth requirements for life cycle greenhouse gas (GHG) analysis. In August 2017, a 1st exploratory draft of the guidance has been completed. In January 2018, the plan for a second draft of the guidance document has been finalized, based on stakeholder feedback. By fall, the second draft of the guidance document will be released to the public.

System Boundary: Do I have to model the entire life cycle?

Cradle-to-grave is preferred, but system boundary can be reduced once equivalence of the CO_2U product and the SOTA (State-of-the-art) product have been determined to provide (or will provide) the same service or function to society.

LCA must include the "cradle-to-equivalence" for both systems of comparison. Documented justification/ rationale for reducing the system boundary is required.

Functional Unit: Defining the "system" of Comparison:

System expansion:

- Aligns with NETL's goals to compare overall systems rather than single products
- Multi-product functional unit avoids allocation and displacement
- Better accuracy of comparability

Guidance on allocation and expansion with displacement will be included to enable single product/functional unit.

Comparison System (SOTA: State-of-the-art)

The conventional technology will be compared to the CO_2U technology in terms of cost and life cycle impacts. SOTA shall be based on the known level of commercial representativeness.

CO_2U technology developers will be required to define and justify their choice of SOTA which is dependent on:

1. The best available commercial technology that provides the same service or function to society, and
2. The current ability to define the competing market.

SOTA choice depends on "how" it will impact the market (additive vs disruptive)

Modeling/Reporting Platform

- Spreadsheet Template: For simple GHG analysis documentation and results; template includes data and example of LCA.
- openLCA (free and open source) allows for expanded inventory and uncertainty analyses (NETL to provide template, data).

Data: Upstream CO_2 Profiles

Upstream CO_2 source profiles (cradle-to-gate) will be provided by NETL (tentative list):

- Captured and Compressed CO_2: Coal-fired Power Plant(s), Natural Gas-fired Power Plant, Petroleum Refinery, Ammonia Plant
- Flue Gas from Coal-fired Power Plant(s)

Additional Guidance Questions Under Review at NETL

- Uncertainty bounding versus scenario bounding
- Vertical System Boundary – cut-off rules and documentation requirements
- Time Scales – service life versus study period versus level of commercial deployment (1st of a kind versus nth of a kind performance)
- Technology Learning in the SOTA
- Uncertainty/flexibility in CO_2U Process Design (system could be operated in multiple ways)

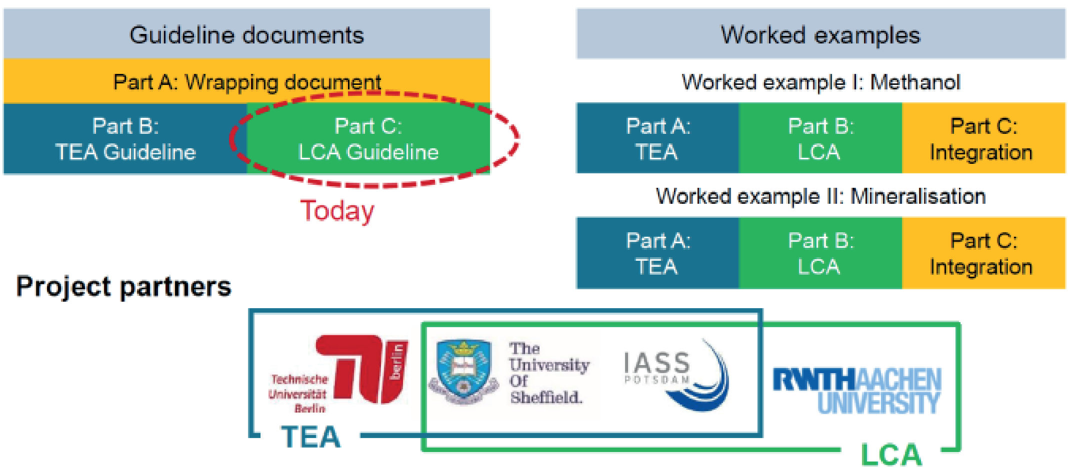
10. International-LCA guidelines from CO_2 Global Initiative

Leonard Müller, Aachen University

Sponsored by CO_2 Sciences and EIT Climate KIC, the LCA & TEA guidelines project aims to:

- Enhance transparency and comparability
- Enable large acceptance and adoption of guidelines
- Align life cycle assessment (LCA) and techno-economic assessment (TEA)

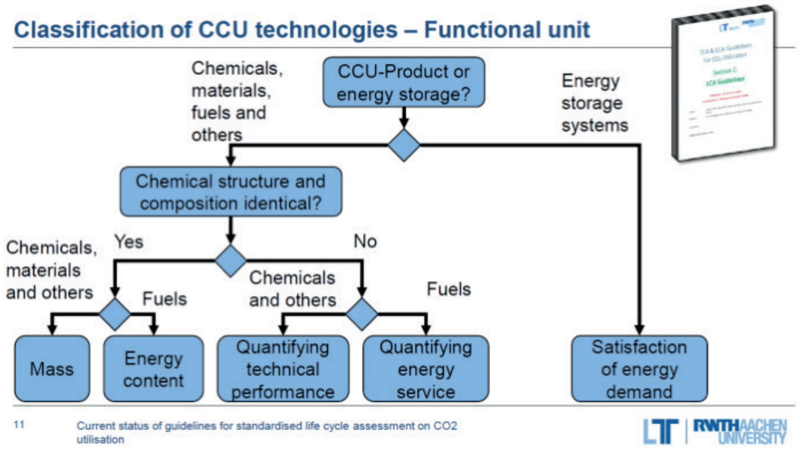
Guideline documents and worked examples have been the output of the project:



LCA guidelines follow the 4 LCA phases detailed in ISO 14044: goal and scope definition, inventory analysis, impact assessment and interpretation. Each chapter is made of a general introduction, challenges and recommendations specific to CCU and guidelines.

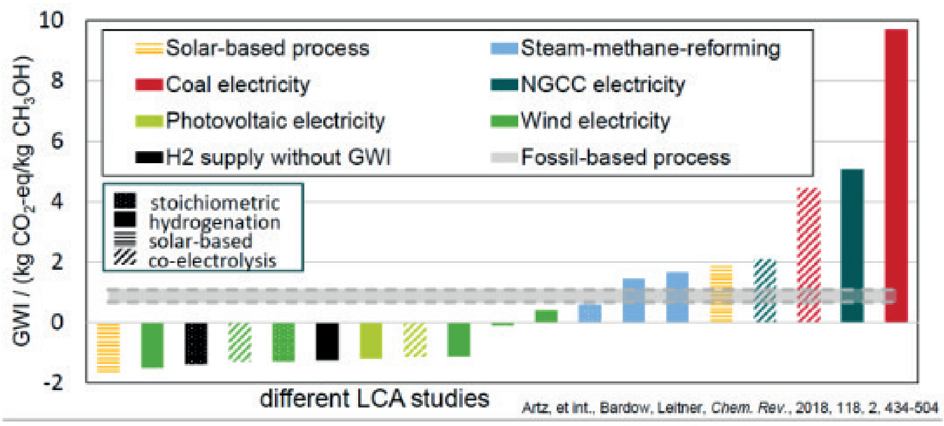
Case study of **CO_2 conversion into methanol** is presented:

1) Classification :

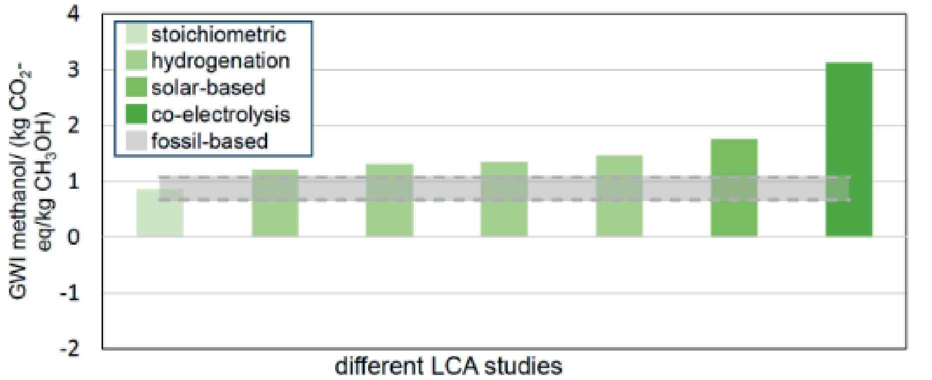


2) Problem of the multi-functionality of the system: in the CCU system, methanol is produced from H2 and CO_2, the latter by-produced from electricity generation.
   Following the ILCD Handbook, the **hierarchy to solve multi-functionality** is the following:
   1. Double check (apply subdivision)
   2. Joint assessment (apply system expansion)
   3. Product specific assessment: first, substitution shall be applied and if not, apply allocation (physical or other relationship)
3) Rules for selecting data inventories (cf. ILCD Handbook): **use process specific inputs if available, otherwise, market-average data**
4) Clearly define the decarbonization scenario (low / full)

Doing so, range of GWI from various LCA studies on methanol is significantly narrowed from a **-2 to +10 kg CO2 eq / kg methanol** to **0.8 - 3 kg CO_2 eq / kg methanol** for a low-decarbonized scenario and to about -1.2 CO_2 eq / kg methanol for a full-decarbonized scenario:

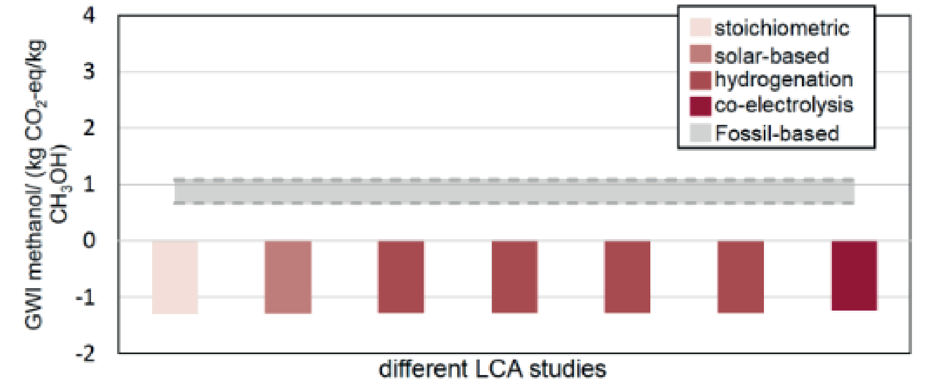


Harmonized inputs: Low decarbonized scenario



Artz, et int., Bardow, Leitner, *Chem. Rev.*, 2018, 118, 2, 434-504

Harmonized inputs: Full decarbonized scenario



Artz, et int., Bardow, Leitner, *Chem. Rev.*, 2018, 118, 2, 434-504

11. Workshop : mains outcomes

Many standards are related to LCA (ISO 14040, 14044, 14047, 14048 and 14049) and LCA review (ISO 14071). Meanwhile, **current methodologies are vague and allow too many approaches** (It is the purpose of the standard to be as generic as possible to be applicable to any system (eg: from a shoe or a TV to an organization)).

The participants were divided in small group for the workshops to be held simultaneously. The main goal was to recognize **what works using the existing standards** and what are the o**bstacles related to CO_2-to fuels, CO_2-to chemicals, CO_2 mineralization and bioconversion of CO_2**. Another workshop has been dedicated on h**ow standardization could help** to assess and deploy CCU.

Hereafter are summarized the nine recommendations coming out of these five workshops:

Reco #1	**Improve the definition of the "Goal and Scope"** (System boundaries, function, functional unit). **Application and local market should be identified in a first step to serve as basis for LCA.**
Reco #2	**Use LCA for screening and optimizing new CCU technologies at an early stage (even at lab scale).** It should not be the final analysis to perform after technology development at TRL9.
Reco #3	**Consider two different references for the reference scenario** (to be compared with the CCU-scenario): 1. The current, most available process/technology, 2. An environmentally competitive solution even if it's currently not economically viable.
Reco #4	**Make available more specific & reliable data:** eg: CO_2 captured, data of CO_2 utilization processes, hydrogen,...
Reco #5	**A LCA is a multicriteria analysis to identify environmental burden transfer. Therefore, the global warming potential (GWP) should not be the only environmental impact assessed. The most relevant environmental impacts should also be assessed** (eg: land use, human toxicity, resource depletion, etc.). This assessment will be communicated to the **scientific community.** Specifically regarding CO_2, there is a need to figure out: 1. The amount of CO_2 utilized into the process 2. The amount of CO_2 avoided into the process 3. The GWP (considering upstream).
Reco #6	If it is decided to **aggregate the impacts:** • **An aggregation method of impacts orshould be agreed upon** • Or, at least, **a list of methodologies of aggregation should be clearly presented and defined.** This assessment will be used forby **policy makers to make arbitrages decide between technologies.**

Reco #7	**If system expansion is not considered, allocation of impacts should be done over the whole value chain from the CO_2 emitter to the actor using CO_2:** there is a need to define economic value creation/penalty and environmental benefits/burdens, and to share these values. **Make integrated assessments (economic and environmental)** even for low-TRL technologies.
Reco #8	**Make ISO technical prescriptions** of processes, properties and performances of products.
Reco #9	**Harmonized LCA guidelines for CCU processes through ISO standard should be define to address the main pitfalls (eg definition of FU, goal and scope,...).** **Technical prescriptions and standards may help to create a label for CO2-based products/services.**

Not all shortcomings are linked to CCU technologies, many other inputs are related to the general methodology of LCA:

- Methodology of calculating impacts
- Which database to use, how to share and align on LCA data?
- Geographical and temporal horizons must be consistent for comparison
- Sensitivity analysis
- Scenario
- Start analysis in attributional, then in consequential if any secondary effects will impact other actors.

Conclusions

Anne Varet, ADEME

The "**International Overview on CCU Symposium**" is associated to the ISO TC/265 Plenary Meeting: all the entire week, there will be discussions on the extension of the TC's scope from CCS to CCUS. One first discussion will be to **develop LCA guidelines for CCU** and we hope that today's discussion will generate input for this work.

CO_2 utilization is a subject for many countries, linked to climate policies. It has a clear role to play for many countries at different time scales. Hence, most of them plan to **support research and demonstration projects** in order to encourage new technologies and to improve their performances. Supporting countries' strategies, transnational actions pave the way for the deployment of CCU:

- **ERANET ACT CCUS** is an international initiative aiming to facilitate innovation,
- **Initiative Phoenix** is linking national and European RD&I activities on CCU,
- **ECCSEL** network gathers world-class research infrastructure in Europe for developing CCUS technologies,
- **Mission Innovation Carbon Capture Challenge** targets to enable near-zero CO_2 emissions from power plants and carbon intensive industries.

Strongly involved in climate actions, DG-RTD presented H2020 outcomes, the new Programme Horizon Europe and SAM. CCU decarbonization potential is still debated and DG-RTD considers that a **harmonized Life Cycle Assessment** is a key tool to assess this potential.

According to Global CO_2 Initiative, **from a business point of view, insights are promising:** by 2030, there's a potential to utilize over 6 Gt CO_2 per year and to generate **1 trillion US$/year**. However significant progress towards scalable technologies is needed. Building materials, chemical intermediaries, fuels and polymers represent the biggest markets.

The International Energy Agency reminded us the **important place of CCUS in achieving global climate targets**. The portfolio of technology should represent 15% of cumulative reduction in 2060 (about 100 Gt) to comply with a 2°C-scenario and up to 32% (close to 200 Gt CO_2) to be below 2°C. IEA identified mineralization technologies as promising.

During the workshop session, AFNOR highlighted how standardization could support the assessment of CCU and its deployment. Existing methodologies of LCA are not precise enough and work should be continued in order to define **harmonized guidelines**: three different methodologies have been presented:

- EU-Methodology for quantifying GHG for fuels from CCU (JRC)
- US Department of Energy's CO_2U guidance and tools
- Global CO_2 Initiative LCA & TEA guidelines

From discussions with the attendees, **nine recommendations have been produced** to ease the assessment of CCU technologies. Among them, it has been agreed that:

- A **combined technical, economic and environmental assessment is mandatory**, even for low-TRL technologies,
- Regarding LCA, the **Goal and Scope definition should be stipulated** and more data is required to have more accurate to analysis,
- Assessment of impact must not focus only on Global Warming Potential but must **take into account other impacts to avoid any transfer**. Furthermore, an **aggregation methodology is needed** to make clear arbitrage between technologies,
- **ISO could support CCU** by releasing **technical prescriptions** and **standards** which may help to **create a label** for CO_2-based products/services.

I would like to thank Club CO_2 for organizing this symposium and more specifically the Working Group on CCU, many thanks to Valérie Czop, David Savary, Aïcha El khamlichi, and AFNOR.