Market-driven future potential of Bio-CC(U)S

Workshop Brussels, Belgium, 22 June 2017

Photo: Riitta Nyholm, VTT

IEA Bioenergy

IEA Bioenergy: Task 41: October 2017

Market-driven future potential of Bio-CC(U)S

Workshop summary

Authors:

Kristin Onarheim

Antti Arasto

Acknowledgement:

Juho Lipponen, IEA

Christian Bergins, EPPSA/Mitsubishi Hitachi Power Systems Europe GmbH

Benedikt Stefànsson, Carbon Recycling International

Jussi Manninen, VTT Technical Research Centre of Finland, Ltd.

Published by IEA Bioenergy

EU Sustainable Energy Week

The third IEA Bioenergy Task 41 workshop on Bio-CC(U)S was organized as an event during the EU Sustainable Energy Week in Brussels 19 – 25 June 2017. The topic of the workshop was *Market-driven future potential of Bio-CC(U)S*. Four speakers were invited to give a short presentation on the topic:

- Juho Lipponen (IEA) – Bioenergy with CCS: Achieving a 2°C target and beyond
- Christian Bergins (EPPSA/MHPSE) – Synergies of Bio-CHP and Bio-CCU for combined heat and fuel production
- Benedikt Stefànsson (CRI) – CO_2 utilization for production of sustainable transport fuels
- Jussi Manninen (VTT) – Bio-CCS and the forest industry?

The speakers also participated in a panel discussion led by Luc Pelkmans from IEA Bioenergy. The report below gives a short summary of the individual presentations and the panel discussion that was held during the event and reflects the distinct viewpoints of the panelists.

Background

The last few years have seen a radical transformation in the global energy market, especially in terms of electricity demand. Renewable energy sources continue to penetrate the electric market. Only in 2016 half of the growth in global electricity demand was supplied by renewable electricity and the sales of electric cars increased by 40%. The energy sector is currently the overall largest source of greenhouse gas emissions, being responsible for 60 – 70% of total global GHG emissions.

The IEA has previously developed a series of scenarios outlining alternative energy system pathways including different emission trajectories in an attempt to predict the resulting average global temperature increase. In the scenario simulations various energy technologies have been optimized in order to predict the potential of driving down CO_2 emissions while simultaneously providing sufficient energy services to the society.

Traditionally the 2°C Scenario (2DS) has been the main focus, depicting the energy system deployment consistent with limiting the temperature increase to 2°C. Achieving the 2DS restricts the total cumulative global energy-related CO_2 emissions to 1 000 Gt by 2100. This includes reducing CO_2 emissions by up to 60% (compared with 2013) by 2050. The total global CO_2 emissions in 2013 were approximately 32 Gt, which translates into a reduction in CO_2 emissions the next roughly 30 years of more than 19 Gt CO_2, or more than 0.5 Gt per year starting immediately (IEA, 2016). This number, which makes just below 2% of the total annual CO_2 emissions may seem low, and reaching the 2DS is still technically possible, provided that the reductions start immediately. This time scale poses challenges. Even though the energy system is transforming quickly the increased penetration of renewable energy into the energy system will most probably not be able to make up for this reduction in such a short time frame.

In the recently published Energy Technologies Perspectives 2017 (IEA, 2017) IEA takes a new approach towards the scenario development. The new baseline scenario, the Reference Technology Scenario (RTS), takes into account the pledges made in the Paris Agreement. In the new RTP, CO_2 emissions will continue to increase towards 2040 and somewhat beyond, but by 2050 the emission trajectory will even out. The new 2DS is still central in the future projections. The 2DS optimizes the energy system to cut the CO_2 emissions to less than 1/3 of today by 2060. In addition, the modelling horizon has been extended from 2050 to 2060. As illustrated in Figure 1, the major CO_2 emission reduction options in the 2DS consist of energy efficiency and renewable energy, together providing 75% of the CO_2 emission reduction. CCS accounts for 14%, which is an increase from the previous edition of the 2DS where CCS contributed to 12% of the emission reduction (IEA [a], 2016). CO_2 capture from both the power sector and industrial sectors are included in the CCS technology area, including also BECCS and Bio-CCS.

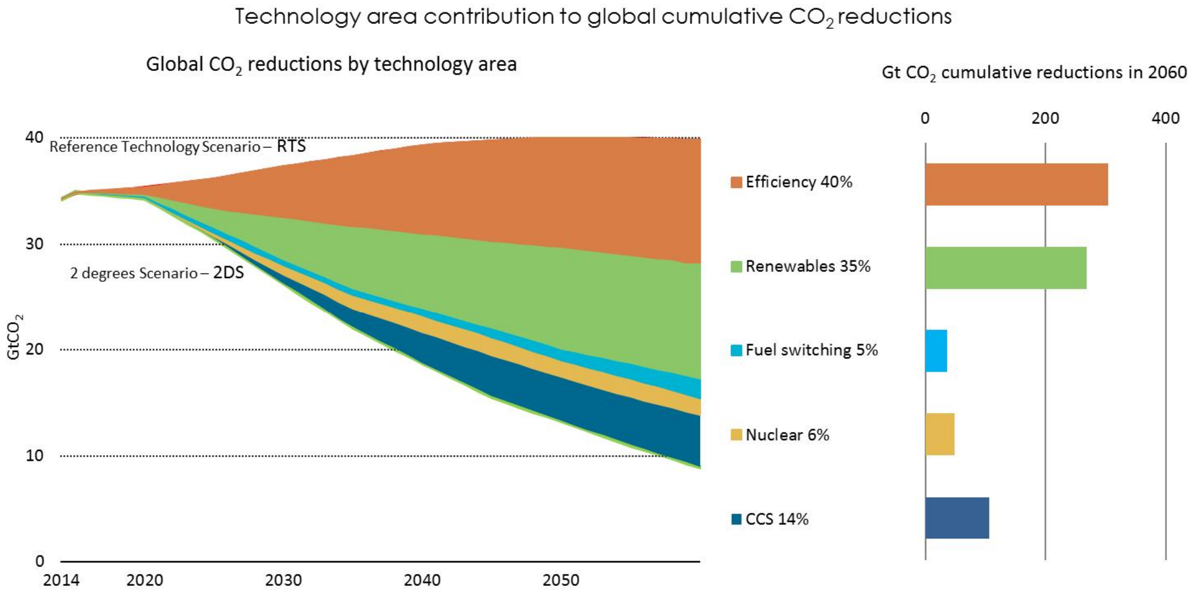

Figure 1 Updated IEA 2°C Scenario in Energy Technology Perspectives 2017.

The new ETP also presents a new, additional scenario; Beyond 2°C Scenario (B2DS). This scenario is more ambitious than the 2DS. In the B2DS all the available technologies are exploited to the maximum practical limit. The realization of the B2DS would allow for a CO_2 neutral energy sector by 2060. Also in the B2DS the main technology areas include energy efficiency and renewable energies, totalling almost half of the contribution needed. However, the shares of both energy efficiency and renewable energies decline in the B2DS. The reason is that in the 2DS there are still CO_2 emissions being released to the atmosphere as the reduction potential of the abatement technologies in the 2DS are not pushed to the limit as in the B2DS. In the 2DS the less expensive technology areas have been applied first, which results in the renewable energy option being the best option. The B2DS exhibits a more significant reduction pathway, exploring alternatives that were too challenging and complex for the 2DS such as CCS from industrial sectors such as cement production and iron and steel production. As a result, the role of CCS as an emission reduction technology becomes much more important in the B2DS.

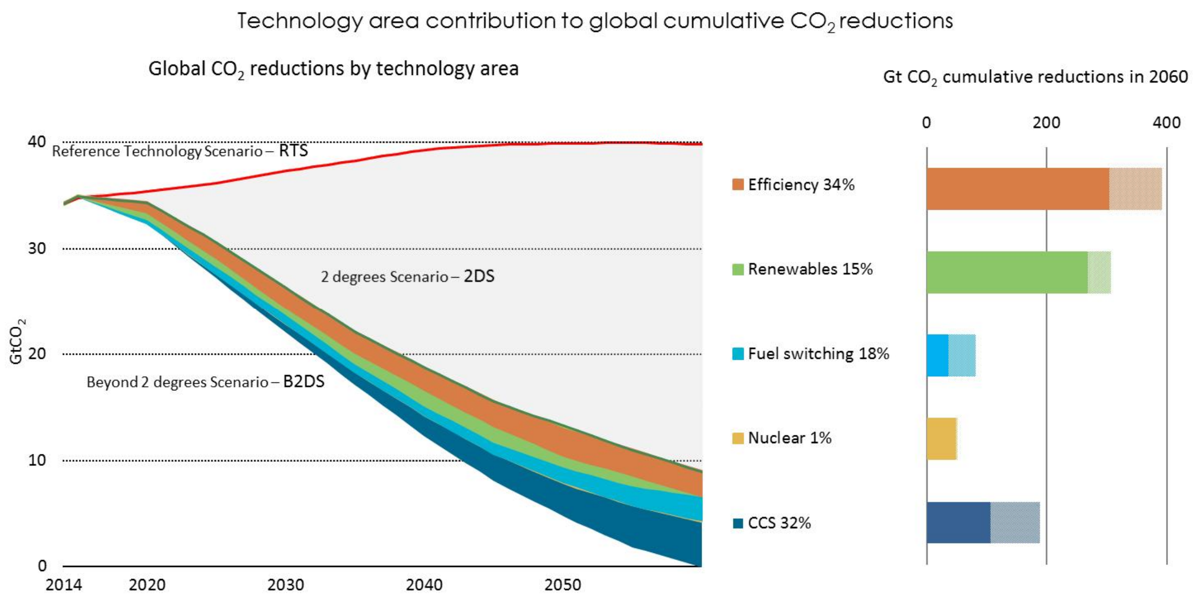

Figure 2 The IEA Beyond 2°C Scenario in Energy Technology Perspectives 2017.

Bio-CCS is included in the IEA scenarios. Negative emissions have two principal roles;

a) Compensate for residual emissions in sectors where direct mitigation is difficult or cost-prohibitive, and

b) Counterbalance near-term carbon budget “overshoot”, which increases with more ambitious reduction targets

According to the IEA, negative emissions are needed in order to achieve net-zero emissions by 2060. In the 2DS negative emissions start to contribute before 2020, while in the B2DS negative emissions will be effective already at present. Both power production and biofuel production (other transformation) play an important role in achieving negative emissions, especially in the B2DS. The cumulative negative emissions of these two sectors amount to 70 – 75 Gt. This translates into a power production coefficient of -10 g CO_2/kWh in 2060, which will be an important measure for removing CO_2 from the atmosphere.

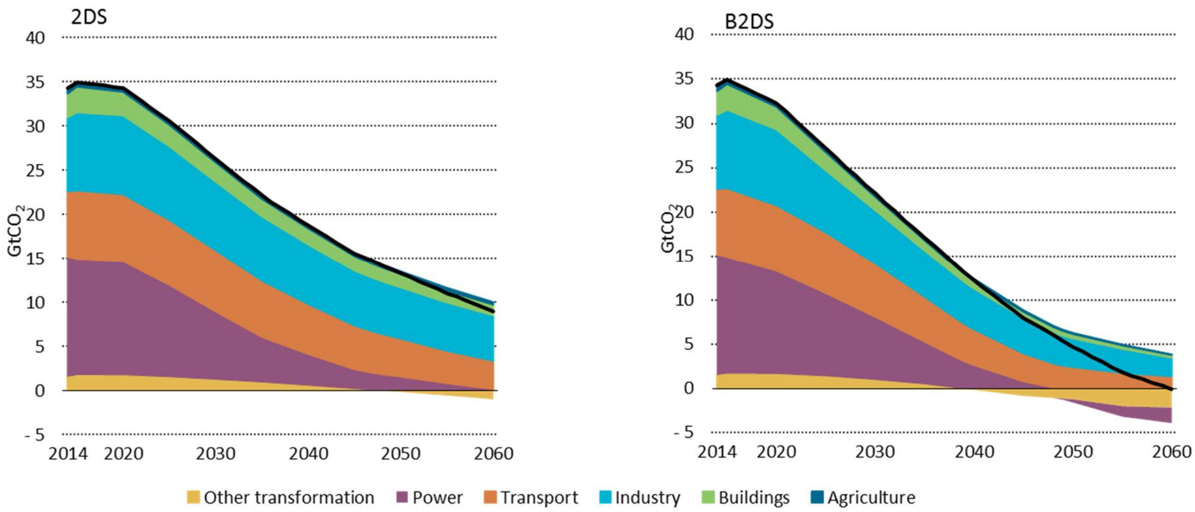

Figure 3 Negative emissions in IEA scenarios.

The implementation of Bio-CCS and negative emissions is not on track to realize the emission reductions required in order to meet the 2DS or B2DS targets, mainly as a result of missing policy incentives. The implementation of Bio-CCS combines challenges from two already challenging sectors; the biomass sector demanding sustainable bioenergy feedstock and the CCS sector where infrastructure could pose a major obstacle, especially for small bioenergy installations that have no possibility for developing CCS infrastructure.

CO_2 utilization for production of sustainable transport fuels

Increased use of bioenergy already leads to the situation where the heat production, power production and transport sector compete for biomass. This is the situation for instance in Germany. One solution in the future is to utilize more low-carbon electricity and convert this into the two other sectors via power to heat or power to fuel.

Two new fuels have been introduced to the European Commission Fuel Quality Directive and the Renewable Energy Directive;

- Renewable fuels of non-biological origin
- CCU fuels for transport purposes

For renewable fuel of non-biological origin one possible option would be to combine fuel production with a combined heat and power (CHP) plant. CHP plants can be fired with both biomass and waste. If the demand for heat is high, the plant will produce excess electricity, risking suffering from a saturated electricity market. Importing more electricity would enable the plant to utilize the CO_2 emissions from the plant for fuel production. This would enable the plant to produce more heat also for electrolysers for hydrogen production. The expanded plant model could reach an energy efficiency of approximately 70%.

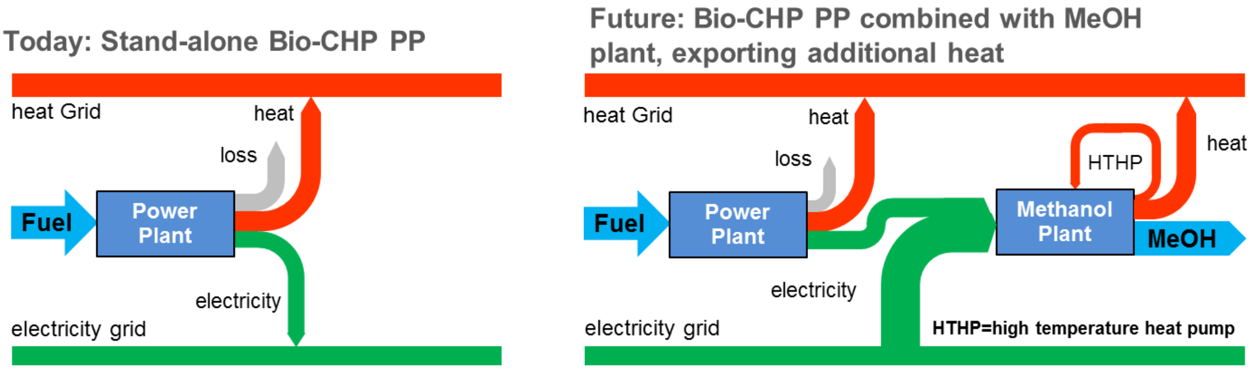

Figure 4 Current CHP plant vs. possible option for a future CHP plant based on CCU.

For the future option illustrated in Figure 4 the low-carbon certification system is of major importance as long as the plant is connected to the grid. Only few countries base their major energy supply on low-carbon sources. One example is Norway, where approximately 96% of electricity produced is from renewable sources (IEA Statistics, 2017). With a biomass feed input of 56 MW_{th} and 116 MW_e electricity import from the grid the plant can produce around 65 MW_{th} methanol and 17 MW_{th} additional heat for export to the heating grid. The process enables a reduction in CO_2 footprint of more than 90% compared to fossil gasoline, and the carbon footprint of the heat production is comparable to biomass carbon footprint. The total conversion efficiency of the process (fuel + electricity towards heat and fuel) is around 65%. An example of an integrated plant in Norway is illustrated in Figure 5.

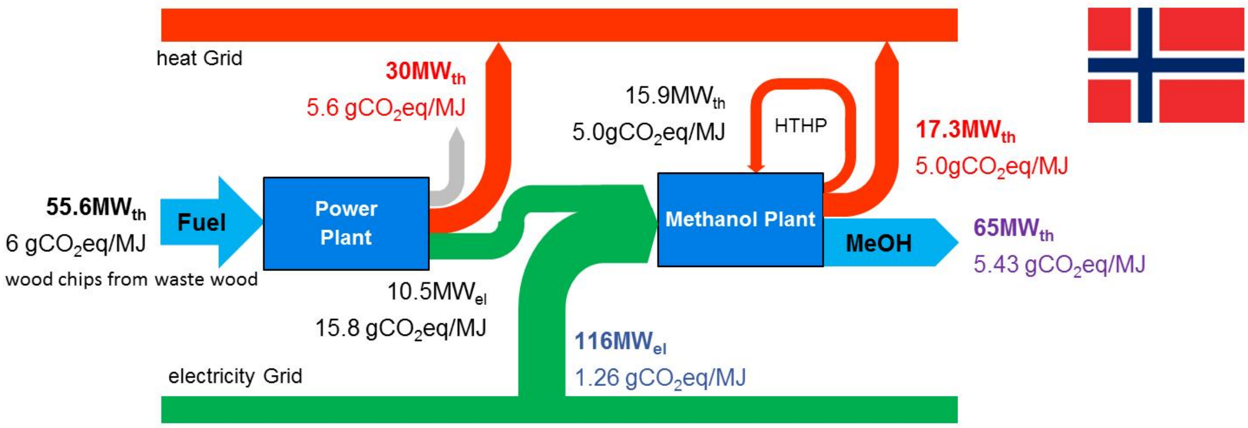

Figure 5 An example of low-carbon methanol production in Norway.

Comparing the process to traditional biofuels and photosynthesis in terms of land demand the Bio-CCU alternative is favourable. The land demand for producing 1 MWh of bioethanol in for instance Germany, Brazil or the USA can be up to 700 m^2. Utilizing PV significantly reduces the land demand as the solar energy capture efficiency of PV is more than a factor of 10 higher than photosynthesis, effectively decreasing land demand by 15 – 50 times compared to biofuels. This adds to the benefits of Bio-CCU for fuel production for instance in countries like Iceland and Norway where there is abundant renewable electricity production and little competition for land use from other sectors such as agriculture.

Currently, EU is not on track to achieve the 2020 target of 10% of transport energy from renewable energy sources. A major obstacle to boost the implementation of CO_2-derived fuels and

CCU is the prevailing insecurity around EU legislation and the re-negotiation of the Renewable Energy Directive (REDII). The REDII proposal does not yet define the GHG criteria for CCU fuels, but empowers the Commission to give delegated acts on the issue. In general, the proposed GHG emission calculation rules of the REDII define that fuel producing plants are bound to use grid mix average on an annual basis to establish the product carbon footprint. This is rather limiting for the production of CO_2-derived fuels, if the CO_2 intensity of the grid mix electricity is high. The REDII proposal states that an emissions intensity of a specific power plant can be used in the GHG calculation only, if the plant is not connected to the grid. This clause disables balancing the system from the demand side by dispatchable utilization of electricity. For the producers of CO_2-drived fuels it would be crucial to define the EU sustainability criteria and GHG calculation rules as soon as possible. One solution could be to utilize guarantees of origin to show a lower emission intensity of electricity production.

Bio-CCS and the forest industry?

The society is in urgent need of action to significantly curb the emissions of greenhouse gases at reasonable costs. The established forest industry, the largest user of sustainable biomass resources, may seem to hold a potentially large role in reaching the required emission reductions. However, measured in CO_2 emissions, the forest industry is small compared to other sectors such as the chemical industry and utility sector. The total CO_2 emissions from the forest industry annually amount to approximately 50 Mt of oil eq., of which 60% is of biogenic origin. In order for the forest industry to implement CO_2 reduction technologies there must be a business case that fits this small scale scenario. Still, the forest industry has a potential in reducing the overall CO_2 emissions. Both afforestation and reforestation can have a potentially large role in reducing CO_2 emissions, perhaps even larger than applying CCS to the forest industry.

Figure 6 Two viewpoints; society and industry

Other aspects affect the potential of implementing CCS or CCU to the forest industry and its role in reducing the global CO_2 emissions. The industry is constantly looking at options to increase the carbon efficiency by building business cases from side streams. For instance, lignin is increasingly extracted and used for products such as for instance carbon fibre or resins. These new processes being developed are not only carbon neutral, but also highly energy efficient. The production of new products by using fibres in for instance structural components and composites originating from the pulp prolongs the life of carbon bound in these products. A longer term target of research is alternative fractionation methods. The end goal is to extract as much as possible from the cellulose, hemicellulose and lignin in the wood. Alternative fractionation methods enable production of for instance materials that reduces the need for combustion and thus the CO_2 emissions to the atmosphere. These new developments within the forest industry will, over time, decrease the potential of this sector to implement Bio-CC(U)S. Furthermore, the forest industry is already part of a sustainable carbon cycle, which means that investment into greenhouse gas reducing technologies for this sector must be duly incentivized.

The most promising application for establishing business cases from Bio-CC(U)S would probably be the production of hydrogen enhanced synthetic biofuels where hydrogen is produced from low-carbon sources. This route has the potential to increase the output two-fold. For instance, for biomass-to-liquids the forecasted price in Finland is 100 US$/oil eq. Applying the thermal conversion CCU route with hydrogen enhancement would increase the economics by 1.5 times [Hannula, 2016].

Changing trends in carbon capture and electricity production

The last years have seen a shift in carbon capture from carbon capture and storage (CCS) towards carbon capture and utilization (CCU). This shift is driven by the lack of internationally binding agreements to significantly reduce CO_2 emissions, including functional emission trading systems and emerging economic opportunities. In North America both fossil and biogenic CO_2 is used for enhanced oil recovery (EOR) and development is driven by the demand side. Over several years the EOR business has provided development of the CCS and CCU technologies, resulting in existing infrastructure such as pipeline systems that is vital to new investments. In Europe, on the other hand, the situation is radically different. CCS is for the most part a stranded discussion, except in Norway where the infrastructure for storage is to a large extent existing. Europe has abundant biomass resources and biogenic CO_2 emissions. However, these facilities are often significantly smaller than the typical coal-fired power plants in North America providing CO_2 for EOR. Since EOR is not a big business in Europe the European model is dependent on a situation where everything fits together to fit a business case. As a result, a more probable pathway for implementing bio-CC(U)S in Europe would be based on decentralized installations with stranded electricity and CO_2 resources.

In addition to the economic driver timing is another argument concerning the renewable electricity market. Much of the renewable electricity currently produced is concentrated far away from consumers. With production rates reaching several terawatts the lack of gridlines and suitable and sufficient electricity storage electricity is in some cases produced in excess. This could be an advantage in the implementation of Bio-CCU technologies by transforming excess electricity into energy storages that can be easily transported to consumers. Another important driver is the end use; CO_2 used as feedstock for fuels will have a larger demand than chemicals, materials and mineralization.

Industrial implementation of (Bio-)CCUS under the current market conditions and policy scenarios will be expensive. However, changes in these conditions may facilitate large scale implementation in certain sectors. These first movers in Europe will most probably be restricted to certain locations with ideal boundary conditions for businesses based on CO_2 capture. One important aspect to consider will be the supply of hydrogen. Several terawatts of excess hydrogen is currently combusted annually to produce heat and electricity. Investing in electrolysers to make use of the excess electricity and convert it back to hydrogen would not be feasible. As a result, industrial processes that today burn hydrogen or carbon monoxide, for instance in the steel industry and chemical industry could be suitable first movers. Important features for scaling up the technologies will among other issues be the ability to manufacture large scale key components such as for instance electrolysers. Large scale production will drive down costs. Whether Bio-CC(U)S itself will drive implementation is another aspect. The oil and gas industry has been in the front seat concerning development of CCS for a long time, but still fuel manufacturers who see a business possibility are thought to drive the implementation of Bio-CC(U)S in the short term. In the longer term, policies and regulations instigated by the growing urge to reduce emissions and even realize negative emissions would need to become the main driver for wide Bio-CC(U)S deployment.

Conclusions

The shift in discussion from Bio-CCS to Bio-CCU is mainly based on development driven by industry being based on commercial interest. One major reason for this in Europe is the incapacity of the EU ETS and the lack of recognizing negative (biogenic) CO_2 emissions in the trading system. As a result, with the current low price of CO_2 there is no incentive to invest in Bio-CCS.

Liquid fuels from CCU can replace oil derivatives in both light and heavy duty transport. In addition, CO_2-derived fuels could offer a dispatchable service to the grid in an energy system where the main renewable energy sources are intermittent. This enables a flexible grid system during high and low load periods. Liquid CO_2-derived fuel also offers a sustainable alternative to for instance transport sectors that are more resilient to change and where electrification is more challenging. However, economics is a major concern for Bio-CCS and Bio-CCU. In Bio-CCU the CO_2-derived product can pay for the capture and for the CO_2 avoidance cost, but the emission reduction potential is weaker than for Bio-CCS as the CO_2 used in Bio-CCU will anyways be emitted back to the atmosphere.

One key question is what the EU will do in terms of regulations that govern the use of CO_2, and some of the open elements in the REDII will be a key factor in this development. In order for the industry to be able to create business cases from Bio-CCU the EU must incentivize production of sustainable fuels from CCU as they scale rapidly without side-effects. How life-cycle analysis is applied to carbon capture and energy transformation is also a key to business models.

Bio-CCU is claimed to be an enabler for Bio-CCS, by setting the scene for industrial CO_2 capture and providing infrastructure that can be further developed. However logic this assertion may sound, the reality is not quite that simple. Bio-CCU could probably contribute to increased understanding of industrial CO_2 capture from biomass-based industries. On the other hand, permanent storage is one of the most preeminent bottlenecks for Bio-CCS, and Bio-CCU would not facilitate the storage infrastructure that is needed for large scale Bio-CCS. Another controversy with Bio-CCU in general and Bio-CCU as an enabler for Bio-CCS is the urgency in reducing emissions and mitigating climate change. It has been shown above that a reduction in emissions and realizing negative emissions needs to start before long. As a consequence, there is no time to wait for Bio-CCU to pave the way for Bio-CCS. Based on this, the latest shift in focus away from Bio-CCS to Bio-CCU could be an unsound diversion from the real aim – to mitigate climate change.

Abbreviations

B2DS	IEA beyond 2°C scenario
CCS	carbon capture and storage
CCU	carbon capture and utilization
CHP	combined heat and power
CRI	Carbon Recycling International
eq	equivalent
EPPSA	European Power Plant Suppliers Association
ETP	Energy Technology Perspectives
g	grams
GHG	greenhouse gas
Gt	gigatonne
HTHP	high temperature heat pump
IEA	International Energy Agency
kWh	kilowatt hour
m^2	square meter
MeOH	methanol
MHPSE	Mitsubishi Hitachi Power System Europe
MJ	megajoule
MWh	megawatt hour
MW_{th}	megawatt thermal
MW_e/MW_{el}	megawatt electric
REDII	EU Renewable Energy Directive proposal
RTP	IEA reference technology scenario

VTT VTT Technical Research Centre of Finland, Ltd.

2DS IEA 2°C scenario

References

Hannula, I. 2016. *Hydrogen enhancement potential of synthetic biofuels manufacture in the European context: A techno-economic assessment*. Energy, 104, pp. 199 – 212. DOI: 10.1016/j.energy.2016.03.119

IEA. 2016. *IEA finds CO_2 emissions flat for third straight year even as global economy grew in 2016*. International Energy Agency, Newsroom. Available at: https://www.iea.org/newsroom/news/2017/march/iea-finds-co2-emissions-flat-for-third-straight-year-even-as-global-economy-grew.html

IEA [a]. 2016. *Energy Technology Perspectives 2016 – Towards sustainable urban energy systems*. OECD/International Energy Agency, Paris, France. ISBN 978-92-64-25234-9/PDF 978-92-64-25233-2.

IEA. 2017. *Energy Technology Perspectives 2016 – Catalysing energy technology transformations.* OECD/International Energy Agency, Paris, France. ISBN 978-92-64-27050-3/PDF 978-92-64-27597-3.

IEA. 2017. *Norway: Electricity and heat for 2014*. International Energy Agency, Statistics. Available at: http://www.iea.org/statistics/statisticssearch/report/?country=NORWAY&product=electricityandheat&year=2014