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- The scope of the global climate policy is changing towards the post-2020 situation and the stringent regulation of carbon-intensive activities. A more ambitious climate policy is needed because global climate change shows no signs of abating – on the contrary, it seems to be worsening.
- The third period (2013–2020) of the EU's emissions trading scheme, the EU ETS, is critical because during this time European carbon markets should finally start to function as planned since the initiation of the market mechanism.
- Carbon capture and storage (CCS) is one of the solutions associated with the success of the EU ETS, and numerous CCS technologies are already technologically viable, but the EU ETS is still not capable of encouraging investments in CCS.
- The biggest short-term challenges in the promotion of CCS are: 1) increasing financial interest in supporting the further development of different forms of CCS, and 2) achieving a wide consensus on the significant decrease of emission allowances.
- During the 2020–2050 time period, the largest CCS potential will be found outside traditional energy production. CCS applications that are based on mineral carbonation or bioenergy are good examples of promising CCS technologies.

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Carbon capture and storage (CCS) refers to a process in which waste carbon dioxide is first captured from the combustion gas of energy plants or other point sources and subsequently stored in a safe location. Since around the early 2000s, the Intergovernmental Panel for Climate Change (IPCC) along with other distinguished research communities has considered CCS one of the key methods of mitigating climate change globally.[1] Since about the same time, different policy mechanisms have been developed in many areas to support different ways of decreasing greenhouse gas emissions. Among those policies, support for the widespread implementation of CCS has played a remarkable role from the outset. Still, the number of existing CCS demonstration plants has thus far remained small and CCS as a phenomenon has been a disputed issue in many countries. In this briefing paper, I discuss the reasons behind the controversial views and the slowness of CCS implementation, especially in the European Union (EU).

Current turbulences in the EU's climate policy

The EU's climate policy leans on the trading of greenhouse gas emission allowances. The trade was implemented in 2005 through the *emission trading scheme*, the EU ETS. Today, the EU ETS comprises the world's largest carbon markets. The basic idea behind the mechanism is that the emitting of greenhouse gases will gradually become more expensive for actors in carbon-intensive fields, such as energy production, heavy industry and transportation, with the increased cost of emitting finally leading to a significant and continuous decrease in greenhouse gas emissions.

The idea seems rather simple but its operationalization has proved to be a much more complex task. Until 2012, the EU ETS functioned as more of a "creation exercise" of a market mechanism than a truly functional carbon trading system. During the first EU ETS period (2005–07), the amount of required emission allowances was not correctly estimated, which led to a situation in which allowances were basically worthless. During the second period (2008–12), the economic downturn reduced emissions, which again led to a surplus of allowances. Additionally, as a great number of allowances were allocated for free until 2012, the carbon markets have not really emerged.

Until recently, the so-called 20-20-20 strategy has been at the core of the EU's climate policy, but times are changing. The 20-20-20 strategy means that by the year 2020, member countries should reduce their greenhouse gas emissions by 20 per cent compared to 1990 levels, and additionally, that energy efficiency should be improved by 20 per cent, while 20 per cent of produced energy should come from renewable sources. At the moment, the EU is on a relatively good track regarding the possibility of achieving these targets. At the same time, however, the scope of the climate policy is changing towards the post-2020 situation both within the EU and globally. In 2014, the EU Commission agreed on the 40 per cent reduction target for greenhouse gas emissions by 2030, compared to 1990 levels. The longer- term goals have also been discussed and the roadmap communication by the EU Commission suggests an 80 per cent reduction target for greenhouse gas emissions by 2050.[2]

Right now we are in a situation in which the EU's climate policy can make significant progress in the promotion of CCS. The third EU ETS period started in 2013 and will last until 2020. During that time, actions really need to get underway in European carbon trading. It can be said that so far the EU ETS has been in a state of continuous crisis and the third period will very likely determine the future of the whole scheme.

If we choose to promote CCS, then the EU ETS mechanism should be rather quickly re-adjusted so that it really starts to encourage the utilization of different CCS features. The odds are rather good for the significant improvement of the EU ETS during its third period. Importantly, a revised version of the emissions trading scheme introduced significant

1 Metz, B., O. Davidson, H. de Coninck, M. Loos, and L. Meyer (eds.), 2005: *IPCC Special Report on Carbon Dioxide Capture and Storage*. Cambridge University Press, New York, USA; IEA (International Energy Agency), 2013. *Technology Roadmap: Carbon Capture and Storage*, 2013 edition. International Energy Agency, Paris, France.

2 European Commission, 2011: *A Roadmap for moving to a competitive low carbon economy in 2050*. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions (COM(2011)112).

tightening in carbon trading practices. Now, for example, power producers must buy all of their allowances by international auction[3] and by 2020, manufacturing industries' free emitting allowances will be gradually reduced from 80% to 30%. These modifications alone will contribute significantly to the development of the EU ETS and associated policy mechanisms.

CCS and energy production during the third EU ETS period

The EU ETS is a key mechanism in the promotion of CCS in Europe, because without a truly functional carbon market there is no incentive that would encourage the development of new technologies for carbon sequestration. The EU ETS also influences the development and status of CCS at the global level. The functional EU ETS mechanism shows that it is possible to create carbon markets that facilitate competition between different CO2 reduction methods. During the third period, the EU ETS should be developed to the point where it provides a truly functional incentive for the wide demonstration of CCS in many EU countries, especially in the field of energy production.

If these demonstrations do not materialize, CCS will probably remain on the periphery far into the future. On the other hand, a successful shift towards a functional trading system would serve as an important example that would probably boost the utilization of CCS globally. The capability of the EU ETS to promote CCS depends on many interlinked issues. Among the most critical of these are: 1) the experts' divergent conceptions concerning the "developmental stage" of CCS, 2) the short-term development of emission allowance prices, and 3) the prices of the fuels that are used in energy production. Each of these issues will be briefly discussed below.

A major difficulty in discussing the "developmental stage" of CCS is that there is a large number of technologies at very different stages in their development. Technologies are also developed for different purposes and their development reflects divergent interests. An often- heard estimation is that CCS will be commercially and technologically viable in energy production only after 2020, perhaps not until 2030.[4]

Just as easily, however, we can say that CCS is already viable in many ways. Sufficient technological performance of different CCS applications has been demonstrated through numerous lab- and pilot-scale projects around the world.[5] In 2014, Canadian SaskPower reported that they were the first company to launch a "commercial-scale" CCS demonstration in energy production.[6] A total of twelve power plants utilize CCS in carbon capture in one way or another at the moment, and an additional nine plants are under construction, with dozens more in the pipeline.[7]

In many cases, experts who refer to the "developmental stage" of CCS are actually talking about a particular stage in the development of the economic competitiveness or cost-effectiveness of CCS, which causes various kinds of misunderstandings and complicates discussions. The economic feasibility of CCS depends on issues that can be dealt with through policy and thus they should not be seen as static facts. Additionally, despite its relativity, the economic feasibility of CCS can also be approached analytically. For example, a research team at VTT Technical Research Centre of Finland has modelled the economic feasibility of CCS applications.[8] They

3 Eight member countries (Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Lithuania, Poland, and Romania) are an exception in this respect; they will get a limited number of free allowances for existing power plants until 2019.

4 E.g. IEA (International Energy Agency), 2013: *Redrawing the Energy-Climate Map: World Energy Outlook Special Report.* OECD/IEA, Paris, France; McKinsey, 2008: *Carbon Capture & Storage: Assessing the Economics.* McKinsey Climate Change Initiative.

5 For a good summary of existing pilot-scale projects, see: https://sequestration.mit.edu/tools/projects/.

6 See: http://www.saskpowerccs.com/consortium/.

7 Venesmäki, E. Hiilidioksidin talteenotto kehittyy – ilmastonmuutosta se ei ratkaise *Helsingin Sanomat*, 9.12.2014.

8 Tsupari, E., J. Kärki, A. Arasto, and E. Pisilä, 2013: Post-combustion capture of CO2 at an integrated steel mill – Part II: Economic feasibility. *International Journal of Greenhouse Gas Control* 16: 278–286; Tsupari, E., J. Kärki, A. Arasto, J. Lilja, K. Kinnunen, M. Sihvonen, 2015: Oxygen blast furnace with CO2 capture and storage at an integrated steel mill – Part II: Economic feasibility in comparison with conventional blast furnace highlighting sensitivities. *International Journal of Greenhouse Gas Control* 32: 189–196.

found that the current break-even price of captured CO2 emissions varies between 64 and 72 EUR/t. In the light of these findings, we can say that experts' conceptions of the "developmental stage" of CCS seem to go hand in hand with their conceptions of a suitable price tag for a carbon ton. As long as the price of an emission allowance remains distorted in comparison to the EU climate targets, many will regard CCS as an immature or unrealistically expensive technology.

Another factor that will affect the attractiveness of CCS in the energy sector is that of fuel prices. At first thought this may appear surprising because the cost of fuel is generally seen as an independent issue from the cost of emissions management. But on closer inspection, this is not the case. With existing CCS applications, capturing carbon dioxide from combustion gases requires a significant amount of electricity. Thus, to maintain the existing production capacity of a power plant, more energy needs to be squeezed from the process and consequently more fuel needs to be burned. Depending on the type of power plant, the required increase in the amount of fuel – with existing CCS applications – varies between 10 and 40 per cent.[9]

At the same time, other additional costs would come from the transportation and storage of the captured carbon dioxide. With existing CCS applications, the total increase with regard to the costs of energy production is estimated to vary between 50 and 100 per cent.[10] It is logical to assume that if the energy producers' costs were to rise this much anyway, the significant increase or the large variation in fuel prices could break the camel's back and lead to withdrawal from the CCS investment.

The above-mentioned reformulation brought about by the third EU ETS period – namely that all emission allowances of energy production are now traded by international auction – is a significant improvement vis-à-vis the promotion of CCS. This change alone, however, is not enough to really trigger even small-scale investments in CCS. If the aim is to promote the implementation of CCS, the break-even prices of existing and emerging CCS technologies need to be reduced. In practice, this means systematic development and demonstration of CCS applications in different operational environments, which can be brought about by means of both public and private funding.

At the same time, the EU must achieve a broad consensus on a significant decrease in the emission allowances cap within the EU ETS. A significant cut in the total amount of available allowances is likely to steer their prices towards a more reasonable level according to the expectations of the EU ETS. It is also important to tackle the aforementioned challenges related to fuel prices, which will not be an easy task. It is very difficult to anticipate the long-term development of fuel prices, as the current oversupply together with the recent developments related to the Russian situation have highlighted. Still, the combined effect of the positive developments in these directions together with the reduced break-even prices of CCS technologies indicate that, before long, we may well find ourselves in a situation in which a surprising number of CCS applications suddenly turn out to be "well-developed" options whose utilization is also profitable in various contexts.

The role of CCS in the post-2020 Europe

As the global scope of climate policy is gradually turning towards the post-2020 situation, it is worthwhile taking a look at the key possibilities and challenges that lie ahead. The future of CCS in Europe can be regarded as cautiously optimistic. With sufficient policy support, the use of CCS could be more or less established practice in energy production rather soon after 2020, at least in the context of new power plants that use fossil fuels. Wide-scale implementation of CCS may materialize if three conditions are fulfilled.

Firstly, if the pre-2020 demonstrations of CCS in the energy sector are economically and technologically successful. Secondly, if the policy incentives discussed above function efficiently and encourage actors towards the continuous development of

9 Teir, S., A. Arasto, E. Tsupari, T. Koljonen, J. Kärki, L. Kujanpää, A. Lehtilä, M. Nieminen, and S. Aatos, 2011: *Hiilidioksidin talteenoton ja varastoinnin (CCS:n) soveltaminen Suomen olosuhteissa*. VTT, Espoo, Finland. Teir, S., T. Pikkarainen, L. Kujanpää, E. Tsupari, J. Kärki, A. Arasto, and S. Aatos, 2011: *Hiilidioksidin talteenotto ja varastointi (CCS) Teknologiakatsaus*. VTT, Espoo, Finland.

10 Ibid.

emission management practices. And thirdly, if the development of CCS technologies reaches a point relatively quickly at which the replication of the most suitable applications makes their purchasing prices attractive enough for energy producers.

At the same time, we need to note that CCS can be much more than just a tool that helps to synchronize the existing energy infrastructure together with the energy production policy targets. It seems that CCS may have an even more promising – yet also more challenging – future outside the energy sector. Therefore, the biggest CCS-related challenge in the post-2020 Europe, and also globally, is the successful introduction of different forms of CCS into various sectors of society. The section below will briefly discuss what this introduction could mean in practice by means of two examples of emerging technologies that are in many ways potential, but also challenging, options. Some challenges deal with the technological development, but there are also policy-related obstacles that need to be dealt with before we are able to redeem the potential of these and similar CCS applications.

The first technology example is called bioenergy with CCS (BECCS), which refers to the production of negative carbon dioxide emissions by coupling biomass conversion with geological carbon storage. Negative emissions can be achieved from the process, which removes more carbon dioxide than is produced. The key idea in BECCS is based on a lifecycle perspective of biomass. During its growing stage, biomass removes carbon from the atmosphere, and once the carbon that is released in the burning stage of that biomass is captured and stored underground, negative emissions can be achieved from the overall process.

Existing practical examples of BECCS applications are different forms of biomass-based power, heat and biofuel production, and more ambitious applications are under development. The International Energy Agency has estimated that different forms of BECCS could reach up to two gigatonnes of negative carbon dioxide emissions in 2050.[11] At the same time, however, it needs to be stressed that BECCS represents an early stage technology and its potential is overshadowed by a large number of different uncertainties.

A similarly promising idea is the applicability of CCS in industry. Certain heavy industrial units generate comparable amounts of greenhouse gases as power plants. These industries can also utilize the same CCS applications that are and will be used in energy production. Consequently, when compared to energy sector actors, industrial actors may get better economic benefits from CCS because they can choose from the technologies that have already been tested in "real-world conditions" in the energy sector. Changing climate policy generates significant pressure towards the implementation of CCS in heavy industry. Recall, for example, that during the third EU ETS period, manufacturing industries' free emitting allowances will be reduced from 80% to 30%. This policy reformulation alone may arouse industries' interest in existing CCS applications in the near future. Emerging CCS applications and a somewhat longer time frame, however, are even more interesting in the industrial context than the short-term potential of existing CCS applications.

Perhaps the most promising industrial CCS application is based on mineral carbonation, namely the *mineralization* method. By means of mineralization, it is possible to store carbon dioxide emissions in minerals that are largely and readily available. For example, carbon dioxide can be captured in different slags, which are residual materials from steel production or rock materials that are generated in mining.[12] Different mineralization-based methods are currently in the development stage and there is a lot of know-how related to mineralization among the Finnish research communities.[13] Generally speaking, some emerging mineralization-based CCS applications that indicate great potential in the industrial

11 IEA (International Energy Agency), 2009: *Technology Roadmap: Carbon Capture and Storage*. International Energy Agency, Paris, France (p. 16).

12 Eloneva S., A. Said, C.-J. Fogelholm, and R. Zevenhoven, 2012: Preliminary assessment of a method utilizing carbon dioxide and steelmaking slags to produce precipitated calcium carbonate. *Applied Energy* 90 (1): 329–334; Mattila, H.-P., H. Hudd, and R. Zevenhoven, 2014. Cradle-to-gate life cycle assessment of precipitated calcium carbonate production from steel converter slag. *Journal of Cleaner Production* 84: 611–618.

13 In particular, the Thermal and Flow Engineering Laboratory at Åbo Akademi and the Energy Engineering and Environmental Protection group at Aalto University.

context are also ahead of many of the most promising forms of BECCS in their development.

Mineralization-based applications offer significant win-win opportunities for industry because they not only enable a new avenue for carbon sequestration, they also offer the possibility to significantly increase the material efficiency of industry due to the above-described utilization of residual materials. Another important feature of mineralization-based CCS applications is that they may enable system-level optimization of the whole CCS process in different contexts. By the whole CCS process, I mean three steps: the capture, transportation and storage of carbon dioxide. Mineralization-based applications have the potential to make the transportation and storage steps significantly cheaper because intelligent planning "stores" would be nearby and they would be cheap to access. This would obviously reduce the break-even price of the overall CCS processes and potentially increase the attractiveness of CCS in new contexts.

Policy challenges related to CCS

While promoting the further development of climate policies at the different levels of governance, we should keep in mind that environmental threats are systemic by nature; they are interconnected and they overlap with each other in various ways. For this reason, responses should not only be built on sectorial approaches either. Let us look at how this issue becomes emphasized in the context of CCS, especially among the emerging CCS applications.

As discussed above, during the third EU ETS period, the EU's climate policy targets will begin to materialize in the industrial context, to which end the emitting of carbon dioxide will gradually become more expensive for industrial companies. And even though the details concerning the fourth EU ETS period have not yet been decided, we can estimate that emission costs are likely to increase, while industrial emission allowances will probably be traded fully by auction after 2020.[14] This development, however, represents only one dimension of the wider structural change that industrial production systems will face in the near future.

Policies that encourage the sustainable use and the appropriate recycling of material resources are needed, along with stringent climate policies. For example, the World Business Council for Sustainable Development has estimated that production systems must be made four to ten times more material-efficient by 2050, compared to the current situation.[15]

Consequently, different policy mechanisms that promote the circulation of materials are under development[16] and the purpose of these mechanisms is to make the utilization of virgin natural resources gradually more expensive for industry. Development strategies for emission and material management will be on the industrial agenda during the third EU ETS period, and thereafter. Long-term industrial development requires the capability to anticipate the policy changes, which in turn requires policy-making to be predictable. Optimally, policy mechanisms can support such desired developments that will open up new market opportunities. In the context of industrial management in the post-2020 Europe, this could mean intelligent coupling of climate and material efficiency targets.

Unfortunately, current developments do not actually promote the above-discussed need for policy integration. A case in point is the legal treatment of CCS by the EU. In the so-called CCS directive,[17] CCS is defined as "environmentally safe capture and geological storage [...] of CO2" (Article 10a). In practice,

14 E.g. the European Commission has proposed a 43% reduction in emissions covered by the EU ETS from 2005 levels by 2030.

15 WBCSD (World Business Council for Sustainable Development), 2010: Vision 2050: *The New Agenda for business*. World Business Council for Sustainable Development (pp. 12–13).

16 E.g. European Commission, 2011: A resource-efficient Europe – Flagship initiative under the Europe 2020 Strategy. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions (COM2011(21)); European Commission, 2011: Roadmap to a Resource Efficient Europe. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions (COM2011(571)).

17 Directive 2009/31/EC.

this definition means that all those CCS applications that do not utilize the geological storage method of carbon dioxide are not formally regarded as "CCS technologies", and because of this, these technologies are not compatible with the EU ETS.

In other words, potential users of such CCS technologies that are not based on geological storage – such as the aforementioned BECCS and mineralization-based applications – cannot count the achieved emission reductions within the EU ETS. There is a risk that insufficient formal delineations of this sort will escalate into institutional obstacles that may jeopardize the development of whole branches of industry. At present, this kind of risk concerns the developers of emerging CCS technologies who are in the front line of building systemic responses to environmental threats.

The ways forward

A research project funded by the Academy of Finland recently concluded that, depending on the perspective, CCS could be seen either as a sunrise or a twilight technology.[18] It appears as a sunrise technology because different applications hold tremendous market potential. At the same time, CCS can be regarded as a twilight technology if we assume that the carbon price within the EU ETS and other emerging carbon markets remains low and the implementation of emerging technologies fails.

It is an understandable and rather well-justified argument that CCS should be seen as a "transition technology" in the sense that it offers a way to bridge our existing energy regime, which is built on the cheap availability of fossil fuels, and the forthcoming energy regime, which is built on the utilization of renewable energy sources. It is also true that, to some extent, CCS maintains the existing regime and may slow down or delay the shift towards renewables in some situations. At the same time, however, we must acknowledge the factual situation of the global energy palette. For decades, energy management in many large countries will be largely based on the utilization of fossil fuels. Hopefully, such countries will benefit from CCS in their emission management. To be able to do so, CCS must be developed further and its break-even price must be made suitable for emerging markets as well.

At the same time, it is important to ensure that the development of CCS does not have a negative influence on the development of renewable energy sources. CCS and renewables should not be seen as competing technologies. Emerging forms of BECCS, for example, illustrate how these two can also be combined in fruitful ways. Additionally, CCS technologies and the required know-how will offer different export opportunities for countries like Finland, especially if the negotiations on global climate change mitigation proceed successfully and culminate in wide agreement on the significant reduction of greenhouse gas emissions.

We must also remember that the most promising CCS applications remain at the lab and pilot scale and the CCS markets are only just starting to emerge. Another reason for the development and promotion of different CCS applications is that the same technologies are not applicable in all environments. A good example of this is that the geological storage of carbon dioxide is out of the question in Finland because the bedrock conditions are unsuitable.

18 Risk governance of carbon dioxide capture and storage (RICCS), 2011–14. Partners in the project: University of Helsinki and Aalto University.

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