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Fighting sustainability challenges on two fronts: Material efficiency and the emerging carbon capture and storage technologies

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ABSTRACT

Technological and regulatory responses to large-scale environmental threats, such as depletion of the natural resources and climate change, tend to focus on one issue at time. Emerging carbon capture and storage (CCS) technologies that are in different stages of development offer a case that demonstrates this dilemma. This article approximates the implications of two emerging CCS applications on existing steel mill's CO_2 emissions and its use of material resources. The evaluated applications are based on the mineralization method and the comparative case represents two versions of a geological CCS method. The results of the evaluation indicate that if technical bottleneck issues related to CO_2 sequestration with mineralization can be solved, it can be possible to achieve a similar CO_2 reduction performance with mineralization-based CCS applications as with more conventional CCS applications. If the CO_2 capturing potential of mineralization-based applications could be taken into use, it could also enable the significant improvement of material efficiency of industrial operations. Urgent problem hampering the development of mineralization-based CCS applications is that the policy regimes related to CCS especially in the European Union (EU) do not recognize mineralization as a CCS method. Article suggests that the focus in the future evaluations and in policy should not be directed only on CO_2 sequestration capacity of CCS applications. Similarly important is to consider their implications on material efficiency. Article also outlines modifications to the EU's CCS policy in terms of the formal terminology.

1. Introduction

The global loss of natural resources together with climate change provides strong grounds for rapid reorganization of production and consumption systems (e.g. Ellen MacArthur Foundation, 2014; IPCC, 2013). These two major environmental challenges, however, appear to be conceptually disassociated from each other in policy. Laws and regulations that are applicable to either for climate change mitigation or improvement of material efficiency have evolved largely in isolation from each other and, as a result, are not designed to address both challenges at the same time. In this article, material efficiency is observed in industrial context and it refers to industries' capacity to use materials in an efficient manner, for example through increased utilization of recycled materials or development of new by-products. Narrow focus in policy tends to translate into support for technologies addressing narrow problems. The focus on single issues may result in solutions that are sub-optimal from the perspective of the overall sustainability. This presents a dilemma, as some emerging technologies may be capable of fighting sustainability challenges on several fronts at the same time.

Certain emerging carbon capture and storage (CCS) applications are examples of solutions capable of pursuing simultaneous reduction of CO_2 emissions and the improvement of industrial material efficiency. In this article, the implications of two mineralization-based CCS applications on steel mill's CO_2 emissions and material efficiency are elaborated and compared to more conventional geological CCS. The studied mineralization-based applications are in early stages of development, which means a detailed side-by-side comparison is not possible. However, the approximate evaluation presented here serves to highlight the value of an analysis that extends beyond just a focus on CO_2 sequestration capacity of CCS applications. This article highlights the importance of considering the overall sustainability performance of different technological solutions, such as material efficiency in addition to CO_2 sequestration capacity in the context of CCS.

1.1. Background

The third period of EU's emissions trading system (EU ETS) started

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in 2013 and will last until 2020 (European Commission, 2013). During this time the emitting of CO_2 should become significantly more expensive for industrial companies as the amount of their free emitting allowances will be reduced from 80% to 30%. Allowances that are not allocated as free are traded by the way of international auction. The rise of emission prices is likely to continue and increase after the third period of the EU ETS even though the details of the post 2020 system have not yet been decided. Therefore, to keep their businesses profitable, companies need to continuously decrease their CO_2 emissions. This development is likely to bring about an economic advantage for the companies that are able to adapt to the tightening emissions trading system and cut down their emissions accordingly.

At the same time, new policies that aim to achieve a more efficient use of natural resources have been developed in many areas including the EU (e.g. European Commission, 2011a, 2011b). Increased material efficiency is needed as many critical natural resources, such as rare earth metals, platinum group metals, magnesium and aluminum, are being depleted at a greater rate than previously has been thought (e.g. European Commission, 2010). 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 (World Business Council for Sustainable Development (WBCSD), 2010). In response, new incentives that encourage material efficient practices and the reuse of industrial waste materials are likely to be introduced in the near future.

1.2. The current position of emerging CCS applications

Over ten years the Intergovernmental Panel for Climate Change (IPCC) along with other research communities have considered CCS as one of the key methods to mitigate climate change globally (e.g. Metz et al., 2005; IEA (International Energy Agency), 2013a. More recently, the IPCC has emphasized the role of CCS in the latest climate change mitigation report (IPCC, 2014) and thus the expectations for CSS as a mitigation technology have increased. At the same time, CCS has gained significant media attention and political interest in many countries. Still, only a few implementations of CCS have been realized and almost all of these represent a small variety of conventional CCS applications (GCCSI (Global CCS Institute), 2013).

Recently, a research project *Risk governance of carbon dioxide capture and storage* by the Academy of Finland investigated why does the development and the demonstration of emerging CCS applications happen so slowly. As a part of the project thematic interviews were conducted with CCS experts in Finland. Information gathered from the interviews enabled the construction of a nuanced picture of the problems related to different CCS applications and their regulation, especially in the EU. The interviews also shed light on the experts' risk perceptions concerning emerging CCS applications.

Analysis of the interviews showed how especially mineralization-based CCS applications are pushed to the margin in experts' discussions on CCS. (For more information about the experts' interview analysis see: Kainiemi et al., 2015.) Mineralization is emerging CCS method that allows converting CO_2 into solid inorganic carbonates (e.g. Eloneva, 2010). The dismissal of mineralization-based CCS applications is often justified by the high costs or the technical immaturity of the currently developed mineralization applications. Related to these justifications it is important to remember two things: 1) they are based on estimations about the current performance of emerging applications and thus they do not take into account the future potential of emerging CCS applications if technical bottlenecks will be solved, and 2) they focus only on CO_2 sequestration capacity and thus they do not consider additional benefits, such as increased material efficiency.

The performance of CCS applications looks very different if material efficiency is included in the evaluation in addition to CO_2 sequestration capacity and from this perspective mineralization-based applications are especially interesting. It is possible that in the post 2020 situation some of the mineralization-based technologies would be technically and economically feasible options for large-scale sequestration of CO_2 (e.g. GCCSI (Global CCS Institute), 2011, 41), which can also mean achievement of a new level in material efficiency of CCS. Economic competitiveness of mineralization-based CCS has been discussed by Khoo et al. (2011) and they have assumed the cost of avoided CO_2 tonne to vary from 106 to 127 US dollars. It needs to be emphasized, however, that the purpose of this article is not to comment on discussions on the economic competitiveness of emerging CCS applications because here evaluated applications are in early stages of development.

1.3. The research question

The combined effect of policies related to climate change mitigation and required improvements in material efficiency will mean a tipping point for industries: soon it will be too expensive to continue with business as usual. Thus many industrial managers and researchers think how to pursue both decreased CO_2 emissions and increased material efficiency at the same time. Motivated by this challenge and the promising results from the early research on mineralization-based CCS, we set the following research question: *How the implementation of mineralization-based CCS is estimated to affect the CO_2 reduction capacity and the material efficiency of a steel mill?*

The focus in this article is on the future prospects of emerging CCS applications with the aim to trigger discussion on the strengths and weaknesses of different applications and to highlight technical and regulatory issues that affect their development. Point of view is not only on CO_2 emissions but also on material efficiency of heavy industries. In the next section we introduce the evaluated applications, a comparative case and the case company. After that, in the third section, we present our findings and answer the research question. In the fourth section we discuss the findings and the question of how the legal treatment of emerging applications in the EU is assumed to affect their future development and potential as credible options. Lastly, in the fifth section, we draw brief conclusions of this work.

2. Approximate evaluation of CCS applications

The idea in the evaluation presented in this article is to approximate how the adaptation of two different mineralization-based CCS applications would affect the CO_2 emissions and the material efficiency of an existing steel mill and compare those with more conventional forms of CCS that are based on geological storage of CO_2. Before moving forward in the description of evaluation, it is important to clarify the terminology used throughout this article:

- CCS method refers to a way of CO_2 sequestration. CCS methods include, for example, geological storage of CO_2 and mineral carbonation, i.e. CO_2 mineralization. Each method is also an umbrella term for numerous *CCS applications*.
- CCS application means a specific technology for CO_2 sequestration and these include, for example, the applications that are evaluated in this article.

2.1. Mineralization as an emerging CCS method

Post-combustion carbon capture, which utilizes geological storing method of captured CO_2, is the most developed form of CCS and various commercial versions of it are already available (see e.g. Metz et al., 2005; Wang et al., 2011). As compared to post-combustion carbon capture, all other forms of CCS can be seen as an emerging CCS technologies and mineralization together with different forms of biofixation is among the most promising methods. Mineralization means fixing of CO_2 with calcium or magnesium oxide in a silicate mineral to form stable carbonate as the end product (Eloneva, 2010). In this article and in the context of evaluated applications we understand mineralization