Technologies and policies for GHG emission reductions along the supply chains for the Swedish construction industry

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Abstract

As the energy performance of the existing and new built building stock keeps improving and with reduced carbon intensity of electricity and fuel supply and increased electrification, the share of the construction process in the climate impact of buildings and infrastructure will increase. The aim of this paper is to discuss how innovative technologies, business models and innovation support mechanisms can accelerate the transition towards zero-emission practices in the construction and building materials industries. The focus is on the production, supply and final end-use of cement/concrete and steel.

Introduction

The Swedish government has presented a vision for Sweden to become one of the first fossil free welfare states (Statement of Government Policy, 2015) and an All-Party Committee has proposed a target of net zero emissions by the year 2045 (SOU, 2016)). Achieving these targets would require ambitious and rapid mitigation of greenhouse gas emissions across all sectors of the economy – creating a great demand for carbon free materials and services. This paper discusses technologies and policies that could facilitate and accelerate the transition towards zero-emission production and practices in the supply chains for cement/concrete and steel to the Swedish construction industry.

Previous studies (e.g. IVA, 2014) have shown that the total climate impact of building and construction processes in Sweden is around 10 $MtCO_2$-eq per year, with housing project accounting for 4 and civil engineering and public works 6 $MtCO_2$-eq per year. This is a substantial share of the total Swedish CO_2 emissions which amount to around 53 $MtCO_2$-eq per year. Carbon dioxide emissions arising from the primary production of building materials account for more than half of the carbon footprints of typical construction projects, with cement (e.g. concrete framed building and transport infrastructure), steel (e.g steel framed buildings and energy infrastructure) and asphalt (e.g. roads) as major contributors. Thus, a move towards zero emission in the constructions industry will require a complete overhaul of the way building materials are produced and supplied.

Previous works by the authors show that, while investing in new low-CO_2 steel- and cement-making processes results in substantial increases in the selling prices of steel and cement, if instead allocating the costs of such investments at the end of the supply chain would only marginally increase the price of steel- or- cement-containing products (Rootzén and Johnsson (2016a; 2016b)). Taking departure in these and other related works, this paper provides a discussion on how actors involved in the production, intermediate processing and end-use of basic materials could interact and how they through innovative technologies, business models and innovation support mechanisms can accelerate the transition towards zero-emission practices in the construction and building materials industries. The paper is organized as follows: First we introduce the supply chain approach. After that we give a brief introduction to technological pathways that would enable zero emission production in the Swedish cement and steel industries. The following two sections presents (i) a review and a discussion of existing and possible upcoming support mechanisms and policy requirement, targeting the construction and building materials industry; and (ii) a proposition for, and discussion on how, a Green Materials Fund could act as a vehicle for transformative change in the industries for the production of basic materials and how actors in the building and construction industry can work together to be forerunners in markets for low-CO_2 steel and cement. Finally, in the concluding discussion we offer some final conclusions and remarks.

The supply chain approach

The concept of supply chains provides a framework for understanding and analyzing the activities and flows of energy and material involved in the supply of basic building materials to its customers. In fact, as shown in the above-mentioned works by the authors (Rootzén and Johnsson (2016a; 2016b)), a supply-chain view on emissions can facilitate a transparent end-user/customer pricing of carbon emissions, although it is not obvious how such pricing can be established on the market.

The notion of supply chains here refer to the typically cross-sectoral networks of facilities and distribution channels involved in the sourcing and primary production of materials, further processing and assembly and delivery of product or service to the customer (see e.g. Mentzer et al. (2001) and references therein). By focusing on supply chains, rather than individual economic sectors, we are be able to identify key challenges and mitigation opportunities from primary production of materials to final end-uses. The active involvement and willingness of different actors – including industries for the production of basic building materials, firms involved in the production of concrete and the further processing of primary steel, in the building and construction industry, and in public agencies – will be required to make it possible to identify and address innovatively the range of perspectives on how to improve the overall performance and reduce climate impact associated with the respective supply chains. Figure 1 outlines the supply chains, and key actors involved in in the supply chains for steel and cement used as the main examples in the present work.

Choosing conceptual framework of supply chains builds on the recognition that no single actor has the means and tools required to achieve the goal of net-zero emission from Swedish construction and civil engineering projects. Unlocking the transformation process, of the way materials and energy are sourced and in the way the firms involve in the respective supply chain can create and capture value in the process, calls for cross-sectoral analysis and involvement and cooperation of different companies and actors.

Unlike Life Cycle Analysis type studies, which typically are limited to existing measures and materials, we seek to map and describe the energy, material and value flows involved in the construction industry in order to provide the basis for an investigation of how the supply and value chains can be transformed so as to comply with a carbon restricted future, while maintaining competitiveness and harvesting an expected increase in the willingness to pay for carbon mitigation among customers in the end of the supply chain.

Emission reductions along the supply chains

INCREMENTAL MEASURES

Table 1 lists examples of measures which can improve material efficiency and to reduce product-service demand, along the supply chains for cement and steel. Together with continued effort to increase the share of biomass based fuels and to increase energy efficiency in the primary production step these measures will be important in striving to reduce the climate impact of the concrete and steel used in the construction industry.

In principle there is nothing that prevents the consumption of primary steel and cement to be significantly reduced through a strong commitment to material efficiency and material replacement. In practice, however, the versatility, relatively low cost, and wide availability of steel and cement sets high standards for competing materials (Wray, 2012; Smil, 2016). Moreover, there is evidence to suggest that mitigation activities in other sectors, e.g., a large-scale rollout of wind and solar energy facilities, and adaptation measures could result in increased demand for steel and cement and other CO_2 emissions-intensive materials (Vidal et al., 2013; Fischedick et al., 2014a; Jeffries, 2015).

TECHNOLOGICAL PATHWAYS FOR TRANSFORMATIVE CHANGE

As indicated above, the CO_2 emissions arising from production of cement and steel account for more than half of the total carbon footprint in many building and infrastructure projects. There are a number of technological pathways available to de-

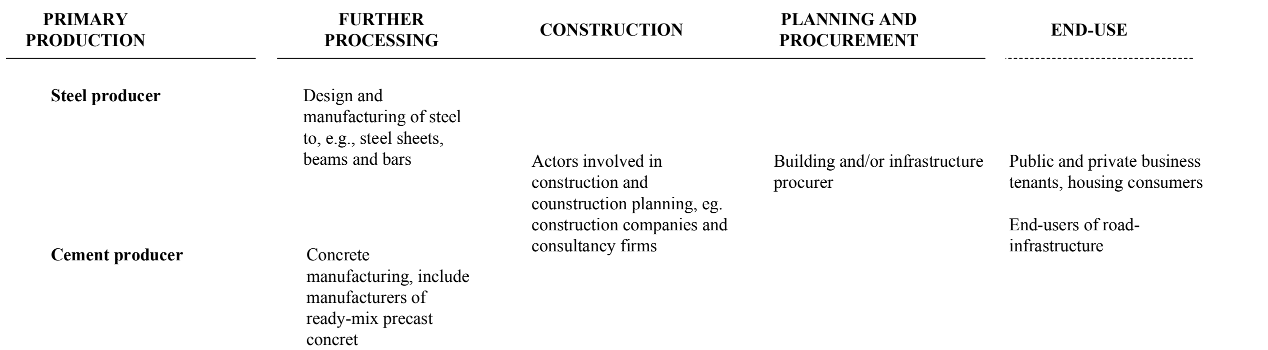

Figure 1. Overview of the supply chains for cement and steel from primary production to final end use in the construction of e.g. a building or a bridge.

Table 1. Examples of measures to improve material efficiency and reduce product-service demand in the production, intermediate processing and use of steel and cement.

	MATERIAL EFFICIENCY	DEMAND REDUCTION
PRIMARY STEEL	Using the supply of steel to a residential building as an example, the possible strategies include: Near net shaping in primary production. Using more efficient designs to avoid material losses during the further processing of primary steel to e.g. beams and bars. Increasing the use of high-quality steels to reduce the total amount of steel required per square meter.	Strategies to reduce the amount of steel-containing products consumed per unit of income include: Shifting to alternative materials (including secondary steel). Increasing the useful lifetime, by means of repair, renovation, and remanufacturing. Recycling/reuse (e.g., reusing structural steel or roof plates).
CEMENT/CONCRETE	Using the supply of cement and concrete to a residential building as an example possible strategies include: Avoiding spill throughout the supply chain (primary production, concrete manufacturing and construction) Increased use of alternative cementitious binders. Optimised construction (using high-quality high-strength concrete to reduce the amount of concrete/cement required).	Strategies to reduce the amount of cement/concrete-containing products consumed per unit of income include: Shifting to alternative structural materials (e.g., the use wood in buildings). Extending the lifespans of buildings and infrastructures or using them more intensely/efficiently.

Source: Adapted from Rootzén (2015). For a comprehensive review, see Ayres and van den Bergh (2005); Allwood et al. (2011a); Allwood et al. (2011b), and Fischedick et al. (2014a).

liver significant decarbonisation from the primary production steps over the next few decades. Yet, investment cycles in the processes of primary materials such as cement and steel are long and, thus, there is an urgency in deciding which measures and technologies are required for deep emission cuts. The studies in the literature that have focused on the potential to achieve significant reductions of CO_2 emissions from the cement and steel industries are generally in agreement that while there remains room for further emission reductions through presently available measures and technologies, reducing CO_2 emissions beyond a certain point will involve significant investments in substantial changes to the manufacturing process (Moya et al., 2011; Pardo and Moya, 2013; IEA, 2013a; IPCC, 2014; Rootzén and Johnsson, 2015; Daniëls, 2002; Fischedick et al.,2014b; Wörtler et al.,2013; Birat et al.,2008; IEAGHG,2013; Ho et al.,2013; Hooey et al.,2013).

Steel

In the past decades significant effort have been devoted to developing new, competitive and low-CO_2, ironmaking and steelmaking processes (for a review see e.g. Smil, 2016 and Jahanshahi et al., 2016). However beyond paper studies and lab scale experimentation development has been slow. In a Swedish setting two options have been at the centre of the discussion:

- *Carbon Capture and Storage (CCS).* To replace or retrofit a conventional blast furnace with a Top Gas Recycling Blast Furnace (TGR-BF). In a TGR-BF, the CO_2 is separated from the BF gas, and the remaining CO-rich gas stream is recirculated back into the furnace. Simultaneously replacing the preheated air with pure oxygen would ensure that the blast furnace gas stream was free of N2, thereby simplifying CO_2 capture. It has been estimated that 70 % of the CO_2 emitted from an integrated steel plant could be recovered by the introduction of a TGR-BF with CO_2 capture (IPCC, 2005; Eurofer, 2013). The TGR-BF concept has been tested in an experimental blast furnace in Luleå, Sweden, but plans to scale up trials have been put on hold awaiting better financial conditions.
- *Hydrogen based steel making*. Recently Sweden's largest steel manufacturer SSAB, mining company LKAB and energy company Vattenfall launched a joint project aimed at developing processes for CO_2-emission free ironmaking (SSAB, 2016). The centrepiece of the project is the Hydrogen Breakthrough Ironmaking Technology (HYBRIT). The idea is to replace the blast furnaces with an alternative process, using hydrogen produced from "carbon-neutral" electricity, to reduce iron ore. Replacing the blast furnaces would require input of alternative fuel in the downstream metallurgy. The plan is to heat all processes up to 1,000 °C with electricity and some combustion of biomass. The concept of using hydrogen to reduce iron ore has been investigated at least since the 1960's (Ranzani da Costa et al., 2013). Lately the idea has gained new traction and "The Flash" iron-melting process investigated in a laboratory at Utah University is the

concept that appears to have come the furthest, with tests in a lab scale reactor (2007-2011) and a bench scale reactor (2012–2017) using both natural gas and hydrogen as reductants. Reports from the project are scarce but the initial trials appear to have delivered promising results (Sohn, and Mohassab, 2015). Still, considerable development work remains before an upscaling to commercial scale is possible. The low level of efficiency in transforming electricity to hydrogen and the challenges involved in developing an infrastructure for transporting, storing and delivering hydrogen to end users also remain major hurdles to overcome (Brolin et al., 2017).

Cement

Cement manufacturing, like the primary steel production, belong to the industrial activities where the options to radically reduce CO_2 emissions tend to be few. Recognising this, the development of CCS is an important part of an overall mitigation portfolio for the Nordic subsidiaries of HeidelbergCement (Norcem (Norway) and Cementa (Sweden)). Two options for CO_2 capture in the European cement industry have been identified as being of particular interest:

- *Post-combustion capture* where CO_2 is removed from the flue gas at the tail end of the clinker burning process using a CO_2 sorbent or a membrane (ECRA, 2012). The world's first pilot test facility for post-combustion CO_2 capture in the cement industry is currently in operation at Norcem/HeidelbergCements plant in Brevik, Norway.
- *Oxy-combustion* with CO_2 capture could be applied both in the precalciner and in the kiln; by targeting the precalciner exclusively, the impacts on the clinkerisation process could be minimised. The basic idea in the oxy-combustion process is to let the clinker burning process take place in oxygen (mixed with recirculated flue gas) instead of air, creating a more or less pure CO_2 stream in the off gases. The development of oxyfuel technology for application in the cement industry is still at lab-scale level but, at least in theory, appears to be more cost effective than post-combustion capture. The European Cement Research Associations, seeking to scale up the trials, has estimated that the total cost of an industrial oxy-combustion testing kiln (a 500 t/d brownfield plant) would amount to approximately €44 M (± 25 %) (ECRA, 2016).

Unlocking investments in transformative technologies

Taken together it seems obvious that unlocking investments in transformative technologies for the production of basic materials like steel and cement will be a key to meet the ambitions to drastically reduce greenhouse gas emissions up to the year 2050 in the construction industry. While significant technical, infrastructural barriers also remain to be resolved, currently, the inability to incentivize and raise capital to finance development and commercialisation remains the most important hurdle to the uptake of alternative low-CO_2 technologies for applications in the basic materials industry. Capital costs related to upscaling to pilot (in the order of tens of millions €) and commercial (in the order several billion €) scale are too high to be borne solely by the industry for primary production itself. At the same time climate policies that target the industrial sectors, in Sweden and the rest of the EU, continue to rely almost exclusively on the price signal imposed through the EU Emission Trading System (EU-ETS). However, the price range expected for emissions allowances under the EU ETS for the period up to Year 2030 (European Commission, 2014a) will not suffice to drive the development high-abatement, high-cost measures discussed in the previous sections. While the precise terms of the post-2020 reforms of the EU ETS is still being negotiated, at the time of writing, steel and cement industry (which belong to the sectors hitherto deemed to be exposed to the risk of carbon leakage) is expected to continue receiving a significant share of their emission permits without costs (Euractive, 2017).

Support mechanisms and policy requirement

Since the cost impact on the primary product of introducing high-abatement, high-cost measures such as CCS will be substantial and far higher than any near-term projection of allowance prices under the EU ETS, together with the fact that cement and steel industries, for various reasons, belongs to sectors of our economies with the lowest levels of R&D spending (Grubb et al., 2014; Wesseling et al., 2016), make non-incremental innovation unlikely (Mazzucato and Semieniuk, 2016). This calls for new thinking on how to speed up and support technology development towards transformative changes. Developing and phasing in near zero- or low-carbon technologies, at scale, will require complementary support mechanisms and policy interventions, including RD&D funding, support for niche markets, and adaptation of infrastructure policies (Wilson and Grubler, 2011; Azar and Sandén, 2011; Vogt-Schilb and Hallegatte, 2011).

Recognising this, the literature dealing with new complementary policy options aimed at enabling a low carbon transition of the basic materials industry has grown in recent years. To date most of the studies has been focused on how to incentivise emissions reductions in industries for production of carbon-intensive materials in a world without a global price on carbon. Denise Denis-Ryan et al. (2016) discusses some of the main policy options proposed, including:

- Different variants of border-tax adjustments, ranging from unilateral initiatives, to avoid carbon leakage from countries or regions with carbon pricing to countries or regions without, to universal system of carbon-based border taxes.
- Sector-based climate agreements, sectoral ETS or carbon tax regimes, which would divide the mitigation challenge up into pieces that are more manageable by focusing on action within specific sectors with e.g. uniform products and/or production processes (see e.g. Bradley et al., 2007).

Another common theme in the literature is the deficiencies in the current set up of the EU ETS and on strategies to restructure and complement the trading scheme:

- Neuhoff et al. (2014a; 2014b; 2015) review and discuss a range of options to revise the trading scheme and suggest the inclusion of consumption of cement, steel and other CO_2-intensive commodities in the EU ETS as a way to ensure an effective carbon price.

Yet, similarly to the development of low-carbon production processes for carbon-intensive materials, the uptake of these more comprehensive policy measures has been slow. New perspectives as to how to allocate the costs required to develop and deploy new low-carbon cement and steel-making processes may however provide new openings. Thus, as mentioned above, previous works by the authors and other related works (Allwood et al., 2011b; Skelton and Allwood, 2013; Rootzén and Johnsson, 2016a; 2016b) show that investing in new low-CO_2 steel- and cement-making processes would only have marginal effect on the overall costs facing end users of steel- or- cement-containing products provided the costa could be allocated to end-use products in a transparent way, as shown in Figure 2.

These findings points to the importance of involving actors further down the supply chain so as to incentivize and share the costs associated with developing transformative technologies. Acknowledging that, while there is no guarantee that investments in the development and implementation of CCS and other low-carbon technologies for industrial applications will pay off, choosing not to, or failing to, unlock investments in the development of such technologies within the next few years will severely compromise the chances of a successful and timely rollout of alternative low-CO_2 production processes up to Year 2050. While this discussion has only just begun, a number of such possible support mechanisms and policy requirements have materialised. These include:

- Governmental risk sharing and state funding in the early phases of the development and implementation of new technologies (Bennett and Heidung, 2014; Mazzucato, 2015);
- The use of sustainable procurement as a tool to create niche markets and to guarantee an outlet for low-carbon cement and steel (Chegut et al., 2013; Simcoe and Toffel, 2014; Uppenberg et al., 2015). The Swedish Transport Administration (Trafikverket) has since April 2016 introduced requirements for reductions of life cycle climate gas emissions for all infrastructure projects in Sweden above 50 million SEK. The Swedish Transportation Administration is planning to evaluate and, if necessary, revise the requirements at a checkpoint 2018 and has a goal of becoming carbon neutral by Year 2030 (Uppenberg et al., 2015); and,
- Innovative business models that create and capture value (Teece, 2010; Chesbrough, 2010) for the actors involved in the production, refinement and use of materials like steel and cement.

Outlining a green materials fund

Whereas increasingly stringent low carbon procurement requirements can drive incremental improvements and innovation (Correira et al. 2013) it will not be sufficient to provide the large upfront investments required for a transformative shift in the production processes used in the steel and cement industries. For this we propose the building up a Green Materials Fund which would actively engage actors along the supply chain for carbon-intensive materials like cement and steel, so as these actors take part in the risk sharing and direct funding involved in the development and scaling up of low-CO_2 cement and steel technology.

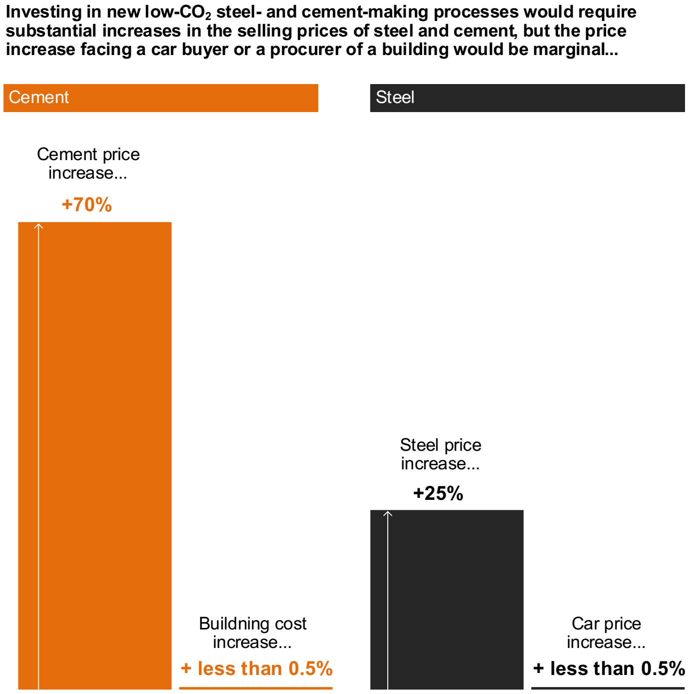

Figure 2. Cost impacts along the supply chains of steel and cement of investing in new low-CO_2 steel- and cement-making processes in primary production. Adapted from Rootzén and Johnsson (2015; 2016a; 2016b).

More specifically, this involves:

- Bringing together a substantial share of relevant stakeholders in industry and public agencies including industries for the production of building materials and actors in the building and construction industry (e.g. public and private procurers, consultants, contractors, suppliers). In Sweden, there are attempts at such an initiative, partly spurred by the results by Rootzén and Johnsson (2016a; 2016b).
- Ensuring that the stakeholders commit to (i) contribute to the building up of the Green Materials Fund paying low-carbon levy for each ton of steel or cement consumed and, and (ii) to guarantee an outlet for low-CO_2 steel- and cement through an innovation procurement scheme. A first estimate suggests that the Green Materials Fund – for the Swedish market – would generate on the order of €420 M in the first 5 years (assuming a coverage of 50 % of annual cement and primary steel use and a levy corresponding to 50 % of the difference between the current prices and estimated price of low-CO_2 cement and steel), which should then be dedicated to funding demonstrating and upscaling of low-CO_2 steel- and cement-making processes, including CCS and BECCS.

While the architecture of the Green Material Fund has yet to be formalised and put into action, the concept has so far received positive response among stakeholders in the Swedish building materials and construction industry. While the limited scope, in terms of the emissions covered and actors involved, obviously limits the overall impact, the concept, if proven effective, may set an example for other to follow.

Concluding discussion

A successful and timely rollout of alternative low-CO_2 production processes up to Year 2050 requires action in three crucial areas: political direction, a business case/market maker and the right funding mechanisms – at the right time (Bellona, 2016). We argue that it is important and logical that actors along the supply chain for carbon-intensive materials like cement and steel become actively involved in incentivizing and sharing the costs associated with developing transformative technologies. Actors involved in infrastructure and building construction industry, private building firms as well as public clients, could potentially play an instrumental role in the transformation process by providing an outlet for low-carbon- cement and steel through the use of sustainable procurement and risk sharing and direct funding through a Green Materials Fund of the type proposed in this paper.

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