Rethinking basic materials production[1]

Energy-intensive processing industries (EPIs) that produce steel, aluminum, plastics, cement, glass and paper are responsible for a large share of global greenhouse gas emissions. These basic materials are essential for society as well as for climate mitigation across all other sectors; for example, through better insulation for buildings, steel for wind turbines or silicon for solar cells. Whereas the prospects for decarbonising the transport, building and energy sectors have significantly improved over the past 10 to 20 years, options for zero emissions from basic materials production have received less attention in R&D, innovation and climate policy. Zero emissions are possible from a resource and technological point of view, but industry and market structures present considerable policy and governance challenges to making low carbon transition in the EPIs.

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Introduction

Globally, industry is responsible for over 30% of all greenhouse gas emissions, of which the majority is emitted by EPIs (Fischedick et al. 2014). Over the past decades, these industries have made significant resource and energy efficiency improvements. However, meeting the EU 2050 emission reductions target of 80% to 95% compared to 1990 levels requires further and extensive low carbon innovation, often of a radical nature. The "well below 2°C" target, recently adopted in Paris, requires emissions to decrease to zero.

Emissions from EPIs arise from the combustion of fuels for energy and from production processes; for example, the calcination of limestone to clinker, the reduction of iron ore to iron and the depletion of carbon cathodes in aluminum production. Industries also cause indirect emissions in the electricity sector (from the combustion of fuels) and in the waste sector; for example, when plastic waste is incinerated. Improvements in material, energy and end-use efficiencies can lead to considerable reductions in demand for materials and thus lower emissions (Allwood and Cullen 2012). The recycling of materials is a powerful strategy as the energy and emissions of recycled materials are typically much lower than of virgin materials. Nevertheless, it is also necessary to decarbonise the processing of virgin or recycled feedstocks such as biomass, iron ore, bauxite, limestone, ethylene, scrap metal or recycled paper and plastics into basic materials.

There are three basic technical options: replacing fossil fuels and feedstock with biomass; electrification of the process; and the use of carbon capture and storage (CCS) (Åhman et al. 2012; Lechtenböhmer et al. 2016). All these entail fundamental technical changes and innovation, including the development and introduction of new core production processes and new associated infrastructures. The technologies are still relative-

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ly unexplored, and they exist only in small demonstration and pilot projects, on the laboratory scale, or as more or less proven ideas. In the case of petrochemicals, the main option is to replace the fossil feedstock with biomass and/or hydrocarbons produced in processes based on renewable electricity (e.g. methane from power-to-gas conversion). For steel production, the options for producing virgin steel without process-related emissions imply either the introduction of new concepts such as process-integrated CCS, electrification (electrowinning) or biomethane/hydrogen direct reduction (DRI). Each sub-sector within the EPIs faces its own specific technical challenges to producing basic materials with zero emissions. However, what all the zero emission solutions for EPIs have in common is that they can be regarded as systemic (i.e. require system-wide changes) and will result in substantially higher production costs, but essentially no co-benefits or advantages.

Electrification of basic materials production

Biomass is a scarce resource and hence its potential use for energy and feedstock in the EPIs is limited. CCS has larger potential but is not a sustainable solution in the long term. New renewable energy (notably solar and wind) comes mainly in the form of electricity and its production is not, for practical purposes, constrained by resource limitations. Electricity is also a versatile energy carrier. This motivates the exploration of electricity as the main future source of energy and feedstock for the EPIs.

A scenario for the EU in which the EPIs are electrified, and electricity is used to produce feedstock for plastics production, shows that about 1700 TWh of extra renewable electricity would be needed (see **Figure 1**, (Lechtenböhmer et al. 2016). This can be compared to the current total electricity use in the EU of 2780 TWh (the industry share is about 1000 TWh). The potentially large increase in electricity demand raises the question of availability. However, the potential for renewable electricity production is much greater than the potential increase in demand.

In a circular economy with increased focus on material efficiency and the concurrent development of bio-based materials, electricity demand could be much lower than suggested in the above scenario. A potentially more challenging problem than energy in a renewables-based circular economy is the closing of the loop on carbon and CO_2, particularly when it comes to plastics (Palm et al. 2016). Assuming the CO_2 use per tonne of feedstock monomers is equal for all plastics (i.e. about 3 tonnes of CO_2/tonne), the total annual CO_2 demand for EU plastic production can be estimated to be between 180 and 190 Mton.

The potential sources of CO_2 can be both fossil and non-fossil. Although air capture removes the scarcity argument, it would be convenient to capture CO_2 in more concentrated streams. In a circular economy, concentrated non-fossil sources of CO_2 may come from, for example, the combustion or pyrolysis of biomass and municipal waste (including end-of-life plastics), or from the production of ethanol and upgrading of biogas.

Governing transitions to fossil-free basic materials production

The fossil-free production of basic materials is technically possible but it will, for the foreseeable future, incur sub-

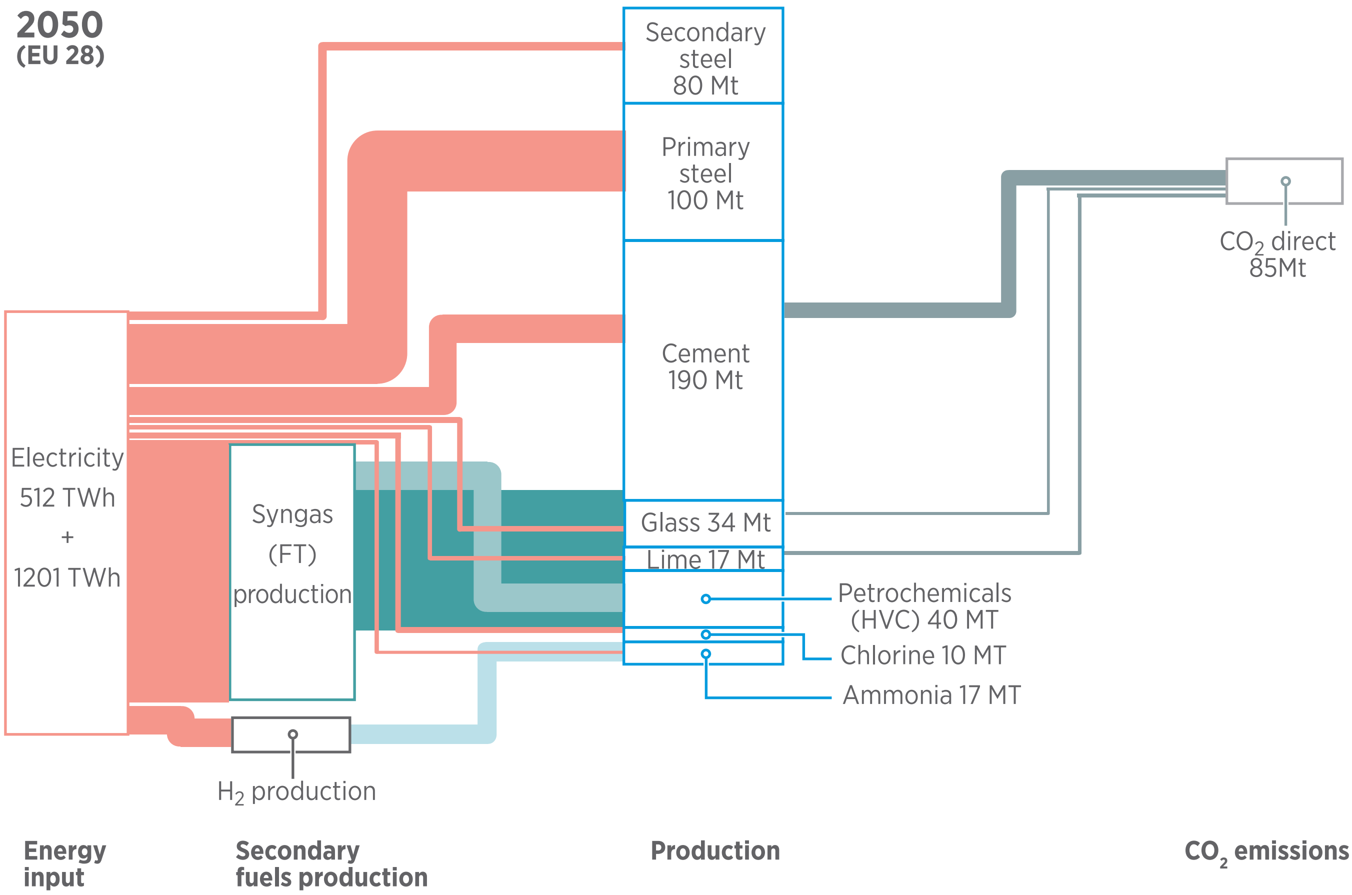

Fig. 1: EU scenario for 2050 with electrified EPIs - Source: (Lechtenböhmer et al. 2016)

stantially higher production costs with no tangible co-benefits. This is a serious problem from an implementation point of view. Most of these industries compete on international markets where cost increases reduce competitiveness, which in turn may lead to geographical relocation and carbon leakage. It is not, however, a problem from the wider economic development point of view. Basic materials generally represent a small share of GDP and also a very small share of the final price of finished products.

The EPI characteristics and innovation systems also present a challenge (Wesseling et al. 2016). EPIs are typically capital-intensive, have long investment cycles and strong economies of scale. Innovation is mainly in incremental process improvements and in product development. Profit margins are often small or cyclical in these bulk commodity markets. Public policy thus far has focused on reducing local environmental impacts and on making efficiency improvements, and it has generally sheltered EPIs from policy impacts that increase costs (for example, through tax exemptions or the free allocation of emission permits).

Based on insights from other sectors, as well as the particular situation of the EPIs, it is possible to identify a number of key elements needed for a low carbon transition. One such element is the need for direction. Stakeholder-oriented, low carbon scenario visioning and pathway processes are important tools for coordinating, directing, legitimising and learning about transitions. Another element is understanding system innovation. A transition is not only about replacing single technologies and processes. It can have system-wide implications on value chains, require institutional innovations and have considerable implications for energy systems and the circular economy as a whole. Deployment requires risk sharing between the EPIs and governments to facilitate stable investment conditions, perhaps similar to those provided for renewable energy technologies through feed-in-tariffs and quota-based systems. Governing a transition also requires institutional capacity and expertise within responsible government agencies. Finally, decarbonising the EPIs requires international coordination and new approaches in international climate and trade policy, as protected spaces for technology development, deployment and upscaling are necessary (Åhman et al. 2016).

Conclusions

Zero emissions is a liberating, albeit challenging, concept. To achieve zero emissions we now must work on fundamental technology shifts in the energy-intensive processing industries. Strategies are needed and steps must be taken to facilitate pilot plants, demonstrations, up-scaling and co-evolution with energy systems over the next 30 to 50 years. With the abundance of renewable energy, the reasonable availability of minerals and feedstock, and the scope for improved materials efficiency and circularity, there appears to be no fundamental resource or technological restrictions to the fossil-free and sustainable production of basic materials. It does, however, require the development of technologies, systems and markets through policy and governance strategies.

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