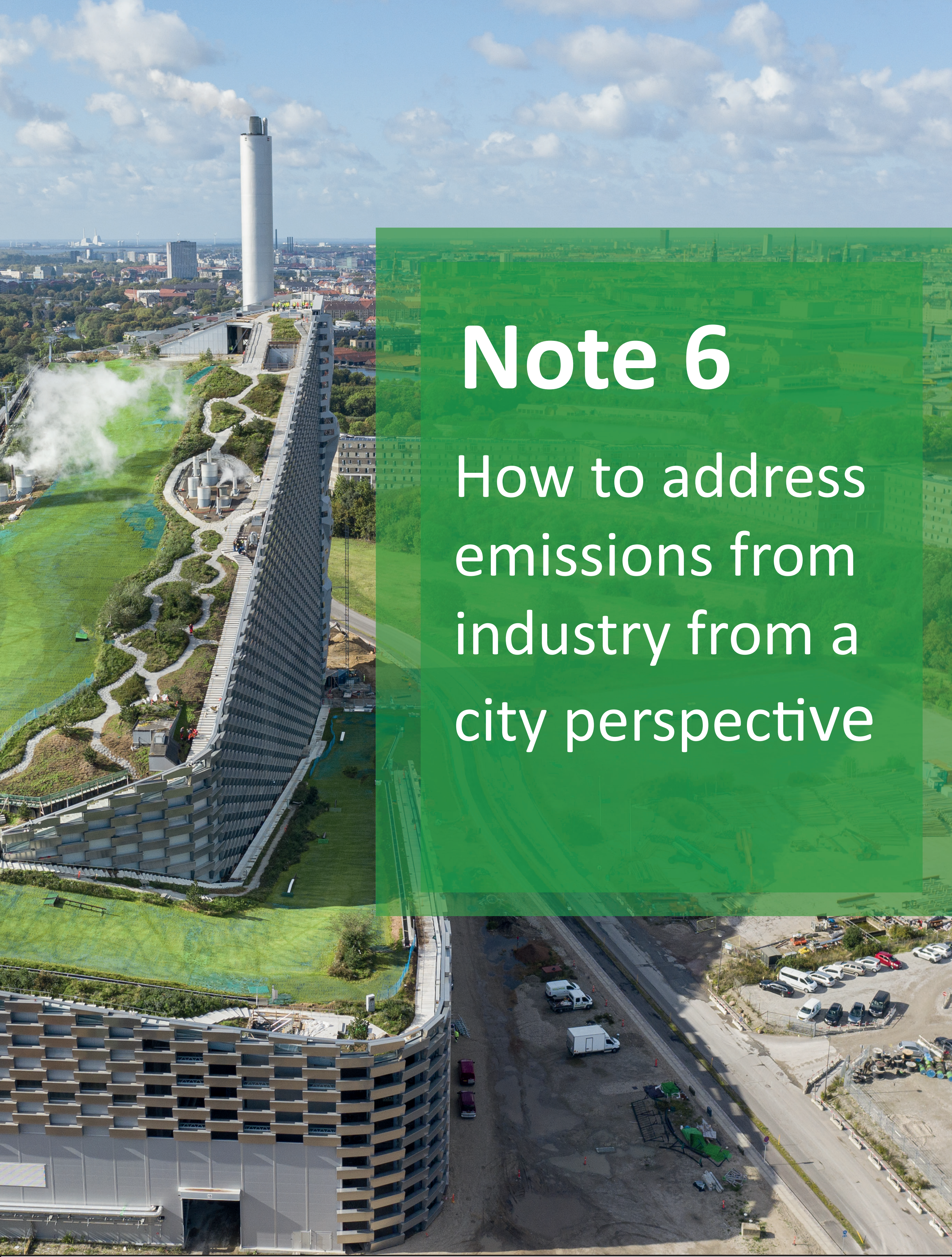

Note 6

How to address emissions from industry from a city perspective

CNCA

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BELLONA

Summary

This note describes issues and solutions for emissions from heavy industry. Industry is a major emitting sector that is currently lacking access to crucial climate measures. The sector's emissions are in most cases not easily solved with renewable electricity. The challenge surrounding process emissions means that industry requires a portfolio of technologies and actions to reduce emissions in line with the Paris Agreement. Such a portfolio will require new infrastructures for Carbon Capture and Storage as well as hydrogen.

Crucially, industry will need to have access to a low carbon goods market to enable first movers to make the necessary investments. Cities are uniquely positioned to support the development of such infrastructures and create local markets for emission free basic materials. This is discussed further in note 10.

1.0 Introduction

The industry sector, although contributing about a fifth to current global emissions, has not received the sufficient attention and action needed to do its part in reducing greenhouse gases in line with the Paris Agreement.

Most cities have direct interest in the operations facilities that are large point sources of greenhouse gas (GHG) emissions. Two of the most common are municipal waste handling and sewage treatment. Both of these have considerable emissions of CO_2 and potentially methane (CH_4), which is an even more potent greenhouse gas (GHG). This note briefly summarises the options available to decarbonising these facilities.

However, for most cities, emissions are indirect – i. e. our use of electricity and heat, our food consumption and in particular our material world. Everything that makes up a city – roads, buildings, bridges, plastic bottles and escalators – is produced emitting CO_2. Take for example the Turning Torsoe, the tallest building in Malmö (and Scandinavia). Its structural integrity depends entirely on a steel exoskeleton and a concrete core. For EU citizens, 1/5 of the indirect emissions are tied to the industry sector.

The industry sector has made significant progress in the last 20 years regarding energy efficiency improvements and material substitutions. These appear to have almost reached their peak. These measures enabled increasing production while retaining approximately constant, absolute GHG emissions. More recently, sector specific emissions have increased. For example, in Europe's largest industry nation, Germany, emissions have risen from 185 Million tonnes of CO_2 ($MtCO_2$) in 2015 to 196$MtCO_2$ in 2018 (Clean Energy Wire 2019). Today, the industry sector points to global competitive pressure as preventing it from further reducing emissions. Without deep emissions cuts and innovative changes to industrial processes, by 2050 industry could be Europe's largest emitting sector and responsible for over 50% of total EU emissions.

This note briefly describes the main options available to cities to reduce their largest direct emissions (waste treatment and district heating), and indirect emissions i.e. those originating from steel, cement and chemical production.European industrial (excluding the electric power utility sector) emissions are already larger than the emissions from all of Europe's coal plants put together. One in five jobs in the EU are related to these sectors, and they generate one-quarter of Europe's GDP, – so action within these sectors is required.

2.0 Municipal Waste and Sewage Treatment

The main legacy waste treatment method was landfilling. There is a general moratorium on landfilling in EU member states, but the practice is not entirely stopped. Furthermore, it is still widely used by cities on all continents. Landfills produce significant amounts of methane (CH_4), which is a more potent GHG than CO_2. A landfill continues to do this long after it has been decommissioned and covered. By using modern waste treatment practices that replace landfilling, this GHG source can be reduced. Complete elimination of landfill methane emissions is possible but requires installing wells into the legacy landfill site that extract the methane gas for using (combusting) it.

Modern waste treatment involves careful sorting of recyclable items before incinerating the residual waste. The incineration process creates significant amounts of heat, which can produce steam to run a steam turbine and electric generator. The final portion of heat can then be used in district heating networks during the heating season. Waste treatment by incineration is often called energy recovery, or Waste-to-Energy (WtE). In some locations, the heat from WtE can also drive evaporative cooling in the summer.

Cities own, operate and lease fleets of personal vehicles and larger vehicles, e.g. municipal buses. The aggregate CO_2 emissions from these can be significant. Several technology strategies are available to reduce these emissions. One technology solution is already widely implemented, namely, use of biomethane as fuel to displace use of diesel and petrol in transport. The biomethane is typically produced from food and agricultural waste converted in anaerobic digesters or from off-gases from processing at waste water and sewage treatment plants. The biomethane is then used as a fuel substitute for diesel, giving emissions-neutral transport services for municipal buses and other municipal vehicles. However, the scope of this strategy is limited by the availability of organic wastes in the various treatment systems. In Northern European cities, this resource is in general fully utilized. In other words, further emissions reductions in cities will need to employ additional solutions for the cities' own transport.

One such additional solution is to replace vehicles with internal combustion engines with electrified vehicles. Electrified transport is gaining wider acceptance for personal vehicles. It is quietly making even more progress in electrifying municipal bus transport, which is poised to outcompete biomethane buses based on the lower (and still falling) life-cycle total cost of ownership of electric buses. This trend is anticipated to spread to other heavy vehicles operated by municipalities.

Consequently, cities will likely have a surplus of biomethane in the future. A potential alternative use can be to supply fuel to existing (or new) electric power and district heating production. And where such power and heat production facilities have CCS installed, this will make the use of the biomethane better than CO_2-neutral. In other words, the combination of biomethane and CCS will result in net removal of CO_2 from the atmosphere. This is further discussed in note 8 in terms of how CO_2 emissions are taxed or emissions reductions incentivised.

3.0 Municipal natural gas distribution systems

For some cities, natural gas is the main source of heating and cooking in homes, offices, businesses and more. The CO_2 and other GHG emissions are two-fold:

- from combusting the natural gas and
- fugitive methane emissions from leaks in the natural gas distribution and end-user installations

Together, these GHG emissions can be significant. While these systems are generally owned and operated by private interests, city governments have a voice in their oversight and in regulating and planning alternative forms of heating. Where there are clear alternatives to heating from distributed natural gas that reduce overall GHG emissions, cities should take the lead in organising their implementation.

One alternative is to modify the natural gas distribution system to transport hydrogen. This is the subject of comprehensive technical-economic studies at several locations in the UK and Germany. The core solution to these are decarbonising the natural gas using reforming units to produce the hydrogen and a CO2 by-product, which is then captured and either stored or used. In other words, this is a potential CCS solution that cities can be instrumental in implementing. In cities where such a hydrogen subsitution is not possible, cities must lead on organising new capacity and infrastructure for either low-emissions district heating or electrifying heating at end users.

4.0 Industrial Emission Sources

Up to 19 % of Europe's total CO_2 emissions are industrial. The bulk of the emissions come from cement, chemical and steel production (EEA 2017). And even when comprehensive energy efficient solutions are implemented, and all energy supply is renewable, there will still be CO_2 emissions from the production process itself: Cement is produced from calcium carbonate – a process which separates out calcium oxide and leaves CO_2 as a residual by-product. All steel is produced by adding carbon to bind and remove the oxygen in the iron ore, which leaves residual CO_2.

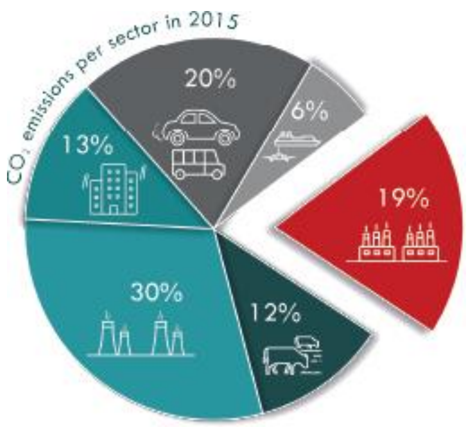

Figure 1. Top-level breakdown of EU emissions by sector. The red sector represents industrial emissions, e.g. steel, cement, chemicals, ammonia, aluminium, etc. (EEA, 2017). Graphic from Bellona (2018).

In energy-intensive industries, such as steel and cement, emissions primarily originate from heat-generation through burning of fossil fuels and through integral industrial processes. Some of these process emissions cannot be avoided through use of alternative feedstock, or only at great cost. These industries therefore require CCS to reach net-zero emissions.

At the same time, the current use of fossil fuels in process heat generation for some industries can be largely replaced with biomass (Arasto et al. 2014). In cement plants, the main source of heat in the kiln is generally coal, oil, petroleum coke and natural gas, but this is already being supplemented by biogenic waste (Chatziaras et al. 2016). The use of biomass to replace fossil fuels is in general limited by the availability of sustainably grown biomass. Current potential to increase supply of sustainable biomass appears limited because producing more biomass competes with other equally or more important services.

The production of carbon for use in steel production, in coke oven plants, also emits CO_2. Such coke oven plants used 11 TWh of coal in Sweden in 2017 – other industry used 7 TWh. Industrial coal consumption in Sweden stands for 90% of Sweden's coal use – combined heat and power plants burn the last 10%

(Energimyndigheten 2017). So improving the efficiency of these ovens, switching to biofuels and cleansing the CO_2 emissions from the coke oven plants are all measures that can provide significant emission reductions. CCS and CCU are candidate technologies for this which have high levels of readiness.

A more long-term and effective solution is replacing coke in the smelting process with the direct reduced iron (DRI) process using gaseous hydrogen. There is commercial experience in this technique at a steel mill in Trinidad (Vogl et al., 2018). DRI is currently being tested in Germany. Hydrogen can be produced using either electrolysis driven by low-emissions renewable electricity, or by reforming of methane in which CCS is installed to permanently store the CO_2 by-product.

4.1 Cement

Concrete is the 2nd most consumed material in the world after water. The production of the main ingredient, cement, emits about 0.9-1.25 tCO_2 per ton of produced clinker (Aitcin 2007). Cement is responsible for approximately 6-8% of global GHG emissions. Limestone and heat energy are the two major inputs in the cement-making process, and its two sources for greenhouse gas emissions.

Energy is required for the limestone conversion process (calcination, which separates the calcium from carbon) that includes the crushing and heating of the limestone at high temperatures. These high temperature levels make cement production an energy intensive process. Each ton of cement produced requires 60 to 130kg of fuel oil or its equivalent, depending on the cement type and the process used, and about 110 KWh of electricity (Cembureau 2019). Currently, energy sources include coal and natural gas, but also waste (including bio waste). In addition to the CO_2 emitted from energy sources used for the heating process, the separation of the calcium releases the now oxidized carbonate in form of CO_2. About 60% of current CO_2 emission from cement production are therefore so-called process emissions and occur regardless of the energy input.

4.2 Iron and Steel

The global crude steel production stood at about 1.69 Gt in 2017 (Bureau for International Recycling 2018). With almost 1.9 tCO_2 emitted per ton of steel (World Steel Association 2019), steel alone contributes about 9% to total global CO_2 emissions.

There are two main routes for steel making. Primary steel made from iron ore is traditionally produced via a blast furnace-basic oxygen furnace (BF-BOF). Additionally, steel can be recycled from scrap via an electric arc furnace (EAF). Around 50% of steel in Europe is from scrap recycling. However, many applications require highest-quality steel, which only newly smelted steel can provide. Steel recycling suffers from increasing impurities as steel demand is expected to exceed scrap availability, meaning CO_2 intensive primary steel will need to make up the shortfall (ESTEP 2011).

The first step in steel production is the iron making process. Raw iron ore needs to be sintered with other fine materials, such as limestone, first. Sintering entails the creation of a single porous mass under high temperatures that can be used in the blast furnace. At the same time, coking coal is needed as a central fuel and reactant in the blast furnace, where it is used as a source of heat as well as the part in the chemical reaction to produce iron. As such, steel's CO_2 emissions originate at three steps: firstly, from the sintering process and production of coking coal, secondly, from the heat generation and the forming of iron in the blast furnace, and lastly from the steel production from iron itself. In shares, most emissions are emitted through the production of coking coal (30-40%) and the blast furnaces, where iron is produced (~50%). Flue gases from the blast furnace contain 55% nitrogen, 15% CO2, 30% carbon-monoxide and 4% hydrogen. Generally, the possibility to use alternative reduction agents to coke exists, however, high quantities need to be available at reasonable prices.

4.3 Chemicals

The chemical sector is one of the biggest CO_2 emitters and consumers of energy, accounting for 10% of global energy demand (IEA 2013). A significant portion of the sales of the chemical industry in Europe, 20.5%, comes from products based on polymers (CEFIC 2018). Nearly all of these polymers are produced from derivatives of fossil natural gas, crude oil and other fossil hydrocarbon raw materials (Plastics Europe 2019; ACC 2019). The global production of these new materials alone could make up 15% of global annual carbon emissions in 2050 (Europe Beyond Coal 2017). The production of ethylene and other olefins, also known as the cracking process, is highly energy intensive.

There are two main sources of emissions in plastic production: (1) producing heat to create the wanted reaction of the chemicals and then (2) processing the raw materials to the desired form. Finally, there is also the emissions that come from incinerating plastic after use, which releases 2.7 t CO_2 per ton of plastic burned (Material Economics 2018)

4.4 Solutions and Limitations

Energy intensive industries have multiple potential options that, when combined, can reduce and even eliminate emissions. No single technology or action represents a silver bullet. An industry's location, available resources, energy consumption and competing energy uses must all be considered when determining which solution to apply.

There are three general levers available to address industry emissions: reducing the amount of raw materials through greater efficiency and recycling, replacing carbon intensive materials with low carbon, sustainable alternatives, and reinventing contemporary production processes in line with zero emission targets.

1. Reduce

Reducing the demand for polluting products plays an important part in cutting emissions. In certain cases materials use can be reduced through improved product design, recycling, and efficient planning and production. There are however limits to these measures, including recycling/circularity (e.g. product degradation and contamination, collection, tracing).

2. Replace

Replacing fossil energy sources and materials with sustainably sourced, low carbon alternatives is possible in many cases, such as packaging and the construction sector. The sustainable sourcing of substitution materials, however, requires the careful consideration of their overall carbon footprint, including indirect emissions, such as emissions from chemicals required to treat timber or energy related emissions in the production of hydrogen to replace onsite fossil fuel use. For wood-based alternatives, the scale of availability and performance are critical to consider. In fact, replacing just 25% of globally used cement of 6.5 billion m^3 with timber would require total global forest cover to increase by about 14%, 1.5 times the land size of India (Oliver et al. 2013).

3. Reinvent

Altering or rebuilding entirely the current industry processes to be more sustainable is another possibility. Reinventing the manufacturing process within industry divides into two groups: avoid (fossil) carbon and therefore CO_2 emissions, which revolves primarily around (indirect) electrification based on renewable electricity and design CO_2 separation, capture and permanent storage into the process.

4.4.1 Electrification, Hydrogen and Other Technological Advancements

Electricity only accounts for around 20% of final energy consumption. That means that other energy uses such direct use of oil in transport, gas and solid fuel for heating make up most of the final energy use. However, integration of renewable energy has started to grow, with 30% of electricity consumed in Europe now coming from renewables (EEA 2018). To transition to large-scale electricity production requires new infrastructure to increase flexibility in both electricity production, consumption and storage. Reaching a predominantly (≈100%) renewable power grid for by 2050 in Europe is a massive challenge. To replace all energy sources through renewable electricity will likely be a task for generations to come, yet there are opportunities in industry.

However, electrification has some limitations imposed by the industrial processes themselves. The electrification of these sectors would require about 5500 TWh of entirely renewable, low cost electricity. In comparison to 974 TWh of renewable electricity produced in Europe in 2017, this estimate seems to be beyond reality (Agora Energiewende and Sandbag 2018).

Industry will also find itself in competition for renewable electricity and hydrogen with other sectors that are planned to be electrified, such as the residential heating and transport sectors. Industries like cement also still retain their process emissions even under full electrification. For industry to become decarbonized therefore requires a mix strategy of Reduce, Reuse and Reinvent. CCS needs to be part of this portfolio as a technology that can (i) directly address process emissions, (ii) tackle energy based emissions in industry and (iii) bridge the transition towards electrification and green hydrogen until these are available at scale and low cost.

4.4.1.1 Cement

Heat processes currently fuelled by fossil fuels could be electrified in the future. Indeed, to reach high temperature heat, few alternative energy sources exist. The cost of electricity and efficiency losses are a major hurdle. They would nevertheless avoid combustion and reduce emissions by as much as 40% if we assume the electricity is zero carbon. However, the emission reduction potential is limited, as about 60% of process emissions unrelated to energy would remain (Moya et al. 2010).

4.4.1.2 Steel

Coke can be replaced with hydrogen as a reduction agent and heat source, if hydrogen is available at scale and cheaply. Its use would however require a new blast furnace design, requiring significant capital investment. As hydrogen is only low emission if produced through electrolysis with renewable energy (often labelled "green hydrogen") or from natural gas with Carbon Capture and Storage (CCS) ("blue hydrogen"), the availability of sufficient low emission hydrogen is a main hurdle. The scale of hydrogen and thus electricity required for an average European steel mill is very large, at approximately 40TWh, which is equivalent to the amount of electricity used in greater London and has the value of 450 billion € (K1MET 2018; Government of London 2018).

4.4.1.3 Chemicals

The EU's chemical sector is one of the biggest users of electricity. Their use of power is approximately equivalent to the electricity consumption of Spain (CEFIC 2013). They rely primarily on fossil fuels and replacing this consumption would require vast amounts of electricity. It is estimated that converting the European chemicals sector to be based on electricity would require 4,900 TWh, almost 10 times the electricity demand of Germany, and more than all the electricity used in Europe today (DECHEMA 2017). The inefficiencies of the conversion process of electricity would increase overall energy use in the sector 3 ½ times – from 5,059 PJ today to 17,640 PJ in 2050 (CEFIC 2013).

5.0 The role of CCS in reducing emissions

LEILAC Cement is a production process that results in a high purity CO_2 stream when the main raw material in cement making, limestone, is being processed (LEILAC 2018). This allows for easy CO_2 capture, transport and storage. This way of cement making ensures that an industry where emissions cannot be reduced through direct electrification alone has the option (and no excuse not) to capture and store their remaining CO_2 at a low cost.

Tata Steel in the Netherlands have developed a steelmaking process called HIsarna. This new steel making process reduces the complexity of production while allowing for lower quality inputs to be used. Emissions are cut by avoiding coking and sintering in the process. It also reduces initial coal input by up to 20% and coking coal completely (TATA Steel 2018). This coupled with CCS and biomass could make it a zero emission process.

CO_2 capture modules can also be retrofitted at existing conventional cement and steel plants to cleanse the flue gas.

As the resulting flue gas from chemical plants also has a relatively high CO_2 content the industry already capture and sell CO_2 for use today. I.e. Yara's ammonia plant in Porsgrunn (Norway) captures and sells 200.000 ton for use within food production per year. The industry has a large potential for capture CO_2 from several parts of their production chain. For the mentioned Yara plant a feasibility study shows that it would be technically feasible for CO_2 capture from all three process emission sources.

6.0 How can cities influence the deployment of CCS and CCU in the industry sector

A central hen-egg conundrum of climate action relates to the commercial drivers for investing in reductions in CO_2 emissions. The costs of CCS are still much higher than the price of GHG emissions. As a first approximation, therefore, a decision-maker chooses the cheapest option, i.e. to continue emitting. However, costs of installing CCS solutions will very likely fall significantly as more and more installations are in place. This is due to both economies of scale and technology learning and improvement. So there is currently broader interest in how CCS can be implemented by 'first-movers' in anticipation of its improving cost-effectiveness. Before the CCS cost/price of emissions closes, the first CCS installations will be among the most expensive. So there is still a considerable 'first-mover disadvantage'. Meanwhile, the future cost of emitting CO_2 is very uncertain.

Cost recovery for CCS installations is however currently within reach for a number of potential implementers, including cities, and for producers of particularly cement and steel. A combination of prescribed procurement schemes and cost-sharing between a broader set of market players appears viable. The key consideration here is that cities are large purchasers of building materials in their building programs. This can open for market entry of low-emissions cement and steel produced using CCS.

This CCS cost/CO_2 price gap has motivated detailed evaluation of solutions that monetize the captured CO_2 instead of permanently storing it. Selling the captured CO_2 to a product-maker that needs it or can use it would appear to be more commercially viable. This strategy is often called CO_2 Capture and Use (or utilisation), CCU. This topic is discussed in note 9a.

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