Process emissions in German industries and their relevance for Germany's national climate mitigation targets – an outlining of the problem and first options for action

Institute for Resource Efficiency and Energy Strategies (IREES), commissioned by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU)

Executive Summary

Context and object of the analysis

The greenhouse gas emissions of Germany's industry are being dominated by a few industrial sectors, which are, however, important for industrial value chains. It is also characteristic fact that one third of industrial greenhouse gases (GHG) are not related to energy consumption, but to chemical conversions of raw materials used in basic materials industries. The latter are called process-emissions.

The analysis presented herein depicts important emission sources, examines technological innovations which could lead to significant GHG-abatements, and analyses technical and economical obstacles regarding the latter. For this purpose, a range of industrial sectors, which are responsible for a relevant share of industrial process-emissions, are examined exemplarily. These industrial sectors are crude steel production, the production of cement, ammonia, and aluminum. The analysis is based on extensive literature research and a range of expert discussions with representatives of corporations in the aforementioned industrial sectors in Germany.

In 2015, industrial process-emissions had a share of 7 % of Germany's total GHG emissions. In sum, the production of metals, mineral products, and a range of basic chemicals, especially ammonia, where responsible for 43,8 Mio. t $CO_{2\ eq.}$, which equals 71 % of all industrial process-emissions. The latter, in total, have been reduced by 36 % since 1990.

Technological options for action in selected industrial sectors

„Green" hydrogen as a cross-sectoral issue and ammonia production

Hydrogen is being already used quite widely in industries today. Mostly, it is won from fossil carbon-carriers, oftentimes through steam reforming of natural gas. Water electrolysis, which is the most promising technology with regard to GHG-abatement, accounts for only 7 % of total hydrogen production in Germany. If all hydrogen produced from steam reforming today could be substituted by water electrolysis, roughly 5,6 Mio. t CO_2 could be mitigated annually. Unfortunately, the specific energy demand oft the latter is four times as high compared to steam reforming of natural gas. Nevertheless, water electrolysis could be totally free from GHG emissions if green electricity can be used.

Electrolysis itself is a well-known process; the maturity of the respective technologies regarding water electrolysis differs, however. The analysis examines and depicts properties of the most relevant types of water electrolysis technologies in detail. The latter also differ with regard to their potential for further R & D and applications. For example, high temperature electrolysis is currently rather less mature, but its potential application in industries due to its possible use of waste heat, makes it very promising.

The analysis shows that the examined electrolysis technologies are not competitive, e.g. with steam reforming of natural gas, under the given economic conditions (e.g. electricity price). Therefore, specific technology investments need to be brought down through R&D, and/or the utilization of fossil carbon carriers needs to become more expensive.

Primary Steel Production

Worldwide, the integrated blast furnace route dominates primary steel production; as to its use of fossil carbon carriers, it is very emission intensive. Setting aside, having climate mitigation targets in mind, incremental options for the enhancement of efficiencies which stick to the use of fossil carbon carriers, two different technological approaches remain for further investigation. These approaches are electrolysis of iron ore, and different technologies based on utilizing hydrogen won from water electrolysis for the reduction of iron ore. Direct iron ore electrolysis is currently in an early stage of technological maturity; its possible market maturity is foreseen for 2040 in literature. Currently, no relevant R&D project focusing on this approach is known.

The utilization of hydrogen as a reduction gas, however, can be built up on marketable technology. The direct reduction of iron ore based on reformed natural gas is commonly used in some world regions for decades, where competitiveness is given. Substituting hydrogen for reformed natural gas as reduction agent is therefore not a fundamental technological issue. On the contrary, economic efficiency with regard to investments, e.g. in new shaft furnaces, and with regard to the relatively higher operating expenses, is not given, as substituting existing blast furnace routes does not come along with better products.

The utilization of fossil carbon from primary steel production (CCU) seems not to be a favorable option, having in mind its unclear GHG mitigation impact as well as its economic feasibility.

Primary Aluminum Production

With regard to abatement of process emissions from primary aluminum production, a range of different technology approaches have been discussed for long, including the inert anode as decisive technology option. As to expert opinion, there is currently not one pilot plant showing the functioning of the inert anode on industrial scale. For the production process itself, experts do not expect any breakthrough innovations in the medium-term which could bring along relevant mitigation of process emissions. On the contrary, improvements regarding process stability and steering are being expected, which could lead to the mitigation of energy-related emissions.

Production of Cement

The analysis at hand examines three different technology approaches for the abatement of greenhouse gas emissions stemming from cement production: reduction of clinker factor through multiple component cement, alternative binders, and CCU/CCS. As shown, the remaining abatement potential of multiple component cement is very limited. A range of different CCU/CCS technologies are currently being piloted, oftentimes in European consortia funded through Horizon 2020. At the moment, it seems to be still rather unclear if the use of CCU/CCS approaches can be avoided for the mitigation of cement-GHG. The latter statement is grounded in the fact that alternative binders, as the most promising approach, are still in an early stage of technological maturity. It is characteristic for the industry that binders have to guarantee security and functionality of their usage over many decades. This is a clear obstacle for an ambitious innovation approach with regard to the timeframe. The save and functional usage of new binders needs to be proved through long-term piloting, before an investment in demonstration plants on an industrial scale seems feasible.

Political action approaches

The developed action approaches for all investigated industrial sectors comprise the complete range from R&D programs, piloting and demonstration project, economic incentives and regulation, as well as the development of political strategies. However, those action approaches are not comprehensively formulated suggestions for policy measures. In the following, a brief overview of this action approaches is given, for a more detailed depiction one should look into the analysis itself or the more comprehensive summary[1].

Cross-sectoral topic „green“ hydrogen

To enhance competitiveness of hydrogen from electrolysis, cost-cutting potentials through further R&D, e.g. regarding the electric efficiency factor, must be used. An increase in R&D funding is suggested in particular for high temperature electrolysis. Moreover, demonstration plants are necessary to optimize the operational management. Beyond further development of technology, a foreseeable demand for green hydrogen needs to be created on the market. Without incentives or regulatory policies, this seems to be quite unlikely. One possibility seems to be an increase of the share of hydrogen in the natural gas network, which could be incentivized by a feed-in-tariff mechanism. Also, gas network operators could be legally bound to increase the hydrogen share. Moreover, tax reliefs for RES electricity used for water electrolysis, or alternatively higher burden for fossil energy carriers, could better the competitiveness of green hydrogen.

Primary Steel Production

R&D projects should also be promoted in primary steel production, including iron ore electrolysis. However, with direct reduction of iron ore in the shaft furnace, with (proportionate) substitution of the natural gas-based reduction gas with green hydrogen, there is already a technologically mature alternative to the blast furnace route. However, this cannot be operated competitively under the given conditions. End-of-pipe technologies such as CCU do not seem to be either appropriate or necessary for steel production. Since there is currently no clear political strategy for a climate-friendly, innovative future for primary steel production, it is recommended herein to develop and implement such a "steel innovation strategy". Against the background of the long life cycles of the plants, the long innovation cycles, as well as the climate protection target 2050, focusing seems necessary. A clear carbon direct avoidance (CDA) approach is recommended. This strategy would have to, for example, influence research and development agendas at national and European level. The effects of gradual electrification of steel production on total electricity demand, and necessary infrastructures, should also be taken into account. Another approach that could address the lack of profitability of "green" steel would be to open up new specific customer markets to allow additional costs to be passed on. The material value of steel in the production costs of a typical automobile, for example, is in the lower single-digit percentage range, so that it seems to be possible to pass on these additional costs both through incentive mechanisms, as well as through regulation.

Primary Aluminum Production

Despite decades of research, no market-ready technologies for avoiding process emissions from primary aluminum production are available, and this is not foreseeable in the near future either. Therefore, further continuous support of politics through R&D funding programs appears to be the only practicable approach currently.

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[1] Both only available in German.

Production of Cement

The action approaches in cement production essentially focus on promoting the further development of alternative binders. This starts with a specific R&D funding program for alternative binders, which should be longstanding and easily accessible. New binders have to prove themselves especially with regard to safety and durability requirements; therefore it seems helpful to promote particularly promising binders with long-running pilot projects in practical application. Thereby, specific advantages and disadvantages could be uncovered in comparative studies with classical cements, and solutions to overcome foreseeable market diffusion obstacles could be developed. Building on these pilots, a selection of particularly promising binders could then be fostered by funding of demonstration plants for the production of new binders on an industrial scale. Accompanying activities could be carried out to foster market entry. Market diffusion could also be promoted by an obligation to purchase alternative binders for certain construction projects. A prerequisite for this would be the successful demonstration of the manufacturing process on an industrial scale and the long-term stability of the binders in real applications. Scientific preparatory work would have to clarify which construction projects could be suitable for such an obligation. It would be conceivable, for example, that such an obligation would initially concentrate on structures of temporary nature, such as temporary bridges or certain sports and leisure facilities.