Wuppertal Institute for Climate, Environment and Energy

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CO_2 ReUse NRW

Evaluating gas sources, demand and utilization for CO_2 and H_2 within the North Rhine-Westphalia area with respect to gas qualities

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Management Summary

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Dietmar Schüwer (project leader)
Karin Arnold
Katrin Bienge
Prof. Dr. Stefan Bringezu
Laura Echternacht
Andrea Esken
Prof. Dr.-Ing. Manfred Fischedick
Dr. Justus von Geibler
Samuel Höller
Frank Merten
Karen Perrey (Covestro Deutschland AG)
Andreas Pastowski
Katja Pietzner
Clemens Schneider
Julia C. Terrapon-Pfaff
Dr. Peter Viebahn

With support of:

Sascha Eckstein
Kristof Kamps

eit Knowledge & Innovation Community
Climate-KIC

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Contact Wuppertal Institute:

Prof. Dr.-Ing. Manfred Fischedick
Dipl.-Ing. Dietmar Schüwer

Research Group 1 "Future Energy and Mobility Structures" (project management)
Phone: (0202) 2492 - 121 (MF) - 288 (DSch)
Fax: (0202) 2492 - 198
E-Mail: manfred.fischedick@wupperinst.org
dietmar.schuewer@wupperinst.org

Prof. Dr. Stefan Bringezu

Research Group 3 "Material Flows and Resource Management"
Phone: (0202) 2492 - 131
E-Mail: stefan.bringezu@wupperinst.org

Dr. Justus von Geibler

Research Group 4 "Sustainable Production and Consumption"
Phone: (0202) 2492 - 168
E-Mail: justus.geibler@wupperinst.org

Wuppertal Institute for Climate, Environment and Energy

P.O. Box 10 04 80
42004 Wuppertal
Germany
Web: www.wupperinst.org

Contact Covestro:

Dipl.-Ing. Karen Perrey

Technology & Innovation (COV-IO-BC-T & I)
Phone: (0214) 6009 3356
E-Mail: karen.perrey@covestro.com

Covestro Deutschland AG
E60, 323
51365 Leverkusen
Germany
Web: www.covestro.com

Introduction

Today the CO_2 utilisation is discussed as one of the future low-carbon technologies. CO_2 is separated from the flue gas stream of power plants and is prepared for further processing as raw material. Fossil resources will not only be used as fuel in the industrial sector but also as feedstock for production of different products (e.g. urea, fertilizer, polymer materials). CO_2 containing gas streams from industrial processes exhibit a higher concentration of CO_2 than, for instance, flue gases from power plants which contain for example a high percentage of nitrogen. On the one hand it is therefore obvious to use industrial CO_2 sources as raw material for the chemical industry and for the synthesis of fuel on the output side. On the other hand, fossil resources can be replaced by substitutes of reused CO_2 on the input side. If set up in the right way, this step into a CO_2-based circular flow economy could make a contribution to the decarbonisation of the industrial sector and according to the adjusted potential, even rudimentarily to the energy sector.

In this study the potential CO_2 sources, the potential demand and the range of applications of CO_2 are analysed by the case study of North Rhine-Westphalia (NRW). Since activation energy is needed for the reuse of CO_2 and the utilisation usually depends on the use of hydrogen as a source of energy, it is necessary to view also regional sources and usage possibilities of hydrogen. NRW with its high density of (energy-intensive) industry is well suited for this analysis.

Sources of carbon dioxide (CO_2) and hydrogen (H_2)

The current amount of industrial CO_2 sources in NRW amounts to 42.4 Mt/a, when a minimum threshold of 0.4 Mt of CO_2 in the 2012 data is set (due to economies of scale and to keep the clearness in the figures). Additionally, 46 Mt/a are emitted from natural gas and hard coal CHP and waste incineration plants (see Table 1).

Among the industrial plants, four steam crackers in chemical industry are a relevant source with about 3 to 5 Mt CO_2/a and make up 60% of NRW's capacities for ethylene production. In the cement industry, both oxyfuel and amine scrubbing are discussed as techniques for carbon capture for the future. Converter gas and coke oven gas from iron and steel industry contain considerable amounts of CO_2, CO and H_2 that could be used.

Table 1: Overview of the selected branches and the key aspects considered by the analysis (State: 2012)

Branch	**Total CO_2 emissions in Mt/a**	**Numbers of plants**	**Medial CO_2 concentration in the flue gas**
Industrial Plants	42.4	31	1 - 100 %
CHP & Waste-to-energy power plants	46.0	22	3 - 14 %
Biomethane upgrade plants	0.0417	12	40-44 % (in the raw biogas)

Source: (PRTR 2012), (Öko-Institut e.V 2012 p. 26), (Dechema 2008 p. 7), (UBA 2012 p. 30), (Dena 2013) and own estimates

Prospectively 88.4 Mt CO_2/a will be available in North-Rhine Westphalia in the mid term until 2030. Fossil based power plants without CHP are supposed to be almost phased out and substituted by renewable energies and / or cut down by energy savings until 2030. Industrial emissions will still exist and come from chemical industry, coke ovens, iron and steel industry, cement and lime production and refineries.

Additionally **biomethane upgrade plants** could in total deliver ca. 41,700 t/a. However, although at first sight this seems to be a negligible order, those plants may be principally of interest, because they have a high CO_2 concentration in the gas flow, are based on renewable energies and have the process of CO_2 capture already integrated. Nevertheless due to economy of scale those small plants may rather be suitable for pilot applications of CO_2 utilisation.

H_2 is produced as by-product from various processes, especially from chlorine electrolysis. It is purified, dried and compressed for transport and offers greatest potential for utilization in future scenarios. Most of the produced 5 Mt H_2/a in Germany is directly produced for use in chemical industry. In NRW, from 350 kilotons of H_2 produced in 2008 (10 786 kNm^3/day), only 31 kilotons of fossil-based H_2 were available for external use (958 kNm^3/day).

Utilization options for carbon dioxide (CO_2) and hydrogen (H_2)

From our today's point of view and based on input from available CO_2 and H_2 in NRW, mainly four utilization paths are in the scope of analysis:

1. Large H_2 sources would lead to new value chains based on this energy carrier. Direct use of hydrogen for process heating, as fuel or as feedstock might be developed.
2. From CO_2 and H_2 as input parameters, methanol can be synthesized. It can be used as fuel or as feedstock in chemical industry.
3. Additionally, methane might be synthesized (Power-to-Gas) for all kinds of purposes. The advantage is the existing infrastructure for natural gas.
4. A more visionary, but the only utilization path for longer term CO_2 fixation, is the polymerization of CO_2 and H_2 into different kinds of plastics.

First and most important, renewable and economically available H_2 is needed for most value chains with regard to CO_2 utilization – being the major bottleneck for large-scale transformation of CO_2 to hydrocarbons. To stay environmentally friendly, the hydrogen has to be produced by means of renewable energies in a resource efficient manner. Currently, water electrolysis using regenerative energy like wind power is the dominant process route.

Hence, a reliable electrolyser infrastructure is needed. Necessary electrolysers are supposed to be prevailingly constructed close to existing industrial sites and (excess) renewable electricity is transported to these sites.

Sink-Source-Matching of carbon dioxide (CO_2) and hydrogen (H_2) in NRW

When producing methane or methanol for use as energy carriers or energy storage media or as substitute for fossil based platform chemicals significant amounts of CO_2 would be required. For NRW, prospects of utilization of CO_2 is rather focused on material use than on physical application, but it is very difficult to estimate the available potential for the future. Hence, the NRW potential is approached with the following three cases. Among them, the theoretical potential varies largely. It is assumed that each potential will be tapped completely by the year 2050.

Case A: Based on the **global assumption** of 1 to 5 % usage of CO_2 of current emissions:
3 to 14 Mt CO_2

Case B: Based on the estimated **available CO_2** emissions in NRW in the midterm (2030):
88 Mt CO_2

Case C: Based on the volume of **products**, where CO_2 could be integrated:
exemplary for the current production of
methanol: 1 Mt CO_2
polymers: 10 Mt CO_2
and the current demand for
methane: 176 Mt CO_2

In the long run until 2050, the decarbonization of the energy system is supposed to intensify and industry production will be less emission-intensive. If on the one hand, a very ambitious pathway is followed, e.g. as presented by (UBA 2015), CO_2 emissions from iron and steel or chemical industry will almost be completely reduced. In this case, in NRW only 4 to 5 Mt CO_2 would remain in 2050. If on the other hand, the decarbonization of industry will not develop in such an ambitious way, it could be an interesting business case for industrial emitters to provide large quantities of CO_2 for utilization. The production of H_2 and the transformation of CO_2 into a future feedstock will change existing value chains.

It has to be discussed whether the wished industrial symbiosis and integration processes between industries to use CO_2 could provoke less ambitions to mitigate emissions. If the industry shifted towards large use of CO_2 and renewable H_2, there might also be CO_2 logistics introduced which should be accessible beyond 2030 potentially even with neighboring countries. This could lead to a lock-in effect preventing industry to introduce other low-carbon technologies which omit CO_2 completely.

If one day CO_2 from industrial sources or power plants disappears, there will always be the possibility of air capturing. But if R&D will not succeed in significantly lowering the very high specific energy needs (and costs) for this technology of capture, it will rather remain a theoretical option.

Methodological background for a systematic multi-criteria analysis (MCA) of value chains for CO_2 reuse

In order to contribute to a sustainable development, the prospective value chains for the utilisation of CO_2 have to be evaluated not only with regard to their potential technical performance but also in terms of their potential ecological, economic and social consequences. Therefore, a Multi-Criteria Analysis (MCA) can be conducted as an analytical framework which helps to integrate quantitative and qualitative data, consider all dimensions of sustainability simultaneously, compare them in a standardised approach and allows stakeholder participation. Since this study has a more explorative character, the assessment itself will be conducted at a later time, so that results will not be presented in this chapter, but here the focus is on the assessment criteria.

The reference case to which all of the value chains are compared is “Release of CO_2 to the atmosphere”, which describes the current situation. Splitting up the assessment results into the different parts of the analysed value chains enables valuable insights into the “hot spots” which may be considered in detail in a so called “contribution analysis”.

Table 2 illustrates a possible set of assessment principles and belonging criteria for the assessment of value chains for the utilisation of CO_2. Criteria that are marked italic have been seen as of major importance.

Table 2: Overview on possible assessment criteria for value chains for the utilisation of CO_2

Technology	Ecology	Economy	Policy and Social	Systems orientation
Commercial availability	*Life cycle emissions*	*Cost effectiveness*	Conformance to political targets	*Systems compatibility*
Innovation potential	*Life cycle resource consumption*	Export potential	Independency from others measures	*Possible role as mitigation option*
Market potential	CO_2, GHG emissions		Employment effect	
Usability in other fields	Risk in case of mishandling		Social acceptance	
Infrastructure requirement	Irreversibility		Stakeholder analysis	
Technical risk			Drivers and barriers	
			Legislation requirements	

Source: based on (Krüger et al. 2013; Viebahn et al. 2010, 2012; Wuppertal Institut and Alcor 2012)

Current perception of CO_2 reuse: results from survey

Within the project, a survey on the current perception of CO_2 reuse was conducted, that for the first time provides a fundamental database on the existent studies on public awareness, perception and acceptance of CO_2 reuse within the English- and German-language publications. The results provide insights into the public and stakeholder understanding of CO_2 reuse related issues. There is no previous research which reveals consolidated results on public awareness, perception and acceptance of CO_2 reuse. Assumptions were made on strong comparison with Carbon Capture and Storage Technologies (CCS) and the rejections on this technology and also CO_2 pipelines. On the other hand CO_2 reuse was seen as a technical alternative to the storage of CO_2. Recommendations should be derived how to communicate CO_2 reuse in order to enable the public and relevant stakeholder to develop well-informed and well-considered opinions which are valuable predictors of future public acceptance on CO_2 reuse .

Recommended actions – comprehensive aspects of CO_2 reuse

General aspects

In 2011 worldwide anthropogenic CO_2 emissions lay at 34 000 million tons. Referring to the IPCC report 2007, usage of CO_2 amounts to about 178 million tons that means 0.6 % of the current total anthropogenic emissions. In chemical industry there are some new applications that are in a mature R&D state to use CO_2 as polymer building block. Additionally, there is a limited potential of use that could be increased by producing methane from CO_2 and H_2.

CO_2 reuse is one important building block of a strategy to lower CO_2 emissions and R&D efforts has to be continued and intensified. But in general, CO_2 reuse has a limited potential because for all utilization approaches, a huge amount of regenerative energy is needed and scenarios are characterized by a lack of profitability due to the current economic and political environment and frameworks. So, CO_2 reuse has to be flanked by other activities as energy efficiency measures in households, public, industry etc. as well as by R&D activities dealing with a more sustainable energy production including energy storage systems.

Comparative life-cycle oriented analyses are needed for the use of CO_2 and carbon rich waste which is transformed to platform chemicals (such as methanol, methane and syngas) using renewable energy such as wind power in order to determine which process chains and products are associated with the highest resource efficiency and lowest GHG emissions. The analysis should comprise cross-sectoral comparisons in order to determine whether the use of renewable energy capacities and CO_2 sources should be directed towards chemical production or transport (if e.g. renewable SNG is used for either purpose).

The estimations of the theoretical potential for CO_2 reuse vary largely. Hence, uncertainties about utilization potential and/or limited CO_2 sources should be kept in mind for the introduction of policies and measures for CO_2 mitigation.

Ecological soundness

The use of CO_2 is based on the availability of large amounts of electricity and a reasonable infrastructure to produce H_2. CO_2 reuse (including power-to-fuel and power-to-gas) only makes sense if renewable electricity structures (generation and transport) and electrolysis infrastructure are build up at the same time in large scale. If a H_2 and CO_2-reuse infrastructure is constructed, potential lock-in effects might be created in times when renewable electricity is not available. Therefore, risks of increased fossil power use has to be taken in mind. These issues must be politically addressed.

As the capacities for renewable energy supply are limited, its use for CO_2 transformation to hydrocarbons should be directed towards those process chains and final products which provide the highest resource efficiency and least GHG emissions. Political funding should also be oriented towards these aspects.

Systems analytical perspective

Due to the complex structure of systems and relationships linked with the value chains for utilization of CO_2, a systems analytical perspective for process development and assessment is recommended. On the one hand this is of relevance to the assessment of *individual value chains* that should not focus on a single process step but apply a holistic perspective.

One example is to include an Life Cycle Assessment (LCA) into the technology development process in an early stage of technology development. The LCA could focus on a set of specific impact categories including the overall resource implications in the natural system. On the other hand the compatibility of the value chains with the *industrial system and the energy system in general* is to be assessed. Performing a long-term technology foresight process enables to recognize possible chances and obstacles / limitations as well as drivers and barriers for the future implementation of the considered value chains.

Perception

Research activities on acceptance and communication regarding CO_2 reuse technologies are needed. Communication on CO_2 reuse technologies must differentiate between the specific variability of this technology and should include all potential risks and benefits linked with CO_2 reuse technologies.

A multi-criteria analysis (MCA) of selected value chains for CO_2 reuse offers the chance for a broad stakeholder participation. It is, therefore, recommended to involve as early as possible various stakeholders from NGOs, science, industry, economy and policy in both the design of the assessment process and in conducting the MCA. When initiating an MCA and developing its objectives it should be considered how results can be best communicated. This is especially important if results are to be communicated to society and increase acceptance for certain technologies.