JOURNAL OF
BUSINESS CHEMISTRY

ISSUE

Vol. 18 - Iss. 2

The 4th International workshop on "Innovation and Production Management in the Process Industries" will be convened at Provadis School of International Management and Technology in collaboration with the University of Münster in May 2022 in Frankfurt, Germany. Further information will be announced soon on our website.

ISSN 1613-9623

Aim and Scope

The Journal of Business Chemistry (JoBC) focuses on current developments and insights at the intersection of management and chemistry, biotechnology or pharmacy.

The JoBC provides an international forum for researchers and practitioners in companies, research institutes, public authorities, consultancies or NGOs to present and discuss current challenges as well as potential solutions in an interdisciplinary manner. Thus, the JoBC aims to foster the dialog between science and business, to support management practice in the chemical and pharmaceutical industry and to indicate where further research from academia is needed. The JoBC offers high quality publications with academic standards, a fast publishing process and global reach. With this multidisciplinary and boundary-spanning approach, the JoBC intends to become the leading journal for decision makers in the chemical and pharmaceutical industry.

Publisher

The Journal of Business Chemistry (Online ISSN 1613-9623) is jointly published by Prof. Dr. Jens Leker (affiliated with the Institute of Business Administration, University of Münster) and Prof. Dr. Hannes Utikal (affiliated with the Center for Industry and Sustainability, Provadis School of International Management and Technology). It is published every four months as an open access journal.

Subscription

Online-Subscription is possible at:
subscribe@businesschemistry.org
or LinkedIn: www.linkedin.com/company/jobc/
The articles are available for download free of charge at www.businesschemistry.org.

Abstracting and Indexing

The Journal of Business Chemistry is covered by the following abstracting and indexing services:
- EBSCO Publishing
- Hamburg Institute of International Economics
- German National Library of Economics
- Chemical Business NewsBase (CBNB) by Elsevier Engineering Information, Inc.

JOURNAL OF
BUSINESS CHEMISTRY

Vol.18, Iss.2, June 2021

Contents

ISSN 1613-9623

Letter from the Editors

Climate neutrality: 2050 or already earlier?

Last year, everyone was talking about the European Green Deal and the goal of climate neutrality by 2050. Now that the topic is gaining further momentum, Germany has decided to become climate-neutral by 2045. This is one of the key points of a reform of the German climate protection law presented in May of this year. Furthermore, the United States have returned to the global stage in the fight against global warming and have formulated new climate protection targets for 2030. What does that mean for actors in the chemical industry? How can the chemical industry be transformed? Although many questions, especially regarding the practical implementation, are yet to be answered, one thing is clear: No one in the chemical industry can bypass this topic anymore. Two articles in this issue deal with this highly relevant topic while the third article about electronic marketplaces addresses another megatrend - digitalization.

Adam Franz and Manfred Kirchner´s article "Options for CO_2-neutral production of bulk chemicals" addresses the challenge of transforming to more sustainable and in particularly less emission intensive bulk chemical production. Sources of scope 1-3 emissions related to chemicals are discussed and subsequently, options to reduce them are presented using 1,4-butanediol (BDO) and formaldehyde as examples.

The article "Validating the Product-Market-Fit of a B2B Platform Venture with a Minimum Viable Product: The Coating Radar Case Study" written by Lars Schmitt, presents a contribution to the young research field of digital entrepreneurship. It starts by looking at the business model of an electronic marketplace (EM) which is particularly attractive for fragmented markets and emphasizes that not much is known yet about the early validation of a marketplace business model. In the following, the author describes the validation process of an EM by the example of the venture Coating Radar.

Finally, the commentary "Sustainability in Uncertainty?" by Apurva Gosalia raises the question whether sustainability is still a priority in times of uncertainty and in the post-pandemic world. The article offers insights into several sustainability concepts (e.g. 3 P´s of sustainability or 3 C´s to carbon neutrality) and gives some examples from the lubricants industry. By connecting sustainability with the five principles of effectuation, the author emphasizes that sustainability is a solution in times of uncertainty and advocates for further climate action.

Please enjoy reading the second issue of the eighteenth volume of the Journal of Business Chemistry. We are grateful for all the support from authors and reviewers. If you have any comments or suggestions, please do not hesitate to contact us at Janine.heck@businesschemistry.org. For more updates and insights on management issues in the chemical industry, follow us on LinkedIn: www.linkedin.com/company/jobc/ and subscribe to our newsletter: https://www.businesschemistry.org/

Janine Heck (Executive Editor)	Bernd Winters (Executive Editor)

JOURNAL OF
BUSINESS CHEMISTRY

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069429918
DOI: 10.17879/27069428886

Commentary

Apurva Gosalia*

Sustainability in Uncertainty?

1 Introduction

We are living in extraordinary times, stuck between corona crises, climate change and cultural conflicts. It all adds up to uncertainty. In this context, the title of this commentary, „Sustainability in Uncertainty?" has a dual meaning. The first raises a question: Is sustainability still a priority for the chemical industry during these times of uncertainty now and in the post-pandemic world? The second, however, postulates the opposite: Wouldn't the focus on sustainability be just the right strategy for chemical companies to solve the challenges of these days? This commentary looks at both these questions the chemical sector is facing exemplary from the view of the lubricants industry and also provides examples and solutions on successful sustainable business models and new ideas for the future of the sector.

2 The "3 P's" of Sustainability

At the beginning of September 2019, my son and I were admiring the view from the top of Snaeffelsjökull („jökull" meaning glacier) in Iceland. Under our feet was mature ice, thousands of years old. The sun was shining, the sky was blue, and it was bracingly cold. There was no lockdown, everything was free and open, and we could travel, go to restaurants and everything was OK. But was it really OK? „Ok" („Okjökull" in full) was also the name of the first glacier in Iceland to be declared dead in 2014. In other words, it melted – a direct result of climate change. At what was the base of the glacier is a plaque to commemorate its demise, embossed with the global average atmospheric carbon dioxide concentration when the plaque was placed there in 2019 – 415 parts per million. That was the highest CO_2-concentration ever measured in Earth's atmosphere (Luckhurst, 2019).

Oscar Wilde once said: „Everything will be OK in the end, and if it is not OK, it is not yet the end." I believe in the last part; it is not yet the end.

The term sustainability can be traced back to the Latin sustinere (tenere, to hold; sub, up). Sustain can mean "maintain", „support", or „endure". The German term "Nachhaltigkeit", meaning a responsible and long-term oriented management of natural resources, was first introduced by Hans Carl von Carlowitz (1713) in his work "Silvicultura Oeconomica". His concern was to establish a sustainable management of the natural resource wood (Grober, 1999).

Sustainability definitions and business plans often refer to the "3 P's" which consist of profit, planet, and people. These three words that all start with a "P", describe how the goal of sustainability is within the sweet spot of economic, ecological and social values. The "3 P's" are often referred to the Triple Bottom Line, which is described as ensuring business success by overlapping interests of the society and the environment, in addition to business interests (Slaper and Hall, 2011).

On the economic side, the most sustainable target is to continue making a profit. This is not an unethical goal, but some business leaders might consider it an overriding one. If you'd have asked a CEO or CFO one or two decades ago what there "3 P's" were, many would have answered: "profit, profit and profit." If you were to ask the same question today, their answers should be – and in many companies, this is becoming the case more and more – "profit, planet and people." Lubricant companies need to continue making profits, of course, otherwise they are out of the game of making a sustainable difference or contributing sustainable

*Senat der Wirtschaft, apurva.gosalia@outlook.de; Fokus Zukunft, apu.gosalia@fokus-zukunft.com

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069429918
DOI: 10.17879/27069428886

solutions in the future, not to mention socially irresponsible and shedding jobs.

Continuing to have the first “P” stand for profit, companies must be aware of the ecological and social footprint they leave behind while making money. This is where the planet and people dimensions of sustainability come into play. Creating not only economic but also ecological and social value for a company, its employees and external stakeholders is no longer an add-on or nice-to-have but has become an integral part of the strategy of organizations that want to be successful in the future.

3 The “3 C’s” to Carbon Neutrality

Taking the lubricants industry as an example, the ecological footprint must be measured along the process and value chain of a lube manufacturer. Actually, it’s about the “3 C’s” of CO_2 - calculation, cutdown and compensation.

The first step must be to calculate the carbon footprint of a company.

Then the next step is to search for possibilities of avoiding and reducing CO_2 emissions. Around 80% of CO_2 emissions of a typical lube manufacturer are caused by heat and electricity consumption, so energy efficiency is an important lever in avoiding or reducing CO_2.

To achieve carbon neutrality as early as possible, it is important in addition to avoiding and reducing emissions to offset the so far not yet avoided or generally unavoidable emissions at the same time with compensation measures. These come through the voluntary promotion by investing in high-quality climate protection projects in socially, politically and/or economically disadvantaged countries - projects, which would not be possible without such additional income. This voluntary financial support not only helps the selected countries to improve their economic, social and ecological circumstances, but is also a major driver for the transfer of clean technologies and sustainable global economic development into those countries and regions. Is this greenwashing? No, this is not greenwashing: Since CO_2 emissions impact the climate at a global level, it is ultimately irrelevant where on the planet they originate and where they are saved. The aforementioned projects are accredited, approved and monitored according to internationally recognized certification standards and fulfill especially stringent requirements. They not only save CO_2, but also contribute to local sustainable development. The validation of the project results regarding the CO_2 savings achieved, is verified by independent testing bodies such as the TÜV. This mechanism, which is embedded in the Kyoto Protocol, has become firmly established over the past 20 years and proven itself as a central component of voluntary, non-governmental climate protection. The process is supported by the UN, numerous non-governmental organizations and hundreds of large companies, including those in the petroleum and chemical industry.

4 The “5 F’s” of Carbon Calculation

Thus, the solution for the lube industry comes with a stepwise approach or the “5 F’s” – footprint, feedprint, fingerprint, fining print and firing print, as I call it. The stepwise approach is shown in Figure 1.

The first “F” is the “footprint”, i.e. looking at the corporate carbon footprint in the own lube operations at the worldwide locations of a lube manufacturer, which is generated through heat, fuel and electricity consumption in production, administration, business trips, employee commutes as well as through waste generation and waste water in the company. The objective should be to ultimately bring this carbon footprint to zero with measures described above, so that that all customers will receive lubricants produced carbon neutral processes from a carbon-neutral lubricant company.

The second “F” is the so-called “feedprint”. In the long term, a lubricant company will be obliged to sell CO_2-neutral products to its customers. This requires calculating the product carbon footprint of lubricants and it also requires that a lube manufacturer receives carbon-neutral raw materials from its suppliers, as raw materials account for around 90% of the product carbon footprint in a finished lubricant.

The third “F” is the so called „finger print“: Developing, producing and marketing numerous emission-reducing and eco-friendly lubricants which in the application phase, make a greater contribution to saving energy and CO_2 emissions than conventional alternatives thanks to higher reduced friction and ability to protect against wear and corrosion.

JOURNAL OF
BUSINESS CHEMISTRY

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069429918
DOI: 10.17879/27069428886

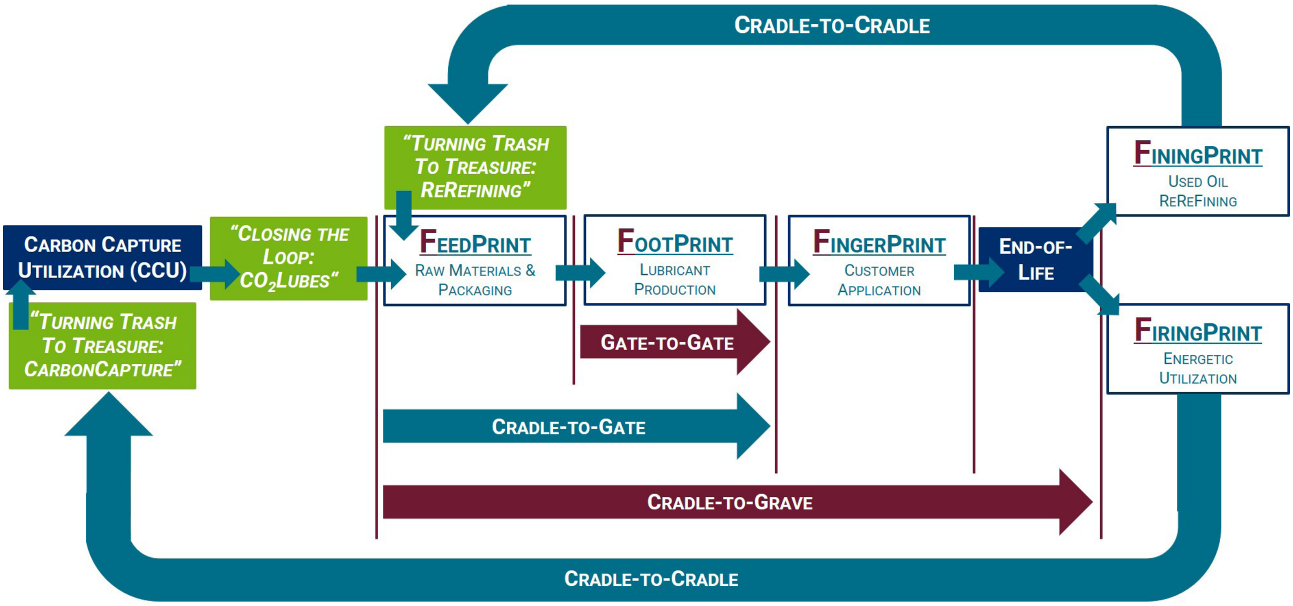

Figure 1 The "5 F´s" of CO_2-calculation (own representation).

The fourth "F" is the so called "fining print". At the end of life of a lubricant in an application, waste oil collection and rerefining into new feedstock instead of being burned in a cement factory, also saves CO_2 – I call this process "Turning trash to treasure".

The fifth "F" is the so called "firing print". When the regeneration of waste oils does not make sense due to their high content of additives or pollutants, they may be recovered for energy purposes as a substitute for normal fuels in combustion plants (Umweltbundesamt, 2014). During this process of course again CO_2 is emitted in the atmosphere, but it can be captured and converted into lubricants again – I call this process: "Closing the loop by CO_2Lubes". A meanwhile completed project named "CO_2Lubricants" was aimed to convert CO_2 into lubricants. The project was funded with ~ € 1.6 million over 3 years by the Federal Ministry of Education and Research (BMBF) in Germany and involved 5 joint partners, including a lubricant company and the Technical University (TU) of Munich. As the supply of CO_2 is on the one hand an atmospheric concentrate and, on the other hand, a gas from combustion processes, this CO_2 in the project was used for the cultivation of optimized algae cultures, which produce a high proportion of lipids. These lipids were used purely or in further processed form for the production of high-performance lubricants. The oil-free residues of the algae biomass could be used for the cultivation of oil yeasts (Technische Universität München, n.d.).

Bringing down the corporate and product carbon footprint of a lube manufacturer has not only to do with planet but also with profit, as receiving carbon neutral products is what big industrial and automotive OEMs expect from their suppliers – also lube suppliers – right now and not only starting many years in the future.

5 The "5 P's" of Sustainability, the 5 Principles of Effectuation, the "5 R's" for Post-Pandemic

The current short-term corona crisis puts pressure on sustainability while the long-term climate crisis gives purpose to it. Therefore, we should no longer only look at the well-known "3 P's" of sustainability but should add two more and think in terms of "5 P's" from now on, as shown in Figure 2.

The fourth "P" calls for an examination of the actual purpose of companies. Employees care more about sustainability than ever before and want to contribute to the higher goals of their company. For companies and their employees, it is therefore a question of finding a balance between profit and purpose. More and more companies are talking about their „purpose," i.e., an objective and raison d'être that goes beyond just making a profit. The predominant purpose of a

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069429918
DOI: 10.17879/27069428886

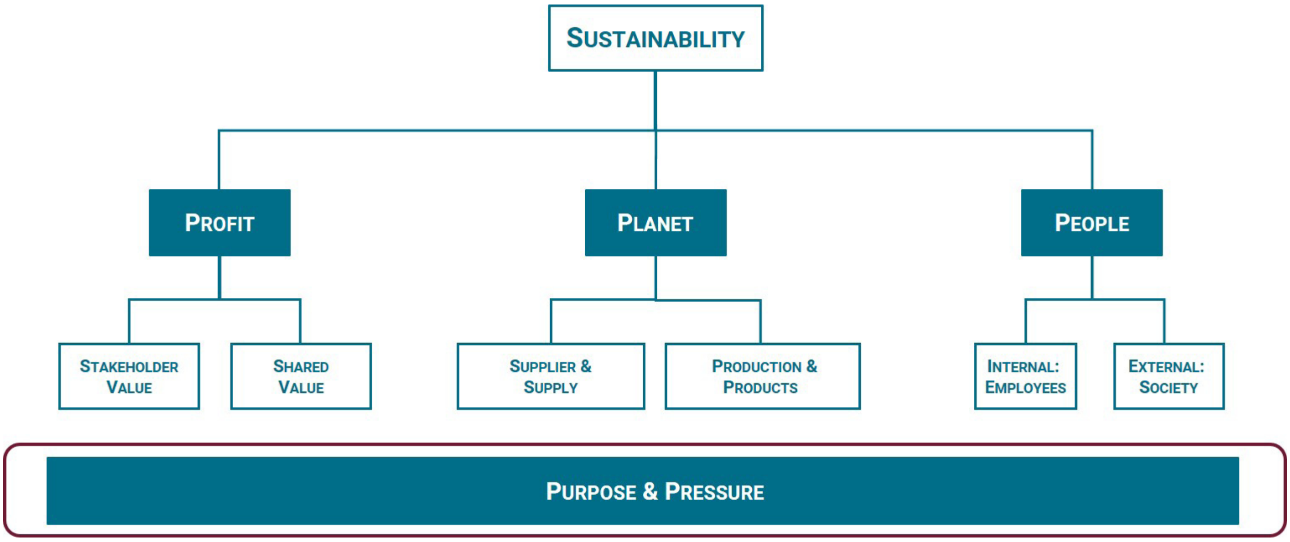

Figure 2 The "5 P´s" of sustainability (own representation).

company in my view must be, to provide sustainable value to its customers.

The fifth "P" is the pressure due to the uncertainty we all face these days. Moreover, companies are confronted with new and changed expectations from various stakeholders in terms of measurement, regulation and establishing sustainability as a business case - this will have a significant impact on the future business activities of companies. In this respect, sustainability can no longer be an add-on, but must be established as an integral part of the process value chain of companies.

The expectations of the stakeholders will continue to stay and even be intensified, while the uncertainty can be managed by an interesting concept called „effectuation." Effectuation is a method of decision making that is used during uncertain times and that has unclear goals. Classical management dictates that one can predict or plan for the future, while effectuation accepts that chaos and the unforeseen can and will happen but that the future can still be shaped. Metaphorically speaking, when friends turn up to your house unannounced in the evening, you feel obliged to feed them. Since the stores are all closed, you improvise the best you can with what is already in the fridge (Küppers, 2020).

The Five Principles of Effectuation are:

1. **Bird in Hand:** Create solutions with the resources available here and now.
2. **Affordable Loss:** Only invest as much as you are willing to lose.
3. **Crazy Quilt:** Enter into new partnerships that can bring new funds and directions.
4. **Lemonade Principle:** Mistakes and surprises are inevitable and can be used to look for new opportunities.
5. **Pilot in the Plane:** Co-create the future with things under your control and with self-selected partners.

How does effectuation connect to sustainability? The answer comes with my "5 R´s": recover, rethink, reset, restart and reduce. **Recover** by means of effectuation from the pandemic. **Rethink** your business model. The current crises revealed to us through a magnifying the mistakes some companies have done in the past. Press the **Reset** button, which many companies have been forced to do. **Restart** your business again in a more sustainable way, for example, by integrating the United Nations' 17 Sustainable Development Goals, which resulted from the Paris Agreement of 2015 as a guideline and framework. **Reduce** resources and base your strategic thinking on repair, recycling, and reuse. This fosters a thinking toward the circular economy and cradle-to-cradle resource management, wherever possible, e.g. by "Closing the loop: CO_2Lubes".

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069429918
DOI: 10.17879/27069428886

6 In Uncertainty: Sustainability!

The word sustainability is overused – in conferences, promotional literature for products, in year-end reports – yet there is still no common consensus on what it means in the business world. I believe that, at its core, corporate sustainability means continuous improvement, in all fields along the process or value chain of the business, to create economic, ecological and social value for the stakeholders of a company, be they customers, employees, investors, suppliers, communities and government. This is especially important during this seemingly endless pandemic.

Thus, sustainability in times of uncertainty takes on another layer of meaning when we examine the word itself: „sustain ability" – the ability to sustain business. Companies are faced with the question: „How can we sustain the abilities of our people, our production, our products and our customers during and after the pandemic"?

Thus, coming back to the initial question with the two meanings of the title of this commentary: sustainability in uncertainty. Is the concept of sustainability uncertain? – Not at all on the contrary: sustainability is a solution in times of uncertainty. And there are new strategic windows of opportunity opening up especially in Europe with the European Green Deal and the plan to be the first climate neutral continent until 2050. To do so, it will carry out a set of initiatives, e.g. decarbonisation targets for 2030 (EU, n.d.). German companies call for COVID-19 state aid to be tied to climate action and that economic policy measures should be closely linked to overcome both climate and corona crises (Schuetze, 2020).

To me, sustainability indeed is between the recovery of the industry post pandemic and innovations which must come as sustainable solutions for companies on their (e)mission to zero alongside the "5 P's" of sustainability.

Going back to Iceland: In August 2019 – one month before I was there with my son – a board plaque was set up at the bottom of the former Ok-glacier, which was titled: "Letter to the future", saying the following: "Ok is the first Icelandic glacier to lose its status as glacier. In the next 200 years all our main glaciers are expected to follow the same path. This monument is to acknowledge that we know what is happening and what needs to be done. Only you know if we did it." (Luckhurst, 2019).

References

EU (n.d.): EU climate action and the European Green Deal, available at https://ec.europa.eu/clima/policies/eu-climate-action_en, accessed 10 Mai 2021.

Grober, U. (1999): Der Erfinder der Nachhaltigkeit, available at https://www.zeit.de/1999/48/Der_Erfinder_der_Nachhaltigkeit, accessed 11.05.2021.

Küppers, A. (2020): The Effectuation Approach – Method of decision making for experienced entrepreneurs, available at https://www.fs-finance.com/the-effectuation-approach/, accessed 10 Mai 2020.

Luckhurst, T. (2019): Iceland's Okjokull glacier commemorated with plaque, available at https://www.bbc.com/news/world-europe-49345912, accessed 10 Mai 2021.

Schuetze, A. (2020): German companies call for COVID-19 aid to be tied to climate action, available at https://www.reuters.com/article/us-health-coronavirus-germany-climatecha-idUSKCN2290LI, accessed 10 Mai 2021.

Slaper, T., Hall, T. (2011): The Triple Bottom Line: What Is It and How Does It work?, Indiana Business Review, 86 (1), pp. 1-9.

Technische Universität München (n.d.): CO_2 Lubricants, available at https://www.department.ch.tum.de/wssb/forschung/abgeschlossene-projekte/co2-lubricants/, accessed 10 Mai 2021.

Umweltbundesamt (2014): Altöl, available at https://www.umweltbundesamt.de/themen/abfall-ressourcen/abfallwirtschaft/abfallarten/gefaehrliche-abfaelle/altoel, accessed 10 Mai 2021.

JOURNAL OF
BUSINESS CHEMISTRY

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069428400
DOI: 10.17879/27069428165

Practioniers's Section

Lars Schmitt*

Validating the Product-Market-Fit of a B2B Platform Venture with a Minimum Viable Product: The Coating Radar Case Study

Both start-ups and established companies have increasingly launched digital business models in recent years. Some of them focus on the business-to-business (B2B) sector and follow the business model of an electronic marketplace (EM). B2B electronic marketplaces are functioning as internet platforms bringing together demand and supply which is why they are often called matchmakers. According to the existing e-commerce and EM literature, the model of an EM is particularly attractive for fragmented markets, with many small and medium-sized suppliers. The argument behind this is that an electronic marketplace can significantly reduce search and transaction costs for the buyers' side due to the aggregation of numerous suppliers. There are many highly fragmented B2B markets, in which such an aggregation via a platform could add value. But less is known about the early validation of a marketplace business model. The case of a venture called Coating Radar shows this validation process based on the concept of a minimum viable product and the lean start-up approach. This represents a contribution to the still young research field of digital entrepreneurship. Furthermore, it turns out that the product-market-fit is negative for the Coating Radar. From this result, a potential generalization could be that fragmented B2B markets might be attractive for new marketplace business models. But only a systematic validation can show whether a platform business idea can become a sustainable business. This complements the literature in the field of electronic marketplaces and B2B e-commerce.

1 Introduction

In the course of digitalization, business-to-business (B2B) trading has changed considerably and is still subject to digital transformation. This transformation affects both internal company processes as well as processes for cooperation and collaboration with other companies. Procurement and sales processes are of particular interest in the context of this paper. Many activities in these areas are still largely analogue or follow the patterns that existed 10 or 20 years ago, i.e. a "classic" B2B deal is often still agreed upon face-to-face or by phone. Nevertheless, there are more alternatives to these conventional processes, which can usually be seen as digital extensions or supplements to the usual procurement and sales activities. E-commerce is a central term in this context. The global B2B e-commerce gross merchandise volume (GMV) was $5,826 bil. in 2013 and increased to $7,661 bil. in 2017 (Statista 2017). E-commerce share of total B2B sales

* Technical University of Munich, TUM School of Management, Chair for the Economics of Innovation, Arcisstrasse 21, 80333 Munich, lars.schmitt@tum.de

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069428400
DOI: 10.17879/27069428165

in the US was 9.7% in 2015 and 12% in 2019. The forecast for 2021 is 13.1% of B2B sales will be generated digitally (Forrester Research 2017). With regard to Germany, there are statistics that show that B2B e-commerce generated revenues of around €1,300 bil. in 2018. Of this, €320 bil. was gained via websites, web shops and electronic marketplaces (IfH Köln 2019). Consequently, a major share of B2B trading is already taking place online and electronic marketplaces (EMs) are becoming increasingly important. EMs can be understood as marketplaces that bring together supply and demand in a digital way. These "matchmakers" are well-known from consumer shopping, e.g., Amazon, Airbnb, or Uber (Evans & Schmalensee 2016).

In the B2B sector, EMs are still perceived as new, although they were receiving a lot of attention during the dot-com bubble (Schmitt 2019). Since hardly any B2B marketplace survived from the dot-com era, interest in them declined, also from researchers. However, more recently B2B electronic marketplaces have been experiencing their "second spring" after their initial rise during the 1990's dot-com bubble boom (ebd.). In fact, the technical conditions are better than 20 years ago and habits or user experiences from the B2C context are increasingly finding their way into the B2B sector (ibi research 2019).

From a scientific point of view, the business model of an electronic marketplace is very attractive for fragmented markets, because the search and transaction costs are usually high in such markets (Bakos 1991; Bakos 1997; Kaplan & Sawhney 2000; Giaglis et al. 2002; Markus et al. 2002; Thuong 2002). Thus, EMs can reduce these costs through becoming an intermediary, platform, or matchmaker (Klein & Alt 2015). In other words, EMs promise that it takes less time and effort to find a new supplier from the buyer's perspective. This clear value proposition and today's appeal of digital business models have encouraged both start-ups and established companies to become active in this area. At the same time, robust and resilient supply chains require close partnerships between buyers and suppliers (Wieteska, 2016). Therefore, frequent supplier changes are usually avoided in many B2B contexts. Every business partnership also comes with dependencies (Padgett et al., 2020). Suppliers are continuously trying to decrease the likelihood of "partner switching" through increasing this dependency (ebd., p. 13). At the same time, one could argue that the buyer's loyalty towards the respective supplier might play an important role as well. Both the dependencies and loyalties are relevant aspects that have an impact on the value proposition of B2B electronic marketplaces. This can also been seen in the single case study of the young venture "Coating Radar". The case study addresses the following two research questions:

a. Does the business model of an electronic marketplace create value in a highly fragmented B2B market (here: industrial coating services)?
b. How to test or validate the idea of a new B2B electronic marketplace with as few resources as possible (following the so-called Lean Start-up approach)?

2 Theoretical Background

2.1 Electronic Marketplaces

Strader and Shaw (2000, p. 78) once defined electronic marketplaces as an "interorganizational information system that allows the participating buyers and sellers to exchange information about prices and product offerings". In addition to the exchange of information, it is also possible for the participating parties to negotiate with each other on an electronic marketplace, or even to conduct business transactions (Archer & Gebauer 2002). The latter concretely means that one party buys a product or a service from the supplying party via the EM (Klein & Alt 2015). Such activities can take place in a business-to-consumer (B2C) context (Evans & Schmalensee 2016), but also in a business-to-business (B2B) context (Timmers 1998; Chow et al. 2000; Thuong 2002).

According to Giaglis et al. (2002) electronic marketplaces can have a major effect in markets with a high fragmentation of the supply side. Such markets "provide opportunities for intermediaries to add value" (ebd., p. 243). The main reason for this is that EMs lead mostly to an aggregation of the supply side (Kaplan and Sawhney 2000). The aggregation achieves low search and transaction costs for the demand side. Electronic marketplaces thus can create a central value in fragmented markets, especially for potential buyers (Bakos 1991; Bakos 1997; Kaplan & Shawney 2000; Giaglis et al. 2002; Markus et al. 2002; Thuong 2002; Klein & Alt 2015). For the suppliers the promise or value proposition of an EM is that these can be found faster by potential new customers. Consequently, it should be possible for suppliers to generate new business opportunities with the help of an EM.

JOURNAL OF
BUSINESS CHEMISTRY

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069428400
DOI: 10.17879/27069428165

2.2 Minimum Viable Product & Lean Start-up

Starting a digital venture is generally considered as resource-intensive and risky because software development is expensive (Pantiuchina et al. 2017; Bohn & Kundisch 2018). A digital venture which focuses on a business model of an electronic marketplace has to deal with the challenge that it is not clear whether the respective user groups will adopt this new procurement and sales channel (Driedonks et al. 2005; Schmitt 2019). To avoid costly developments and to receive first feedback from the target and user groups, so-called minimum viable products (MVPs) are created nowadays. There are several definitions of a minimum viable product which complement each other (Lenarduzzi & Taibi 2016, p. 4):

- "A MVP is a version of a new product that allows to collect the maximum amount of validated learning about the customer with the least effort."
- "A MPV has just those features, and not more, that allow the product to be deployed."
- "A MVP is typically the first version of a product released to customers, and should contain only the absolute minimum in terms of features and design for it to become viable to the customer."
- "A MVP represents the minimum functionality or set of features within the product, allowing the firm to test the product in the market and gather customer feedback."
- "A MVP is an experimental object that allows for empirical testing of value hypotheses."

A frequently used metaphor for MVPs comes from Kniberg (2013) using various means of transportation to represent the development process of a new product (see Figure 1).

The illustration shows that MVPs are about focusing on the actual customer need, i.e., if the customer only wants to get from A to B quickly, several means of transport might solve the customer's problem. Here, a skateboard could already be a MVP to receive initial feedback from the customer. It might not be necessary to develop a car to get feedback, which would be much more costly and time-consuming.

The skateboard is actually a usable product that helps the customer get from A to B. It is not great, but a tiny bit better than nothing. So we tell the customer "don't worry, the project is not finished, this was just the first of many iterations. We're still aiming to build a car, but in the meantime please try this and give us feedback". Think big, but deliver in small functionally viable increments. (Kniberg 2016)

In the context of a digital venture, a minimum viable product can be understood as a digital prototype that shows the most important value proposition towards the user. Here, MVPs represent often so-called landing pages, i.e. websites that have a basic functionality that supports the value proposition and the underlying hypotheses (Khanna et al. 2018). The concept of an MVP can be embedded in the theoretical model of the so-called lean start-up (Frederiksen & Brem 2017; Dennehy et al. 2019; Shepherd & Gruber 2020). According to Ries (2011, p. 9), "the fundamental activity of a start-up is to turn ideas into products, measure how customers respond, and then learn whether to pivot or persevere. All successful start-up processes should be geared to accelerate that feedback loop." Furthermore, he states (ebd., p. 75) that "the feedback is both qualitative and quantitative. […] The products a start-up builds are really experiments, the learning about how to build a sustainable business is the outcome of those experiments." This resulted in the "Build-Measure-Learn" feedback loop, which represents exactly these iterations (see Figure 2).

Running through iterations and experiments serves to validate the idea and should therefore help the entrepreneur to better assess the product-market-fit (Dennehy et al. 2016). The goal of the validation is therefore to make a statement about the product-market-fit, based on the empirical findings of the MVP or from several MVPs (ebd.).

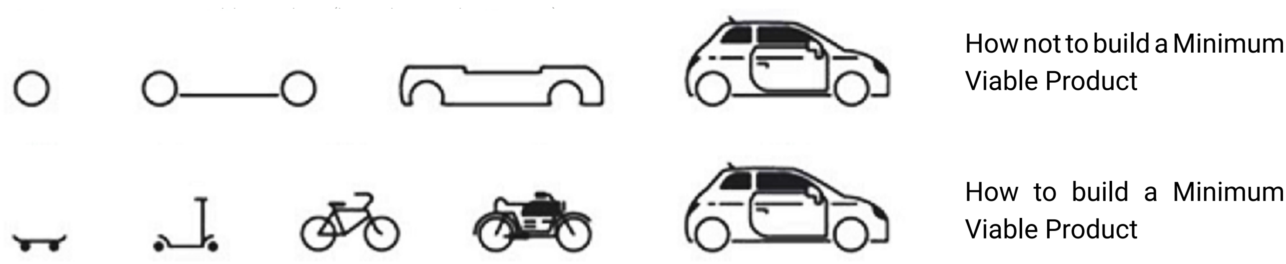

Figure 1 A minimum viable product (based on Kniberg 2013)

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069428400
DOI: 10.17879/27069428165

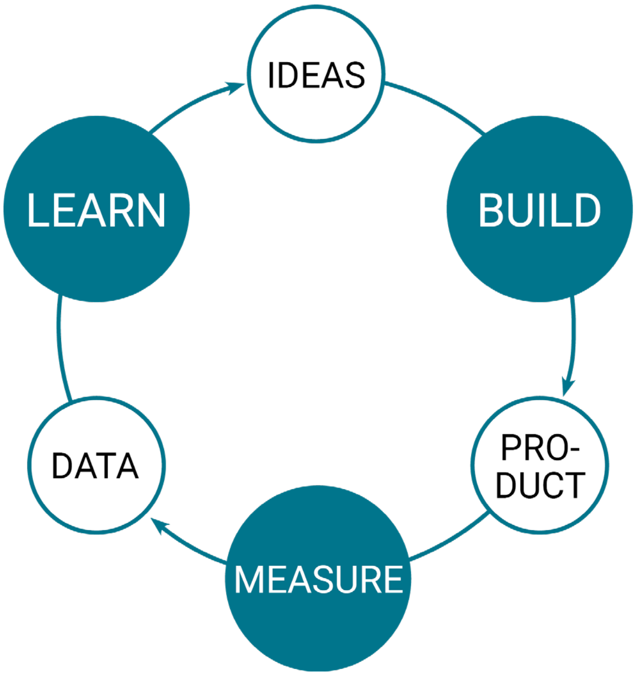

Figure 2 The Build-Measure-Learn feedback loop (Ries 2011, p. 75)

3 Methodology

In the area of case study research, various approaches that can be pursued. Three approaches are particularly noteworthy. These are the Grounded Theory according to Glaser & Strauss (1967) and the case study approaches according to Yin (1981, 2013) and Eisenhardt (1989). A characteristic of the Grounded Theory approach is that a scientist investigates a certain phenomenon without taking a detailed look at the literature in the beginning. The theory development is mainly based on the data of the case. Case studies that follow Glaser & Strauss' inductive approach usually have a very short theory section, so the relevant literature is rather mentioned within the case presentation.

The procedure is different from Yin and Eisenhardt. Both Yin's and Eisenhardt's case study approaches are built on existing literature, so given theories or concepts should be tested and ideally extended. Case studies that follow Yin's deductive approach usually begin with a detailed examination of the literature. Based on this, a new model or synthesis is developed, which is then validated in the case setting.

Compared to Yin, the case selection should take place earlier in Eisenhardt's opinion. Case studies that follow Eisenhardt's abductive approach therefore start with a literature review as well and possibly give a first impression of theory development. Nevertheless, the theory is built in the process, whereas Yin completes the theory building before the case execution. For this reason, it can be said that Eisenhardt's approach lies "somewhere in-between Yin's approach and the Grounded Theory approach" (Seenhuis et al. 2006, p. 7).

The single case study about the Coating Radar is in line with Eisenhardt's hybrid form of case research, considering the process of case and theory development. This process can be described as "highly iterative and tightly linked to data" (Eisenhardt 1989, p. 532). Nevertheless, working strictly according to Eisenhardt would also include a comparison of multiple cases what was not in the scope of this research project. The arguments for and against single or multiple case studies continue to be debated among case study researchers. For this paper, the main objective was to tell a "good story" and to enrich theoretical insights, what is also in line with Dyer & Wilkins (1991).

4 The Coating Radar Case Study

Eisenhardt's scientific approach may sound familiar to entrepreneurs as well. Going through iterations, collecting, and analyzing data are essential components when

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069428400
DOI: 10.17879/27069428165

developing a minimum viable product. In the following, the case of the Coating Radar is examined. It is important to note that the author of this study is also the main character of the case and therefore the founder of the start-up Coating Radar. This is the reason why the case is written in the first person. The name of the venture already reveals which industry was addressed by the idea of the Coating Radar: the coatings industry.

4.1 Context

The coatings industry deals with the production of paints, varnishes, and lacquers. The word "coatings" functions as an umbrella term for these products. The main actors in this industry are the coating manufacturers, such as AkzoNobel, PPG, Sherwin-Williams or BASF (Statista 2020). The probably best-known coating processes are "wet paint" and "powder coating". Companies in these fields are producing specific coatings, often fluid and sometimes powder-like. Private customers can find such products, mostly wet paint, for example in do-it-yourself stores or in specialist shops. However, this case is about one specific B2B context inside the coatings industry: so-called coating services (also: "job coating"). Coating service companies (also: "job shops") are applying special coating solutions on specific components or parts. These parts are mostly out of metal and need to be coated because of corrosion. Almost every surface that we can see our touch is usually protected by coatings. Coatings can also not only protect but also enable various functionalities, such as conductive or antibacterial coatings. The variety of functionalities, application areas, technologies, and coating processes is tremendous. The coating manufacturers supply these coating service companies with their coating material. Accordingly, coating service companies apply the material on the respective surface. This market can be seen as a classical service industry in an industrial B2B context.

4.2 Idea

The idea of the Coating Radar was a "platform for coating services", so an intermediary that brings together supply and demand digitally in the field of industrial coating services (also: "industrial surface treatment"). Consequently, there should be coating service companies on the supply side of the platform that deal mainly with B2B customers. There was consequently no interest in B2C coating services, e.g., car painters or repair shops. On the demand side of the platform, there could be almost any industry since many applications for coatings exist. Important application areas are for example the automotive industry, metal industry, furniture industry, construction industry, mechanical engineering, or electrical industry.

4.3 Market

The coatings industry is an important segment of the chemical industry. Industrial coating services can be considered as a niche market within the coatings industry. The activities of the Coating Radar focused on the DACH region (Germany, Austria, Switzerland). Looking at the figures in Germany, according to the Association of the German Paint and Printing Inks Industry (Verband der deutschen Lack- und Druckfarbenindustrie 2020), 389,000 tonnes of industrial coatings were sold in 2019, worth €2,2 bil.. Since there are hardly any reliable statistics about the coating service companies themselves, I came to an estimation of about 3,500 coating service companies in the DACH region (10,000+ worldwide) based on several industry guides and portals. The majority of the coating service companies are very small businesses with up to 20 employees (Deutscher Sparkassen- & Giroverband 2019). There are also a few big companies and corporates with several thousand employees, such as Aalberts or Oerlikon, but I was mainly interested in the small and medium-sized coating service companies with less "digital capacities" (e.g., modernity/actuality of the website, use of online marketing, etc.). These small and medium-sized enterprises (SMEs) are not necessarily known or particularly visible on the market. This should be changed by the Coating Radar.

4.4 Minimum Viable Product

The highly fragmented market of coating services with hundreds of rather small suppliers seemed to be ideal for a marketplace business model. The value proposition for the demand side was that the Coating Radar reduces the search costs (for finding a new supplier) through fast and digital matchmaking. For the coating service companies on the supply side, the idea of the MVP was to generate high-quality leads through a standardized request tool. Furthermore, their "digital findability" should be improved through the Coating Radar by creating online profiles for each supplier. Consequently, the MVP of the Coating Radar represented a website (or landing page) with the above-described functions. The website domain was called www.coatingradar.com, with the slogan "Find the right coating service" (see Figure 3). There was a German and an English

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069428400
DOI: 10.17879/27069428165

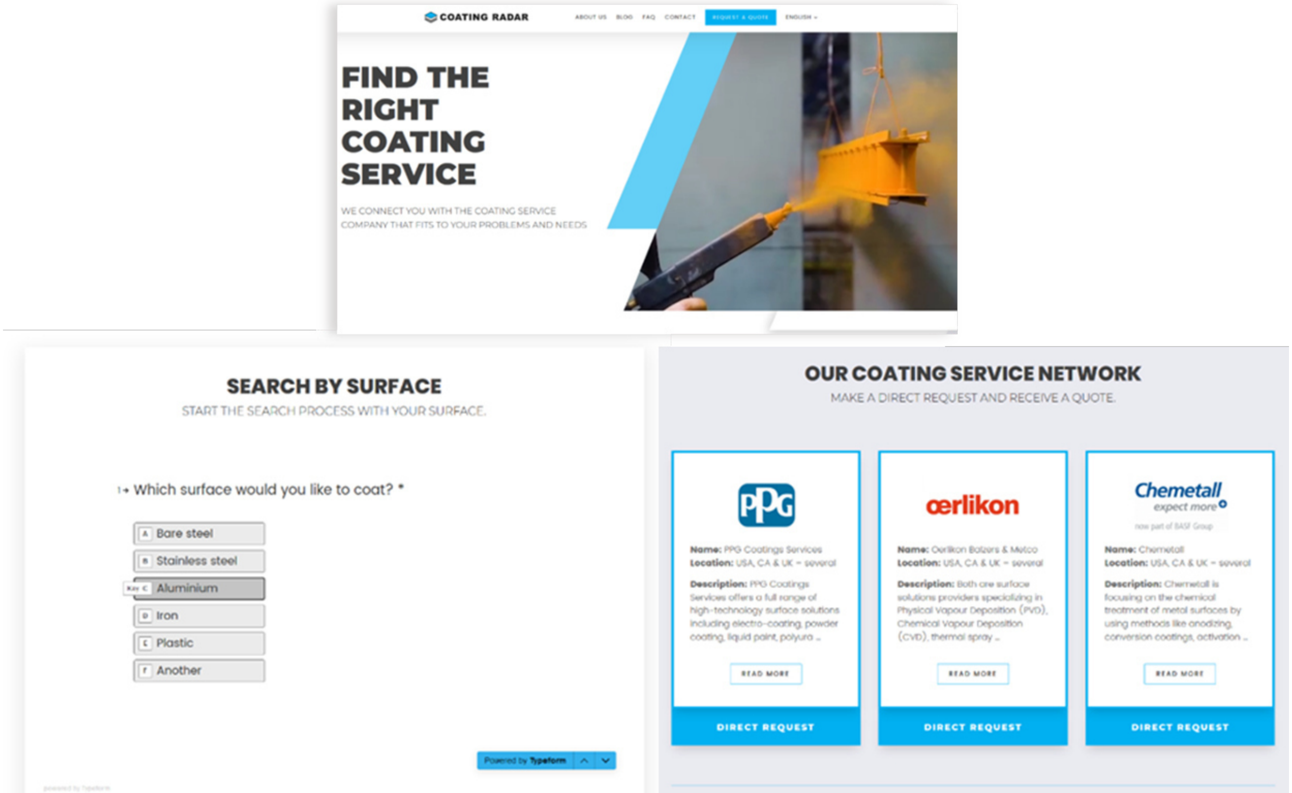

Figure 3 Impressions of the website and its functions (own representation)

version of the website, also with the respective subdomains for Germany, Austria, and Switzerland. The MVP was launched in December 2019 and the experiment lasted six months.

The digital matchmaking between supply and demand should become "smart" over time, so the more the Coating Radar knows about the coating service companies and their capabilities, the easier it would become to address them with suitable requests. The aim was therefore to create a database with detailed technical information for each coating plant, e.g., the maximum size or maximum weight of the component that can be coated in the respective plant. Admittedly, the matchmaking of the Coating Radar was not very intelligent at the beginning, i.e. many requests that were forwarded to the coating service companies did not fit. To resolve this, the coating service companies could register on the Coating Radar's website, providing very detailed information about their capabilities.

A new website like www.coatingradar.com is usually not found by itself, so efforts had to be made to ensure that users visit the landing page. For this reason, a sales campaign was launched in which 250 coating companies were contacted by e-mail. In the e-mail, the Coating Radar was promoted as "the new platform for coating services". The first e-mail was followed by a reminder e-mail after two weeks. The mailing was accompanied by Google advertising campaigns so that the Coating Radar could be found on the first pages of Google, depending on the respective search term. Also here different variants of Google ads were tested, with different advertising texts and broadcasting periods (see Figure 4). The duration of the advertisement was between two and four weeks. Advertisements were published primarily in German, but occasionally also in English. For each click on the advertisement, a certain amount of money has to be paid to Google. When Google advertisements are broadcasted, impressions are generated in addition to clicks. An impression here means that the advertisement was visible to the user but was not clicked. So the user could see the ad when scrolling through the Google search results, for example.

The question of how the Coating Radar wants to earn money was often asked during the experiment. Regarding the business model, the idea was to keep it deliberately open

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069428400
DOI: 10.17879/27069428165

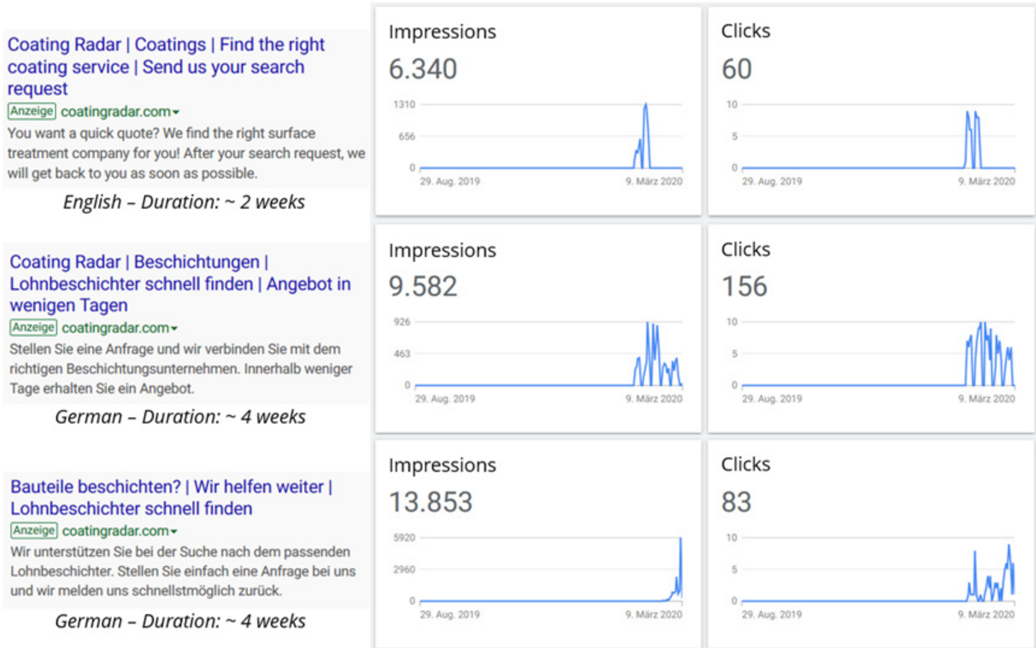

Figure 4 Examples for the conducted Google advertisement campaigns (own representation).

and to understand the industry and its dynamics first. So the matchmaking service has not been monetized. Of course, at that time there were already ideas existing to achieve revenues as a platform operator. An obvious possibility would be a brokerage fee for each match or a subscription model for the supply side. Additional services besides the matchmaking were also considered such as logistics or financial services.

4.5 Hypotheses & Data

A minimum viable product is always based on different assumptions and hypotheses (Shepherd & Gruber, 2020; Khanna et al., 2018). In science, hypotheses are verified or falsified. In practice, it is usually about the validation of hypotheses. Since both time and monetary resources are usually limited for a young venture, hypotheses should be tested easily and at reasonable costs. Scientists usually think a lot about the formulation of the respective research hypothesis, whereas practitioners proceed much more pragmatically. From a scientific perspective, practice-driven hypotheses for MVPs therefore often seem rather banal. Nevertheless, the basic logic and procedures are very similar. After a successful testing of the hypotheses and a positive validation of the overall idea, more cost-intensive realization steps usually follow. Consequently, a substantial value of the new product or solution for the target or user groups should be identified during the MVP phase. The term "substantial" means here that there is a meaningful, empirical proof that the respective business idea should be pursued further. This proof is ideally expressed in numerical values. In the case of the Coating Radar, there were the following three hypotheses which should be validated in the form of the MVP experiment:

- General hypothesis: A B2B marketplace creates substantial value in the fragmented niche market of coating services, both on the demand and the supply side.
- Hypothesis addressing the supply side: The majority of the coating service companies that will be approached during the sales campaign will register via the website.
- Hypothesis addressing the demand side: The majority of the requests received via the website can be successfully matched.

The majority was specified here with 75%, i.e. at least 75% of the 250 approached coating services companies register via the website (hypothesis 2). In addition, at least 75% of the requests can be matched (hypothesis 3). If both hypotheses are validated, hypothesis 1 can also be validated. MVPs are characterized by the fact that they collect data in a variety of places. This data can be of a quantitative and qualitative nature. In the case of the Coating Radar, there were three places or contexts of data collection in particular:

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069428400
DOI: 10.17879/27069428165

1. The website, e.g.,
   - How many users will visit the website during the testing period? (see Figure 5)
   - Where are the users coming from?
   - For how many minutes/seconds are the users staying on the website?
   - How will Google ads increase website's traffic, also with different budgets?
   - Which Google ads will run well and what are the relevant search terms?
   - What budget will be needed in this industry niche to be on page one at Google?
2. The sales campaign, e.g.,
   - How many coating service companies will register via the website during the sales campaign?
   - Will they fill out the online registration form or do they stop somewhere in between?
   - How many coating service companies will answer to the mails or even call?
   - How will the coating services companies react in general about the Coating Radar and its activities (e.g., constructive, skeptical, open, positive, negative, etc.)?
3. The requests and matchings, e.g.,
   - How many requests will be generated via the website?
   - How many of these requests will come from a (potential) private or commercial customer? (The Coating Radar focused on commercial customers.)
   - How many of these requests can be matched with a suitable coating service company?
   - What will be the feedback of the coating service companies on each request?
   - What kind of requests do coating service companies prefer?

Detailed answers to these questions can be found in the appendix.

4.6 Results & Findings

After the data collection, the evaluation of the experiment was carried out. In summary, the MVP came to the following results on a quantitative level:

- In total, 34 requests (demand side) were created and submitted via the website. 20 out of 34 requests were commercial requests made by companies. No match could be achieved for these requests. Private requests dropped out because of the B2B focus.
- Around 30 coating service companies (supply side) registered via the website, with around 60 locations in the DACH region (overall: ~ 90 European locations, ~ 20 US/UK locations)
- Around 28.000 website hits/page views were counted. Around 6.000 visitors were on the website (~ 1.600 US visitors, ~ 1.400 German visitors, ~ 500 Russian visitors). These numbers may include bots.

The number of matches already expresses that the MVP did not achieve a successful or positive result. Although some

Summary

	Visitors	Visits
Online Users:	1	
Today:	14	57
Yesterday:	49	184
Last 7 Days:	259	1,544
Last 30 Days:	1,060	5,437
Last 365 Days:	6,064	28,012
Total:	6,064	28,012

Status: 31.05.2020

Top 10 Countries

Rank	Flag	Country	Visitor Count
1		United States	1,578
2		Germany	1,357
3		Russian Federation	517
4		Netherlands	282
5		France	276
6		China	258
7		United Kingdom	223
8		Ukraine	169
9		Unknown	166
10		Canada	119

Figure 5 Website statistics of the Coating Radar (data collection: ~ 6 months) (own representation).

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069428400
DOI: 10.17879/27069428165

registrations of the coating service companies took place, it was not possible to match the requests with the supply side. To refer to the hypotheses (see Section 4.5), it can be stated that the majority of coating service companies contacted did not register via the website. Furthermore, not a single match between the supply and demand side could be accomplished during the test period.

A product-market-fit is, therefore, not given since this should be the core activity of the Coating Radar. But why did the matchmaking not work out? This analysis took place mainly on a qualitative level. The following aspects were identified during the analysis, from which generalizations were derived (see Table 1).

5 Discussion

Entering a B2B market as a new platform operator is very challenging because of several aspects. Besides the aspects of having domain knowledge (ideally in the founding team) and considerations regarding moderations efforts (and how to reduce them), the aspects of dependencies and loyalties have to be taken into consideration. The case of the Coating Radar shows that there is a high level of loyalty in the respective industry, what also comes with certain dependencies. Here, suppliers are only replaced, if something at the business relationship changes significantly, e.g., the product/service quality gets worse or the price increases enormously. It is assumed that this is the reality in many B2B contexts. Consequently, new B2B platforms should be aware that they cannot acquire relevant market shares immediately or within a few months. It can take years to gain significant market shares. One reason for this is that a new B2B platform usually questions present business relationships that often exist for years or even decades. This

Table 1 Qualitative findings and generalizations.

Case findings	Possible generalization derived from the case
The Coating Radar followed an extremely universal approach which means that there are many different coating technologies and processes, and all should be reflected on the platform. Process-specific expertise is necessary to execute such an approach in a serious way. The Coating Radar would have needed experienced coating experts as team members, which was not the case.	A B2B platform operator should have domain knowledge internally.
Most requests were incomplete in the first moment of receiving the request, e.g., technical drawings of the component, data sheets or specifications were missing. In such a case, questions had to be asked to complete the documents. At the same time, the coating service companies usually had questions as well. Serving as an intermediary, I took over the very demanding moderation.	A B2B platform operator should be aware of high moderation efforts. Also here, domain knowledge brings advantages.
Hardly any match was possible because coating service companies are very selective when it comes to accepting a request. Many requests were just not attractive for them or could not be fulfilled economically, e.g., small batch sizes or special customer requests. So apparently suitable requests were rejected.	A B2B platform operator should know the respective industry very well, e.g., knowing which requests can be realized economically and what is attractive for the supply side in general.
The main reason why the Coating Radar received primarily such "bad" requests was that the market is characterized by strong relationships between customers and coating service companies. Conversely, this means that the “good” requests do not go through a new platform.	A B2B platform operator should be aware of the fact that buyers’ loyalty towards the established suppliers is high in most B2B contexts.

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069428400
DOI: 10.17879/27069428165

questioning is not desired, especially on the supplier side, but the demand side is mostly not interested either due to complex supplier qualification processes. Such processes usually take several months and are cost-intensive.

As far as the quality of the requests is concerned, it can also be stated that low-quality (or “bad”) requests will prevail, especially in the beginning of a new B2B electronic marketplace. High-quality (or “good”) requests have usually already been assigned for a long time or are repeatedly assigned to the same supplier. In the case of the Coating Radar, the problem of “not finding the right coating service company” may only be the situation for companies that have complicated components (e.g., complex geometry) or unusual requirements (e.g., special colour). For them, a platform like the Coating Radar might be helpful. Focusing on this niche (within the niche) would have been a possible option for the Coating Radar. But dealing with requests that normally nobody in the market would like to handle does not sound attractive for an upcoming platform operator, and if it is possible to generate revenues in such a niche needs further considerations as well. Consequently, entrepreneurs who choose the “adventure of starting a B2B platform” will deal in the beginning mainly with requests that do not meet the usual industry standards due to the existing and dominant business relationships. These unusual requests might be rare (depending on the market size) and require internal domain knowledge. Acting here as a consultant for the requesting company could be an opportunity for an entrepreneur as well. An alternative could also be to pursue a new business model with the knowledge achieved during the MVP. Such a major strategy change of a start-up is also called “pivot” (Bohn & Kundisch 2018; Khanna et al. 2018). A young venture that does not give up after a negative validation could therefore also pivot into a new business model, ideally taking advantage of the experiences collected during the first MVP phase.

6 Conclusion & Outlook

In order to address the first research question regarding the value creation of an EM business model in a fragmented chemical services market, this case study indicates that the business model of an electronic marketplace is not necessarily attractive for fragmented B2B markets. The market for industrial coating services can be seen as such a market with a high fragmentation of the supply side. Business relationships are very strong in this industry, so there is hardly any willingness to switch the supplier from the buyers’ perspective. This finding can be transferred to any B2B context in which a high buyers’ loyalty exists. The central EM value proposition of reducing search and transaction costs through aggregation is therefore invalid in such a B2B context. Here, the search and transaction costs are kept low through strong business relationships. This complements the existing literature in the field of electronic marketplaces and B2B e-commerce.

The common limitation of a single case study is that replications might be necessary to be able to generalize the findings. Such a replication could be done in a future research project using a comparable venture. The start-up selected as a research object would need to follow a marketplace business model in a B2B context.

The case of the Coating Radar can also be seen as a pioneering application of the MVP concept and the lean start-up approach in the context of electronic marketplaces, which relates to the second research question. Both the quantitative and qualitative findings of the case have shown that a landing page, in connection with a sales and online marketing campaign, is a suitable instrument for gathering feedback in an early stage of a new B2B EM venture. Very few resources were necessary for the testing or validation of the overall business model idea. In this sense, the case contributes mainly to the research field of digital entrepreneurship. Here, further research perspectives exist as well. A possibility would be to accompany a start-up through various MVP phases. If a venture went through several phases, there are usually “pivot stories” (from the founders). This is the case for many successful start-ups. Here, it would be interesting to describe the strategical changes and its operative execution in detail. How pivots work exactly is still an almost untreated field of research.

References

Archer, N., Gebauer, J. (2002): B2B Applications to Support Business Transactions: Overview and Management Consideration in *Business-to-Business Electronic Commerce: Challenges and Solutions*, Idea Group Publishing.

Bakos, Y. (1991): A Strategic Analysis of Electronic Marketplaces. *MIS Quarterly*, **15** (3), pp. 295-310.

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069428400
DOI: 10.17879/27069428165

Bakos, Y. (1997): Reducing Buyer Search Costs: Implications for Electronic Marketplaces, *Management Science*, **43** (12), pp. 1676-1692.

Bohn, N., Kundisch, D. (2018): Much more than "same solution using a different technology": Antecedents and consequences of technology pivots in software startups, in *Tagungsband Multikonferenz Wirtschaftsinformatik 2018*.

Chow, D., Ghani, A., Miller, M., Takeda, G., Ziffru, S. (2000): *B2B – Beyond the Market Hubs*, Kellogg Graduate School of Management. Working Paper, Northwestern University.

Dennehy, D., Kasraian, L., O'Raghallaigh, P., Conboy, K. (2016): Product Market Fit Frameworks for Lean Product Development in *Proceedings of R&D Management Conference 2016 – From Science to Society: Innovation and Value Creation*, Cambridge: Cambridge University.

Dennehy, D., Kasraian, L., O'Raghallaigh, P., Conboy, K., Sammon, D., Lynch, P. (2019): A Lean Start-up approach for developing minimum viable products in an established company, *Journal of Decision Systems*, **28** (3), pp. 224-232.

Deutscher Sparkassen- und Giroverband (2019): *Branchenreport – Oberflächenveredlung und Wärmebehandlung 2019*.

Driedonks, C. F., Gregor, S., Wassenaar, A. (2005): Economic and social analysis of the adoption of B2B electronic marketplaces: A case study in the Australian beef industrys, *International Journal of Electronic Commerce*, **9** (3), pp. 49-72.

Dyer, W. G., Wilkins, A. L. (1991): Better stories, not better constructs, to generate better theory: A rejoinder to Eisenhardt, *Academy of Management Review*, **16** (3), pp. 613-619.

Eisenhardt, K. (1989): Building Theories from Case Study Research, *The Academy of Management Review*, **14** (4), pp. 532-550.

Evans D.-S., Schmalensee (2016): *Matchmakers – The New Economics of Multisided Platforms*, Harvard Business Review Press, Boston.

Forrester Research (2017): *Forecast B2B sales*, available at https://www.statista.com/statistics/273104/us-b2b-e-commerce-share/, accessed 6 October 2020.

Giaglis, G. M., Klein, S., O'Keefe, R. M. (2002): The role of intermediaries in electronic marketplaces: developing a contingency model, *Information Systems Journal*, **12** (3), pp. 231-246.

Glaser, B., Strauss, A. (1967): *The discovery of grounded theory: Strategies of qualitative research*, London.

Ibi research (2019): *Marktplätze im B2B-E-Commerce in Deutschland 2019*, available at https://de.statista.com/statistik/daten/studie/1040525/umfrage/kritische-faktoren-fuer-den-erfolg-von-marktplaetzen-im-b2b-e-commerce-in-deutschland/, accessed 6 October 2020.

IfH Köln (2019): *Umsätze im B2B-E-Commerce*, available at https://de.statista.com/statistik/daten/studie/254040/umfrage/b2b-e-commerce-umsaetze-nach-marktteilnehmern/, accessed 6 October 2020.

Kaplan, S., Sawhney, M. (2000): E-hubs: The New B2B Marketplaces, *Harvard Business Review*, **78** (3), pp. 97-100.

Khanna, D., Nguyen-Duc, A., Wang, X. (2018): From MVPs to pivots: a hypothesis-driven journey of two software startups, in *International Conference of Software Business 2018*, pp. 172-186.

Klein, S., Alt, R. (2015): B2B Electronic Markets in *The International Encyclopedia of Digital Communication and Society*, John Wiley & Sons.

Kniberg, H. (2013): *How Spotify builds products,* available at https://www.dcc.fc.up.pt/~mcoimbra/lectures/SIM_1415/SIM_1415_T2.3_HowSpotifyBuildsProducts.pdf, accessed 6 October 2020.

Kniberg, H. (2016): *Making sense of MVP (Minimum Viable Product) – and why I prefer Earliest Testable/Usable/Lovable*, available at https://blog.crisp.se/2016/01/25/henrikkniberg/making-sense-of-mvp?ref=https://product-frameworks.com, accessed 6 October 2020.

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069428400
DOI: 10.17879/27069428165

Lenarduzzi, V., Taibi, D. (2016): MVP Explained: A Systematic Mapping Study on the Definitions of Minimal Viable Product in *42th Euromicro Conference on Software Engineering and Advanced Applications 2016*, pp. 112-119.

Markus, M. L., Banerjee, P., Ma, L. (2002): Electronic Marketplaces in Hong Kong's Trading Industry in *Proceedings of the 35th Hawaii International Conference on Systems Sciences*.

Padgett, D., Hopkins, D. C., Williams, Z. (2020): Byer dependence in B2B relationships: The role of supplier investments, commitment form, and trust, *Journal of Business Research*, **119**, pp. 13-24.

Pantiuchina J., Mondini, M., Khanna, D., Wang X., Abrahamsson, P. (2017): Are Software Startups Applying Agile Practices? The State of the Practice from a Large Survey in *Agile Processes in Software Engineering and Extreme Programming*, Springer.

Ries, E. (2011): *The Lean Startup: How Constant Innovation Creates Radically Successful Businesses*, Penguin Radom House.

Schmitt, L. (2019): Challenges affecting the adoption of B2B electronic marketplaces, *Journal of Business Chemistry*, **10**, pp. 154-164.

Shepherd, D. A., Gruber, M. (2020): The Lean Startup Framework: Closing the Academic-Practitioner Divide, *Entrepreneurship Theory and Practice*, **0**, pp. 1-13.

Statista Report (2017): *B2B E-commerce*, available at https://www.statista.com/statistics/705606/global-b2b-e-commerce-gmv/, accessed 6 October 2020.

Statista Report (2020): *Leading paints and coatings companies worldwide in 2019 by revenue*, available at https://www.statista.com/statistics/543989/leading-paint-companies-worldwide-by-revenue/, accessed 6 October 2020.

Steenhuis, H. J., & de Bruijn, E. J. (2006): Building theories from case study research: the progressive case study in *OM in the New World Uncertainties. Proceedings of the 17th Annual Conference of POMS*, Boston.

Strader, T. J., Shaw, M. J. (2000): Electronic markets impact and implications in *Handbook of electronic commerce*, Springer.

Timmers, P. (1998): Business Models for Electronic Markets, *Electronic Markets*, **8** (2), pp. 3-8.

Thuong, L. T. (2002): Pathways to Leadership for Business-to-Business Electronic Marketplaces, *Electronic Markets*, **12** (2), pp. 112-119.

Verband der deutschen Lack- und Druckfarbenindustrie (2020): *Statistiken*, available at https://www.wirsindfarbe.de/statistiken, accessed 6 October 2020.

Wieteska, G. (20169: Building resilient relationships with suppliers in the B2B market, *Management*, **20** (2), pp. 307-321.

Yin, R. (1981): The case study crisis: Some answers, *Administrative Science Quarterly*, **26**, pp. 58-65.

Yin, R. (2013): *Case Study Research and Applications: Design and Methods*, 5th Edition, Sage Publications.

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069428400
DOI: 10.17879/27069428165

Appendix: Detailed answers to the questions posed in Section 4.5

Question	Answer
How many users will visit the website during the testing period?	Around 6.000 users visited the Coating Radar website during the test period (6 months).
Where are the users coming from?	From these 6.000 users around 1.600 were US visitors, 1.400 were German visitors, 500 were Russian visitors (see Figure 5). These numbers may include bots.
For how many minutes/seconds are the users staying on the website?	The average time spend on the website was 2m 46s (during the test period, measured with Google Analytics).
How will Google ads increase website's traffic, also with different budgets?	Google ads increases the clicks enormously. Websites that are new and consequently difficult to find are therefore dependent on Google ads. Here, three campaigns were made, see question below.
Which Google ads will run well and what are the relevant search terms?	The 1^{st} campaign addressed the USA, Canada and the UK: Coating Radar | Coatings | Find the right coating service | Send us your... You want a quick quote? We find the right surface treatment company for you! After your search request, we will get back to... (*Keywords used: powder coating service, powder coating, aluminum coating, coating service, coating service shop*) The 2^{nd} campaign addressed Germany: Coating Radar | Beschichtungen | Lohnbeschichter schnell finden |... Stellen Sie eine Anfrage und wir verbinden Sie mit dem richtigen Beschichtungsunternehmen. Innerhalb... (*Keywords used: Oberflächentechnik, Oberflächen-beschichtung, Oberflächenbeschichtung Metall, Oberflächenbeschichtung Aluminium, Stahl beschichten, Oberflächenveredelung*) The 3^{rd} campaign addressed Germany as well: Bauteile beschichten? | Wir helfen weiter | Lohnbeschichter schnell... Wir unterstützen Sie bei der Suche nach dem passenden Lohnbeschichter. Stellen Sie einfach eine Anfrage bei uns und wir... (*Keywords used: Lohnbeschichtung, Bauteile beschichten, Metall beschichten, Werkzeug beschichten, Stahlträger beschichten, Beschichter Deutschland*) 1^{st} campaign: 6.340 impressions / 60 clicks 2^{nd} campaign: 9.600 impressions / 156 clicks 3^{rd} campaign: 14.100 impressions / 86 clicks

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069428400
DOI: 10.17879/27069428165

Question	Answer
What budget will be needed in this industry niche to be on page one at Google?	1st campaign: ~ 8 €/day (total: 72 €) 2nd campaign: ~ 11€/day (total: 267 €) 3rd campaign: ~ 14€/day (total: 173 €)
How many coating service companies will register via the website during the sales campaign?	Around 30 registrations were made from coating service companies (supply side), with around 60 DACH locations (90 European locations, 20 US/UK locations)
Will they fill out the online registration form completely or do they stop somewhere in between?	There was an online registration form on the website. The average time to complete the detailed registration was ~ 10m. The completion rate was ~ 23%.
How many coating service companies will answer to the mails or even call?	We addressed around 250 coating service companies with our email sales campaign, parallel to the Google campaigns. Here, unfortunately, we did not make a clean collection.
How will the coating services companies react in general about the Coating Radar and its activities (e.g., constructive, skeptical, open, positive, negative, etc.)?	Many coating service companies were interested in our activities and we were surprised about the positive feedback. However, there was a lot of skepticism, and of course there were also people that did not answer or did not show any interest.
How many requests will be generated via the website?	In total, 34 requests (demand side) were created and submitted via the website.
How many of these requests will come from a (potential) private or commercial customer? (The Coating Radar focused on commercial customers.)	20 out of 34 requests were commercial requests made by companies. The requests came from very different industries, e.g., a hotel, a craftsman shop, an architect, or an interior designer.
How many of these requests can be matched with a suitable coating service company?	No match could be achieved for these requests. Private requests dropped out because of the B2B focus.
What will be the feedback of the coating service companies on each request?	In general, the coating service companies were interested and concerned, so there was multiple correspondence, with each request we forwarded. Nevertheless, the result was always that the request itself was not interesting (often because of the low number of components, and/or because of complicated/unclear requirements).
What kind of requests do coating service companies prefer?	Industrial coating service companies prefer requests with a very high number of components to be coated. Also the requirements should be clear from the beginning. Special requests, such as special colors, are usually not welcome.

JOURNAL OF
BUSINESS CHEMISTRY

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069427812
DOI: 10.17879/27069427558

Practitioner´s Section

Adam W. Franz* and Manfred Kircher**

Options for CO_2-neutral production of bulk chemicals

The rising utilization of non-fossil based raw materials in the chemical industry initiates the transformation path to a more sustainable and less greenhouse gas (GHG) emission intensive way of producing consumer goods. In this review, the focus of alternative, large scale synthesis routes for bulk chemicals by the example of 1,4-butanediol (BDO) and formaldehyde from fossil and non-fossil feedstocks-based production processes are discussed. Furthermore, options to lower GHG emissions from scope 1-3 in the corresponding examples are presented and regional and regulatory aspects are discussed. Finally, the demands and needs for a sustainable production of BDO and formaldehyde are shown research-, technology-, feedstock-, and regulatory-wise.

1 Introduction

With climate change, the damage caused by greenhouse gases not only has a global ecological dimension. For operators of emission-intensive chemical plants in Europe, greenhouse gases are now an increasingly noticeable economic burden. Since the European Emissions Trading Scheme came into force, emissions allowances have had to be purchased. The cost of these allowances has been rising for several years and is expected to rise further. Especially emissions from power generation and chemical production (scope 1, 2) have so far been subject to the trading system. These emissions can be reduced by using emission-free energy sources, capture of carbon dioxide and its subsequent long-term storage or use as a carbon source.

The emission potential of purchased raw materials (the so-called raw material rucksack) and the emissions that arise during the use and disposal of the resulting products (scope 3) are not subject to the emissions trading system. In the case of organic chemical products, this is primarily carbon dioxide, which is produced, for example, during the combustion of the carbon-containing products after use. However, it cannot be ruled out that, with the accelerating climate change, the political framework will change in such a way that these emissions will also be covered and thus cause further emission costs. There are several ways to avoid these possible costs. One of them is to switch from fossil to renewable, vegetable carbon sources. Their carbon has been removed from the atmosphere through the natural carbon cycle, i.e. the photosynthetic binding of carbon dioxide in biomass. Therefore, the emission from products made from them does not increase the concentration in the atmosphere and is considered climate neutral. Another option is to create a technical carbon cycle. Methane, carbon dioxide, and carbon monoxide can serve as industrial carbon sources and thus close the carbon cycle.

In the following, scope 1-3 emissions of the chemical industry are analyzed using concrete company examples. Subsequently, options for reducing these emissions are presented by the example of butanediol and formaldehyde.

* BASF SE, Carl-Bosch-Str. 38, 67056 Ludwigshafen, Germany, and Institut f. Organische u. Makromolekulare Chemie, Heinrich-Heine-Universität Düsseldorf, Universitätsstr. 1, 40225 Düsseldorf, Germany, adam.franz@basf.com
** KADIB Kircher Advice in Bioeconomy, Kurhessenstr. 63, 60431 Frankfurt, Germany

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069427812
DOI: 10.17879/27069427558

2 Background

2.1 Scope 1-3 emission sources and volumes in chemical production

Since 2017 the market price for CO_2 European emission allowances has risen significantly from 5 to 38.5 EUR/t in February 2021, thus, emitting CO_2 and other greenhouse gases becomes more and more costly. Consequently, major companies have announced that they intend to operate their sites in a climate-neutral manner within a reasonable period of time. As examples table 1 quotes published statements of three German chemical companies. They have been selected as model examples for companies active on different stages of the chemical value chain. According to its published presentation, BASF (2019) concentrates on the production of petrochemicals, monomers, intermediates, and heterogeneous catalysts, Evonik (2021) on specialty chemistry, and Henkel (2021) on adhesive technologies, beauty care, and laundry & home care. With these statements BASF can be seen as a representative of the early stages of the value chain in high volume bulk and basic chemistry, Evonik as a supplier of medium volume specialty chemistry in the middle stages of the value chain and Henkel rather as a producer and purchaser of medium to small volume specialty and fine chemistry to formulate consumer products. In the following, the influence this positioning can have on the corporate strategy towards climate neutrality by mitigation of greenhouse gas emissions and the contribution of biobased raw materials will be investigated.

The sources of emissions in chemical production are manifold. They include emissions from energy generation for the chemical processes, from emissions from purchased energy, from emitted by-product greenhouse gases from chemical reactions, and from the downstream value chain (i.e. waste, transport, use, and disposal of products). These emissions are systematically defined according to scope 1, 2, 3 (tab. 2). In 2020, the different emissions for the German chemical industry, which will be presented below as a model example, amount to a total of 112.8 million tosns of CO_2 equivalents (DECHEMA, 2019). The data show that, over the entire industry covered by the ETS, on average about half of the emissions are caused by chemical production processes (scope 1, 2) of which roughly one third are emissions of by-products of chemical reactions and two thirds are emissions from the generation of process energies (scope 1, 2) (McKinsey, 2007). The other half contains, inter alia, the emission potential of the chemicals produced (tab. 2).

As a concrete example of a leading chemical company, BASF's greenhouse gas balance for the year 2020 will be presented here. The company has been publishing a comprehensive greenhouse gas balance sheet (Figure 1) in accordance with the GHG Protocol Corporate Accounting and Reporting Standard since 2008 (BASF, 2021; World Resources Institute, 2021).

Table 1 Published emission targets of BASF (2021), Evonik (2020) and Henkel (2021).

Company	Scope 1 emissions	Scope 2 emissions	Sope 3 emissions
BASF	CO_2-neutral growth until 2030. Maintain total greenhouse gas emissions from production sites (excluding emissions from sale of energy to third parties) and energy purchases at the 2018 level (21.9 million metric tons of CO2 equivalents) while increasing production.		
Evonik	Reduction of absolute scope 1 and 2 emissions by 50% by 2025 (reference year 2008).		Reduction of absolute scope 3 emissions of the upstream value chain - mainly from the raw material backpack - by 15% by 2025 (reference year 2020).
Henkel	Reduce the carbon footprint of operations by 65 percent by 2025 and by 75 percent by 2030. Intend to achieve this by continuously improving energy efficiency and by using electricity exclusively from renewable sources.		

JOURNAL OF
BUSINESS CHEMISTRY

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069427812
DOI: 10.17879/27069427558

Table 2 Chemical industry emission sources according to scope 1, 2 3, CO2-equivalents, Germany 2020 (DECHEMA, 2019)

Scope	Emissions	Million tons CO_2-equivalents	Share
Scope 1	Emissions resulting from own production facilities including generation of energy	32.9	29.2%
Scope 2	Emissions resulting from the production of purchased energy	23.4	20.7%
Scope 3	Emissions attributable to purchased materials and services and to further processing, use and disposal	56.5	50.1%

Table 3 shows the share of emissions according to scope 1, 2 and 3 for BASF, for Evonik, and Henkel. The different shares of energy-related emissions scope 1 and 2 of the three companies under consideration are striking. In fact, it seems the different energy-related emissions, respectively energy consumption is reflected in the companies' product range. Plausibly, it can be assumed that BASF's and Evonik´s comparatively high energy-related emissions is due to the energy-intensive basic chemical processes that are carried out there. The lowest energy consumption in this comparison is recorded by Henkel with its specialty chemicals end products geared to consumer applications. This interpretation is supported by a study which reports 80% of the energy-related emissions consumption of the German chemical industry to basic chemicals (World Resources Institute, 2021).

The product range of the three companies also seems to leave an imprint in the share of "end of life treatment of sold products" emissions (scope 3). For example, the monomers offered by BASF are processed by customers into a final plastic product which can be disposed by different methods, one of it is energy recovery by incineration. The release of CO_2 from incineration, the CO_2 emission potential, is included in this category. A personal care product from Henkel applied to the skin, on the other hand, is not disposed of in this way but is consumed with its application; i.e. the CO_2 emission potential is not recorded as "end of life treatment" but as "use of sold products". Table 4 shows that BASF and Evonik with their products to be delivered into the chemical value chain for further processing but not into consumer markets therefore do not report "use of sold products" emissions. The "end of life treatment" emission potential of these companies reach a share of 21% and 25% among total reported emissions. For Henkel, this share is much lower at less than 2%, but the emissions caused by the “use of sold products” are reported at 66% (tab. 4).

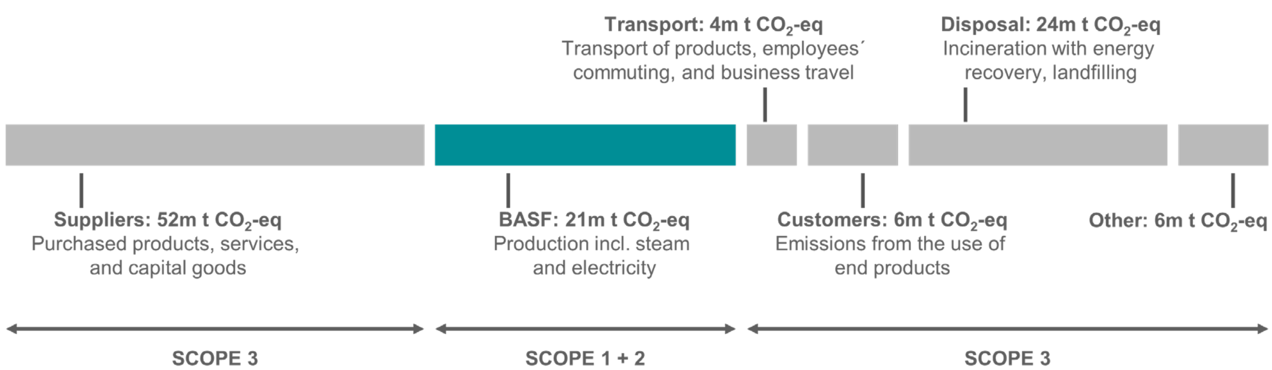

Figure 1 Greenhouse gas emissions in million tons along the BASF value chain according to scope 1, 2, and 3 (BASF, 2021)

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069427812
DOI: 10.17879/27069427558

Table 3 Emissions and their share according to scope 1, 2 and 3 of BASF (2021), Evonik (2020) and Henkel (2020)

Company	Scope 1 [mt CO_2-eq] / share	Scope 2 [mt CO_2-eq] / share	Scope 3 [mt CO_2-eq] / share
BASF	17.53 / 15.7%	3.28 / 2.9%	91.2 / 81.4%
Evonik	4.9 / 21.1%	0.6 / 2.6%	17.7 / 76.3%
Henkel	0.351 / 0.8%	0.351 / 0.8%	43.1 / 98.4%

The product spectrum of a company, which can range from bulk to specialty and fine chemistry, thus influences the energy and product related emissions scope 1-3. As already mentioned, in the context of emissions from chemical processing bulk chemicals are of particular interest because of their large production volume. Table 5 therefore gives an example of the emissions from the production of formaldehyde and butanediol. Both chemicals are repeatedly discussed below as model examples. They were selected for BASF's product portfolio because they fulfil the following, criteria of an important chemical intermediate: High production volumes, worldwide demand in several industrial sectors as they are mostly used as plastics monomers, high potential to replace their fossil based synthesis route by a sustainable one. In the following the possibilities to reduce the emissions that can be attributed to both chemicals will be presented and discussed. To characterize the exemplary products BDO and Formaldehyde, their specific scope 1 and 2 emissions from electric power demand in large scale production and the emission potential of CO_2 from the chemical themselves (part of scope 3 emissions) are listed in table 5.

3 Discussion

3.1 Options to reduce scope 1-3 emissions

The scope 1 and 2 emissions reported come from fossil sources because the ETS only covers those emissions. Therefore, one way to reduce scope 1 and 2 emissions significantly is to switch to emission-free energies (hydropower, photovoltaics, wind energy, geothermal energy, nuclear energy). Henkel for example announces to switch to renewable energies (tab. 1). Bioenergy is also an option, because its CO_2 emissions is considered climate-neutral and therefore not priced by the ETS. Additionally, BASF´s Verbund concept, which is applied at all major sites, makes an important contribution to energy efficiency by linking the production and energy demand. Waste heat from production processes is captured to be used as energy in other production plants. Because of the Energy Verbund, BASF saved in 2019 around 19.2 million MWh per year, equal to an annual reduction in CO_2 emissions of 3.9 million metric tons (BASF, 2020).

Table 4 Volume and share of “end of life treatment of sold products emissions” among scope 3 emissions of BASF (2020), Evonik (2020) and Henkel (2020)

Company	Scope 1-3 total [mt CO_2-eq]	Scope 3: Use of sold products [mt CO_2-eq]	Scope 3: End of life treatment of sold products [mt CO_2-eq]	Scope 3: End of life treatment of sold products - share
BASF	120.5	Not determined	25.8	21.4%
Evonik	23.7	Not determined	5.9	24.9%
Henkel	43.8	28.9	1.6	3.6%

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069427812
DOI: 10.17879/27069427558

Table 5 Estimated emissions balance of 1,4-butanediol and formaldehyde production (PERP Report, 2016)

Product	Scope 1, 2	Emission potential from the product[b]
1,4-Butanediol	79[a] kg CO_2-eq / ton BDO	2.2 t CO_2-eq / ton BDO
Formaldehyde	18[a] kg CO_2-eq / ton formaldehyde (37% in H_2O)	1.5 t CO_2-eq / ton formaldehyde (37% in H_2O)

3.1.1 Scope 1 and 2: CCS

Large CO_2 flows are in principle suitable for capture and long-term storage (carbon capture and storage; CCS). In this way, emissions into the atmosphere are avoided by creating a CO_2 sink as defined by the Paris Climate Convention.

The economical features of these processes are that they can save ETS allowances, but otherwise they do not generate value.

Alternatively, CO_2 can be captured and stored biologically in the form of biomass, for example in tree wood (Nijnik, 2010). A recent study reports that afforestation could contribute significantly to the greenhouse gas reductions required by 2030.(Austin et al., 2020) However, there are economical costs of land use and the ecological impact of indirect land use change to be considered, and it must be ensured that this wood is not used in an emissions-releasing manner in the long term.

3.1.2 Scope 1 and 2: CCU

The situation is different for sinks that store CO_2 emissions through utilization (carbon capture and utilization; CCU) as technical gas and as carbon source in chemical and biotechnological catalysis including photosynthesis.

Pure CO_2 is required by the food and beverage industry and the pharmaceutical sector as a product component (beverages), and protective gas in packaging (Deerberg et al., 2020). In these fields most important by volume are the food and beverages applications consuming globally more than 31 mt (2018). However, these applications are no real option for CO_2 sinks as the gas is released with the use of the products.

Established is the use of CO_2 as carbon source in chemical synthesis. In Germany, for example, 75% of the CO_2 produced during ammonia synthesis is captured and used, among other processes, in the production of urea and methanol (Krämer and Bazzanella, 2017). More commercial examples, their global production volume, and global CO_2-input are shown in table 6.

Around 120 million tons of CO_2 are used worldwide in the production of basic chemicals and intermediates. The carbon contained in these intermediates remains bound as long as the end products made from them are in use.

Table 6 Use of CO2 as carbon source in commercial chemical synthesis (Krämer and Bazzanella, 2017)

Product	Production volume [kt]	Input CO2 [kt]
Urea	150,000	110,000
Poly-carbonate	250	50
Cyclic carbonates	80	40
Methanol	80	2
Salicylic acid	70	25
Polyol	5	1

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069427812
DOI: 10.17879/27069427558

3.1.3 Scope 3: CCS and CCU

Scope 3 emissions originate from business and administration activities, transport of sold products to customers, further processing along the value-added chains, and the disposal of consumer products.

The use of emission-free power and fuels such as electricity, hydrogen, or e-fuels is an obvious way of reducing business, administration, and transport-related emissions. Because of the large number of small-volume emission sources like buildings and transport units, neither CCS nor CCU is an option here. This also applies to many installations at processing plants, unless they reach a size that is covered by the ETS itself.

The situation is different for emissions from the disposal of sold end products. Especially in urban areas, large volumes of waste are produced in a limited area and are collected centrally by municipal waste management authorities. In Germany and other countries in Western Europe, a significant share of municipal waste is recovered for energy (Scarlat et al., 2019) i.e. by its incineration. The resulting CO_2 emissions are emitted into the atmosphere but could theoretically also be subject to CCS. However, the necessary infrastructure is not available, and it must be assumed that social acceptance of geological storage of CO_2 in settlement areas will be difficult or even impossible to achieve (Tcvetkov et al., 2019). On the other hand, if small-scale CCU technologies would be available, the utilization of waste management emissions is an option to be discussed further below.

3.1.4 Scope 3: Switch to biogenic feedstock

One way to make the end-of-life share of scope 3 emissions more climate-friendly would be to change the raw material base of chemical products from fossil to renewable carbon sources. Biological carbon sources, on the other hand, contain carbon that was removed from the atmosphere by the photosynthetic carbon cycle and is therefore considered climate neutral in balance terms. Although the production of biomass is not entirely without greenhouse gas emissions, the release of this carbon does not generally increase the atmospheric CO_2 concentration. Biological carbon sources thus offer a largely climate-neutral alternative to fossil raw materials, both for energy and material recycling.

The status of bio-based raw materials in the chemical industry is presented in the next section.

3.2 Status of biogenic carbon sources and chemicals

3.2.1 Biogenic raw materials

In the EU, the share of biogenic raw materials for chemical use is currently 10%, (Parasi and Ronzon, 2016) respectively 13% in the German chemical industry in 2018 (VCI, 2021). The spectrum of biological raw materials is shown in Figure 2.

At 34%, fats and oils have the largest share, followed by sugar and starch (32%). These, as well as pulp, fibers, and protein represent fractions of the biomass of oil plants (fats

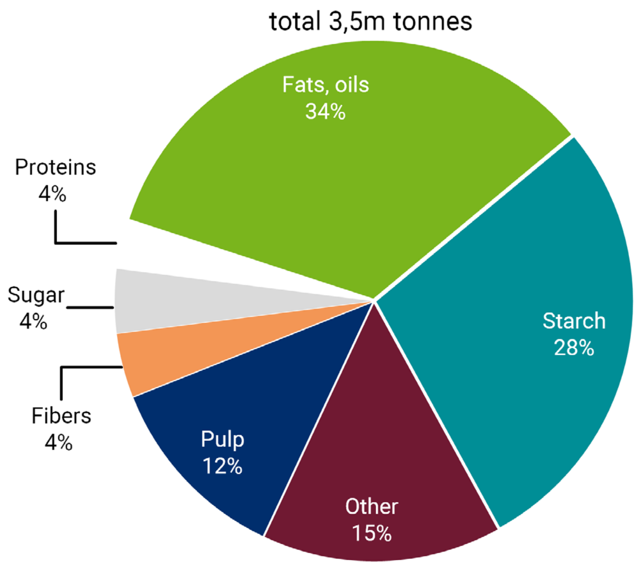

Figure 2 Spectrum of biological raw materials in the chemical industry, Germany, 2018 (VCI, 2021)

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069427812
DOI: 10.17879/27069427558

and oil, protein), sugar and starch plants (sugar, starch), wood (pulp), and fiber plants (natural fibers). These are the raw materials for bio-based products listed in table 7.

Amongst the bio-based chemicals shown in table 7, surfactants and cosmetics are the most important ones in terms of share, followed by lubricants, paints and coatings. These products are classified as fine and specialty chemicals, which account for a comparatively small share of volume in the entire chemical portfolio. Their market success is based on a combination of technical performance and of customer expectations. The specific performance of lubricants, paints, and coatings depends in part on the properties of the raw materials, whereby, for example, natural fatty acids have advantages over synthetic fatty acids in terms of the proper chain length. In terms of customer expectations, surfactants and cosmetics meet a market that basically prefers biogenic products.

From the point of view of scope 3 emission reduction, it would be advantageous if large-volume basic chemicals and monomers were also produced on a bio-based basis. In fact, among bio-based chemicals, biopolymers are most relevant by volume. In the biopolymer market, PLA (polylactic acid) and PBAT (polybutyleneadiptate-terephtalate) are leading with 19%, respectively 14% (FNR, 2021). However, as shown in table 7, the share of biopolymers compared to total polymer production is only 2% in Europe, globally even smaller.

The reason lies often in significant cost disadvantages. In 2016, cost for PLA and PBAT were estimated at 2,000 respectively 3,500 EUR/t; 50-100% more than the fossil-based alternatives (van den Oever et al., 2017). These additional costs are partly due to a lack of technological maturity and insufficient economies of scale but are also due to the basic properties of bio-based raw materials. Biomass has a lower carbon density compared to fossil raw materials. While natural gas and crude oil contain 75-87% carbon, dry biomass offers only about 50% of the sought-after element. On the other hand, the carbon yield of biotechnological processes is much lower than that of synthetic processes based on fossil carbon sources. The reason for this is that biological whole-cell catalysts extract energy for biocatalysis from the raw material and the energy metabolism leads to the emission of CO_2, thus the loss of carbon. In addition, unavoidable by-products are created, and part of the raw material is consumed to build the biomass of the biocatalyst. The low carbon density of feedstock and carbon losses in processing explain why the bio-feedstock share of 10% results in the bio-product share of only 4%.

Table 7 Volume and share of bio-based chemicals, EU, 2018 (Dechema, 2019)

Product class	Total production [kt]	Biobased production [kt]	Biobased production share
Plastics / polymers	71,000	1,130	2%
Adhesives	8,580	86	1%
Man-made fibers	5,404	627	12%
Solvents	5,000	0.5	0%
Lubricants	3,900	627	16%
Surfactants	3,500	1,100	31%
Agro-chemicals	1,800	0.5	0%
Cosmetics	1,263	556	44%
Paints, Coatings	882	164	19%
Total	101,329	4,291	4%

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069427812
DOI: 10.17879/27069427558

The example of bio-1,4-butanediol, which is produced based on sugar, demonstrates that these hurdles can also be successfully overcome. In the following, butanediol is presented as an example of a commercial bio-based bulk chemical.

Figure 3 shows an important chemocatalytic route to butanediol and formaldehyde via Reppe synthesis (Arpe, 2007). Today, one of the industrial, large-scale synthesis route for BDO using fossil-based feedstocks begins with the conversion of methane from natural gas with oxygen to acetylene and syngas (CO and H_2). In a second step, syngas reacts to methanol under catalytical conditions. Formaldehyde is being produced by the conversion of methanol with oxygen with a silver or Fe/Mo/O catalyst. In the following synthesis step, formaldehyde is being added to acetylene with the usage of a copper catalyst to yield in 1,4-butynediol. Finally, butynediole is hydrogenated with H_2 to give 1,4-butanediol.

A biotechnological route for the production of BDO from a biobased feedstock at a scale of several kilotons was introduced through the collaboration of BASF and Purac (Figure 4). This fermentation process of renewable feedstocks such as glycerol, dextrose syrup, or maltose does not result in BDO, but in succinic acid giving a yield of minimum 1.0 g/g glycerol (Murzina and Ingram, 2017). With a theoretical yield of 1.28 g/g glycerol, the yield is about 80%. From succinic acid, however, two further synthesis steps are required to produce the desired 1,4-butanediol. Since direct reduction is not possible in a large-scale production process, the first step is esterification, e.g. with ethanol to form succinic acid ethyl ester. This ester is finally hydrogenated with H_2 to give BDO and ethanol, the latter of which can be recycled for the esterification of succinic acid.

The large-scale biotechnological production route for BDO today is the Genomatica process. Together with Novamont, a 30 kt production plant for biofeedstock was started up in Italy in 2016. Starting from glucose or molasses, the fermentation process with the biotechnologically produced BDO pathway in E. coli delivers the desired 1,4-butanediol with a final concentration of up to 140 g/L (Figure 5). (Culler, 2016) However, exact yields are not published by Genomatica. Starting from glucose (six carbon atoms), two molecules of carbon dioxide are released per molecule of 1,4-butanediol (four carbon atoms).

3.3 Sustainable supply of bio-based bulk chemicals

BASF is one of the leading BDO producers with an annual capacity of 190,000 tons in Germany (PERP Report, 2004). Switching total BDO production to sugar-based fermentation would result in a sugar demand of 350,000 tons of sugar (roughly estimated at 53% yield) (Forte et al., 2016). Measured against German sugar production of around 4.3 million tons (2019/2020), the supply of only bio-BDO would therefore take up 8% of the harvest.

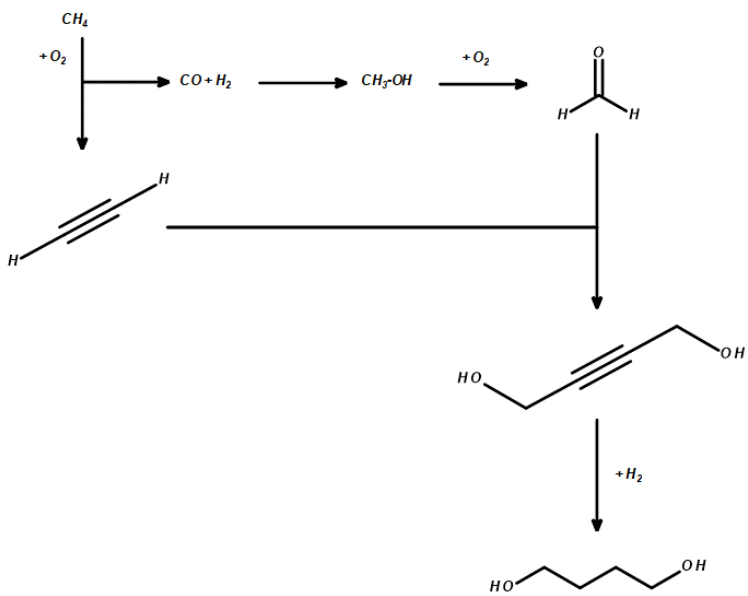

Figure 3 Chemocatalytic route via Reppe synthesis to butanediol and formaldehyde (own representation)

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069427812
DOI: 10.17879/27069427558

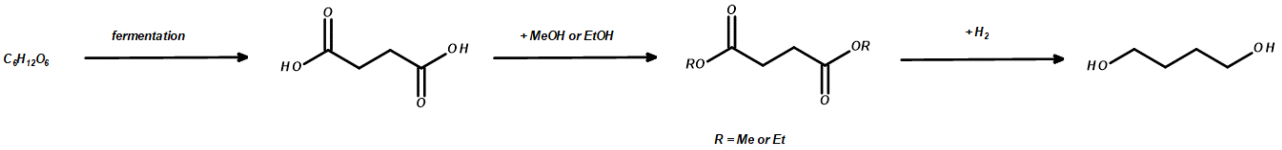

Figure 4 Biotechnical route for BDO production via fermentation of bio-based feedstock with succinic acid as intermediate (own representation)

If butanediol, as just one example of a high-volume chemical, is already taking up a significant portion of the sugar crop, the question arises whether and how the necessary raw materials can be provided in a sustainable manner. After all, it has to be taken into account that the chemical industry, as a major buyer of raw materials, is entering a market to be supplied by the very same arable land area that today at 86% is used for the production of food and feed (Bioplastics study, 2017). Increasing production or expanding acreage is limited because natural resources are already stretched to the limit, and in some cases beyond, in terms of ecosystem services (Costanza, 2014) and planetary boundaries (Rockström, 2009; Steffen, 2015). Concerning greenhouse gas mitigation, it should be considered that agriculture is a significant emitter, and that intensification of farming inevitably will increase emissions. The future supply of biobased carbon sources to the chemical industry as a whole should increasingly be based on cascading and recycling according the principles of a circular economy (European Commission study, 2018). Alternatives in this regard are offered by non-food biomass, industrial residuals, and waste materials. Options will be presented by the example of biobased BDO in the following.

3.4 Sustainable options of biogenic carbon sources

3.4.1 Lignocellulosic sugar

One option is the utilization of lignocellulolic non-food biomass from either agricultural residues such as straw, corn cobs, or rice husks or woody residues from forestry or wood processing, and green cuttings from municipal waste management. After separating lignin and the cellulose fraction (hemicellulose, cellulose) the C_5- and C_6-sugars, that build the cellulose fraction, are released (Kucharska et al., 2020). C_5- and C_6-sugars are to be transformed to bio-BDO or other chemicals in principle the same way as sugar from sugar crop. Concerning the lignin fraction methods to produce various chemicals (Yu and Kim, 2020) or construction materials (Wu et al., 2020) are under development.

3.4.2 Methane

In the medium term, another pathway to bio-based BDO from renewable feedstocks can be considered. Starting from biobased methane, which can be produced by anaerobic fermentation of organic waste, e.g. from agricultural residues, livestock farming, food waste etc., a wide variety of organic materials becomes available as raw material for further processing. The anaerobic fermentation to biogas (bio-methane) standardizes the various starting materials to a uniform carbon source, which is rich in energy, established as a starting material for chemical syntheses, easily transportable, and storable. In this respect, biogas can play a key role in closing the technical carbon cycle.

In the case of producing bio-BDO from methane, the classic chemical Reppe synthesis route via acetylene, syngas, methanol, formaldehyde, and 1,4-butynediole can be applied for the large-scale manufacturing of biobased BDO (Figure 6). The only raw material missing in this synthetic route is hydrogen for the reduction of the triple bond in 1,4-butynediol to yield in 1,4-butanediol. The hydrogen required for this can be produced by conventional water electrolysis using electricity if sufficient emission-free power is available. Alternatively, hydrogen could be obtained from biomass pyrolyzed and gasified in a gasifier reactor in a similar way as for coal, (Meramo-Hurtado et al., 2020) avoiding the use of conventional fossil raw materials. Also, biotechnological

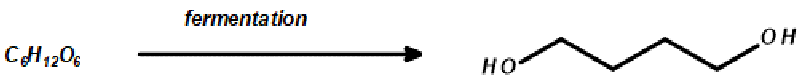

Figure 5 Biotechnical route with sugars as starting material yielding in BDO as direct fermentation product (own representation)

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069427812
DOI: 10.17879/27069427558

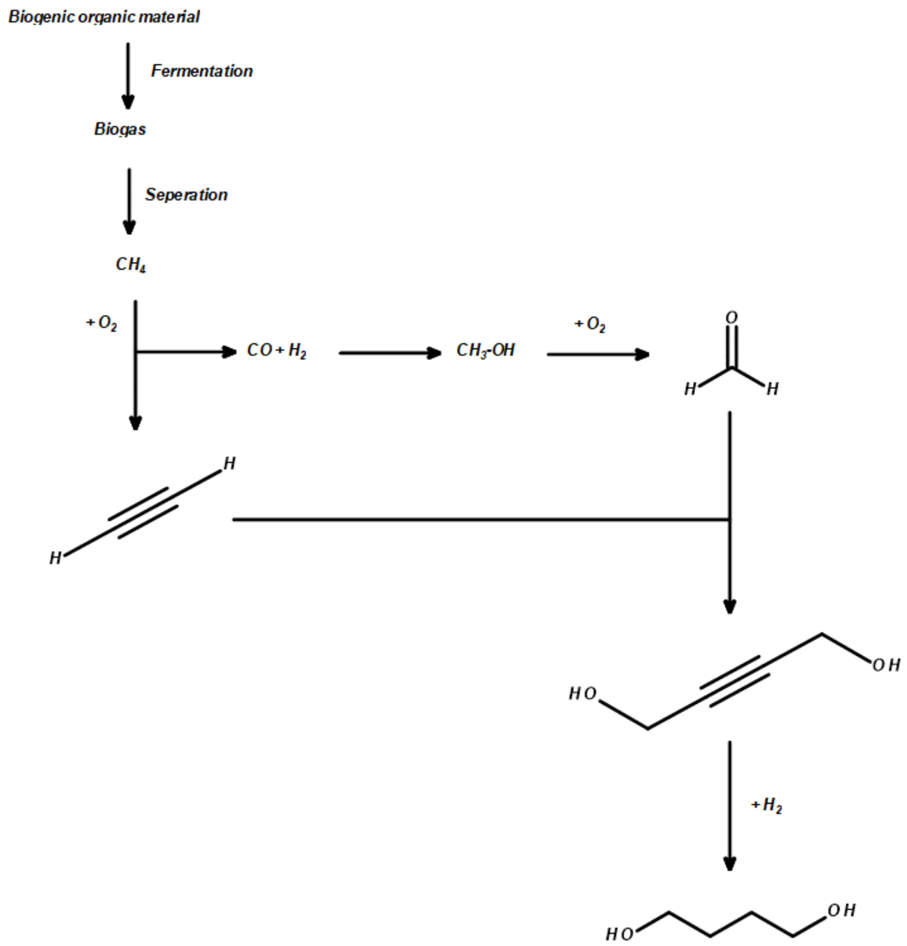

Figure 6 Biotechnical route with biogenic organic materials as starting material yielding in methane as direct fermentation product, which is then used in Reppe synthesis route towards BDO (own representation)

pathways to hydrogen using algae and bacteria are under development but still not ready for industrial practice (Gupta et al., 2013).

The demand of biogenic material to produce methane from biogas plants can only be estimated, due to the fact that different biogenic feedstocks give different biogas yields. The production of 190,000 tons of 1,4-butanediol requires 904 million Nm^3 methane (with a given density of 0.7175 kg per 1 Nm^3 methane). Estimating an average yield of 100 Nm^3 of methane per ton of biogenic starting materials (estimating an average methane content of 52% in the obtained biogas and calculated as average mixture of raw materials shown in table 8 as dry mass input), one would need 4.7 million tons of biogenic feedstock for the production of 190,000 tons of BDO.

In the long term, basic chemical building blocks such as methane or methanol should be accessible in a CO_2-neutral way by reducing carbon dioxide or even by capturing CO_2 out of the atmosphere. The conversion of CO_2 with water to methanol is already experimentally available in lab scale. This process consumes 5.85 MWh/t methanol (Pant et al., 2020), oxygen is derived hereby as a by-product. When the basic chemicals methane and methanol from carbon dioxide are available, the mature established, and optimized synthesis route can be used for large-scale production of BDO and formaldehyde in a sustainable manner.

3.4.3 CO_2

In addition to atmospheric CO_2, emission streams from technical plants can also be directly biologically bound. Examples are the cultivation of algae to produce fatty acids as a source for biodiesel (Khan et al., 2017) or fine

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069427812
DOI: 10.17879/27069427558

Table 8 Methane yields per biomass input in biogas fermentation plants

Source	Dry mass % of corresponding source	Biogas Nm^3 / t of fresh mass	CH_4 content of obtained biogas	CH_4 Nm^3 / t
Gras silage	40%	208	54%	45
Corn silage	33%	185	52%	32
Wheat straw	86%	292	51%	128
Meadow hay	86%	426	53%	194

chemicals (Seungjib et al., 2017). These photosynthetic organisms use light as energy source. Also, some bacteria are able to metabolize CO_2, for example into bioethanol, if hydrogen is provided as an energy source. One advantage of these processes is that CO_2 emitted from one process can be fed directly into another technical unit, thus avoiding emission into the atmosphere. Examples for suitable CO_2-emission streams are given in table 9 (Ausfelder et al., 2018). Another advantage is the robustness of these biological systems, which allow the use of polluted emission streams that would inactivate synthetic catalysts. Another option is technical photosynthesis, which converts CO_2 into chemical products also by the use of microbes using electrical power (Haas et al., 2018).

Actual research efforts focus on the catalytic transformation of CO_2 with hydrogen to formaldehyde (DECHEMA, 2019). In this approach, CO_2 is catalytically reduced with hydrogen to give with two equivalents of methanol dimethoxymethane as an intermediate. The hydrolysis of dimethoxymethane yields in one part of formaldehyde and two parts of methanol, which is used for the first synthesis step in the first loop. The net reaction therefor is $CO_2 + H_2 \rightarrow HCHO + H_2O$. The described Ruthenium catalyzed reaction approach could utilize up to 1.46 tons of CO_2 per ton of formaldehyde and is therefore suitable for the conversion of a greenhouse gas to a basic chemical.

However, CO_2 as a carbon source also has a price, because the provision of hydrogen is very energy-intensive. This will be explained using the example of butanediol and formaldehyde, since hydrogen is required for the synthesis of the precursor of formaldehyde (methanol from CO hydrogenation) for the final synthesis of 1,4-butanediol (hydrogenation of 1,4-butanediol) and for the hydrogenation of carbon dioxide to obtain methane as a C_1 synthesis block. In table 10, the specific demand of hydrogen and the corresponding electrical energy for generating the amount of hydrogen per 1 ton of BDO is shown.

3.4.4 CO

Syngas, mainly consisting of CO, is another potential industrial carbon source. If produced by gasifying biogenic organic materials, it is a biogenic carbon source. Microbes like Clostridia, which have already been mentioned for metabolizing CO_2, are able to use CO as well, even without offering hydrogen as energy source (Stoll et al., 2019; Abubackar et al., 2015).

Table 9 CO_2 streams of processing bio-based feedstock (Ausfelder et al., 2018)

Source	CO_2 concentration	Average CO_2 volume flow [m^3/h]	Average CO_2 volume flow [kg/h]
Biogas fermentation	45% in biogas	500	924
Biomass gasification	< 50% in syngas	2100	3881
Ethanol fermentation	100% in exhaust gas	5000	9240

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069427812
DOI: 10.17879/27069427558

Table 10 Specific demand of H_2 and the corresponding electrical power for its production per 1 ton of BDO

Specific H_2 demand per 1 ton of BDO	Amount of H_2	Electrical power demand to generate corresponding H_2 amount
As for methane synthesis	0.89 t	46.63 MWh
As for formaldehyde synthesis	0.104 t	5.45 MWh
As for 1,4-butynediol hydrogenation	0.055 t	2.88 MWh
Combined demand	1.049 t	54.96 MWh

If this technology is available along with a scalable process, this would open the possibility for a combined biotechnological and chemical route to formaldehyde (Figure 7). This route starts with biogenic organic material as feedstock, which after gasification yields carbon monoxide. Carbon monoxide can be reduced to methanol with hydrogen. As mentioned before, the utilized hydrogen should be produced with power supply from renewable energy sources, e.g. in a water electrolysis process, to ensure the sustainable approach of the entire production process.

The synthetic pathway of carbon monoxide to BDO via Reppe synthesis would require the conversion of CO either to acetylene in a direct way or CO conversion to methane. While the first route is unknown yet, the latter process – conversion of carbon monoxide to methane – is subject of actual research (Mok, 2013). However, acetylene synthesis from methane with oxygen produces syngas (mixture of carbon monoxide and hydrogen) as the main product. The gained syngas could be used in the production of formaldehyde via methanol as an intermediate, as described above, to avoid any by-products and to establish a sustainable approach of the entire production process.

4 Conclusion and Outlook

There is widespread agreement in politics, industry, the scientific community, and society in general, that greenhouse gas emissions must be drastically reduced in the interests of climate protection. This includes the chemical industry, which has been subject to a tightening emissions regime under the European Emissions Trading Scheme since 2005. This applies above all to scope 1 and 2 emissions, which primarily concern emissions from generating energy. Therefore, it is obvious to switch energy production to emission-free energy sources and, as shown, many companies also follow this strategy.

There are several options for reducing scope 3 emissions which include among other things transport, and the use and disposal of consumer products. In the case of bulk chemicals, as discussed here, transport is a relevant source of emissions, because both, BDO and formaldehyde are intermediate products which have to be transported from plant to plant in the multi-stage processing chain to e.g. polymers or crop protecting agents. Transport emissions are reduced if the receiving chemical plant for further

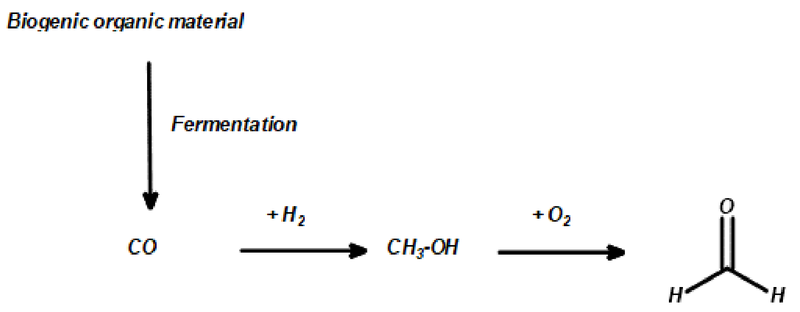

Figure 7 Biotechnical route with biogenic starting material providing carbon monoxide as direct gasification product which is then used in chemical synthesis to produce formaldehyde (own representation)

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069427812
DOI: 10.17879/27069427558

processing is located close to the production site, ideally even in the same chemical park, and the advantages of the Verbund model are used.

Emissions from waste management of consumer goods can be reduced by recycling if the polymers in these products can be separated from each other. This is a characteristic that must be taken into account as early as the product design stage.

Another option is to use biogenic raw materials for the carbon bound in the products. This is state of the art, particularly in the fine and specialty chemicals sector. However, significant reduction of the chemical sector's scope 3 emissions can only be expected once the raw material base of large-volume basic chemicals and products such as the butanediol discussed in this article has also been converted to a more sustainable basis. If this option were to be comprehensively realized, it is clear that the chemical sector would evolve from an insignificant consumer of agricultural feedstock today to a very large one. This may lead to conflicts with the supply of food, land use changes, and increased emissions of agricultural greenhouse gases, and thus could violate planetary boundaries and further damage ecosystem services that are already at risk. An exclusive focus on raw material change to primary biomass in the chemical industry therefore does not seem advisable.

The use of CO_2 could have a relieving effect. However, the necessary technologies are still lacking. In addition, these processes will be energy-intensive and will depend on the availability of emission-free power. Concerning costs, biobased BDO and formaldehyde are still economically not competitive to their fossil-based equivalents due to comparatively high feedstock cost.

The competitive position of the established biobased processes, such as the Purac or Genomatica process, would improve if the ETS were to burden the scope 3 emissions of processes and products that are still fossil-based today.

Finally, it is to be discussed, which of the suggested options for a non-fossile feedstock supply for BDO and formaldehyde is to favour and to strike for in the long term. In the authors´ opinion, there is no single and simple answer for this. The favored synthesis route has to be chosen by the given regional and regulatory conditions. For example, in a regional setting that is able to provide non-food biomass in sufficient quantities for industrial purposes, in a sustainable manner and at competitive prices, the transformation of biomass to biogas, the separation of bio-methane and its further processing to BDO and formaldehyde would be the preferred option. However, the further processing of biogas respectively of the separated bio-methane to chemical products can be done efficiently in large scale chemical plants, utilizing the economy of scale and already installed equipment. Therefore, an infrastructure for biogas transportation to such central chemical plants has to be installed. Where available, using the existing grid for natural gas is an option.

In another scenario, where the biomass amount is limited, but electrical power from emission-free energy sources is sufficiently available at competitive prices, the synthesis routes from carbon monoxide or carbon dioxide feedstocks can be preferred.

All options for switching the feedstock base to biogenic carbon sources, i.e., primary biomass from agriculture and forestry, biogas from residues, CO_2 from industrial emission streams, and CO from waste, probably cannot by themselves meet the high demand for bulk chemicals, but they can contribute, depending on local conditions. In this context, the coming transition phase from fossil to biogenic feedstocks is a significant challenge, because for a long time both carbon sources, fossil and bio-based, will be on the market in direct competition.

In summary, an emission-neutral chemical industry must avoid both energy- and product-related scope 1-3 emissions. Biogenic carbon sources can contribute together with technical carbon recycling. To ensure that the comparatively high feedstock, respectively, transformation costs of these carbon sources do not manifest themselves as a competitive drawback, and thus block the realization of these sustainability measures, the economic policy framework must be adapted to the requirements of a climate-friendly chemical industry. A globally coordinated system of greenhouse gas pricing scope 1-3 is a key element in this.

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069427812
DOI: 10.17879/27069427558

References

Abubackar, H. N., Veiga, M. C., Kennes, C. (2015) *Carbon monoxide fermentation to ethanol by Clostridium autoethanogenum in a bioreactor with no accumulation of acetic acid, Bioresour*. Technol., **186**, pp. 122-127.

Arpe, H.-J. (2007), *Industrielle Organische Chemie*, **Vol. 6**, Wiley-VCH.

Ausfelder, F., Dura, H. E., Dechema study (2018): *Optionen für ein nachhaltiges Energiesystem mit power-to-x Technologien*, available at: https://dechema.de/dechema_media/Downloads/Positionspapiere/2018_Power_to_X.pdf, accessed 16 March 2021.

Austin, K. G., Baker, J. S., Sohngen, B. L., Wade, C. M., Daigneault, A., Ohrel, S. B., Ragnauth, S., Bean A. (2020) The economic costs of planting, preserving, and managing the world's forests to mitigate climate change, Nature Comm. **11**, article number: 5946.

BASF (2019): *Committed to your success*, available at https://www.basf.com/global/en/products/chemicals.html, accessed 16 March 2021.

BASF (2020): *Emissionsreduktion entlang der Wertschöpfungskette*, available at https://www.basf.com/global/de/who-we-are/sustainability/we-produce-safely-and-efficiently/energy-and-climate-protection/reducing-emissions-along-the-value-chain.html, accessed 16 March 2021.

BASF (2021): *Our climate protection goal*, available at https://www.basf.com/us/en/who-we-are/sustainability/we-produce-safely-and-efficiently/energy-and-climate-protection/climate-protection-goals.html, accessed 16 March 2021.

BASF (2021): *Wo wir stehen: Die BASF-CO_2-Bilanz 2020*, available at https://www.basf.com/global/de/who-we-are/sustainability/we-produce-safely-and-efficiently/energy-and-climate-protection/corporate-carbon-footprint.html, accessed 16 March 2021.

Bioplastics study (2017): *Land use estimation for bioplastics in 2017 and 2022*, available at https://www.european-bioplastics.org/how-much-land-do-we-really-need-to-produce-bio-based-plastics/, accessed 16 March 2021.

Costanza, R. (2014) *Changes in the global value of ecosystem services*, Global Environmental, **26**, pp. 152-158.

Culler, S. (2016) *Che. Eng. Progress*, **9**, pp. 42-51.

DECHEMA (2019): *CO_2Plus – Stoffliche Nutzung von CO_2 zur Verbreiterung der Rohstoffbasis*, available at https://co2-utilization.net/uploads/CO2plus_Abschlussergebnisse.pdf, accessed 16 May 2021.

DECHEMA (2019): *Roadmap Chemie 2050*, available at https://dechema.de/dechema_media/Downloads/Positionspapiere/2019_Studie_Roadmap_Chemie_2050-p-20005590.PDF, accessed 16 March 2021.

Deerberg, G., Hensmann, M., Sprecher, M., Hoppe, H., Hannes, J., Merretig-Bruns, U., Sayder, B., Schwarze-Benning, K., Körner, H.-J. (2020) Möglichkeiten der Integration in bestehende industrielle Anlagen mit relevanten C_1-Gasströmen, in: Kircher, M., Schwarz, T. (ed.) CO_2 und CO *- Nachhaltige Kohlenstoffquellen für die Kreislaufwirtschaft*, Springer, pp. 169-218.

European Commission study (2018): *Expert Group Report Review of the EU Bioeconomy Strategy and its Action Plan*, available at https://gbs2018.com/fileadmin/gbs2018/Downloads/Expert_group_report.PDF, accessed 16 March 2021.

Evonik (2020): Evonik carbon footprint 2019, available at https://corporate.evonik.de/downloads/corporate%20responsibility/evonik_carbon_footprint_de.pdf, accessed 16 March 2021.

Evonik (2020): *Top 10 Nachhaltigkeitsziele*, available at https://corporate.evonik.com/Downloads/Corporate%20

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069427812
DOI: 10.17879/27069427558

Responsibility/Nachhaltigkeitszeile%20dt%20Überblick%20groß.jpg, accessed 16 March 2021.

Evonik (2021): *Leading beyond chemistry*, available at https://corporate.evonik.de/en/company, accessed 16 March 2021.

FNR (2021): *Basisdaten biobasierte Produkte 2021*, available at https://fnr.de/fileadmin/allgemein/pdf/broschueren/basisdaten_biobasierte_produkte_2021_web.pdf, accessed 16 March 2021.

Forte, A., Zucaro, A., Basosi, R., Fierro, A. (2016) *Materials*, 9, pp. 563-570.

Gupta, S. K., Kumari, S., Reddy, K., Bux, F. (2013): Trends in biohydrogen production: major challenges and state-of-the-art developments, *Environ. Techno.*, **34**(13-16), pp. 1653-1670.

Haas, T., Krause, R., Weber, R., Demler, M., Schmid, G. (2018) Technical photosynthesis involving CO_2 electrolysis and fermentation, *Nature Catalysis*, **1**, pp. 32-39.

Henkel (2020): *Sustainability report 2019*, available at https://www.henkel.com/resource/blob/1038544/af1684b38200328128a80b5dd18e485e/data/2019-sustainability-report.pdf, accessed 16 March 2021.

Henkel (2021): *Brands and Businesses*, available at https://www.henkel.com/brands-and-businesses, accessed 16 Mach 2021.

Henkel (2021): *Climate protection strategy and targets*, available at https://www.henkel.com/sustainability/positions/climate-positive, accessed 16 March 2021.

Khan, S., Siddique, R., Sajjad, W., Nabi, G., Hayat, K. M., Duan, P., Yao, L. (2017), Biodiesel Production From Algae to Overcome the Energy Crisis, *Hayati J. of Biosciences*, **24**, pp. 163-167.

Krämer, D., Bazzanella, A. (2017): *Technologien für Nachhaltigkeit und Klimaschutz - Chemische Prozesse und stoffliche Nutzung von CO_2*, Dechema, pp 12-31.

Kucharska, K., Słupek, E., Cieśliński, H. (2020): Advantageous conditions of saccharification of lignocellulosic biomass for biofuels generation via fermentation processes, *Chem. Pap.*, **74**, pp. 1199–1209.

McKinsey (2007): *Kosten und Potenziale der Vermeidung von Treibhausgasemissionen in Deutschland*, available at https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/Sustainability/Our%20Insights/Costs%20and%20potentials%20of%20greenhouse%20gas%20abatement%20in%20Germany/Read%20the%20Deep%20Dives%20Industry.pdf, accessed 16 March 2021.

Meramo-Hurtado, S., Puello, P., Cabarcas, A. (2020): Process analysis of hydrogen production via biomass gasification under computer-aided safety and environmental assessments, *ACS Omega*, **5**, 31, 19667–19681.

Mok, Y. S. (2013): Production of methane from carbon monoxide in a plasma-catalytic combined reactor system, *Int. J. Sus. Dev. Plann.*, **8**, pp. 186–196.

Murzina, A., Ingram, A. (2017): *PERP Report 1,4-Butanediol/Tetrahydrofuran*.

Nijnik, M. (2010): Carbon capture and storage in forests, in: Hester, R.E., Harrison, R. M. (ed.) Issues, in: *Environmental Science and Technology*, Vol. 29, Royal Society of Chemistry, pp. 203-239.

Pant, D., Bulut, M., de Wever, H. (2020) , in: Kircher, M., Schwarz, T. (ed.) *CO_2 und CO - Nachhaltige Kohlenstoffquellen für die Kreislaufwirtschaft*, Springer, pp. 316-319.

Parisi, C., Ronzon, T. (2016): *A global view of bio-based industries: benchmarking and monitoring their economic importance and future developments.*

PERP Report (2004): *1,4-Butanediol/THF*, 02/03-7, pp. 155-156.

PERP Report (2016): *Formaldehyde and resins*, p. 66.

Rockström, J. (2009): Planetary Boundaries: Exploring the Safe Operating Space for Humanity, *Ecology and Society*, **14**(2), pp. 32.

Scarlat, N., Fahl, F., Dallemand, J. F. (2019): Status and Opportunities for Energy Recovery from Municipal Solid Waste in Europe, *Waste Biomass-Valorization*, **10**, pp. 2425–

Vol.18, Iss.2, June 2021
URN: urn:nbn:de:hbz:6-27069427812
DOI: 10.17879/27069427558

2444.

Seungjib, J., Byeongryool, J., Yong, K. C. (2017): *Consequences of Microbial Interactions with Hydrocarbons, Oils, and Lipids: Production of Fuels and Chemicals*.

Steffen, W. (2015): Planetary boundaries: Guiding human development on a changing planet, *Science*, **347** (6223), p. 1259855.

Stoll, K., Boukis, N., Sauer, J. (2019): *Syngas Fermentation to Alcohols: Reactor Technology and Application Perspective*.

Tcvetkov, P., Cherepovitsyn, A., Fedoseev, S. (2019): Public perception of carbon capture and storage: A state-of-the-art overview, *Heliyon*, **5**.

Van den Oever, M., Molenveld, K., van der Zee, M., Wageningen, H. B. (2017): Bio-based and biodegradable plastics: facts and figures, *Food & Biobased Research*, **1722**, pp. 1-65.

VCI (2021): Rohstoffbasis der organischen Chemie in Deutschland, Anteile in Prozent, *2018*. available at https://www.vci.de/themen/rohstoffe/vci-statistik-energie-klimaschutz-rohstoffe-in-der-chemie.jsp, accessed 16 March 2021.

World Resources Institute (2021): *Corporate standard*, available at http://www.ghgprotocol.org./standards/corporate-standard, accessed 16 March 2021.

Wu, J., Liu, Q., Wang, C., Wu, W., Han, W. (2020): Investigation of lignin as an alternative extender of bitumen for asphalt pavements, *J. Clean. Prod.*, **283**, 124663.

Yu, O., Kim, K.H., (2020): Lignin to Materials: A focused review on recent novel lignin, Applications, *Appl Sci.*, **10**, p. 4626.

JOURNAL OF BUSINESS CHEMISTRY

ISSN 1613-9623