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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.

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Contents

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Letter from the Editors

The 19th volume of the Journal of Business Chemistry: The journey continues

The Journal of Business Chemistry is publishing its 19th volume with the first issue of the year 2022. Since 2004, 52 issues with over 200 contributions have been published and the Journal of Business Chemistry has developed continuously. We are pleased to announce that a special issue is planned in the context of the 4th International Workshop on Innovation and Production Management in the Process Industries (IPM2022) which will take place on the 12. & 13. May 2022 at Industrial Park Höchst, Germany. We would like to draw our readers' attention to the possibility to hand in an abstract and present their research at the workshop. The workshop is intended to shed light on various aspects of the transformation to climate-neutral process industries.

In his article titled "Joint product analysis of rare earths: economic, market and technological insights" Philipp Werner describes an approach to analyze joint products and specifically, the rare earth Gadolinium is investigated. The author gives an overview of the most important rare earth mining areas, capacities, applications, and estimated growth rates. Additionally, he includes political aspects and points out changes in Chinese regulation.

Secondly, Katharina Zander´s article "The influence of market orientation on innovativeness" analyses the overlap of those two concepts. Moreover, she describes current innovation projects of a chemical company as an example.

In the article "Gender – an essential substance for sustainable chemistry" Anna Holthaus and Minu Hemmati provide an overview of gender dimensions and inequalities in the chemical industry. Based on this, they describe three criteria for a gender-just and sustainable chemical industry and develop initial ideas for the integration of gender in sustainability management.

Sascha Nowak´s and Simon Wiemers-Meyer´s article "Better batteries – better recycling" discusses the recycling of Lithium-ion batteries (LIBs) which are used in modern day electronics like laptops, smartphones, or tablets. They emphasize that the diversity of batteries presents a huge challenge for recycling procedures. To foster the recycling of batteries, they propose that all necessary information about batteries is provided by the manufacturer.

Lastly, Nikolaus Raupp shares his experiences as seed investor in the commentary "My personal view on investment in chemistry start-ups". To increase the likeliness of building a successful chemistry start-up, he points out three important aspects: First, follow the "bio-pharma example" and look for strategic cooperation. Second, focus more on your desired features than on raw material prices as they may change until your product is on the market. Third, select your team carefully and think about including a process engineer and a sales professional early even though this will lead to additional costs.

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

Janine Heck (Executive Editor)

Bernd Winters (Executive Editor)

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Practitioner‘s Section

Philipp Werner*

Joint Product Analysis of Rare Earths: Economic, Market and Technological Insights

Rare earths, classified as critical elements by the European Commission, are of high importance to the automotive, chemical, and pharmaceutical industries. They are produced simultaneously and therefore can be referred to as joint products. In this paper, an approach is presented to analyze the drivers behind supply and demand changes of joint products to reveal cross-industry relationships between rare earths. The approach is based on a techno-economic analysis and includes economic, market, and technological evaluations. The heavy rare earth Gadolinium is analyzed in detail to give insights into applications, capacities, the rare earth industry, estimated growth rates, and strategy recommendations.

1 Introduction

1.1 Joint Products

In the chemical and pharmaceutical industry, joint & by-products occur in several process steps. According to Drury (2011), they arise in production processes where the production of one product causes the simultaneous production of other products. These products are directly connected and cannot be produced separately (Drury, 2011). Various examples can be found in the industry. Traditionally, most joint products occur in the chemical industry. Joint and by-products can be distinguished by their sales value. If products are produced simultaneously and have a similar sales value, these products are called joint products. Products that have a lower sales value compared to the other products are called by-products (Drury, 2011). Figure 1 illustrates an exemplary joint production process and explains the most important terminology.

A characteristic of joint processes is that the products cannot be classified as individual products until the split-off point, depicted as a dashed line. Before that point, all occurring costs are joint costs and cannot be allocated to individual products. In general, joint costs contain the costs for labor and overhead, raw materials, and processing. The costs after the split-off point, for further processing and distribution, can be allocated to specific products and are called separable costs (Drury, 2011; Horngren, Datar, Rajan, 2012).

1.2 Rare Earth Elements & Applications

An example of joint products are rare earth elements (REE). REEs arise together in nature and are mined simultaneously (Haque et al., 2014). According to the European Commission, rare earths are considered critical raw materials (European Commission, 2017). In the table of elements, REEs are found in the lanthanide series between lanthanum and lutetium plus the element’s scandium and yttrium. These elements are known for their interesting magnetic properties (Gupta, Krishnamurthy, 2005). Rare earths are very important elements for the catalysis of chemical reactions and are used in magnets and batteries. The major applications of

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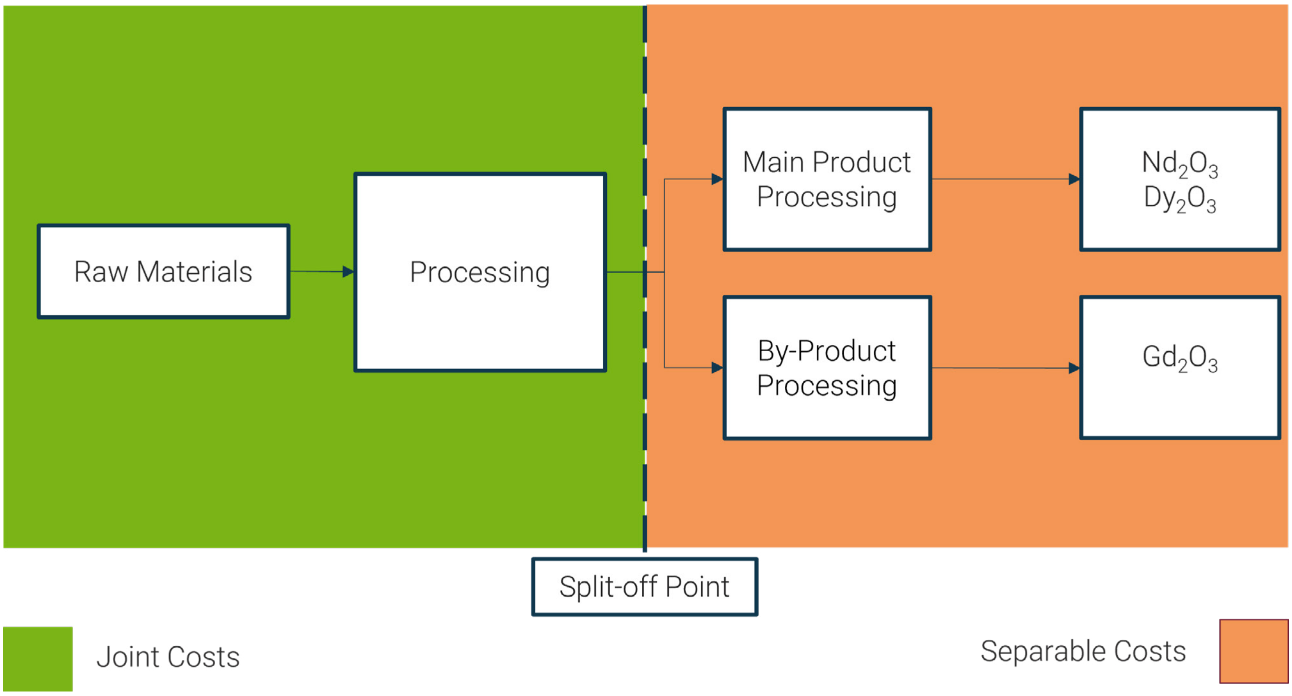

Figure 1 The production process for joint and by-products (based on Drury, 2011, p.169).

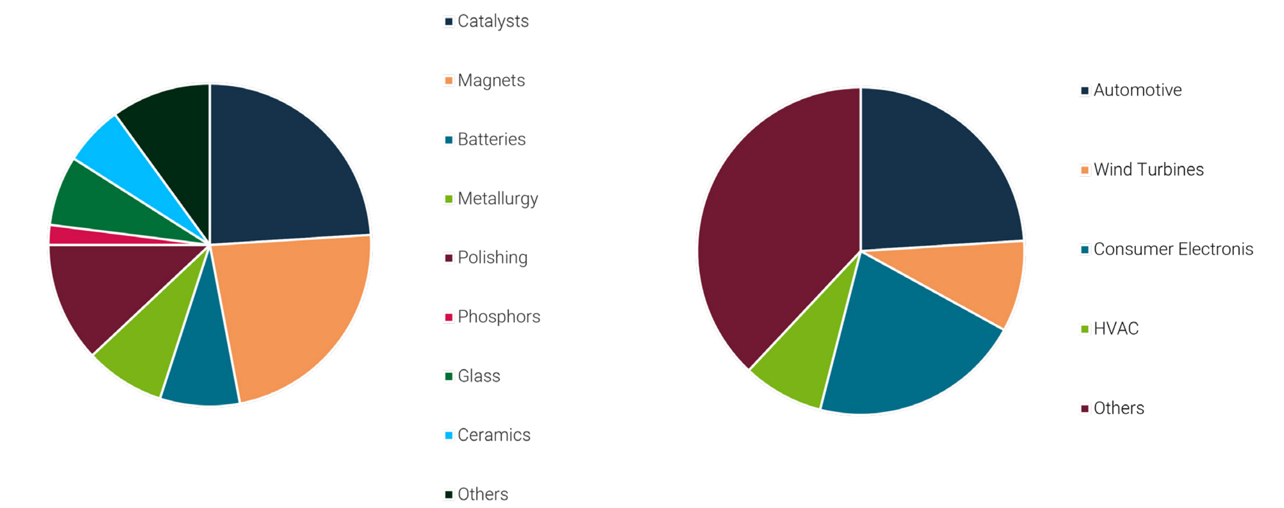

Figure 2 Usage of rare earths in 2016 (left) and usage of NdPr in 2020 (right) (Goodenough, Wall, Merriman, 2018, p.202; MP Materials, 2020a, p. 24).

all rare earths are shown in figure 2 (Goodenough, Wall, Merriman, 2018).

Of particular interest are the elements Neodymium and Praseodymium. These elements are used for permanent magnets in electric vehicles and wind turbines. Other major applications are consumer electronics and heating, ventilation, and air conditioning (HVAC) (MP Materials, 2020b). The heavy rare earth elements Dysprosium, Gadolinium, and Terbium are found in various applications, as well. Dysprosium is to 98 % used as an additive in NdFeB magnets. The applications of Gadolinium are more diversified. Gadolinium is used in magnets, alloys, luminescent material, nuclear technology, and MRI technology. Terbium is mostly used in luminescent material and as an additive in magnets (Marscheider-Weidemann et al., 2016).

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1.3 Microeconomic Concepts of Joint Production

In figure 3 it is shown how joint products are joint in supply but not compulsory in demand. Rising demand for the main product leads to higher prices for the main product. Coupled production increases the supply of by-products. If the demand for the by-products remains the same, this leads to a price drop. An example of this scenario are the falling prices for Lanthanum and Cerium. These two elements are the by-products of rare earth mining (Kwatiah, 2020).

However, the main product Neodymium-Praseodymium (NdPr) is exposed to higher demand and therefore higher prices in the long term. This correlation of falling prices for Lanthanum and Cerium will increase if more NdPr is demanded.

However, the main product Neodymium-Praseodymium (NdPr) is exposed to higher demand and therefore higher prices in the long term. This correlation of falling prices for Lanthanum and Cerium will increase if more NdPr is demanded.

Besides, the opposite scenario of the falling demand for the main product can be found in the industry (figure 4). Reduced demand leads to a drop in the price of the main product. The coupled by-product increases in price since the reduced production volume reduced the supply while demand remained the same. If a larger amount of the by-product is required, the production costs for the main product may have to be paid as well (Kwatiah, 2021).

Several events can cause a market equilibrium disturbance. Price increases can appear during a supply shortage or a demand increase. Potential reasons for a supply shortage

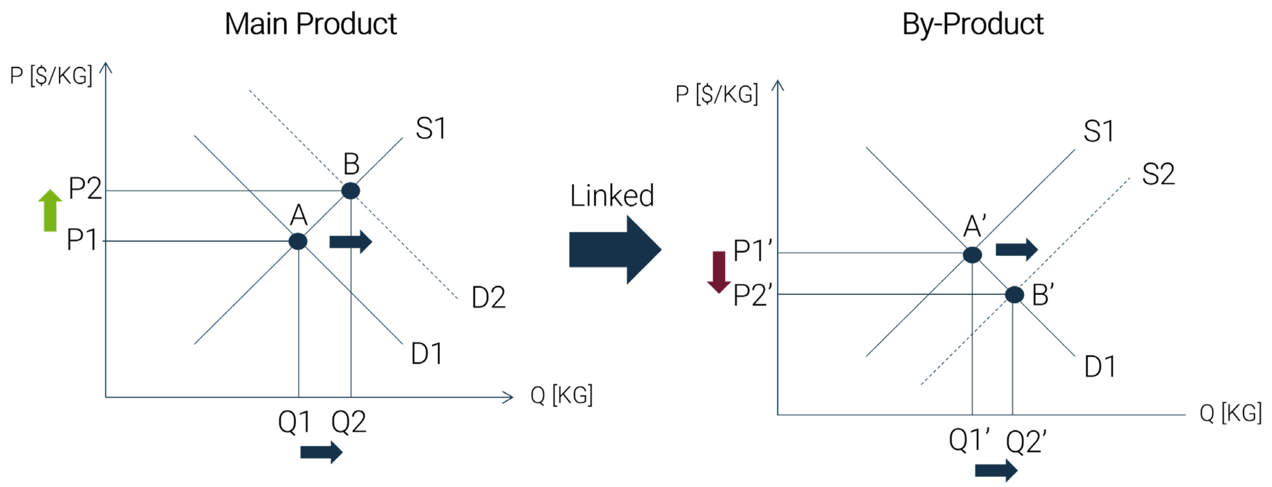

Figure 3 Connected supply and demand curves for joint products (based on Kwatiah, 2021).

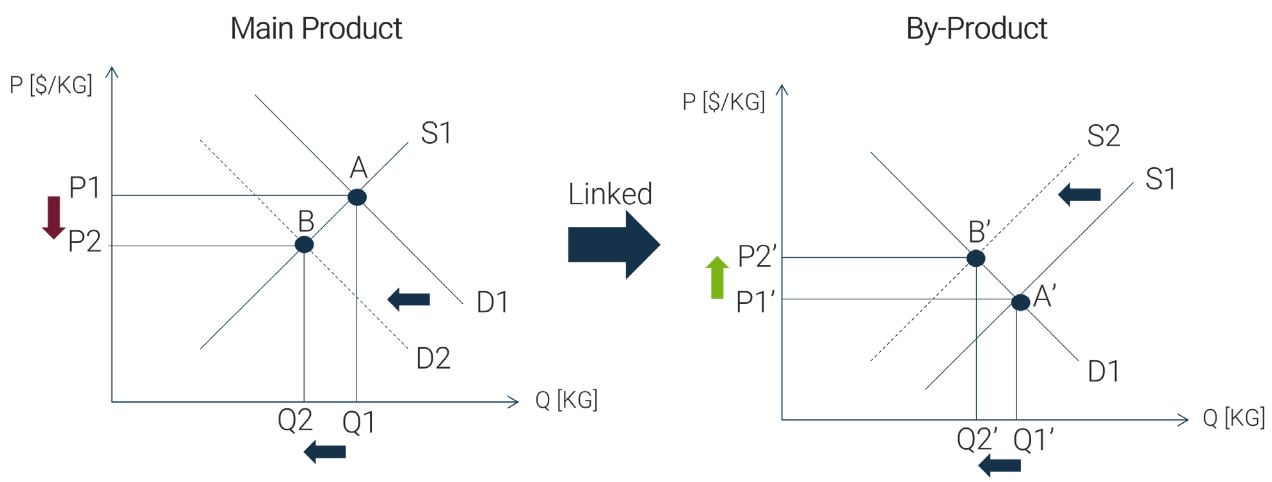

Figure 4 Connected supply and demand curves of joint products (based on Kwatiah, 2021).

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could be investment restraints, trade conflicts, monopoly, political crises, natural disasters, or warehouse problems. Factors that affect demand increase are economic growth, increasing resource intensity, or technology change. However, it must also be mentioned that technology change can also lead to demand decreases if products are substituted. Through changes in supply and demand, a new market equilibrium adjusts with a new market price. In general, higher market prices cause adaptation mechanisms which lead to lower market prices afterward. An increase in market prices can motivate new market players to enter a market. New production capacities are established which can lead to overcapacities. In an adjustment phase, only the most profitable companies can remain business. If demand cannot be covered by suppliers a good becomes more valuable and increases in its price. If the prices get too high the market will start to research for product substitutions or recycling which can ease price increases (Glöser-Chadhoud et al., 2016).

2 Joint Product Analysis

For the analysis of joint products, an approach is presented to evaluate joint products and give strategic management decisions regarding estimated production capacities and price trends, see figure 5.

The approach contains six steps to analyze joint products. Step one is about setting up a goal and the scope for the analysis, what production process, and which products should be analyzed.

Step two is about dealing with the identification of the main and by-products of the process. For that purpose, the product composition (product mix) must be evaluated and the amount of each product in the production process must be determined. In the case of rare earth processing, there are 15 elements having shares from <1 % to above 40 %. The main product is determined by using the weight, sales, or margin of each product. For that, current capacities, sale prices, and production costs are used to determine the main product. Because joint products are produced simultaneously, the main product influences the whole production process and affects the production of by-products as well.

Therefore, in steps three and four, the market and the technology of the products are analyzed. Current and expected market players, supply developments, and supply chain risks are demonstrated. Changes in the market and technology of the main product can influence the availability of the by-product. After that, the technology trends of the by-product are studied as well, and depending on the market foresight of the main product, it is estimated if the expected supply will cover the expected demand.

After analyzing the technology trends, political and societal risks are researched and evaluated. In countries with unstable governments or unpredictable law and regulation changes, the available production capacity might be affected. In step six the results of the previous analysis steps are interpreted to give a conclusion and answer the research question based on technological, economic, and political factors.

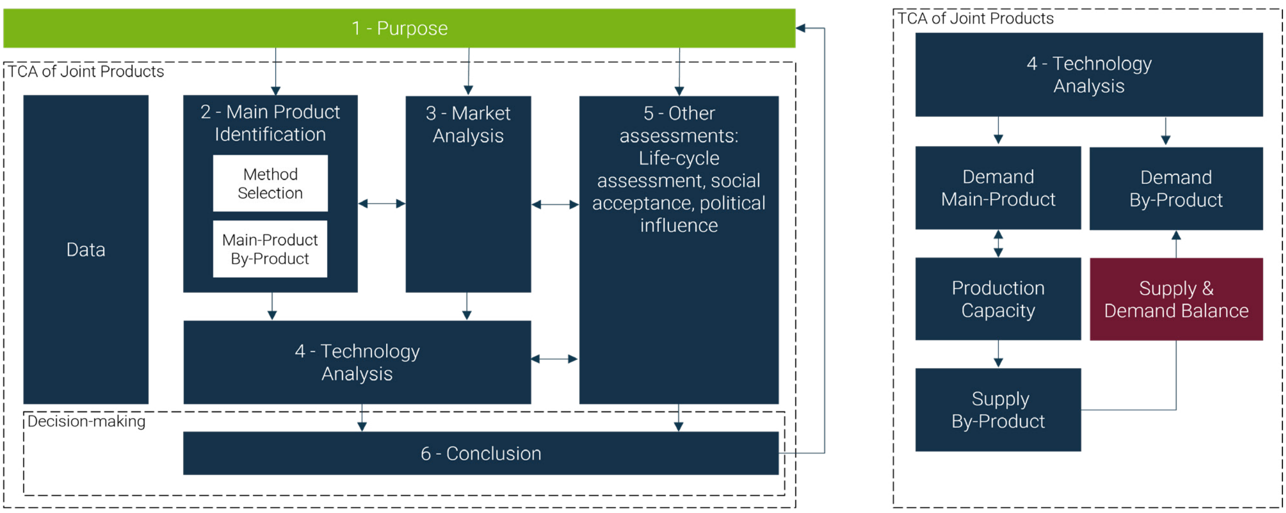

Figure 5 Approach for the analysis of joint products (own representation).

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3 Methodology

For data generation, a multi-language and open-source approach was used. Except for English literature also Chinese literature was reviewed. The data were categorized into four different categories (figure 6). Scientific, economic, governmental, and internet data. Scientific journals found on Google Scholar or Chinese National Knowledge Infrastructure (CNKI) were reviewed. Information on companies was analyzed by using company websites, company presentations, and company databases. As databases for Chinese companies Tianyancha was used (in Chinese). Information about the current status of the rare earth industry feasibility studies of new rare earth projects and announcements by the Ministry of Industry and Information Technology (MIIT) (in Chinese) were used. Further information was provided by Baotou Rare Earth Exchange and Xinhua News (in Chinese). Internet data was searched with Google and Baidu (in Chinese).

4 Economic Analysis

The joint production analysis starts with an evaluation of the main product of the process. The main product can be estimated by revenue and margin. For the calculation of the revenue share, the product composition and the market prices are needed. Margins are calculated by using production costs provided by Arafura Resources (Arafura Resources, 2019).

In a typical rare earth mining company, Neodymium and Praseodymium have together a revenue share of about 80 %. Gadolinium has a revenue distribution of about 2 %. It can be stated, that the main products of rare earth mining are the elements Neodymium and Praseodymium (figure 7). These products influence the expected production capacity of rare earths. Gadolinium is only a by-product of rare earth mining, with less contribution to the revenue.

5 Market Analysis

5.1 Overview

The rare earth elements are mainly mined in China. However, some other countries are also active in the mining of rare earths (figure 8). The following figure shows an overview of the most important areas for rare earth mining and what areas have larger reserves (USGS, 2021).

5.2 Countries and Capacities

According to the U.S. Geological Survey (USGS), the worldwide production in 2020 was about 240.000 mT of rare earths (table 1). The most important countries for rare earth mining are China, the USA, Myanmar, and Australia. The most reserves are in China, Brazil, Vietnam, and Russia. In 2018 the United States restarted its rare earth mining operations and Myanmar entered the market.

About 60 % of the rare earths are mined in China. However, more than 90 percent of the separation is done in China (table 2). That's because most countries do not have the mining capacities to process the rare earths themselves[1].

[1]MP Materials does not have a separation facility and sells rare earth concentrate (2020a, p.29).

Figure 6 Data collection (own representation).

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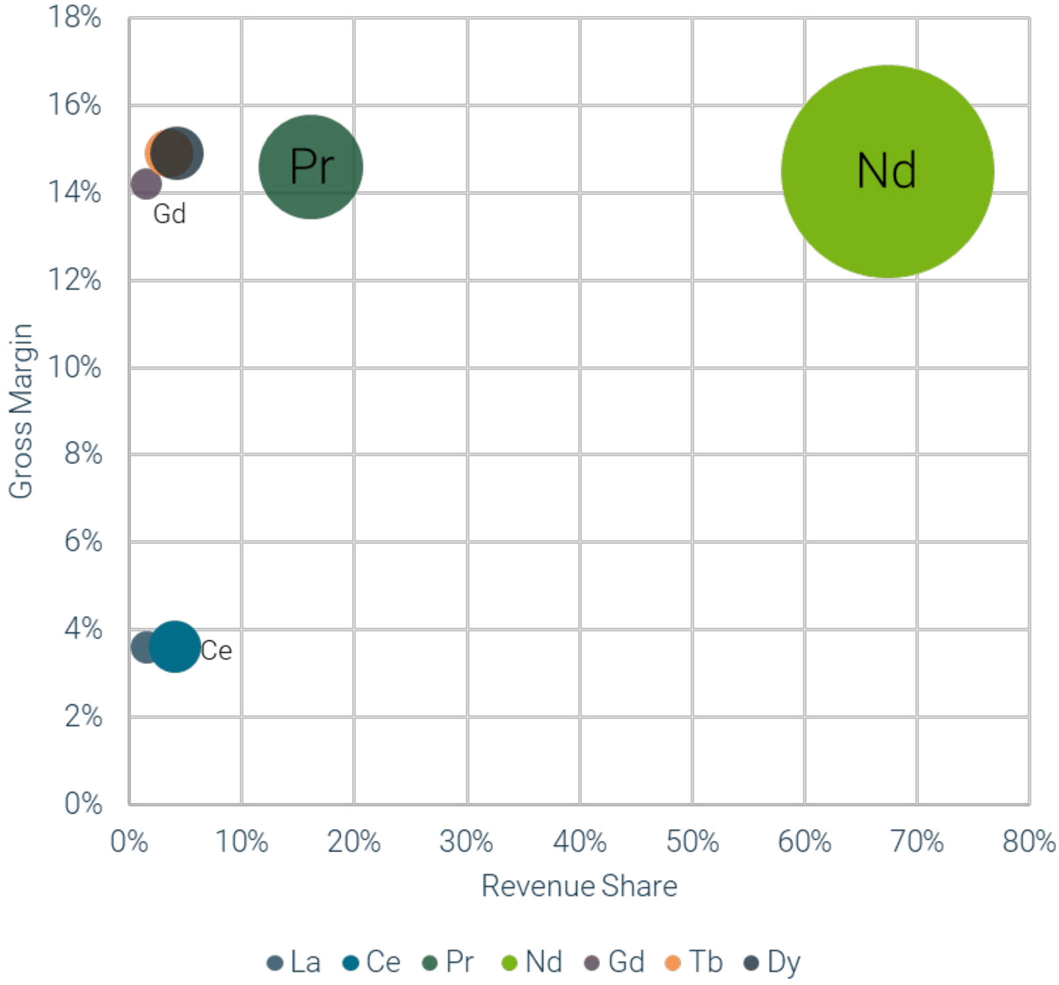

Figure 7 Revenue Distribution of Selected Rare Earth Elements (own representation).

Figure 8 Overview of the most important rare earth mining areas (own representation).

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Table 1 Worldwide production of rare earths (based on USGS, 2019-2021, p. 2).

Country	2018	2019	2020	Reserves
USA	18,000	26,000	38,000	1,400,000
Australia	21,000	21,000	17,000	3,300,000
Brazil	1,100	1,000	1,000	22,000,000
Myanmar	19,000	22,000	30,000	N.A.
Burundi	630	630	500	N.A.
Canada	-	-	-	830,000
China	120,000	132,000	140,000	44,000,000
Greenland	-	-	-	1,500,000
India	2,900	3,000	3,000	6,900,000
Madagascar	2,000	2,000	8,000	N.A.
Russia	2,700	2,700	3,000	12,000,000
South Africa	-	-	-	790,000
Tanzania	-	-	-	890,000
Thailand	1,000	1,800	2,000	N.A.
Vietnam	920	900	1,000	22,000,000
Other Countries	60	-	100	310,000
World Total	**190,000**	**210,000**	**240,000**	**120,000,000**

Table 2 Comparison between production and separation capacity in 2020 (own representation).

Country	Production	%	Separation	%
China	140,000	58	223,000	92
USA	38,000	16	-	-
Myanmar	30,000	13	-	-
Australia	17,000	7	17,000	8
Rest	15,000	6	-	-
Total	**240,000**	**100**	**240,000**	**100**

China functions as a contact point for rare earth concentrate worldwide. As we will see in the following chapter, some countries with higher resources of rare earths are planning to build their own separation facilities to be less dependent on China.

The top five players in the market dominate over 80 % of the available capacities (table 3). However, the data of the key companies in rare earth mining also shows that the smaller companies located in South China are more dominant in heavy rare earth mining (USGS, 2021; MIIT, 2019; MIIT, 2020).

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Table 3 Largest mining companies of rare earths in 2020 (own representation).

Country	English Name	Domestic Name	LREE Capacity	HREE Capacity	Location
China	China Northern Rare Earth Group	中国北方稀土集团高科技股份有限公司	73,550	-	Inner Mongolia
China	China Southern Rare Earth Group	中国南方稀土集团有限公司	32,750	8,500	Sichuan, Jiangxi
USA	MP Materials	-	38,000	-	Nevada
Myanmar	ME 2[2]	အမှတ်(၂) သတ္တုတွင်း လုပ်ငန်း	12,000	18,000	Kachin, Shan
Australia	Lynas	-	17,000	-	Western Australia
China	China Rare Earth Co.	中国稀有稀土股份有限公司	14,550	2,500	Shandong, Guangxi
China	Xiamen Tungsten	厦门钨业股份有限公司	-	3,440	Fujian
China	Guangdong Rare Earth Group	广东省稀土产业集团有限公司	-	2,700	Guangdong
China	Minmetals Rare Earth	五矿稀土集团有限公司	-	2,010	Hunan, Yunnan
Rest	-	-	18,300	-	-
Total	**-**	**-**	**206,150**	**37,150**	**World**

5.2.1 Companies

China's rare earth mining sector is dominated by six companies called China Minmetals Corporation, China Rare Earth Co. Ltd., China Northern Rare Earth (Group) High-Tech Co., Ltd., Xiamen Tungsten Co., Ltd., China Southern Rare Earth Group, and Guangdong Rare Earth Industry Group. Among these six companies, China Northern Rare Earth (Group) High-Tech Co., Ltd. is the biggest manufacturer of rare earth oxides. China Northern Rare Earth is operating the well-known production site in Baotou, Inner Mongolia China (China Northern Rare Earth Group, 2020). Chinese databases like Tianyancha.com give insights into the shareholder structure of Chinese rare earth companies. Table 4 shows major shareholders of Chinese rare earth companies (Tianyancha, 2021).

All six of the above-mentioned companies are state-owned. However, there are differences in their sizes and their state-owned shareholders. Three out of six companies are controlled directly by the State Council of the People's Republic of China (SASAC). The other three are controlled by province authorities. In China, there are asset supervision authorities at the county, province, and state levels. With a market share of 53 and 27 % China Northern and China Southern Rare Earth Group are controlling 80 % of the rare earth market in China (Tianyancha, 2021). In December 2021 a merger of Southern Rare Earth Group, Minmetals Rare Earth, and China Rare Earth Co. was announced. The new company will operate as China Rare Earth Group. This new company will be the second biggest player in the rare earth industry after China Northern Rare Earth Group and the worldwide largest producer of heavy rare earth elements, accounting for 70 % of China's heavy rare earth production. Additionally, the Jiangxi Ganzhou Rare Metal Exchange will also be part of the newly established company (Reuters, 2021; NikkeiAsia 2021).

[2]Distribution between LREE and HREE capacity for ME 2 estimated. Overall capacity 30.000 metric tons.

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Table 4 Major shareholders of Chinese rare earth companies (own representation).

Major Shareholder	Mother Company	Subsidiary
SASAC	Aluminum Corporation China	China Rare Earth Co.
SASAC	China Minmetals Group	Minmetals Rare Earth
Inner Mongolia Government	Baotou Iron & Steel Group	Northern Rare Earth Group
SASAC	Fujian Metallurgical Holding	Xiamen Tungsten
Ganzhou Government	Ganzhou Rare Earth Group	Southern Rare Earth Group
Guangdong Government	Guangdong Asset Management	Guangdong Rare Earth Group

5.2.2 South China & Myanmar

Most of the heavy rare earths are mined in Southern China and Myanmar. In figure 9, the most important locations for heavy rare earth mining are shown (Zhang et al., 2016).

Most of the rare earth mines in South China are in the triangle of Jiangxi, Guangdong, and Fujian. The most important mines are in the following areas. The first name refers to the province and the second name is the city within each province: Jiangxi, Xinfeng; Jiangxi, Longnan; Jiangxi, Xunwu; Guangdong, Dapu; Fujian, Ninghua; Guangxi, Jiaoguo; Hainan, Longliu; Hunan, Jianghua; Yunnan, Chuxiong; and Zhejiang, Daxi (Zhang et al., 2016).

Attention must also be paid to Myanmar. Since 2018, Myanmar's rare earth industry sector is growing increasingly. According to the U.S. Geological Survey, Myanmar is responsible for about 12 % of rare earth oxides which is comparable with the production capacity of Australia (USGS, 2021). Although the production capacity has increased much in the last years, still not much information about the mining companies in Myanmar is available. The rare earth mining sector is mostly controlled by a company referred to as Mining Enterprise 2 (ME2) in various industry reports (PWC, 2019). Most of the rare earths are mined in the two provinces of Kachin and Shan in Myanmar (Lynn, Oye, 2014). These two states are close to the Chinese border and are neighboring states of Yunnan Province, China. The border control point of Myanmar and China at Tengchong Houqiao Port, Yunnan, China is therefore of interest in analyzing price fluctuations of heavy rare earth elements like Dysprosium or Gadolinium (China Rare Earths Holdings, 2020). Closure of the border can lead to strong price fluctuations caused by supply decreases. This case appeared from June to August 2019 when the prices for Dysprosium, Gadolinium, and Terbium escalated (Xinhua Indices, 2021). Further developments must be evaluated regularly to keep risks within a limit.

6 Technology Analysis

6.1 Permanent Magnets

The rare earth oxides of Neodymium, Praseodymium, and Dysprosium are mostly used to manufacture Neodymium-Iron-Boron permanent magnets ($Nd_2Fe_{14}B$). Permanent magnets play an important role in establishing a carbon-neutral industry because permanent magnets are used in electric vehicles, wind turbines, and consumer electronics (MP Materials, 2020b). Currently, the most used permanent magnets are NdFeB and NdDyFeCoB magnets. By adding Dysprosium, the thermal resistance can be increased up to 200 °C which makes them useful for applications in electric vehicles. Another option would be SmCo magnets. However, the low concentration of Samarium makes them impractical for large-scale industrial applications. Except for NdFeB and SmCo, other permanent magnets like GdCo, PtCo, and MnAl can store less magnetic energy and are therefore weaker than currently used NdFeB magnets (McCallum et al., 2014; Cui et al., 2018).

6.2 Rare Earth Free Motors

A big threat for the rare earth industry would be the large-scale implementation of rare earth free electric motors. There are different kinds of electric motors available and most of them currently use permanent NdFeB magnets. Table 5 should give an overview of the different motor types

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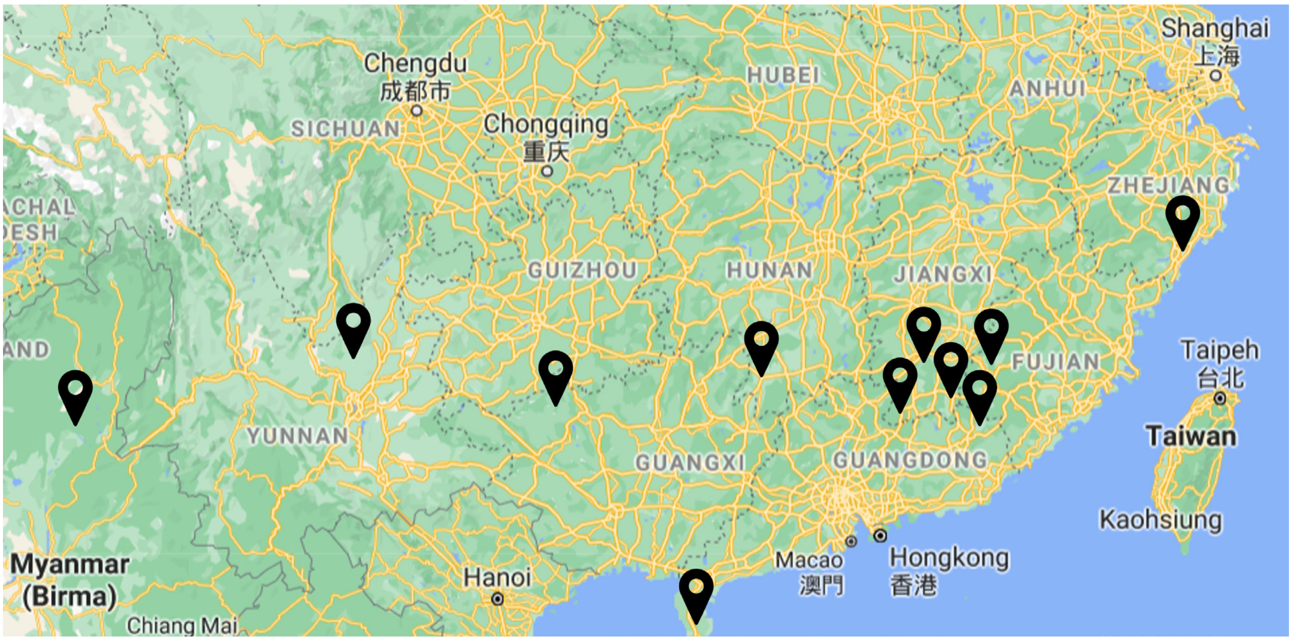

Figure 9 Map of the most important rare earth mining locations in South China (own representation).

Table 5 Electric motors used in electric vehicles (own representation).

Motor Type	Abbreviation	Rare Earths	No Rare Earths
Squirrel Cage Induction Motor	SCIM		X
PM Brushless DC	BLDC	X	
PM Synchronous Machine	PMSM	X	
Switched Reluctance Machine	SRM		X
Wounded Field Flux Switching Machine	WFFSM		X
PM Flux Switching Machine	PMFSM	X	
Synchronous Reluctance Motor	SynRM		X
Ferrite-PM-Assisted synchronous reluctance motor	PMaSynRM	X	

and if rare earths are used or not (Riba et al., 2016; Widmer, Martin, Kimiabeigi, 2015; Cabezuelo et al., 2018).

Motors that do not consist of rare earths use copper and aluminum instead. The most common motor types PM-synchronous motor, asynchronous motor, reluctance motor, and induction motor are illustrated in the figure 10 (Glöser-Chadhoud et al., 2016).

The majority of manufacturers nowadays use the PMSM technology because of its features and high-power density (Cabezuelo et al., 2018). Examples of cars which are using this type of motor are VW ID.3, BMW i3, Nissan Leaf, Volkswagen e-Golf, Mitsubishi i-MiEV, Volkswagen e-UP, Citroën C-Zero, Peugeot iOn, Citroën Berlingo Electric, Ford Focus Electric, Fiat 500e, Bolloré Bluecar, Chevrolet Spark EV, and Kia Soul EV. However, cars based on permanent magnet-free induction motors are more frequently seen in the industry. Ever since Tesla introduced this type of technology with the Tesla S model in 2014, companies like Toyota and Mercedes Benz have used this technology in certain models like the RAV4 or Mercedes-Benz B-Class as well (Riba et al., 2016). In 2020, BMW announced that it will use rare earth free electric motors in its fifth generation of electric vehicles, which became available in 2021 (BMW, 2020).

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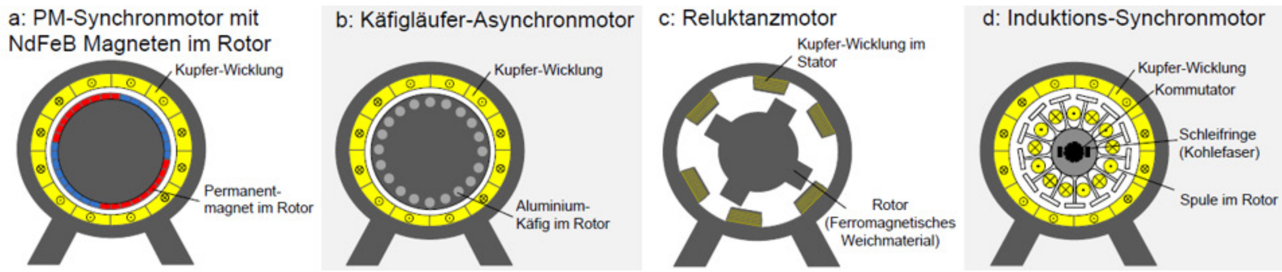

Figure 10 Electric vehicle motor types (Glöser-Chahoud et al., 2016, p.37)

A deeper look at the features of different motor types shows that NdFeB-PMSM motors are still the best option in terms of mechanical power (Riba et al., 2016). However, in terms of efficiency, torque density, or speed, other motor types show similar results (Cabezuelo et al., 2018). Considering costs, rare earth free motors are also cheaper in manufacturing (Widmer, Martin, Kimiabeigi, 2015). It is expected that both motor concepts will be used in the future. The development of motor concepts must be evaluated regularly because the Neodymium and Dysprosium content in motors is indirectly connected to the quantity of mined Gadolinium. Electric vehicles without rare earths could still be an option in the future due to the supply risk and ecological aspects. Not to mention rare earths are coming more into the focus of society and companies could use a free rare earth strategy to convince customers of buying their products. Market outlooks expect that about one third of NdFeB magnet capacities are used in electric vehicles (Arafura Resources, 2020). If rare earth free motors achieve a higher market share, there could be a conflict between higher production capacity and substitution of technology, which could lead to slower increasing prices than expected.

6.3 Estimated Rare Earth Supply until 2030

It is estimated that the global demand for NdPr will increase from 35-45.000 up to 75-98.000 mT by 2030 (MP Materials, 2020b; Arafura Resources, 2020; MP Materials, 2020a). The whole NdPr market is supposed to grow with about 8.0-8.2 % p.a. The biggest driver of this development is the automotive sector with expected growth rates of 16.2-16.5 % p.a. To cover the demand the total rare earths supply must increase to 375-490.000 mT by 2030[3]. A minimum Total Rare Earth Oxide (TREO) supply of 375.000 mT would mean the following capacities for the most important rare earths (see table 6)[4].

For the pharmaceutical industry especially, Gadolinium is of interest. The estimated supply is calculated to be around 2.900 mT by 2030. The next chapters are dealing with Gadolinium applications and estimated growth rates of the Gadolinium market to analyze if the estimated supply covers the estimated demand in the next decade.

6.4 Gadolinium Applications

In 2020 the Gadolinium Oxide demand excl. China was 1455 mT (Statista, 2021a). Assuming that China accounts for 17 % of worldwide BIP and it already has similar demand as industrial states it can be concluded that the worldwide demand for gadolinium oxide in 2020 was about 1600-1800 mT (Statista, 2021b). Compared to a supply of 1.600-1.800 mT the supply and demand of Gadolinium Oxide were in balance[5]. Figure 11 illustrates the major applications of Gadolinium Oxide (Pöttgen, Jüstel, Strassert, 2020; Marscheider-Weidemann et al., 2016).

Gadolinium is used in a variety of industrial applications. The most important ones are magnets, metallurgy, phosphors, and MRI contrast agents. The next chapter analyzes the expected growth rates of the major application fields.

[3]For the calculation a NdPr share of 20 % is assumed.
[4]For the calculation it is assumed that heavy rare-earths are not separated from monazite and bastnasite because of its low content. The share of heavy rare-earths is about 15 % of the total rare-earth capacity. Within the heavy rare-earths the share of Dy is 5.5 %, Gd 5.2 % and Tb 0.9 %.
[5]The calculated supply and demand of gadolinium is based on own assumptions.

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Table 6 The estimated minimum supply of selected rare earths by 2030 (own representation).

Element	Capacity 2030 [mT]
NdPr	75,000
Dy	3,100
Gd	2,900
Tb	500

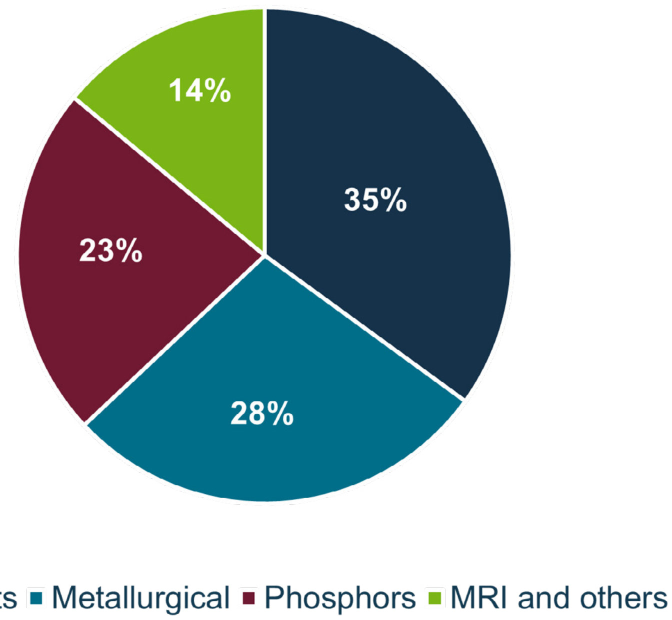

Figure 11 Application fields of Gadolinium Oxide (based on Marscheider-Weidemann et al., 2016, p. 275).

6.4.1 Magnets

Gadolinium compounds can be used as additives in magnets to improve thermal resistance. It is assumed that the total magnets market is growing at 7.0-8.0 % per year. The main drivers are the automotive, energy, and consumer electronics industry (Arafura Resources, 2020; MP Materials, 2020b).

6.4.2 Metallurgy

Gadolinium compounds like Gadolinium Oxide or Gadolinium Nitrate are used in alloys and nuclear technology. Gadolinium used in metallurgical processes could be a big driver in the future because the world has a high demand for energy and construction. Looking at nuclear technology, nuclear technology is still a major energy source in the United States, China, and France. The capacity of nuclear energy plants in 2019 was 392 GW(e). In a low scenario, the nuclear energy capacity is declining to 362 GW(e) and in a high scenario, it is increasing to 715 GW(e) by 2050. In the low scenario, nuclear energy is declining -1.0 % p.a. until 2050. In the highest scenario, the electricity generated by using nuclear energy could double by 2050 with growth rates of about 2.8 % p.a. (IAEA, 2020; IEA, 2020). The different scenarios and the fact that besides Gadolinium Oxide also other compounds both in alloys and nuclear technology can be used makes it difficult to give precise assumptions for the future.

6.4.3 Phosphors

Gadolinium compounds are used in phosphors. The market for phosphors is saturated and is not the biggest driver for Gadolinium demand in the future. 0-2.0 % growth is estimated (Binnemans et al., 2018).

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6.4.4 MRI Technology

Currently, there are three different major MRI contrast agents on the market. Gd-DOTA sold as Dotarem and Clariscan by Guerbet. Gd-DO3A-butrol sold as Gadovist and Gadavist by Bayer and Gd-HP-DO3A sold as ProHance by Bracco (Pöttgen et al., 2020). The global MRI contrast media market is expected to grow by 4 % p.a. (Guerbet, 2020).

6.4.5 Estimated Gadolinium Oxide Demand by 2030

Based on the assumptions in this technology analysis the demand for Gadolinium Oxide is estimated to the future, see figure 12, table 7 and table 8.

The future demand for Gadolinium Oxide should vary between 2.400 mT-2.800 mT by 2030. Based on the market and technology analysis of the main product NdPr, the estimated supply of Gadolinium Oxide, which is coupled to the production of other rare earths, should be a minimum of 2.900 mT. The estimated supply of gadolinium is based on current supply, estimated growth rates, and the rare earth ore composition. The demand for the main product NdPr is growing faster than the demand for the by-product Gadolinium. A supply and demand imbalance should not appear because of technological reasons. Binnemans et al. confirmed this estimation and expect a slight oversupply of Gadolinium Oxide, as well (Binnemans et al., 2018). However, the supply is not significantly higher than the demand and

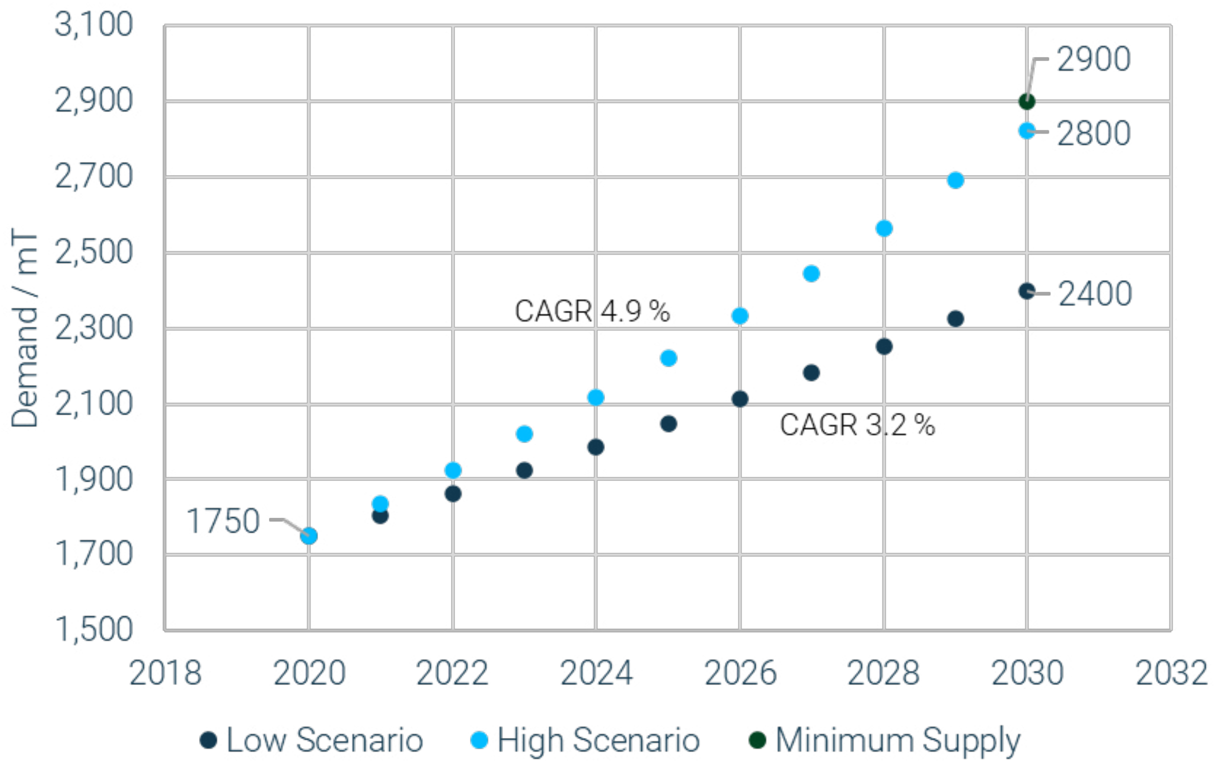

Figure 12 Estimated Supply and Demand of Gadolinium Oxide by 2030.

Table 7 Low scenario of Gadolinium Oxide demand (own representation).

Application	Demand '20 [mT]	%	CAGR	Demand '30 [mT]	%
Magnets	610	35	7.0 %	1200	50
Metallurgy	490	28	-1.0 %	440	18
Phosphors	400	23	0.0 %	400	17
MRI and others	250	14	4.0 %	370	15
Total	**1,750**	**100**	**3.2 %**	**2,410**	**100**

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Table 8 High scenario of Gadolinium Oxide demand (own representation).

Application	Demand '20 [mT]	%	CAGR	Demand '30 [mT]	%
Magnets	610	35	8.0 %	1320	47
Metallurgy	490	28	2.8 %	650	23
Phosphors	400	23	2.0 %	490	17
MRI and others	250	14	4.0 %	370	13
Total	**1,750**	**100**	**4.9 %**	**2,830**	**100**

the balance between supply and demand could turn into an imbalance if parameters like growth rates or mining activities in Southern China change in the future. A supply shortage could appear in the case of force majeure, regulations, or if supplies are suspended by the main producers.

7 Politics and Society

The market and technology analysis from previous chapters have shown that the supply and demand of rare earths will increase in the next few years. However, the market is dominated by only a few players, whereby political decisions can influence the availability of rare earths more than the potential centralization of the mining and separation in a few countries can. Chinese, Myanmarese, and German regulations which could influence the availability and trading with rare earths must be discussed and evaluated.

8 Chinese Regulation

In January 2021 the Chinese Ministry for Industry and Technology Information (MIIT) published a new draft law for the regulation of the Chinese rare earth industry. The publishing of a new draft law was a foreseeable incident because the Chinese government is trying to get more control over the domestic rare earth industry for a longer period. The whole draft law (稀土管理条例) can be read at the website of the MIIT (MIIT, 2021). The most important facts are summarized in this chapter.

The new draft law describes in 29 articles the new regulatory environment of the rare earth industry. The core is about stopping illegal rare earth mining, which is still a major problem in China (Packey, Kingsnorth, 2016). New rare earth projects must pass through an approval procedure and are only allowed to start operating once the approval is confirmed. All approved rare earth projects are forwarded to the State Council, which will publish new rare earth projects regularly (Article 7). According to Article 8, the state can restrict or stop rare earth mining and processing if it harms the ecological environment. The selling and purchasing of illegally mined rare earths will be prohibited and convicted organizations will be fined (Article 11, 20-24). Like in all industries in China, the State Council plays an important role in strategic management decisions. It decides regional economic policies and requirements for the layout of the rare earth industry, and also determines production capacity and production and operation conditions (Article 9). The most important changes for foreign companies will be articles 14-16. According to article 15, the state will control the import and export of rare earth compounds more precisely. This has to do with the aspiration of the Chinese government to increase the strategic reserves of rare earths (Article 16). Furthermore, the industry will establish a tracking information system for rare earth compounds (Article 14). It is expected that through these changes in the law, the illegal mining of rare earths will be more sanctioned in the future which could have an impact on the supply of rare earths from China. Higher prices for rare earths might be one of the consequences. However, through the tracking system, a more transparent tracing can be expected. This would justify higher rare earth prices.

9 Conclusion

A strength of heavy rare earth mining is that it is coupled to the production of NdPr. This joint production is an advantage because the demand for NdPr is increasing steadily. A weakness is a strong dependence on just two countries China and Myanmar which account for almost all heavy rare earth mining activities worldwide. However, there are also

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	Positive	Negative
Internal	Gadolinium by-product of NdPr & Dy mining	Main suppliers are concentrated in Southern China and Myanmar
External	Electromobility China net-importer of rare earths since 2019 Improvement of separation technology	Substitution of PMSM Regulation & Trade War

Figure 13 SWOT-Analysis of heavy rare earth elements (own representation).

some opportunities coming up in the next years. First China became a net importer of rare earths in 2019 which should increase the number of rare earth projects outside of China (Xinhua News, 2019).

Also, the prices for rare earth separation are decreasing continuously which makes rare earth processing more economical. Last but not least, electromobility will boost the demand for rare earths much in the following years and decades. The biggest threat for heavy rare earths is the substitution of PMSM motors. By substituting NdPr through Aluminum and Cooper the mining activities of NdPr will decrease which will automatically influence the supply of heavy rare earth elements Dysprosium, Gadolinium, and Terbium. Because mining is concentrated on just two countries' regulations, trade wars, export restrictions, natural disasters have a strong impact on the availability of heavy rare earths on the market.

The production capacity of light rare earths is driven by electric vehicles and wind turbines. If no substitution with rare earth free motors appears in the market, then the production capacity will increase according to the annual growth rates of Neodymium and Praseodymium. Current market players expect a growth rate of about 8 % which is also incoherence to the annual production plan by Chinese authorities. The MIIT announced a production increase of light rare earths of 7 % in 2020 (MIIT, 2020).

The supply of heavy rare earths could decrease in the future because new laws and regulations should stop illegal mining in Southern China, which is dominated by heavy rare earths Dysprosium, Gadolinium, and Terbium. In the last three years, Myanmar has increased its heavy rare earth mining activities. The capacities developments of heavy rare earths will depend on the development of the mining business in Myanmar and how China will face the issue of illegal mining in Southern China. A possibility of how the supply of heavy rare earths should not decrease is the integration of previously illegal mining into the company structure of the six main manufacturing companies. For that purpose, the companies need to receive a mining license and have to stick to the national regulations.

In conclusion, the joint product analysis showed that the production capacity of Gadolinium Oxide which is used in the pharmaceutical industry is directly influenced by technological developments in the automotive industry. This cross-industry relationship between joint products is frequently seen in the industry and demonstrates that for a complete evaluation of production capacities, the industry of the desired product plus the industry of the main product must be examined.

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Introduction to Innovation Management

Katharina Sophie Zander*

The Influence of Market Orientation on Innovativeness

With a constant demand for new products, shorter product life-cycles, and a rise in global competition, innovativeness and the generation of innovations are imperative for a company's growth and competitiveness in today's market. Market orientation is a concept that leads to better firm performance and competitiveness and has been shown to influence innovativeness. Due to the significance of innovativeness for a company's success, understanding what influences it is quite important. This article first examines the individual concepts of market orientation and innovativeness and then evaluates the depth of the connection between these concepts. The results demonstrate significant overlaps. Also, an expansion of the traditional market orientation concept to include additional stakeholders and sustainability concerns is discussed. A look at current innovative projects of a selected chemical corporation demonstrates, that both the significant influence of market orientation on innovativeness as well as the consideration of sustainability and additional stakeholders can be observed in the chemical industry.

1 Introduction

The seemingly ever faster-moving world is constantly subjected to change. Subjects like global warming, sustainability and fair trade have gained considerable importance. These changes strongly influence the behaviors and wants and needs of the consumers, leading to shorter product life-cycles and high demands for new products, especially products that address the before-mentioned challenges. At the same time, there is more competition and resources are declining (Damanpour and Wischnevsky, 2006). To succeed in the changing market and stay ahead of their competitors, companies need to create innovations (Gopalakrishnan and Damanpour, 1997). This means, that in today's market, being innovative is essential for a company's survival. Therefore, the question of what makes a company innovative or what influences a firm's innovativeness is more important than ever, because innovativeness and performance are closely linked (Wang and Miao, 2015). Over time, several concepts have been developed that are supposed to lead to better performance and competitiveness. One of these concepts is market orientation, which refers to an organization's specific approach to dealing with the market (Kohli and Jaworski, 1990). Customer orientation is one of the components of market orientation, it may even be the most obvious one. Since market orientation is said to lead to better performance (Narver and Slater, 1990), it is argued that it achieves this partly by influencing a company's innovativeness. But how deep is the connection between market orientation and innovativeness?

This article has several goals. The first one is to describe the concept of market orientation and highlight the importance of customer orientation. Then the differentiation between innovativeness and innovation will be discussed, followed by an examination of how deeply the concepts of market orientation and innovativeness are connected, to discover how market orientation influences innovativeness.

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Additionally, a potential expansion of the market orientation concept to include other stakeholders and sustainability concerns will be discussed. Lastly, there will be a very brief look at a chemical company to determine if a connection between market orientation, innovativeness and the resulting innovations can be observed in current innovative projects.

2 The concept of market orientation

To understand how market orientation influences innovativeness, it is important to first clarify what exactly market orientation is. Even though the concept of market orientation was most closely defined in the 1990s, these definitions are still used in the more recent literature (e.g. Kamboj and Rahman, 2017; Wang and Miao, 2015) and as such can still be considered as the current state of the art.

2.1 General definition of market orientation

The most frequently used definition is, that "market orientation refers to the organizationwide generation, dissemination, and responisiveness to market intelligence" (Kohli and Jaworski, 1990, p. 3) and that "effective market intelligence pertains not just to current needs, but to future needs as well" (Kohli and Jaworski, 1990, p. 4). The gathered intelligence is more than just the verbalized needs or preferences of the customers. It also includes analyzing a myriad of factors that influence changes in customer behavior, such as examining exogenous factors (e.g. government regulations), changing conditions in the customers' industry or actions undertaken by the competition. Both current and future needs and preferences of the customers are considered, with the understanding that the development of future products can take years. Since the gathering of market intelligence takes plake across the entire organization, it is necessary for the different departments to exchange information. (Kohli and Jaworski, 1990).

Bearing the already mentioned facets in mind, market orientation is composed of the three behavioral components customer orientation, competitor orientation and interfunctional coordination as well as the two decision criteria profitability and long-term focus (Narver and Slater, 1990). A market-oriented organization stands out compared to non-market orientated organizations in its "superior market sensing, customer linking and channel bonding capabilities" (Day, 1994, p. 41). This enables the organization to sense market trends earlier than their competitors giving it both the opportunity to react quickly and accurately to the coming changes as well as being able to predict what the competition might do next.

2.2 Customer orientation as part of market orientation

As already mentioned, customer orientation is one of the three main behavioral components of market orientation and it might be the most obvious one. After all, "the customer is king" is a well-known concept. Customer orientation encompasses actions with the intention of collecting customer information as well as distributing it throughout the organization. The purpose of customer orientation is to continuously produce superior value for the customer. To achieve this goal it is necessary to not only understand the current and future needs of the intended customer but also the customer's entire value chain as well as the customer's customers, for these are factors that influence the customer's needs (Narver and Slater, 1990).

Another aspect of customer orientation is the capability of "customer linkage". This refers to the abilities and processes that are necessary for the establishment of customer relationships with the purpose of faster determining individual customer needs and therefore potentially creating long-term customer value (Day, 1994).

3 The concepts of innovation and innovativeness

The terms "innovation" and "innovativeness" are sometimes used interchangeably but efforts have been made to differentiate between them. The following sections describe the differences between these two terms, showing clearly that though they are closely related, innovation and innovativeness are distinguishable from each other.

3.1 Innovation

Innovation is the development and implementation of new ideas (Salavou, 2004). To grow and keep up with competitors an organization must implement innovations. This can be

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done through innovation generation or innovation adoption. An organization's ability to generate its own innovations is dependent on the organization's market capabilities and technological knowledge, whereas the adoption of innovations refers to the assimilation of an innovation, that was created elsewhere and is new to the adopting organization (Damanpour and Wischnevsky, 2006).

The most commonly used dimensions of innovations have been summarized as being technological innovations, which consist of new products, technologies, or services and administrative/managerial innovations, which include new policies or procedures or changes in the organizational form. A combination of these two dimensions can lead to higher competitiveness of the organization (Mohd Zawawi et al., 2016).

Another way to classify innovations is by their level of newness, making them either radical or incremental. They also differ in their uncertainty. Incremental innovation refers to an innovation that builds on something that is already known, making it less risky than a radical innovation, which can be something that is previously unknown. Also important to consider is the level at which the innovation takes place. A challenge in the innovation process can be to ensure, that an innovation that takes place at a "component level", meaning only a part of an established product is replaced, still functions in the overall system. And when innovation takes place at a higher level in the system, it might become necessary for a firm to change its already established processes and channels to sufficiently support this innovation (Tidd and Bessant, 2021).

In the following chapter, it will become clear, that innovations are a consequence of innovativeness.

3.2 Innovativeness

Innovativeness is a precursor for innovations. Innovativeness is a cultural aspect of an organization and refers to the organization's openness to new ideas. It can be used to measure the organization's inclination towards innovation (Hurley and Hult, 1998). Several dimensions have been formulated and validated for innovativeness, namely "creativity", "openness", "future orientation", "risk-taking" and "proactiveness" (Ruvio et al., 2014). In addition to that, a multitude of cultural characteristics, such as "market focus", "learning and development" and "communication" have been established (Hurley and Hult, 1998). All these characteristics are indicators for an organization's innovativeness and it was found that innovative firms showed a long-term high level of innovativeness (Salavou, 2004).

As mentioned before, innovations can be seen as a result of innovativeness. Therefore, innovativeness is a desirable aspect of the organization's culture, as it is expected to lead to a higher number of innovations, making it a key factor in supporting a company's continuous growth (Salavou, 2004).

4 Market orientation and innovativeness

The previous chapters discussed market orientation, innovativeness and innovation as individual concepts. The following chapter will demonstrate, how these concepts are connected.

4.1 Connecting market orientation and innovativeness

Having ascertained what market orientation, innovativeness and innovation are, the next step is to find the connection between these concepts. As it has been established, that innovativeness is a precursor to innovation, making innovation the product of innovativeness (Mohd Zawawi et al., 2016), the link between these terms is clear. Now the goal is to determine how market orientation influences innovativeness.

Seeing as innovations are made for the market, it is obvious that there must be a connection between these concepts and several aspects of the relationship between market orientation and innovativeness have been studied. One example is that market orientation seems to influence the balance of radical and incremental innovations (Baker and Sinkula, 2007). A different study found that innovativeness could be enhanced through market orientation (Kirca et al., 2005) and a meta-analysis showed market orientation as having a strong positive effect on the success of new product innovations (Evanschitzky et al., 2012). These studies confirm the correlation between market orientation and innovation. However, previous literature seems to be lacking a direct comparison of the concepts. So to better

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understand the depth of this correlation, a comparison of the already established characteristics and aspects of both market orientation and innovativeness can be made to determine the intersections between these concepts. Figure 1 depicts a selection of these aspects and characteristics that have either been directly mentioned or can be discerned from several sources, grouped in a way that illustrates their connection.

4.1.1 Keeping the market in mind

The first two characteristics of innovativeness to discuss are "market intelligence" and "market focus" (Hurley and Hult, 1998). These characteristics show the most obvious connection to market orientation, considering there is even the word "market" in their name. And market orientation is centered on market intelligence and market focus, so the first correlation between market orientation and innovativeness can easily be seen in these characteristics. As to why these characteristics play an important role in innovativeness, as mentioned before, the market is who innovations are made for, so naturally, a focus on the requirements and changes of the market is necessary for the development of successful innovations. And so, a focus on these aspects influences the innovativeness of an organization.

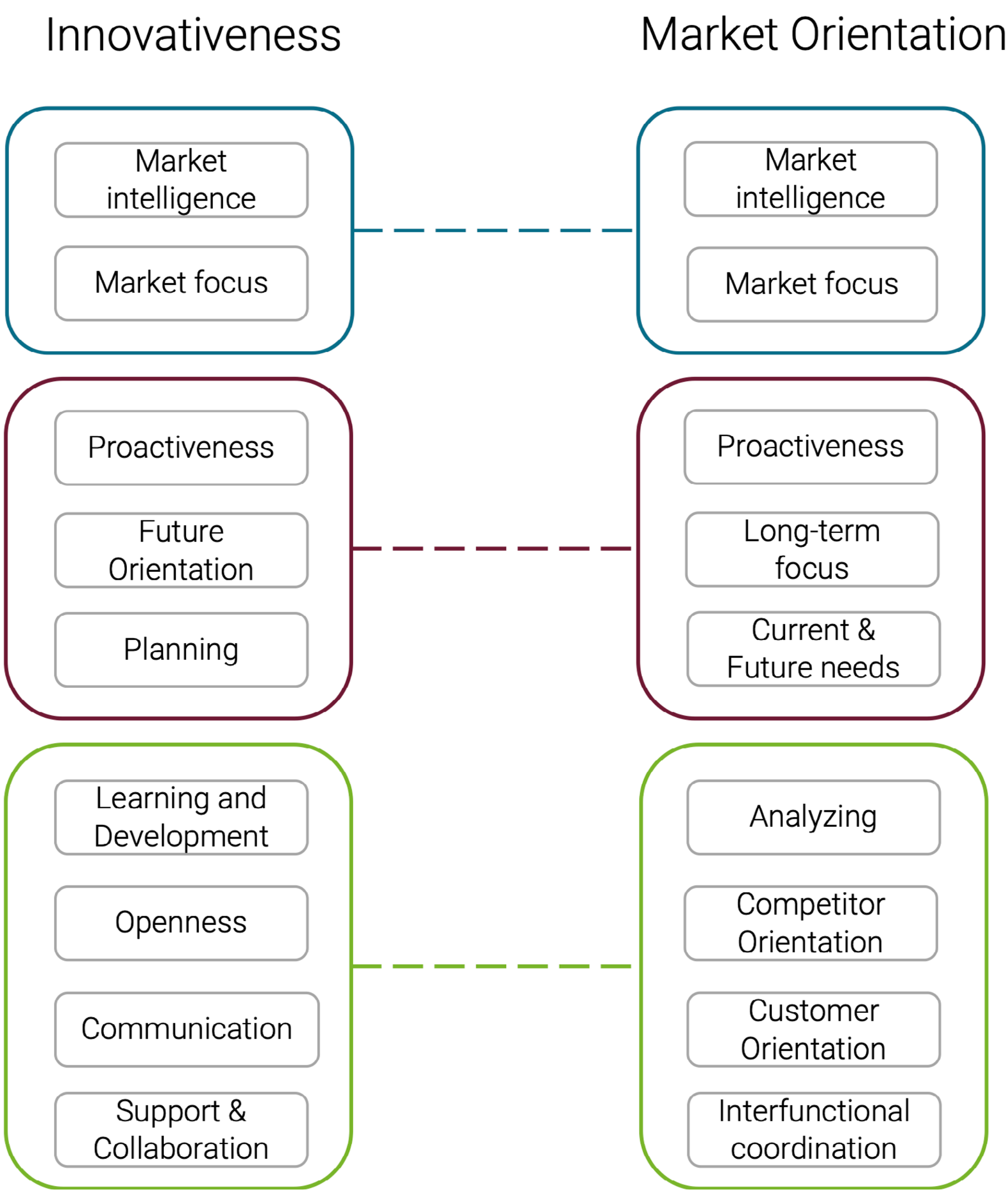

Figure 1: Aspects of market orientation and innovativeness as found in different literature sources (Atuahene-Gima et al., 2005; Hurley and Hult, 1998; Kohli and Jaworski, 1990; Narver and Slater, 1990; Ruvio et al., 2014).

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4.1.2 Considering the future

The next characteristics to look at on the innovativeness side are "planning" (Hurley and Hult, 1998), "proactiveness" and "future orientation" (Ruvio et al., 2014). On the market orientation side, there is also "proactiveness" (Atuahene-Gima et al., 2005) as well as "long-term focus" and "current and future needs" (Kohli and Jaworski, 1990). The reason these aspects have been grouped is that they all have a connection to the future. To be proactive is to consider opportunities, be they related to current products or not and to take the initiative to act on possible future needs (Ruvio et al., 2014). Therefore, proactiveness is closely connected to the aspects of "future orientation" and "planning". To be proactive, one needs to consider what could happen in the future and plan accordingly. This is a very important aspect of innovativeness, especially because it can take several years to develop an innovation (Kohli and Jaworski, 1990). Additionally, product life-cycles are getting shorter, meaning the time between the launch of a product or service and the need for new products or services and therefore innovations is also getting shorter. As a result, companies require an increase in innovativeness. Because it can take a long time to develop an innovation, companies must plan ahead of time and try to estimate what consumers might want in the future, ensuring the company has enough time for the innovation process. This already shows the correlation between the concepts of market orientation and innovativeness because market orientation is future-oriented too and considers both current and future customer wants and needs. These wants and needs are some of the main things that drive the innovativeness of an organization.

4.1.3 Finding inspiration

The last group has the aspects "openness" (Ruvio et al., 2014), "learning and development", "support and collaboration", and "communication" on the innovativeness side (Hurley and Hult, 1998). On the market orientation side, there is "analyzing" (Kohli and Jaworski, 1990), "customer orientation", "competitor orientation" and "interfunctional coordination" (Narver and Slater, 1990). At first glance, it might seem that these characteristics do not have much in common. However, if looked at more closely, one could say that the overall theme in this group is "inspiration". For companies to be innovative, they need to have a certain level of openness. Because only if they are open to new ideas and inputs can they be innovative (Ruvio et al., 2014). They need the ability to learn (Hurley and Hult, 1998), both from the consumers' wants, this being the link to customer orientation, and from the way their competitors' act. Competitor orientation is also an important aspect of market orientation because to keep up with the competition it is important to understand what it is that they do, learn from that and channel it into the company's innovativeness. This is also where one can find the connection to the aspect "analyzing", since both customer and competitor behaviors and exogenous factors that might influence them should be analyzed if companies want to learn from them (Kohli and Jaworski, 1990).

The aspects "support and collaboration" and "communication" are most closely linked to the market orientation characteristic "interfunctional coordination". Inspiration for innovations does not just come through customer and competitor observations. They also come through communication with other people and other departments which is why "openness" is such an important aspect of innovativeness. To get inspired and to come up with new ideas, one needs to be open and accepting of different and new things. This could be a different opinion of a co-worker. Because every person is different, has different ideas, perhaps grew up in a different culture or made different experiences from one's own, they might come up with or see things that another person does not. Exchanging opinions and experiences can lead to new innovative ideas. The market orientation concept of "interfunctional coordination" is about a business coordinating the market intelligence gathering and evaluation intra-departmental, so that all departments are included in the process and the information is looked at from different viewpoints (Narver and Slater, 1990). This aspect reflects the aspects of "support and collaboration" as well as "communication", showing a correlation between market orientation and innovativeness.

4.1.4 Discussion of the comparison results

Having now compared characteristics that make a business innovative with those that pertain to market orientation, it is clear that these concepts show large overlaps in their characteristics. Many aspects that make a company market-orientated help with a company's innovativeness. Because the characteristics are so closely connected or sometimes even identical, businesses that are market-

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orientated have an advantage at being innovative, since they already fulfill many criteria for being innovative and already work with the information that can lead to innovativeness. One could even question whether these concepts are truly distinguishable concepts at all. Because of the extensive overlap, it is debatable, whether a company can truly be innovative in the long term if it is not market-oriented. So perhaps innovativeness could be considered a goal or positive consequences of market orientation, instead of a separate concept.

The significant overlap of the concepts also reaffirms the importance of market orientation to a company's success and shows, that careful and continuous monitoring of the market conditions, as well as the analysis and estimation of future changes, are some of the most important aspects of the innovation process, especially in a time where the market is constantly changing. However, it is also important to note, that market orientation alone and especially the thus far used traditional definition of market orientation is not enough to ensure a firm's success. One of its weak points is that it focuses so largely on the consumers who, while important, are not the only players on the market. Other concepts and factors could and should also be considered. Some of these potential supplemental concepts are discussed in the following chapter.

4.2 Expanding the market orientation concept

While the traditional market orientation concept focuses mainly on customers and competitors, this might be to narrow a view for contemporary businesses. To the end of expanding the market orientation viewpoint, more recent literature has suggested two additional concepts, stakeholder orientation and sustainability orientation.

4.2.1 The concept of stakeholder orientation

Stakeholder orientation has been defined as the "organizational culture and behaviors that induce organizational members to be continuously aware of and proactively act on a variety of stakeholder issues" (Ferrell et al., 2010, p. 93). In 1984 stakeholders were defined as "any group or individual who can affect or is affected by the achievement of the organization's objectives" (Freeman, 1984, p. 46). While stakeholder orientation recognizes customers and competitors as important stakeholders, it is not limited to them. Suppliers, employees, regulators, shareholders and local communities are some of the additional stakeholders that hold importance within this concept (Greenley and Foxall, 1997). Stakeholders are part of an interconnected relationship network (Rowley, 1997), with every stakeholder having their interests and issues. These issues range from the environmental impact of products to the transparency of company records. The natural environment has also been suggested as an additional stakeholder, and considering the ongoing climate change, this stakeholder is bound to gain further attention (Haigh and Griffiths, 2009). The different stakeholder interests may not necessarily all align, resulting in a higher coordination effort for the firm. The goal of stakeholder orientation is the long-term welfare of all stakeholders. To that end, stakeholder-oriented firms gather information about stakeholder issues to successfully address them. Overlaps between market orientation and shareholder orientation have been demonstrated, but mostly they are still considered separate concepts (Ferrell et al., 2010). However, some research also suggests, that the market orientation concept has already widened to include additional stakeholders in the overall concept of market orientation (Wilburn Green et al., 2015).

4.2.2 The concept of sustainability orientation

As climate change and sustainability become some of the predominant global challenges, the concept of sustainability orientation becomes more important for today's businesses, as well as governments. The goal of this concept is to balance current and future concerns that deal with social, ecological and economical needs (Sayem, 2012). An orientation towards sustainability is especially necessary, if the business acknowledges the natural environment as one of its stakeholders (Haigh and Griffiths, 2009). The concept also goes hand in hand with the increasing customer demand for ecological and sustainable products and production processes (Han et al., 2009), demonstrating the connection to a company's market orientation that leads to the businesses' awareness of customer wishes (Wilburn Green et al., 2015). Since sustainability orientation shows considerable overlaps with market orientation or is a result of market orientation, previous research has suggested the inclusion of sustainability aspects in the market orientation concept (Hult, 2011). Sustainability orientation has also been shown to influence a firm's innovativeness, another linkage to market orientation (Sayem, 2012).

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4.2.3 Aggregation of the different concepts

As mentioned before, previous research has suggested the combination of the market orientation, stakeholder and sustainability concepts, sometimes known as "market orientation plus" (Crittenden et al., 2011; Hult, 2011; Wilburn Green et al., 2015). The fact that all these concepts impact a firm's innovativeness has also been shown in studies (e.g. Flammer and Kacperczyk, 2016; Sayem, 2012). One of the main points is the stated necessity to include additional stakeholders to the traditional customer and competitor (Hult, 2011), while still acknowledging customers as a main stakeholder.

Building on this research, this article illustrates a theoretical aggregated market orientation concept that combines the traditional market orientation concept with stakeholder orientation and sustainability orientation (Figure 2). In terms of this illustration, innovativeness is not seen as a separate concept but rather a consequence or shared goal of the different orientations. This is due to the before shown large overlap of the innovativeness and market orientation concepts.

It can also be argued that stakeholder orientation and sustainability orientation could already be included in traditional market orientation anyway, by widening the "customer" definition. If a customer is no longer just a firm's buyer but rather an entity that makes demands of the firm, then a larger group of stakeholders would automatically fall within this customer definition. The traditional customer demands products, the natural environment demands more ecological products and processes, governments demand the upholding of its laws and so on. And sustainability is

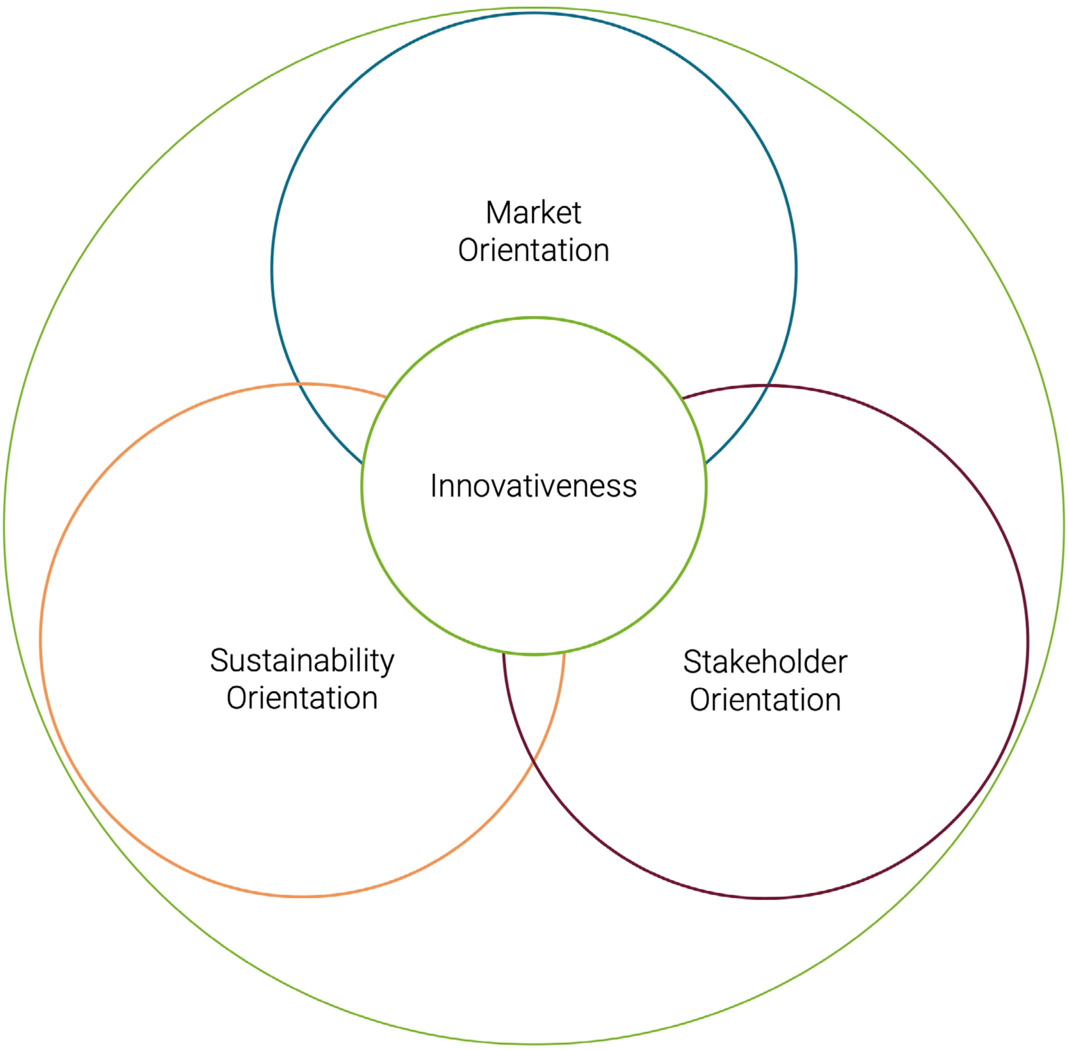

Figure 2: Aggregation of the concepts of market orientation, sustainability orientation and stakeholder orientation. Innovativeness is an expected goal of these concepts. Based on previous work by Hult (2011) and Sayem (2012).

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largely reflected in these demands. So perhaps, when taking this customer viewpoint, the traditional market orientation concept would already encompass these different orientations and through this influence a company's innovativeness.

4.3 Can the influence of market orientation on innovativeness and innovations be observed in the chemical industry?

Having analyzed the influence of market orientation on innovativeness as well as discussed the possible expansion of the traditional market orientation concept, the final part of this article takes a closer look at the BASF corporation to discover, if a connection between market orientation and innovativeness or the resulting innovations can be observed there.

The BASF corporation made a revenue of 59,149 million euros in the year 2020 and has 110,302 employees. As such, it is the world's largest chemical company (BASF, 2021a).
The first step is to examine, whether BASF is market-oriented. They say that their customers are their priority and consider their needs seriously when planning their corporate strategy (BASF, 2021c). This allows the conclusion that BASF is customer-oriented and customer orientation is one of the main factors of market orientation. In addition to that, BASF is improving its organizational structure to increase its ability to address specific market requirements. Among other things, they have created interdisciplinary teams to better attend to customer needs (BASF, 2021b). Understanding and addressing market requirements and coordinating across different departments are also aspects of market orientation. Considering this, it seems that the BASF corporation is a market-oriented organization.

As discussed before, market orientation can influence the company's innovativeness and the resulting innovations. Therefore, the next step is to examine the innovativeness of the BASF corporation. In the year 2020, BASF developed a total of 950 new patents worldwide with about 10,000 employees working in research and development. For the purpose of this article, these factors will be considered indicators for innovativeness. Recognizing that their employees are a key factor for success, BASF tries to build a working environment that supports them in achieving their goals. BASF considers itself the "innovation leader" in the chemical industry. In addition to that, two of their main values are "creativity" and "openness" (BASF, 2021e). As already discussed in a previous chapter, these are aspects that are important for innovativeness (Ruvio et al., 2014), allowing the conclusion, that innovativeness is an important aspect of the BASF corporation.

The final part of this chapter is to take a look at two current innovative projects of BASF with the intent to determine if a connection to market orientation can be ascertained.

The first project to discuss falls in the category of technological innovation. It pertains to the development of products for the sustainable cleaning process for recycling plastic waste (Chemetall, 2021). Over the past 70 years, there was a sharp increase in plastic production (Chemetall, 2021), but today, sustainability and environmental consciousness are becoming bigger and more important demands on the market. Customers are more aware of the repercussions of plastic waste, so they desire more ecologically friendly alternatives. One possibility is the use of recyclable products. The project to create products to help with the recycling process shows, that BASF is aware of this consumer trend, meaning they analyzed the changes in the market and customer behavior, which are all aspects of market orientation. The obtained information then influenced the company's innovativeness and resulted in the mentioned innovation project. This shows that market orientation influenced innovativeness. Additionally, this product also addresses sustainability aspects, and it can be argued, that additional stakeholders, like the natural environment and potentially governments, profit from this project.

The second project is a joint project between BASF, SABIC, and Linde and the goal is to develop the world's first steam cracker furnace that is electrically heated. This can be categorized as administrative/managerial innovation, as it concerns the process of production in the petrochemical division (BASF, 2021d). The project also follows the market's demand for sustainability, the focus being on the reduction of CO_2 emissions. In recent years, customers have also started to take a closer look at how the products they buy are produced, with fair trade and organic products gaining popularity. The electrically-heated steam cracker furnace would still be able to produce the same products, so the products would stay the same, just as an organic banana is still a banana. However, the production process would change significantly resulting in a potential reduction of CO_2

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emission by 90% (BASF, 2021d). This project also shows a clear future orientation and long-term focus, aspects that, as already discussed, connect market orientation and innovativeness. In addition, this is a joined project between competitors, showing that BASF analyzed who is researching in the same field and decided to cooperate with them, so that they can potentially learn from one another. This can be seen as one of the aspects of competitor orientation. Here it is demonstrated, that this innovation project was also influenced by the company's market orientation and as with the first example, sustainability and other stakeholders also play a role.

Market orientation and market demand are an inspirational source for the innovativeness of the firm and as the examples above show, in the case of the BASF corporation, the influence of market orientation on innovativeness and the resulting innovations can be seen.

5 Conclusion and Outlook

This article has discussed market orientation, innovativeness, and innovation. Market orientation refers to an organization's dealing with market intelligence (Kohli and Jaworski, 1990), with customer orientation being one of its main components (Narver and Slater, 1990). Innovativeness is an aspect of the organization's culture that leads to innovations, innovations being most often classified as technological innovation or administrative/managerial innovations (Mohd Zawawi et al., 2016).

The depth of the overlap between the market orientation concept and innovativeness was analyzed by comparing certain aspects of the individual concepts. It was found that market orientation and innovativeness have an extensive overlap in their characteristics, which can explain their influence on each other. A widening of the market orientation to include sustainability and additional stakeholders was also discussed and look at the BASF corporation served as an example to show, that the influence of market orientation on innovativeness and innovations, as well as sustainability and additional stakeholder considerations, can be found in the chemical industry.

It is clear, that market orientation and innovativeness are closely linked to one another. Both concepts are fundamental parts of the organizational culture. Considering exactly how close these concepts are linked, perhaps it should be further examined, whether they are truly separate concepts or if one is the antecedent and the other the resulting consequence. The question of whether a business that is not market-oriented can be innovative at all, especially in the long-term perspective, should also be discussed further. Lastly, expansions to the traditional market orientation model and the question, if sustainability orientation and stakeholder orientation could not already be included in the traditional market orientation concept simply by widening the customer definition, are also interesting subjects to consider in the future.

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Commentary

Anna Holthaus, Dr. Minu Hemmati*

Gender - an essential substance for sustainable chemistry

Introduction

In July last year we, the *MSP Institute – Multi-Stakeholder Processes for Sustainable Development*, invited various stakeholders to discuss how to shape chemicals management in Germany in a gender-responsive way and were surprised by the interest of many industry stakeholders, especially small and medium sized enterprises, in the topic. Ranging from large chemical companies celebrating pride month to quite specific discussions on gender-sensitive language in chemistry journals, the chemical sector seems to be searching for its own interconnections to gender and how to deal with them. To support this development, this commentary provides an overview of the gender dimensions and inequalities in chemistry and offers initial ideas for the implementation of gender mainstreaming as an integral part of management for sustainable chemistry and beyond.

Gender Dimension in Chemistry

The interconnections between gender and chemicals are complex and multi-dimensional. In summary, the following key dimensions justify serious consideration of gender within the world of chemistry (see Hemmati and Bach, 2017):

a. Biological dimension: Women's and men's bodies are affected differently by certain chemicals – risk and impacts can be different between the sexes. Women, for example, tend to store more environmental pollutants in their body tissues than men due to a higher body fat content. In addition to puberty, women live through other phases of life such as pregnancy, breastfeeding and menopause, during which their bodies become more susceptible to health damages from chemicals due to the significant physiological changes. Furthermore, chemical exposure can also be passed on to the next generation (UNDP, 2011; IPEN and SAICM, 2020). Consequently, non-employability for health protection reasons during pregnancy and breastfeeding is a common dilemma for women in the chemical sector. On the other hand, men are particularly susceptible to chemicals in other ways: researchers regard hormonal chemicals and pollutants as a possible cause of the global increase in testicular cancer and the massive loss of male sperm count in industrialized countries (Levine et al., 2017).

b. Social dimension: Gender is also linked to gender-specific norms of behaviour, roles in society as well as the development of 'feminine' and 'masculine' identities, which in turn influence people's behaviour, including their impact on the environment, the levels to which they are affected by their access to and power over resources: Due to the division of labour between the sexes, men and women are often affected by different chemicals. For example, men are more likely to work in construction and thus come into contact with chemicals from building materials, while women are more likely to work in the care sector with cleaning agents and cosmetics or care products. Additionally, the division of labour also causes differences in exposure within individual sectors: For example, women in agricultural are more affected by indirect exposure, e.g. from harvesting and handling chemically-treated plants or contaminated clothing, while men are often more directly exposed, e.g. when mixing chemicals. Women are also more severely affected by indoor pollution, e.g. from the burning of household fuels or chemical pollution from furniture, especially in poor population groups (UNDP, 2011; ILO, 2021).

c. Transformative dimension: However, the gender perspective enables us to understand and unpack root causes of unsustainable behaviour, and helps us to find new solutions for sustainable chemistry. Gender

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analysis can be used, for example, to find out why protective measures are repeatedly disregarded when dealing with toxic chemicals: Women, especially those from developing countries, are less likely to be able to afford appropriately-fitting protective clothing than their male colleagues (if it is available at all) (OWD, 2006). Men, on the other hand, often believe that wearing protective clothing is unnecessary and indicates a level of weakness, and tend to use risky behaviour and dangerous practices in order to improve their status in a group (Andrade-Rivas and Rother, 2015).

Gender Inequalities in Chemistry

Even though these gender dimensions cause inequalities that have negative impacts on human health and the environment and a gender perspective might reveal better solutions, specific and widespread knowledge on gendered ways of exposure and differentiated and long-term effects of chemicals on women and men as well as comprehensive consideration of gender in the chemicals management is still lacking in politics, sciences and industry. Consequently, the chemistry sector is mostly gender blind (see also MSP Institute, 2021):

For example, in chemical science and product development, there are huge research gaps on gender and its interlinkages in toxicology and risk assessments. Biological differences do not find sufficient consideration, the white male body still being used as the general prototype (IPEN and SAICM, 2020).

The field of occupational safety and health is strongly marked by social gender differences. Men tend to work in high-risk industries and suffer from more short-term but acute exposure with significant health or even fatal consequences. On the contrary, typical "women's jobs" mean more indirect and long-term exposure, which is presumed to be less hazardous and often receives less attention in terms of protection measures. Consequently, women's occupational diseases are under-diagnosed, under-reported and under-compensated (ILO, 2021).

In chemicals management, women are underrepresented at all levels of political and industry leadership. Women's concerns, capacities and capacity gaps, as well as proposals are often overlooked in project design and implementation activities. The same applies to innovations and opportunities for being agents of change: women's specific experiences, expertise and feminist perspectives are often not acknowledged, structural barriers and less funding for women's businesses and start-ups continue to be the norm, and due to the masculine image of chemistry, women and girls still face discrimination in the discipline (Royal Society of Chemistry, 2018; ISC_3, 2020).

Gender and Sustainable Chemistry

In order to use chemistry as an important driver towards sustainable development, holistic approaches are needed, which consider the economic, environmental and social dimensions of sustainability, including gender (ISC_3, 2021; Hemmati and Bach, 2017). One essential aspect of strengthening decision-making and actions related to chemicals is gender mainstreaming. Gender mainstreaming is the internationally agreed strategy for implementing Sustainable Development Goal (SDG) 5: gender equality (UN Women, 2020). Additionally, gender mainstreaming is a cross-cutting task for the whole of society, and hence reflected in several other SDGs in the 2030 Agenda for Sustainable Development (UN Women, 2018), a fact that underlines further that we need sustainable chemistry and gender mainstreaming in order to achieve sustainable development. Furthermore, due to the aforementioned interconnections of gender and chemicals, we conclude that there is no sustainable chemistry without gender equality and no gender equality without sustainable chemistry.

But what would a gender-just and sustainable chemistry look like? Three criteria seem important:

1. no gender suffers from toxic chemicals nor from structural inequalities in chemicals production, chemicals use, or chemicals policy;
2. all gender are seen as agents of change and can take leadership roles in the chemistry sector; and
3. all gender benefit equally from sustainable chemistry.

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Gender and Sustainability Management

How can industry realize such a vision of a gender-just and sustainable chemistry?

Gender experts differentiate between various forms of gender integration into project management: 1) individual gender-activities, mostly with a focus on empowering women and girls; 2) gender-sensitive project management that takes gender roles and the diverse needs of all gender into account so that projects contribute to gender equality in their respective project thematic contexts; and 3) gender-responsive project management by which the project aims to change structures of gender inequality in our societies and to transform gender relations.

This differentiation is similar to the differentiation of sustainability management: 1) Corporate Citizenship stands for individual, additive and external measures mainly with the focus on a single issue; 2) Corporate Social Responsibility describes internal and external measures accompanying the core business and focusing primary on transparent communication and social benefits for employees; and 3) Corporate Sustainability includes the sustainable design of the core business, a rethinking of the business strategy and contribution to structural changes in economy and society (Schaltegger, 2011).

By combining both approaches we can identify strategies for integrating gender in sustainably management (see figure 1): 1) individual gender activities can be described as a part of Corporate Citizenship and focus mostly on external actions for the empowerment of women and girls independent from core business, e.g. the sponsoring of a women's charity run; 2) gender-sensitive management can be part of the Corporate Social Responsibility approach and describes internal and external measures regarding gender with a focus on human resources development and gender-sensitive communication, e.g. the use of gender-sensitive language and women's quota for leadership positions and a considerate handling of the dilemma of health protection and employability of pregnant and breast-feeding women; and 3) gender-responsive management might be part of Corporate Sustainability and describes the approach of

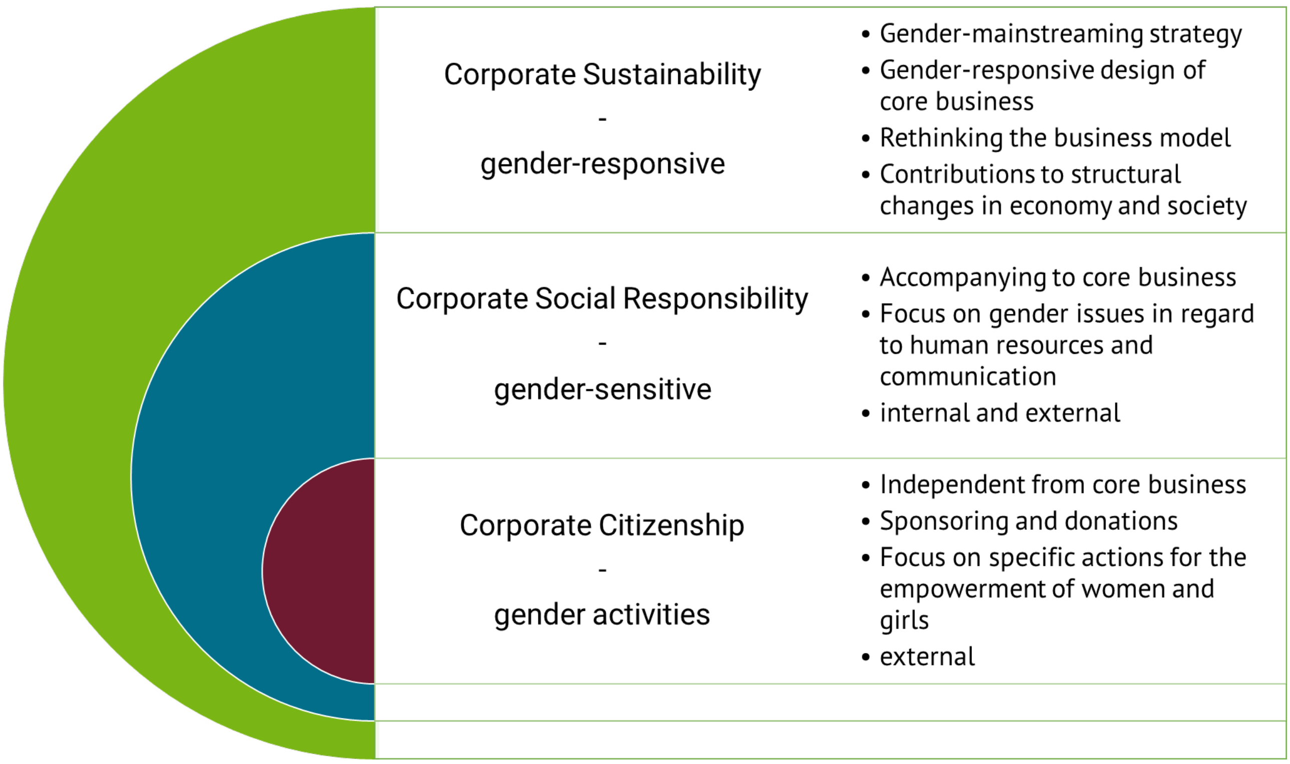

Figure 1: The Integration of Gender and Sustainability Management Approaches (own representation based on Schaltegger, 2011).

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developing a gender-mainstreaming strategy that includes the gender-responsive design of the core business as well as contributions to structural changes in economy and society for gender equality, e.g. the collecting and open access publishing of gender-disaggregated health data for the support of gender medicine.

Gender-responsive Management for Sustainable Chemistry

The Corporate Citizenship approach and gender activities independent from core business are not used widely (anymore) in the chemicals industry as they might pose a reputational risk for the chemicals industry. In fact, the term "pinkwashing" originates from criticism against US cosmetic and pharmaceutical companies that advertised their products with pink ribbons, the symbol of commitment against breast cancer, even though others among their products were suspected of causing cancer (Selleck, 2010). Instead, the approach of gender-sensitive management and Corporate Social Responsibility seems to be used more widely: chemical companies set themselves higher targets for the proportion of women in leadership positions, support flexible working conditions and internal LGBTQI+ staff networks or use gender-sensitive language and the hashtag #chemequality.

In our view, these are initial, and promising steps towards gender equality, but they are not enough: a recent study on equal opportunities for women and men by the Association of Executives in the German Chemical Industry (VAA) shows that only 44 per cent of all respondents experience equal opportunities as part of their company's philosophy, and there are significantly different gender perspectives: only 28 per cent of the women stated this, compared to 51 per cent of the men (VAA, 2020). In addition, the issue of gender equality is increasingly important for young professionals (e.g. the jungchemikerforum in Germany was hosting a series of online diversity talks focussing among others on women in chemistry and LGBTQ* support & gender consulting in Nov 2021) and, as part of social sustainability, the issue could become more important as a selection criterion when choosing an employer.

Therefore, gender-responsive management seems essential and promising for sustainable chemistry, but what might that look like? From our perspective, **gender-responsive management for sustainable chemistry** means that the three key criteria of a gender-just and sustainable chemistry mentioned above are mainstreamed into all of the company structures and processes, taking into account all internal and external stakeholders: employees, the planet and society as well as customers, owners and partners (see figure 2):

For employees, gender-responsive management might mean that there is gender-balance in the workforce, flexible working arrangements and transparent and equal pay. Additionally, regular gender and diversity training are offered, the company has strict non-discrimination policies and strives for a gender-sensitive communication culture and gender-sensitive occupation safety measures.

Gender-responsive management for sustainable chemistry might also contribute to the health of our planet and society with strong company commitments to human rights, gender equality and diversity, the use of gender-sensitive language in external communication and no use of gender stereotypes. The support of women in STEM and legal frameworks, policy processes and initiatives for sustainability and equality might be additional contributions to structural changes in economy and society.

As said before, gender considerations regarding employees and/or the planet or society are already in the focus of gender-sensitive management. Gender-responsive management would go beyond that and also consider gender issues regarding costumers, owners and partners:

For costumers, gender-responsive management might mean that a company uses gender-sensitive marketing strategies, is aware of and responding to gender-differences in consumer behaviour and product use as well as gender differences in potential health impacts of the products, and collects and publishes gender-disaggregated consumer and health data.

For business owners and partners, gender-responsive management for sustainable chemistry might mean that ownership and profit is gender-balanced, investments in sustainability and gender mainstreaming strategies are the norm, and that human rights and gender equality are being standardized in the supply chain.

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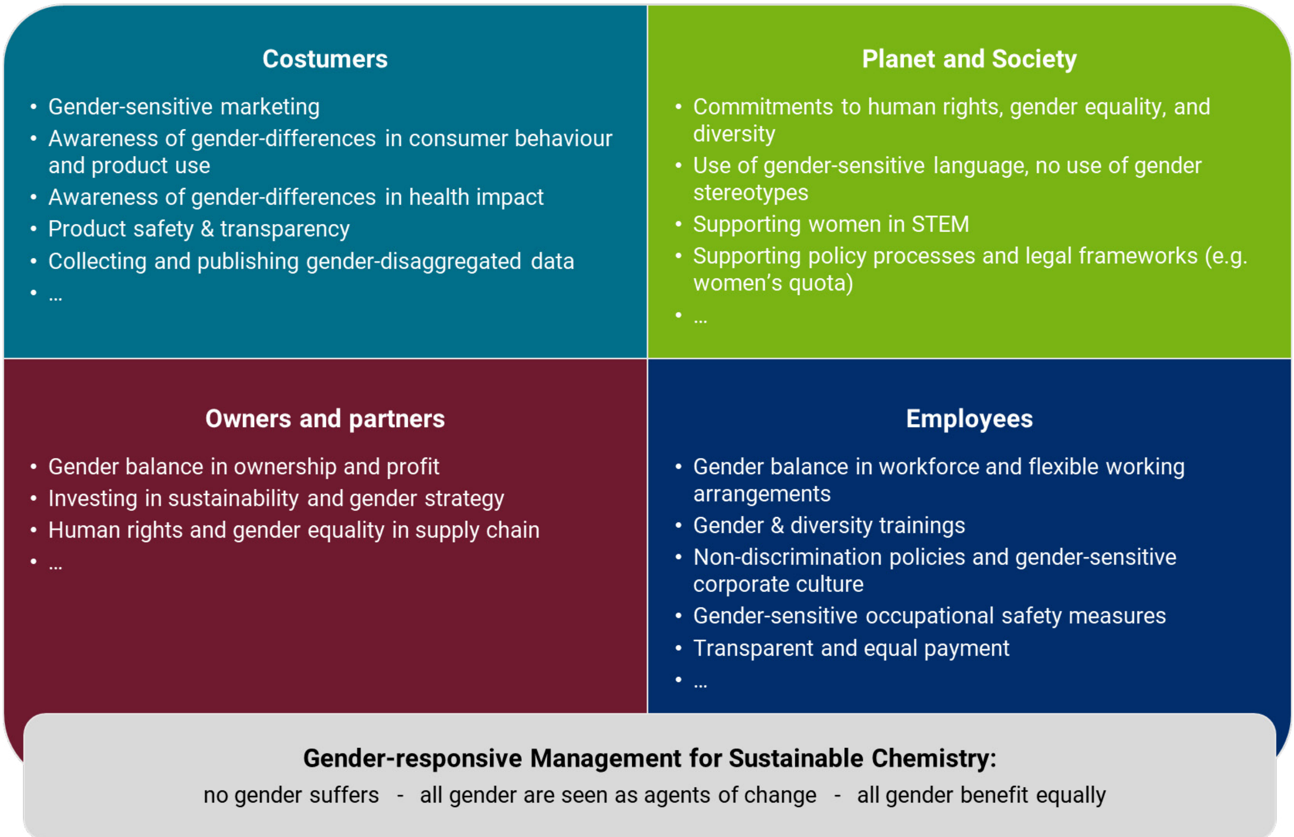

Figure 2: The Integration of Gender and Sustainability Management Approaches (own representation based on Schaltegger, 2011).

Conclusion

Gender inequalities are omnipresent in our societies, and their complex multidimensionality also permeates the world of chemistry, e.g. in occupational safety, academic career paths and consumption choices. Negative but often avoidable effects of chemicals on human health and the environment are the result. The chemical industry should step up its efforts, take more responsibility and contribute to the necessary transformation towards sustainable development in whatever way it can. The implementation of gender-responsive management as an integral part of sustainability management is essential for sustainable chemistry and offers a promising path for the chemical sector, especially for small and medium-sized companies, to deal with its interconnection to gender issues, to sell good products and to contribute to a healthy planet and society.

With this commentary, we hope to stimulate further research and discussions on gender within the chemical industry and would welcome exchange with interested readers.

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Commentary

Sascha Nowak*, Simon Wiemers-Meyer**

Better Batteries – Better Recycling?

1 Introduction

Lithium ion batteries (LIBs) are used in modern day portable consumer electronics like laptops, smartphones or tablets due to their high energy density and high specific energy. Furthermore, as the most interesting battery technology for pure and hybrid electric vehicles, they offer a widespread applicability for private and industrial processes. In addition, the increasing energy consumption, due to the world population growth and the depletion of fossil-fuel resources lead to a strong demand for more renewable energy sources. However, many renewable energy sources produce electricity very unsteadily. To compensate these fluctuations, energy storage solutions are needed which is another important application of LIBs. Overall, this is directly related to the recycling of LIBs and the respective components and materials. However, the recycling of lithium ion batteries is still under development and has not reached its full potential so far. The complexity of the batteries with varying chemistries interferes with the development of a single robust recycling procedure for all kinds of LIBs. Furthermore, the next generations of batteries will further increase the diversity of cell chemistries and components. Therefore, the current processes and technologies needs to be further investigated and adapted to handle the upcoming stream of new batteries.

2 Current State of the Art – Regulations and Economic Aspects

Legislative and economic aspects mainly drive the recycling of LIBs. The legislative aspect is encouraged on the one hand due to hazardous battery components that can pose a threat for the environment and human health if released. On the other hand, mass homogenization for a functioning European market, exclusion of market distortions as well as independence from mining sites and countries is also of great importance. Present regulations include the *Battery Directive* (Directive 2006/66/EC) and the *Waste Electrical and Electronic Equipment* (WEEE) *Directive* (Directive 2012/19/EU). These regulations are precisely defined targets for collection rates and recycling efficiencies. The directives also set disposal responsibilities and safety requirements. Therefore, government authorities can and should contribute to the establishment of an effective circular economy. The Extended Producer Responsibility (EPR), an important concept for recycling, is also defined by these guidelines. Due to the EPR, the physical (e.g. collection, handling and recycling) and financial responsibilities (e.g. internalization of the related cost and incorporation to the prices) are distinguished and assigned for the treatment of spent LIBs. According to the EPR, the costs for collection, treatment, recycling and disposal must be financed by the battery producers. Furthermore, they are obligated to take back portable, automotive and industrial batteries free of charge. Industrial, automotive and collected portable waste batteries must undergo a treatment and recycling using the best available techniques to protect health and the environment before residual compounds can be landfilled or incinerated. The directives also set minimum collection targets and recycling efficiencies for member states. The collection rate is calculated by dividing the mass of portable waste batteries collected in one year by the average annual mass of portable batteries placed on the market in the previous three years. The minimum collection rates were set at 25 % by 2012 and 45 % by 2016 (Neumann et al., 2022). These directives were evaluated regarding their effectiveness showing that only 14 member states could achieve the 45 % goal in 2016 and over 50 % of the portables batteries were not collected in

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the mentioned period. However, the targets were considered insufficient, since only portable batteries were considered and the varying lifetimes for different battery types were neglected. In 2020, as a part of the green deal of the EU, a replacement of the Battery Directive was proposed. New collection targets for portable batteries, which now include light means of transport e.g. E—bikes/E-scooters, were set: 45 % by 2023, 65 % by 2025 and 70 % by 2030. Nevertheless, targets for LIBs from EV are still missing; however, the legal framework was established. The overall weight of the recycled LIBs was raised as well as single targets were set for several materials, including lithium. This refers directly to the economic part of the recycling due to the price of the different constituents. The transition metals, but also lithium and graphite are considered bottleneck materials for LIB production. However, graphite is so far not included in the target materials and should be mandatory implemented in further revisions of the Directive. In average, state-of-the-art high-energy LIBs normally contain 5 %–20 % cobalt (Co), 5 %–10 % nickel (Ni), 5 %–7 % lithium (Li), 5 %–10 % other metals (copper (Cu), aluminium (Al), iron (Fe), etc.), 15 % organic compounds, and 7 % plastic (Ordonez et al., 2016). To maximize the overall LIB recycling efficiency the recovery of none of these materials can be neglected. In addition, the European Commission should include a uniform labelling with information about the manufacturer, date of manufacture, date of market introduction, battery type, battery model, chemistry, hazardous substances, carbon footprint, recovered materials, and critical raw materials. Furthermore, the heterogeneity of battery types available on the market could be managed by implementing a battery passport which should provide all necessary information (Neumann et al., 2022). To overcome the issues, the legislative should not only include targets but also encourage to achieve them by establishing even a system of penalties in the worst case.

3 New Chemistries, new Challenges

Overall, recycling processes are the only option to re-introduce spent batteries and their components into the economic cycle, reducing the need for primary raw materials and promoting an improved acceptance of pure and hybrid electric vehicles and other battery electric transportation applications. However, a LIB is composed of several components: typically a graphite based anode, a lithium transition metal oxide cathode and an electrolyte soaked polyolefin-based separator that is placed between anode and cathode. Furthermore, while around 2005 only one cell chemistry was applied (lithium cobalt oxide, LCO), nowadays several different cathode materials such as varying stoichiometries of lithium nickel manganese cobalt oxides (NMC) or materials like lithium nickel cobalt aluminum oxides (NCA) or lithium iron phosphate (LFP) are applied. Additionally, mixed streams of materials are caused due to the differences in the lifetime depending on the application, e.g. cell phones 2 years, other consumer electronics 3-4 years and electric vehicles 10 years or more. This complexity and diversity offers quite a challenge for the recycling of LIBs. Nevertheless, recycling processes are already applied to handle the rising stream of spent cells. Nowadays, mostly pyro- and hydrometallurgical processes, or a combination of both, are established to deal with the current cell chemistries. However, so far, a completely closed loop was not achieved. A major obstacle to a completely closed loop are the high requirements for the purity of battery materials. After recycling, LIB materials are often used for other applications not requiring very high purities. In addition to this so-called downcycling, the recovery of low-cost battery materials is another obstacle for high recycling rates in a closed loop. Components like the binder, the anode or the electrolyte which contains for example lithium, are mostly not recovered but have recently gathered more attention. With this in mind, the development of future generation materials will intensify this situation. In comparison to the numerous reports in literature about the recycling of LIBs (whether as a pilot process or new processes for single components), nearly no reports or industrial activities can be found with regard to the upcoming cell chemistries. Therefore, an early consideration of possible recycling methods for these types of upcoming batteries is important. One development, the application of Li-metal electrodes will introduce much higher contents of lithium into the system so that much higher recycling efficiencies for lithium will be needed. During pyrometallurgy, lithium normally ends up in a slag, so refinement by hydrometallurgy will gain more and more importance. But because of the higher energy densities and reactivity, another challenge not only for the actual recycling but also for the handling, transportation and storage of spent Li-metal batteries arises. In this regard, a deactivation of the Li-metal batteries as an early step of the recycling procedure, e.g. by extraction of the metallic lithium would increase safety and it would allow for a subsequent transportation of the deactivated batteries.

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Especially in case of damaged batteries with an unclear hazard potential, long transport routes should be avoided, which could be achieved by a decentralized distribution of small deactivation facilities. A promising candidate for a future battery generation is the lithium sulfur battery. For the recycling of lithium sulfur batteries, most of the technical challenges are attributed to their metallic lithium anodes. However, toxic gases like H2S can be formed when the compounds inside a lithium sulfur battery get in contact with moisture, which can further complicate the recycling of future batteries. In comparison, less safety concerns need to be addressed when dealing with all-solid-state batteries (ASSBs). However, mechanical handling will be more difficult compared to current state-of-the-art batteries. Furthermore, due to the introduction of new chemical compositions the hydrometallurgy will be affected as well. There is also a variety of non-Li chemistries including batteries based on sodium, zinc, magnesium or calcium currently investigated. The main motivation is the development of new batteries based on naturally abundant elements. Among those non-Li batteries, sodium-ion battery technology is most similar to commercial LIBs. From a recycling point of view, however, battery chemistries with low-cost elements such as sodium or sulfur are accompanied with little economical interest for the recycling industry. Therefore, the recycling of the new batteries in general needs to be supported by legislation with specific regulations for the efficiency of the new processes.

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Commentary

Dr. Nikolaus Raupp*

My personal view on investment in chemistry start-ups

As a former employee of one of the largest chemical companies, I had the chance to learn about the true impact and the importance of chemistry in all different aspects of our modern life. I truly believe that chemistry is at least part of the answer to all our global challenges. Climate change, mobility, sustainable construction, sustainable agriculture, health, nutrition and last, but not least, the conversion to a circular economy. All major challenges of the next decades depend on innovative solutions from the chemical value chains (Deloitte and VCI, 2017).

As much as I am convinced, that the importance of real break-through innovation is understood and desired by the chemical industry and its key actors, I have some doubts about the magnitude and the speed of innovation in well-established corporations. I do not perceive the corporates of the chemical industry as worse than other corporates in other industries, but corporate culture ("bureaucracy"), short-term financial targets, and a huge impact of path dependency have proven to be solid roadblocks for real break-through in the past. It might not be considered too pessimistic, if you do not believe the speed and impact of innovation will increase drastically in the next couple of years, especially in a tougher economic environment. Unfortunately, this drastic increase in speed and impact of innovation is necessary.

I do not want to repeat the well-known reasons, why a strong start-up ecosystem will lead to more and more impactful innovation (see e.g. Christensen, 1997). So far, I am not aware of any reasons, why this should not also be true for start-ups in the field of chemistry. However, despite the obvious connections between the need for more break-through innovation in the chemical industry and the fact that a strong start-up ecosystem offers the highest likelihood of delivering break-through innovation, chemistry start-ups have not really been very much in the spotlight.

First, this is a problem of definition: what is a chemistry start-up?

There are so many ways to categorize start-ups and chemistry is quite a broad technology field with many different applications in nearly all industries. At High-Tech Gründerfonds we categorize around 4-5% of all relevant high-tech companies in our deal flow (companies we take a closer look at) as "chemistry or material science start-ups". Each year, we receive between 40 and 70 seed-financing requests from technology companies, which we internally classify as "chemistry or material science start-ups" in a broader sense. These numbers strongly correlate with other sources: e.g., in the public database of the Forum Start-Up Chemie, you will find corresponding numbers[1]. Compared to other fields like biotechnology, especially in drug development, or IT, chemistry start-ups have also never been a focus for venture capital investors.

During the so-called "clean tech boom" between the early 2000s and 2010, a lot of the companies, that were labeled as clean tech, have actually been chemistry or material science start-ups, especially in the field of renewable fuels and materials. Unfortunately, most of these clean tech investments of the past can be considered as a failure and a lot of venture capital investments have been lost in this field (e.g., Eilperin, 2012; Owen, 2019; van Lierop 2021; Temple, 2020). Unfortunately, this history of unsuccessful investments has increased the hurdles for all investors raising money for new venture capital funds in this area – including chemistry or material sciences.

Besides the difficulties in creating specific funds, there are two main reasons why financing chemistry start-ups is still challenging in many cases: building a relevant chemical production facility (world-scale plant) is very expensive and venture capital investors usually do not like investment in

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[1] https://forum-startup-chemie.de/startup.html

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physical assets ("bricks and stones" or here more accurately "steel and processing equipment"). Once you have this huge plant running at full capacity, you need to invest again to build another plant. This takes a lot of time and does not really scale well at least not in the sense of a VC investor.

Based on my own experience working in different roles within the chemical industry as well as searching and evaluating chemistry start-ups as a seed-investor at High-Tech Gründerfonds, I would like to share three aspects, that I perceive as important to consider carefully to improve the likelihood of success for building more chemistry start-ups.

1 Following the "bio-pharma example"

Any bio-pharmaceutical start-up that is pitching to an investor and claims to be able to develop, go through all stages of approval until the patient, to produce and to sell their innovation totally on their own, without any strategic partners from the pharmaceutical industry will have a very hard time to convince most investors.

Why do many founders as well as investors think, this all can be done by a chemistry start-up?

Of course, I am aware of the challenges and costs to go through all stages of approval and registration of a pharmaceutical drug and how this is different to develop e.g., a new polymer for sustainable packaging – but I think the analogy is still valid enough.

So why not copy the successful cooperation model that has been established in the pharmaceutical value chain in the last three decades?

The start-ups should focus on what they can do best: to innovate quickly and to adapt to the market and to develop a new product, that is really needed without being stopped by any kind of established solution or organizational path dependencies.

Once the product development has reached a certain stage (about which stage exactly can be argued - for sure), the product should be moved into an "established production set-up". Of course, I am aware of all limitations and challenges of specific process requirements, raw material availability, regulatory approvals for productions, etc.

There might be requirements for investment, even to enable just a small scale – not yet industrial or commercially viable production. However, at least all additional infrastructure will be available and economies of scale for logistics can be utilized. Negotiating such kind of deal with a strategic partner from the chemical industry will require a certain level of openness and understanding of the start-up ecosystem. Of course, the usual cost allocation mechanisms for costs of general site services and utilities like the site fire department in chemical parks must not be applied here.

Once the final proof of concept is done and the next level of a significant investment into industrial scale production assets is necessary, the potential value of the innovation must be big enough to enable either the set-up of a joint-venture with an established partner or to completely license the technology out directly.

This is usually the point in time when chemistry start-ups get in big trouble to raise huge rounds of several tens of millions of euros, just to build and operate one first industrial scale plant. From an investor's point of view, it is very difficult to justify a reasonable (VC) return on invest (ROI) and usually, it will be very hard for any kind of start-up team to build and operate an industrial scale plant economically.

Here, the cooperation with a partner, who is already running several chemical plants on an established infrastructure with all economies of scale of operations, maintenance, logistics, etc. will save a lot of money and deliver a higher return on investment for all parties involved – the founders, the investors, and the strategic partner.

Once this is done successfully, the same process can be repeated in other parts of the world with the same or other partners as well – creating a lot of additional value via the desired scaling. What might sound too easy here, is for sure very tough to realize.

I think there are three main requirements to open this way of strategic cooperation or licensing for chemistry start-ups:

1. The value of the innovation must be high enough to enable a sufficient margin split. Here again, the question is, how much margin is required by which partner and how much volume can be sold to justify even lower margins per kg?

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2. The intellectual property (IP) must be very comprehensive, global IP and absolutely "tight". The start-up needs to prepare for the partnering option since day one – the same way as all good bio-pharmaceutical start-ups are doing it. The patent portfolio must include a product as well as process patents as well as ideally also some application patents, so enough resources need to be budgeted to ensure this IP can be sufficiently created with the right partners.

3. The preparations for the negotiations with the right partners will require some time, even a few years, I guess. First, the right potential partners need to be identified (more than one, of course), the existing production infrastructure of these partners needs to be understood (at least a basic understanding) and then all these options need to be included in the development of the own process. Of course, this will also create additional complexity and costs, but in the end, all this might be of incredible value once you have reached the level of negotiation with any kind of industry partner.

Again – I know, this is a highly complex topic even in theory and it might not work in most cases. However, I think there are enough chemistry start-ups, that should consider this strategy and discuss it with their investors during the earlies stages already!

And quite recently, I have learned about some interesting examples, where service providers for infrastructure/ chemical production sites are starting to become more active in the start-up ecosystem, either directly as an investor or as a network partner and sponsor of supporting activities.[2]

Hopefully, we will see growing business opportunities for specialized service providers who can help to fill the existing gaps with their knowledge, their services, and their facilities for the chemical value chain in the future. Looking at the highly specialized ecosystem supporting drug-development activities that has developed over the last two or even three decades, I know it will take some time, but just a few contract development and manufacturing organizations in the field of chemistry could really make a huge difference for chemistry start-ups.

2 The business case

When you are pitching as a material science or chemistry start-up to any kind of investor, you will hear a lot of questions like:

- "Can this material be produced at competitive costs/ sold at competitive prices?"
- "Long-term B2B customers will not accept a premium compared to the existing solutions"
- "How do you ensure the raw material costs will be competitive in the future?"

These questions might often be perceived as a kind of "torture" and to be honest, they are also some of my favorite questions.

But to be fair – there are huge limitations to any kind of answer you can give or receive.

Please do not get me wrong here, it is absolutely crucial to understand the potential cost structure of any kind of product that you want to bring into the market in the future and of course, economies of scale, as well as realistic alternatives for own as well as for competing solutions.

However, raw material prices are volatile and sometimes (often?) driven by unexpected developments. I have seen projects being killed because of a high oil price as well as because of a low oil price. And I have seen projects failing that showed a very competitive price during the initial evaluation when they were started but just due to unforeseen developments the product was totally uncompetitive when the product was finally available.

Nowadays, you also need to consider potential CO2 prices, crazy fluctuating energy prices (very recently?), more and more government interference, potential trade policy impacts, etc., so investing in chemistry start-ups might get even more complicated for some investors.
To make a long story short: yes, a very detailed understanding

[2] Two examples of this kind of activities are Brightland Venture Partners in the Netherlands (https://brightlandsventurepartners.com/about-us/) or ChemstarsNRW (https://chemstars.nrw/)

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of raw material costs, the main cost drivers for the production process, economies of scale and the alternative solutions is crucial, but I do not necessarily need a "yes – that is a competitive price already today – all problems solved" business case as a basis to start detailed due diligence.
Looking at the potential benefits, the differentiation potential of the new solution is, for sure, as important to determine the potential value of innovation. Unfortunately, to do so is as complicated as guessing the raw material prices for certain materials in five to ten years from now.

To make this aspect even more complicated, the products of chemistry start-ups can usually be used in more than one application and often in even more than one industry. So, evaluating a potential value leading to a certain price premium compared to currently existing solutions based on additional features, cost savings or customer requests requires a lot of "industry insides".

My past experience has taught me, that it is really important to find at least three (two might not be enough in the long-term) generally desired "features" and not to be caught up too much in very recent trends or specific customer requests, that might end up being unique or depending on a certain individual process or even worse some individual decision makers.

3 Last but not least – stating the obvious: "the team"

As much as this is important for any start-up, this is also important for any chemistry start-up, but of course, with some specific aspects to consider:

All investors want a great and well-balanced team, that has some experience (or at least some prospect) to cover all challenges, that can be foreseen along the way.

However, besides the normal roles and requirements that need to be filled, a chemistry start-up ideally should also cover two more aspects: while there is usually at least one chemist in the team (otherwise who will do the development work in the lab?), I consider chemical process engineering and or manufacturing expertise as equally important.

Other investors might argue that this role is not yet needed at a very early stage, but my personal experience has taught me, that product and process development need to be aligned as early as possible and any process engineer joining later, has much less influence on this super crucial aspect of the company´s key asset.

I know, that adding a great (not just any) chemical engineer will cost more in the beginning, but I am sure, this money as well invested as the company will avoid a lot of expensive mistakes that might also take a lot of time to be solved later.

In case any start-up is considering following a "partnership/ licensing model" as suggested earlier, the process engineer will even be more important as the responsible team member to understand existing production options and their impact on the own development.

The second role to be filled very early (but maybe not as early as the process engineer) is a sales professional, ideally experienced in at least two of the most likely customer industries. Selling chemical products into construction, cosmetics, pharmaceutical, agricultural, automotive, or consumer goods industries requires credibility, deep understanding of the customer industries processes, needs and pricing strategies.

Unfortunately, most start-ups (and or investors) are reluctant to hire a salesperson as long as there is nothing to sell – what a waste of money…

I think, valuable (honest and realistic) customer feedback about requirements, pricing and long-term demand is worth hiring an expert to get this as early as possible. Usually, these experienced experts can easily utilize their network to learn, what others might never find out and as an investor, I also want to know more about "my potential customer" as early as possible.

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Conclusions

As a critical conclusion of my own suggestions, I need to make one important comment: yes, everything I am suggesting here will cost more money in the beginning and might not work out as planned during the later stages.

However, compared to some years ago, financing rounds are growing bigger and bigger, even in the initial seed-phase. I see three main reasons to be optimistic here:

1. There are more and more VC investors willing to look into material science and chemistry cases. Some are driven by sustainability/impact investing, some are really focusing on a certain market segment with a highly specialized team and some others just need to diversify their portfolio.

2. There are some new fonds specifically targeting the financing gap in later stages, when really huge amounts are needed to invest in larger production assets.

3. There are more and more industrial investors looking into the start-up ecosystem, searching for disruptive innovation, new products, new cooperations and new solutions to utilize their assets either directly in production or logistics.

Overall financing a chemistry or material science start-up will always be challenging, but if you have the right vision, the right people and of course the right innovation, the chance of being successful are improving for sure!

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