Chemistry 4.0

Growth through innovation in a transforming world

Final report

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Foreword by the VCI President

Chemical and pharmaceutical companies in Germany have shown time and again that they can successfully master the tectonic shifts in our competitive environment; examples in the 150 year old history of industrial chemistry are changes in raw materials, relocation of growth centers to emerging economies, and the call to make business more sustainable, which has been receiving broad public support recently.

The key to our competitiveness is the innovative power held in our companies: new and improved molecules, production and business processes. In Europe, our sector has been characterized by globalization, specialization, and focusing on the core business since the 1980s. We have now reached the next level: Chemistry 4.0. Digitalization and circular economy are the key characteristics, and these two elements will fundamentally alter the way we work, as well as support sustainable management.

Digitalizing the chemical industry offers new opportunities as well as risks. Research and development, manufacturing, and business models will be transformed. It is not easy to separate myths from real risks and opportunities, take appropriate measures, and gain a competitive advantage. This transformation offers great opportunities for the highly developed chemical industry in Germany in terms of enhancing its global competitiveness. The chemical and pharmaceutical industry's innovative processes, products, and services make a significant contribution to sustainable development of our society. Our sector will continue to be a traditional supplier of materials, while our role as a service provider will grow in importance at the same time.

Against this background, the VCI, its member companies, and Deloitte Consulting have examined which developments will influence the chemical and pharma business up to 2030, and what we need to do today in order to take advantage of opportunities through transformation tomorrow. From this foundation, we have derived recommendations aimed at the association and its member companies, as well as policy-makers. If we all work together, we will be able to expand the role of the chemical industry as an innovation center for Germany.

I would like to express my special thanks to the many experts, particularly from the member companies, who took part in numerous workshops and contributed to this study, as well as the medium-sized enterprises that responded to the online survey.

Dr. Kurt Bock,
President, German Chemical Industry Association (VCI).

Executive Summary

In order to be successful in the long term, the chemical industry needs to expand its existing business model.

This is the result of a systematic analysis of relevant trends in the German chemical and pharma business[i] (summarized under the term "chemical industry"). Improved political framework conditions should support this process.

The study "Chemistry 4.0" highlights the growth chances that chemistry in Germany can realise with innovations in a changing world, what profound changes in the companies are needed for this, and how associations and politicians can accompany this process. Here, the term "Chemistry 4.0" stands for a new development phase of the chemical-pharmaceutical industry where the key topics of digitalization (see chapter "Digitalization in the chemical industry") and circular economy (see chapter "Circular economy and the chemical industry") as well as their interplay have a central role. With a successful transformation towards "Chemistry 4.0", the industry can make a major contribution to reaching the UN Sustainable Development Goals (SDGs).

Development from Chemistry 3.0 to Chemistry 4.0

	Chemistry 3.0 Globalization & specialization	Chemistry 4.0 Digitalization & circular economy
Drivers for transformation	Globalization, the European internal market, growing competition from gas-based chemistry, the influence of financial markets on corporate strategies, commodification	Digital revolution, sustainability, climate protection, closing material cycles
Raw materials	Increasing use of renewable raw materials and natural gas	Intensive use of data, recycling of carbon-containing waste, H_2 from renewable energies in combination with CO_2 used to produce base chemicals
Technology	New synthesis and production processes through biotechnology and gene technology, enlargement of individual processes	Digitalization of manufacturing processes
Research	Close cooperation between basic research in universities and application-oriented research in companies	Decentralization of R&D in customer markets, utilization of Big Data, joint development with customers
Corporate structure	Internationalization of trade and on-site production abroad, specialization and growth in SMEs, consolidation through M&A, creation of chemical parks	More flexible cooperation as part of economic networks, digital business models, and consolidation
Products	Expanding product range, specialty chemicals oriented to specific customer requirements, new drugs, replacement of traditional materials with chemical products	Expanding the spectrum of value creation: chemical sector becomes a supplier of extensive and sustainable solutions for customers and the environment
Environment, health and safety	Environmental protection integrated into production, increasing product safety through expanded review of material properties, Responsible Care	With Chemie³ (ecology, economy, and social affairs), sustainability becomes a comprehensive model and future concept for the industry

[i] Delimination of sectors according to NACE 20/21

Situation and trend analysis

At present, good economic environment
Germany is doing well in an international comparison. The labour market is in excellent shape. German products are in demand worldwide. The foreign trade balance is strongly positive. To a particular degree, this good performance depends on the economic strength and the ability to innovate of the domestic industry. A strong chemical and pharmaceutical industry is a major partner and an essential growth driver in this context. However, politicians and industry need to actively work on continuing this success story: because the industry location Germany – and thus also the chemical and pharma location – are faced with huge strategic and structural challenges.

Change in a societal environment
Sustainable management and sustainable consumption are getting ever more important in society. This is reflected, inter alia, in efforts for better resource efficiency, greenhouse-gas neutral production, and the further expansion of renewable energies and bio-economy ("biologization" of the industry). Growing health awareness, the wish to individualize products and changing consumer preferences in a "sharing economy" are further important development trends to which the companies will need to attune in the future. Moreover, the developments summarized under the keyword "digitalization" bring comprehensive changes for all sectors of the economy.

Competition intensifies in chemistry
The competitive environment is changing for chemistry in Germany. In the decades to come, the total demand for chemical products will increase only moderately. Growth chances are higher in the emerging markets of Asia, South America and, in the longer term, also in Africa. German companies and international competitors are investing in these markets, replacing exports by local productions. Local producers, too, are expanding their production capacities; this applies particularly for China. Furthermore, because of favourable energy and raw material costs through shale gas, new petrochemical plants are built in the USA. In the raw material-rich Middle East, petrochemical production capacities have doubled over the past 10 years; further capacity expansion is foreseeable. Such additional capacities bring a large and, by comparison, favourably priced offer of basic chemicals on the world market.

Incremental innovations and disruptive changes in chemical business
The classic chemical business continues to hold good growth chances for the companies: through continuous innovations that bring improved customer benefits and largely materialize within existing product portfolios, process technologies and inside established business models. These include, for example, lightweight construction in the automobile industry, innovations based on existing active substances in medicine, and products for energy- and material-efficient building. Such innovation processes are part of the existing business and success model of the chemical industry in Germany. The chemical industry in Germany is well-prepared for facing this challenge. Also in the future, it will make a decisive contribution and maintain its role as a driver of innovation and growth in German industry overall. However, today the environment for the chemical industry in Germany is changing more dynamically

than in the past decades. Disruptive changes will increase in technology and society and also in the market and competitive environment of chemistry. Therefore, companies are forced to review existing business models, develop new ones and adopt new strategic orientations where necessary. The Energy transition (Energiewende) with the changeover in energy supplies to renewables and the Mobility transition (Mobilitätswende) with the changeover to partly self-driving, electric car-sharing fleets are prominent examples of changes with significant impacts on chemical business.

Such disruptive changes have sweeping effects on product portfolios, process technologies and value creation structures. The development of e-mobility with newly forming value chain structures in battery technology is a good example of technologically driven disruptive change. On the one hand, it brings chances in new fields of growth for chemical companies; on the other hand, there are huge challenges in adapting products and services to such new framework conditions. Moreover, the value creation structures are changing: In the coming years, progressing digitalization and the further development of circular management models can fundamentally change the business models and role distributions in the network of industries.

Focal points: digitalization and circular economy

Digital transformation in the chemical industry

Digitalization can be broken down into three categories with various focuses:

- Transparency and digital processes comprise the gathering and first use of digital data in operative processes inside chemical companies. Thus, efficiency potentials are leveraged within largely unchanged production and business processes. Especially in its continuous and discontinuous production processes – but also in business processes – the chemical industry is comparatively advanced in this respect. All the same, with the possibility of systematically gathering digital mass data, digitalization provides a new basis for a further automation of production processes.

- Data-based business models intensively use mass data from business operations or decision-making and efficiency increases; where necessary, they are additionally linked with external data. Relevant applications – e.g. in predictive maintenance or forecasting methods and in the use of virtual reality concepts and advanced simulation in research – are currently driven forward in chemistry.

- Digital business models are value creation structures that fundamentally change existing processes, products or business models. Digital business models are characterized by digital additions to products and services in order to enhance customer benefit. Often, this does not happen in one single company but within digital networks where various suppliers provide joint solutions for customers. Here, the customers are actively involved and specify their individual needs in a flexible manner. The linking of digital services and chemical industry products in the digitalization of agriculture, in additive manufacturing (3D and 4D printing) and in e-health concepts in the health sector are examples of current developments in this field. Here, the industry is in a start and development phase at the moment.

The digital transformation of the German chemical industry has begun. Data-based operating models are being applied increasingly. The great importance of digital business models for future viability has been recognized. In the next 3 to 5 years, chemical companies are planning to invest over 1 billion euros in digitalization projects or new digital business models.

Key role of the chemical industry in the circular economy
The circular economy concept, on which this study is based, comprises all contributions to saving resources. This is about all activities

- to improve resource efficiency at all levels of value creation (suppliers, chemical industry, customers),
- to increase the lifespan of products and components and to reduce resource consumption in their application,
- to close cycles to the extent possible, i.a. by way of reuse, recycling, material and energy recovery or biodegradation, and to use residual materials where this is possible.

Only such a comprehensive understanding of the circular economy clearly highlights its importance and the contribution that the chemical industry can make here. It is a task, a challenge and an opportunity for chemical companies to take into account all the aspects of the circular economy throughout entire product life cycles. The chemical industry can support circular economy concepts, especially by optimizing the product design, increasing resource efficiency in its own processes and in its customers' production processes, through feedstock and material recycling, and the reprocessing and cleaning of products.

Mutual strengthening of digitalization and circular economy
In all of the above-mentioned aspects, the generation and analysis of digital mass data and their exchange have an ever more important role. Digitalization can speed up the expansion of circular business models and make them more efficient. Digitalization processes support a sustainable product design, improve resource efficiency in the production of the chemical industry and at its customers, and enhance the efficiency of take-back and recycling systems. The interplay between circular economy and digitalization brings additional options for reaching the UN Sustainable Development Goals.

Potential in economic networks
Many digital business models and business models in the circular economy are based on networks consisting of various companies. Networks are characterized by their ability to offer customers a whole package of services and products from all the companies that are part of them. Companies that want to be successful in such complex and dynamic economic networks need to prove that they have the relevant network competencies.

As they have always been moving in a complex environment, in principle many chemical companies have a great readiness and ability to form and operate in networks: They are part of complex interlinked production structures (Produktionsverbünde) at integrated sites (Verbundstandorte) or at chemical parks, and they are dealing with a large number of diverse suppliers

An extraordinarily high share of future changes has disruptive character for the chemical industry.

and customers in a wide range of customer industries.

However, the chemical industry is not yet fully using the opportunities of digital economic networks. In order to better open up these chances, it is not enough for chemical companies to identify early the emergence and dynamics of economic networks; they also need to identify the role of their own company inside these structures and shape it strategically. But for many companies, such complex economic networks with new partners from other sectors are uncharted territory where uncertainty and risks are the outstanding features.

Recommendations for action

Recommendations to companies and their associations

Use the chances and set strategic goals
The future importance of digital business models makes it necessary for the chemical industry in Germany to look even more intensively into identifying, assessing and introducing such models. Business models developed by networks require a comprehensive analysis of incentive structures, value contributions and remuneration structures.

Companies need to define digitalization, circular economy and innovation as elements of the corporate strategy. The interplay between digitalization and circular economy, too, needs to be seen for the business model. Furthermore, new assessment criteria have to be added to the classic success parameters of business management. They should take into account the properties of new production and value creation structures (higher flexibility, smaller lot sizes/personalization, appraisal of existing and newly generated data).

Enhance resources
Digital and circular business models call for technical and network competencies. The chemical industry has a good starting position, as its core business is characterized by complex value creation and composite (Verbund) structures and by cooperations between large businesses and medium-sized specialists. But these competencies and structures of chemistry need to be expanded and adapted, in order to overcome the remaining barriers and to fully use the chances for growth. Such change involves many risks and requires high investments in education, tangible assets and software.

Transform corporate culture
The successful development and scaling of new business models for digitalization and circular economy – especially at the interface between both fields – call for corporate cultures of start-up character. Innovation cycles are becoming shorter, and new products and business models need to be implemented in an agile and timely way. Important elements of the required corporate culture are transparency and openness, agility and failure tolerance as well as a culture of cooperation and communication, also across companies. In their operations, the companies have to cope with potential tensions between traditional business and new business models. Furthermore, they need to create structures that allow them to operate in parallel within different models. This includes enabling and permitting the scaling of new business models that can be directed against the core business ("managed cannibalization"). Moreover, large parts of the chemical industry's business model are based on protecting intellectual property: This is another potential obstacle to a fast cultural change towards openness and cooperation across companies and needs to be discussed in a frank manner.

Digitalization can enable the expansion of circular business models and make it faster and more efficient.

The associations should actively support the change in the industry's culture.

Build up cooperations and platforms
Digital and circular business models require far-reaching cooperations, both within the chemical industry and across industries. Through its associations the chemical industry can promote the development of platforms for knowledge exchange and initiating partnerships inside the industry, position itself as an open and attractive partner for start-ups and technology companies, and expand research collaborations. Chemical industry associations can actively support this by developing catalogues of criteria (best practice analyses, toolboxes, guidelines) for adequately assessing digital and circular business models and implementing them in the companies.

Develop new participation concepts
There is a risk, that the speed and complexity of this change provokes a rejection of innovations. Therefore, beyond stronger communication, the associations and companies should open up their innovation development for a stronger participation of politicians and other interested groups in society. Thinking and acting in networks is necessary for the success of digitalization; this should also include the cooperation with societal stakeholders. For this purpose, companies and associations can jointly develop new participation concepts.

Recommendations for political and regulatory framework conditions

Actively support digital education
The needs-oriented and target group-specific dissemination of digital competencies in vocational and academic education and advanced training is a success factor for the German economy. The political side can support such knowledge-building by creating suitable framework conditions and infrastructures for teaching digital know-how at schools and universities. Furthermore, universities need to be open to offer extra-occupational training.

Expand technical infrastructure, improve data security, review data protection rules
A fast and stable internet that connects companies, suppliers, customers and staff in an all-area approach is urgently called for. Broadband expansion needs to be driven forward fast. It is imperative to expand the telecommunications infrastructure with full regional coverage by 2025. The technical expansion of infrastructure needs to be accompanied by the development of a high-performance IT security network between public authorities, companies and research facilities in Germany and Europe. It should be examined to what extent the data protection rules can obstruct the development of end customer-oriented, individualized business models and whether it is possible and necessary to

make adaptations to data protection law. Machine data must be usable in such a way that innovations are not hampered in the development of products and services. Here, contractual agreements on the use and safe handling of data are preferable to (ownership) regulations.

Promote cooperation and unbureaucratic development of platforms
The public sector should support the development of the necessary network structures and the establishment of cross-industry platforms and innovation clusters for knowledge exchange. Here, it is important to give equal consideration to all sectors, in order to identify and use all synergies as comprehensively as possible.

Engage in a dialogue on the necessity of and perspective for digitalization
Politicians should take fears about changes through digitialization seriously and initiate dialogues with citizens (Bürgerdialoge). This should be supplemented with online forums and accompanying media work on the topic of digitalization. Although digitalization means a continuous process of change and adaptation, it is important to show that it can also increase the productivity of the overall economy, support a self-determined life and enable more sustainable living. Moreover, the close connection with Germany's demographic problems should be highlighted: Digitalization is an important component for resolving the economic problems of demographic change in Germany.

Understand circular economy as a holistic and open approach
Circular economy provides efficiency gains at every level of value creation and in entire product life cycles. Waste avoidance through multiple use, improved efficiency through the use of by-products and wastes as raw materials, energy recovery of wastes, use of renewables as CO_2 cycle and use of CO_2 as raw material as well as feedstock recycling: All these are options for development towards an efficient use of resources through effective recovery. A detailed feasibility analysis is needed to determine which of these methods should be applied in each individual case. This analysis should include technical options and weigh the ecological, economic and social aspects. The existing regulatory framework needs to be reviewed for any obstacles to expanding circular economy concepts.

Raise societal awareness for circular economy
Circular economy cannot be successfully established without the joint efforts of all sectors and consumers. Therefore, the political side should foster a fundamental understanding of the circular economy; this should be done by way of suitable dialogues and educational offers on a societal level. Furthermore, the political side should create transparency regarding objectives and costs.

Expand innovation support
Political support measures should accompany the paradigm change in the chemical industry and its customer industries. Investments in future-oriented fields should be stimulated through research funding open to all companies. This should take the forms of project funding and additional fiscal incentives, start-up finance for novel projects in the circular economy, easier access to venture capital as well as support for start-ups and private-public partnerships (e.g. pilot projects). Such measures would meet the needs of the new dynamic business environment.

Review the regulatory framework
In view of the dynamics and openness of current developments in the digital and circular economy, it is important to allow for leeway to act. Politicians should aim to harmonize laws and regulations throughout Europe and across industries, eliminate contradictory or redundant rules and reduce regulatory uncertainties through consistent, holistic legislation with high transparency regarding future framework conditions. New and existing regulations should undergo an "innovation check", focusing on whether and to what extent they are conducive to innovations and the further or new development of business models or whether they rather impair them.

The chemical industry needs to put under scrutiny and adapt its management style and portfolio of products, services and business models. Politicians are called upon to support such efforts in their industrial policy concepts and to create globally competitive framework conditions for the chemical industry.

Motivation and goal of the study

The chemical industry is an important growth driver for the currently strong performance of the German economy.

However, great efforts are needed for this effect to last in the long term. Like German industry overall, also the chemistry and pharma location is faced with elementary strategic and structural challenges.

Firstly, a paradigm change has been taking place already for some time in the demand structures and societal goals. The will to use resources efficiently and in an environmentally sound manner has noticeable effects on energy supplies and consumption habits. The trend towards a "sharing economy" is a prominent example of this change process. As a result, companies are expected to have sustainability strategies that contribute to the UN sustainable development goals. Furthermore, digitalization leads to major and fast changes in business and everyday life. This brings major challenges for the chemical industry where innovation and investment cycles are usually longer than for the industry's partners in the value chains. Across all sectors, the industry is looking for ways to better understand these new requirements and to offer suitable solutions. In this context, especially digital and sustainable innovations are significantly gaining in importance.[1] For the next 3 to 5 years, chemical companies are planning to invest over 1 billion euros in digitalization projects or new digital business models.

Secondly, the demand for chemical products in Western Europe will grow only moderately in the coming decades. Therefore, the emphasis is on Asia and South America and, in the longer run, on Africa. As international and local competitors have expanded their production capacities in these markets and due to new capacities in raw material-rich regions, the entire competitive environment of chemistry will undergo dramatic change. Moreover, producers in emerging markets and raw material-rich countries have expanded their focus to fields of specialty chemistry which are frequently still covered by German exports at present.

Moreover, new technologies are changing the competitive environment and the business basis of chemistry. For example, for medium-sized enterprises and start-ups biotechnology or additive manufacturing open up attractive business chances with fast scalability or low volumes in market segments that have been served so far mainly by large companies. Digitalization and the formation of new economic networks bring an increase in the number of competitors for chemistry and pharma. This is because new undertakings, often with a background in digitalization, are seeking their chances in both established and newly developing markets.[2]

For the chemical industry in Germany, these changes mean another increase in competition intensity, both in the home market Europe and in export markets.

In Europe, import pressure from raw material-rich regions is increasing for basic chemistry and intermediates. In export markets, competition intensifies with local suppliers and other importers. The German chemical industry will continue to grow by ca. 1.5% per annum. However, lasting strong growth of chemical production in emerging markets – mainly in China – will cause a drop in Germany's market share: Back in 2005 chemistry from Germany still had a global market share of 7% as compared with under 5% in 2015. The market share is anticipated to be under 4% in 2030.[3]

Consequently, the environment of the chemical industry in Germany is not only changing more strongly than in earlier decades. In the future, there will also be disruptive changes for which the companies need to get ready. The digitalization of agriculture, personalized medicine or the Mobility transition (Mobilitätswende) are prominent examples of changes with considerable impacts on chemical business.

These changes show that the chemical industry in Germany is in a transition to a new development phase. After industrialization and coal chemistry (Chemistry 1.0), the emergence of petrochemistry (Chemistry 2.0) and increasing globalization and specialization (Chemistry 3.0) the industry is entering the new phase of Chemistry 4.0 in which digitalization, sustainability and circular economy play key roles (see diagram). These topics are not detached from each other: In particular, the interplay between digitalization and circular economy is growing in importance and contributes to achieving the UN sustainable development goals.

The chemical industry in Germany is undergoing a transition to a new development phase: the era of Chemistry 4.0.

The characteristics of Chemistry 4.0

Chemistry 1.0: Industrialization & coal chemistry	Chemistry 2.0: Emergence of petrochemistry	Chemistry 3.0: Globalization & specialization	Chemistry 4.0: Digitalization & circular economy
1865	1950	1980	**2010**

Driver for transformation	Digital revolution, sustainability, climate protection, closing material cycles
Raw materials	Intensive use of data, recycling of carbon-containing waste, H_2 from renewable energies in combination with CO_2 used to produce base chemicals
Technology	Digitalization of manufacturing processes
Research	Decentralization of R&D in customer markets, utilization of Big Data, joint development with customers
Corporate structure	More flexible cooperation as part of economic networks, digital business models, and consolidation
Products	Expanding the spectrum of value creation: chemical sector becomes a supplier of extensive and sustainable solutions for customers and the environment
Environment, health and safety	With Chemie³ (ecology, economy and social affairs), sustainability becomes a comprehensive model and future concept for the industry

This study analyzes in detail this dramatic change, with the following guiding questions:

- How can the chemical industry in Germany expand its value creation potentials domestically while improving its international competitive position?
- How can the industry comprehensively use digitalization, identify early attractive digital business models and thus open up new business potentials that go beyond the production of chemical products and materials?
- How can the industry contribute to closing substance cycles, minimize resource consumption and, in this manner, equally achieve social, economic and ecological goals?
- How can the economic framework conditions be brought in a better shape, so that the chemical industry remains also in future the innovation and growth driver of the industry location Germany and continues to make an essential contribution to the prosperity of our country?

Methodology

The study consists of three sections:
- Framework analysis, which describes the major development trends to 2030 and analyzes their impacts on the German chemical and pharma business;
- detailed analysis of chances and risks of digitalization and circular economy;
- deriving recommendations for companies and politicians, based on the above.

The analysis was made in a multi-stage process that included the expertise from VCI member companies, VCI experts, Deloitte, associations of suppliers and customer industries, and delegates from science and politics.

Framework analysis
The major trends were identified in the first phase of the framework analysis, based on a comprehensive, artificial intelligence-supported literature analysis by the Deloitte Center for the Long View. Relying on that, an expert workshop prioritized 30 trends for further analysis. These trends are likely to have a significant influence on the chemical and pharmaceutical industry in Germany to 2030.

That was followed by 5 expert workshops and around 40 expert interviews which analyzed the developments in energy and raw material markets, pharma and health markets, business-to-consumer and business-to-business activities of the chemical industry, and special features of the location Germany. Each of the 30 trends was analyzed in detail, findings were derived on the impacts of a given trend on the chemical industry in Germany, and it was determined whether – in the current framework conditions – a given trend constitutes a chance or a risk for the chemical industry in Germany.

Detailed analysis
Building on the framework analysis, the detailed analysis looked into the impacts and chances of digitalization and circular economy as key topics. For this purpose, two workshops were held on digitalization and circular economy, with experts from member companies and associations and further external experts from science and politics. In a next step, the starting points discussed during the workshops were examined in more depth within literature researches and additional analyses. In particular, the connection between digitalization and circular economy was addressed more profoundly, and potential roles of chemical companies in (digital) economic networks were considered.

Survey among medium-sized enterprises
The analyses were supplemented by a broadly structured survey among medium-sized chemical and pharma companies. The survey wanted to find out to what extent medium-sized enterprises have made their preparations for the digital and circular transformation, what challenges specific to medium-sized enterprises arise, and what expectations the medium-sized enterprises have to politicians and associations. In total, 124 medium-sized enterprises from the chemical and pharma industry took part in the survey (response rate >15%).

Recommendations for action
Several recommendations for action were derived from the sum of the results. The chemical industry and politicians should jointly implement these recommendations.

Framework analysis

This chapter names and assesses the trends with special impacts on the chemical business and highlights the underlying patterns.

Within the study, 30 trends were identified that will be of special importance to the chemical and pharmaceutical industry in Germany to 2030. These trends were analyzed regarding their underlying drivers and assessed as to their anticipated scope of impact.

Overview of analyzed environment trends (see "Glossary – Environment trends")

Energy & raw materials
- Reliable raw material supplies/ supply security for raw materials in Germany
- Power-to-X
- Carbon capture storage/ utilization
- Renewable raw materials
- Waste-to-Chemicals
- Bio-refineries
- Industrial biotechnology

Business-to-Business
- Material-efficient building
- Energy-efficient building
- Modern building
- Electro mobility
- Lightweight construction in the automobile industry
- New mobility concepts
- Additive manufacturing
- Material mix in packaging
- Bio-plastics in packaging
- Renewable energies – production technologies

Business-to-Consumer
- Personalization of consumer products
- Perception of chemistry
- Change in the relationship between the chemical industry and end customers

Agriculture
- Urban farming
- Agricultural turnaround (Agrarwende)
- Genetically modified crops
- Genome editing as precision breeding
- Digitalization of agriculture

Pharmaceuticals & healthcare
- Personalized medicine
- Genome editing in medical applications
- E-Health
- New medical technology
- Self-medication

Energy & raw materials

Mineral oil derivatives are eminent in the raw material supplies for the chemical industry in Germany. In 2015, this was the raw material base of organic chemistry: 75% naphtha and other mineral oil derivatives, 11% natural gas, 1% coal and 13% renewables.[4] In the years to come, fossil energy sources will continue to dominate the energy and raw material input of the German chemical industry. Unlike the gas-based US chemical industry, petrochemistry in Germany largely relies on naphtha as the basis for organic chemical products. This structure is unlikely to change in the foreseeable future, as favourably priced shale gas is not available in Germany and the existing production structure is geared to the processing of mineral oil derivatives.

All the same, the energy and raw material mix in the chemical industry is changing in a longer-term trend where two basic tendencies are important: firstly, the growing share of renewable energies (mainly wind and solar energy) in electricity generation and, secondly, the stronger use of alternative raw materials (renewables, i.a. in bio-refineries, CO_2 through carbon capture utilization, carbon-containing wastes / waste-to-chemicals). There is potential in the coupling of energy generation and electricity consumption control in chemical production, the conversion of electricity from renewable sources to gas, fuels or chemicals (Power-to-X), and the further development of industrial biotechnology for the processing of renewable raw materials.

Sector coupling and Power-to-X

Quick view

- Conversion of electricity in gas, fuels or chemicals
- Key technology for carbon neutrality
- **Huge potential for chemistry, with effects materializing mainly after 2030**

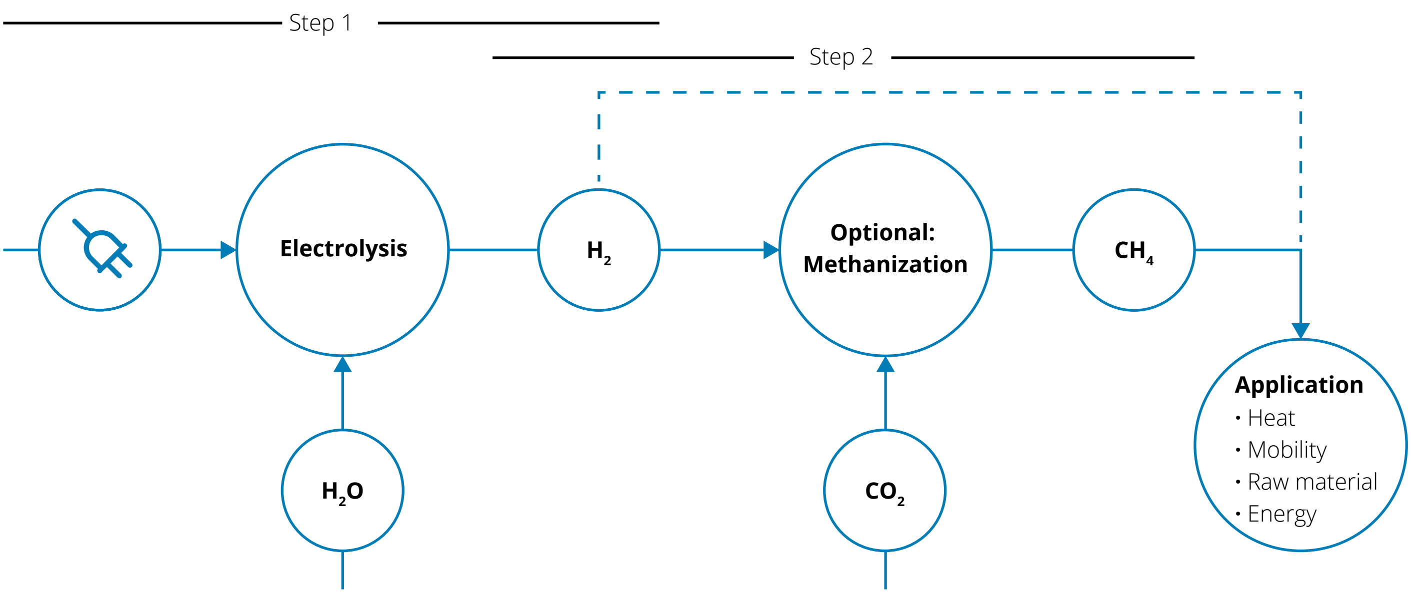
Power-to-X describes the possibility to reduce or intelligently utilize the volatility in the amounts of generated electricity as is caused by the rising share of renewable energies.

In the year 2016, a total of 648.4 TWh of electricity was generated in Germany.[5] Out of this total, roughly one third (188.3 TWh) came from renewable sources, with weather- and daytime-dependent photovoltaics and wind energy contributing 115.5 TWh. According to the Federal Network Agency, around 4.7 TWh of electricity from combined heat-and-power (CHP) plants and renewable energies fell under temporary reductions or shutdowns (Abregelung), because grid capacities were not sufficient.[6] This problem will increase with the further expansion of renewable energies.

Batteries cannot remedy the fluctuations in the availability of renewable energies, neither concerning the necessary capacities nor regarding the needed storage times. Coupling the energy sector with other industries, which require energy for various purposes, is an environmentally sound solution for making good use of surplus electricity. Chemistry can play a key role in such sector coupling. Firstly, within certain bounds "smart grids" can adapt the production in electricity-intensive plants to the available electricity. Secondly, supply peaks of volatile renewables can be used to produce raw materials for chemical production. Power-to-X means technologies that use electricity, preferably from renewable sources, to generate hydrogen from water by electrolysis and, optionally, to convert and thus obtain hydrogen into synthesis gas and methane by the reaction with CO_2. Such gases can serve to store energy, or they can provide the basis for synthetic fuels and chemical production processes.

Consequently, Power-to-X is of outstanding importance not only for easing strains on supply grids but, beyond that, for sustainably producing input resources and reducing the share of fossil raw materials. Beside electricity from renewable energies, the technologies use CO_2 as a carbon source. This is a form of carbon capture utilization.

Graph showing the Power-to-X process



Carbon capture storage / Carbon capture utilization
Carbon capture storage (CCS) and carbon capture utilization (CCU) describe the storage (e.g. subterranean) or the raw material use of CO_2 from processes or air. If the thus used CO_2 is managed in full cycles, this could lead to a greenhouse gas-neutral future. Power-to-X gives chemistry the chance to centrally participate in a cross-sector system of energy supply and sustainability.

Already now, many innovative small companies are active in Power-to-X. With over 100 power-to-gas pilot plants[7], Germany is intensively engaged in research into new, efficient and favourably priced Power-to-X technologies. Funded under the Kopernikus programme of the German federal research ministry, the national platform "Konsortium P2X" is also dedicated to this goal.[8] It wants to try out, inter alia, whether the conversion of water and CO_2 by electrolysis or co-electrolysis – for obtaining hydrogen or synthesis gas as inputs for manifold uses – is worth it and whether, building on this, hydrocarbons or oxo-compounds can be synthesized.[9] Within the Kopernikus project, initially the available starting points and technologies are to be analyzed, in order to be able to assess the full information on technical maturity, societal acceptance and possibilities for implementation in today's infrastructures. Within 10 years, new technological developments are to be brought to industrial maturity, with a view to providing the large-scale prerequisites for storing over 90% of renewable energies.[10]

Surveyed within this study, experts from chemistry and the raw material and energy sector see Power-to-X as a trend of great relevance which, however, only gradually gains in importance in the study's time horizon to 2030. But significant impacts on chemistry can be expected by 2050. The speed of this process also depends on the framework conditions under innovation and energy policies (see chapter "Support by improving the general political framework conditions").

Industrial biotechnology

Quick view

- Process optimization through biotechnology methods in industrial production
- Impulse giver for the bioeconomy
- **Great growth potential for chemistry**

Industrial biotechnology (IBT) means the use of biotechnology methods in industrial production. With their help, biomass can be processed more effectively and efficiently into bio-based products like bio-pharmaceuticals, chemicals or plastics – up to energy sources.

The use of biotechnology is not new in the chemical industry. It has prevailed wherever it brings technical and economic advantages over traditional methods. Generally, this is the case where the manufacture of products in the classic way is not possible at all or very difficult and where better performing or environmentally sounder synthesis methods are available (e.g. by using certain strains of bacteria or enzyme systems). Just one example is the amino acid L-cysteine which is traditionally based on animal substances. By contrast, in industrial biotechnology this amino acid is obtained by fermentation from glucose and inorganic salts.[10]

The real synthesis work is done by metabolically improved bacteria (Escherichia coli). In molecular biological interventions, their metabolism was optimized in a targeted manner for L-cysteine production.

Industrial biotechnology has a wide field of application. At present, it is applied most frequently for the production of bio-pharmaceuticals and bio-ethanol. But industrial enzymes, glucose, amino acids and fine chemicals like vitamin B2 and vitamin C are established IBT products too. For example, the global enzyme market is estimated to have an average growth rate of 8% and to grow from 4.8 billion US dollars in 2013 to over 7.1 billion US dollars in 2018.[11]

In terms of innovation politics, great importance is attached to industrial biotechnology: It is deemed the technical basis and the impulse giver for a bio-economy and a "biologization" of chemical and pharma production. Today many microorganisms are not yet known or cannot yet be cultivated. Therefore, biodiversity has enormous potential. Against this backdrop, great chances for growth are seen for IBT. It is rated as one of the key technologies for maintaining and enhancing the international competitiveness of German industry. For this reason, the chemical industry in Germany – which is traditionally research-intensive and innovation-oriented – has built up strategic competencies and networks, with a view to assuming a key role in industrial biotechnology.

The focus is on

- establishing environmentally sounder, more climate-friendly and cleaner production processes,
- reducing the dependence on fossil raw materials,
- lowering investment costs,
- cutting energy and disposal costs,
- developing new products and system solutions of high value creation potential, enhancing competitiveness.

In the chemical industry, putting IBT into practice is seen rather as an evolution and not a revolution.[12] Progress in findings and innovations is more likely to be incremental, with gradually increasing dissemination. But Omics technologies[ii], the four pillars of biotechnology and molecular biology methods can contribute to IBT also unfolding a disruptive potential. Future regulation should keep up with scientific and technical progress in biotechnology, enabling the use of biotechnology by small and medium-sized enterprises.

[ii]Omics technologies comprise: genomics, transcriptomics, proteomics and metabolomics. They are used for the analysis and holistic characterization of genes, RNA copies, proteins and metabolic products and their interactions in individual cells up to organisms.

Business-to-Business

Changes in the supply and demand structure are emerging in business with the chemical industry's industrial customers. The trend analysis focuses on the construction and automobile industries as important customers of the chemical industry. Furthermore, digitalization widens the possibilities for shaping business models with industrial customers. 3D printing can be taken as an example of such change: during the examined time period, 3D printing has considerable potential for growth.

Construction industry – product optimization for better efficiency of materials and energy

> **Quick view**
>
> - Product optimization for easier use and longer lifespan
> - Many products are anticipated to reach market maturity soon
> - **Medium-scale potential for chemistry**

Products for the construction industry are continually optimized regarding resource preservation and environmental protection, durability, cost-efficient and environmentally sound processing and better energy efficiency. Material efficient building means the optimization of properties of building components and products in their entirety. Improved material efficiency is to enable faster, simpler and energy-saving processing. The construction industry sees material efficient building as a way of responding to strong competition and cost pressure while counteracting the shortage of skilled junior staff. Better material efficiency in construction is a slowly progressing trend because, on the one hand, many restrictive regulatory influences are determining this industry which, secondly, tends to be conservative when it comes to introducing new materials in the market.

From the chemical industry's perspective, the trend towards material efficient building brings a number of opportunities. For example, the demand for ever more efficient materials comes with a higher demand for additives for classic building materials, functional coatings and innovative multi-component systems. Long life cycles of up to 30 years and more of buildings and building components and products are a special feature of the construction industry. In product optimization, the chemical industry needs to take into account the entire life cycle of new materials. More benefits and efficiency in application need to be seen together with the challenge of recycling the material at the end of its life cycle (example: fibre concete). Already now, building insurers demand this overarching approach; they want to minimize the insured risk of a building across the entire life cycle up until demolition. This calls for an intensive use of data and the digitalization of processes.

Also in future, regulatory requirements and promotion programmes will bring a rising demand for energy-efficient buildings through energy-efficient building materials and energy-efficient building technology. Another field of growth is modular building with prefabricated components. Here, cost-saving standardization and the growing possibility of individualization open up an ever larger market. These developments can benefit the chemical industry in Germany as an innovation partner, together with other stakeholders (construction industry, building materials industry etc).

Electro mobility

Quick view

- Drive systems with electric engines
- Strongly propelled forward by regulation
- **Fields of growth but also risks for the core business**

The trend towards electro mobility describes the change away from combustion motors to electric drive systems in all part-sectors of mobility and particularly in the transport of persons.

The societal and regulatory debate about the sustainability of ca. 45 million passenger cars[13] with combustion motors in Germany has driven forward the development of electro mobility. The goal is to have 1 million electric vehicles on German roads by 2020[14] but there is still a long way to go. From 2015 to 2016, the number of electric vehicles rose by 38% - to a total of just 50,970.[15] This merely corresponds to 0.1% of passenger cars in Germany.

At the global level, electro mobility increasingly gains in importance. In 2016, there were worldwide around 2 million electric vehicles (fully electric and plug-in hybrids), reflecting an increase by 58% against the previous year. Major markets are the USA with 570,000 electric vehicles and China with ca. 643,000 electric vehicles in 2016. Electro mobility will become even more important by the year 2030. For 2030, experts estimate that worldwide 27%[16] and in Europe 20%[17] of new vehicles will be electro vehicles. With global sales of 4 billion US dollars for new vehicles in 2030[18], this would mean a turnover of over 1 billion US dollars for electric vehicles. But such estimates involve much uncertainty. Future market growth will strongly depend on progress in battery technology, the expansion of the charging infrastructure and public support for electro mobility. In view of the forecasted volumes and the scope of change in the demand structure, electric vehicles need to be seen as a disruptive product innovation – with great challenges for all established manufacturers and their supplier industries, including the chemical industry.

The trend towards electro mobility is of major consequence for the chemical industry, as inputs of chemicals and materials connected with combustion motors will dwindle or become almost obsolete for the share of electro vehicles (e.g. exhaust gas catalysts, temperature-resistant high-performance plastics, oil additives, cooling liquids, chemicals for metal processing) – while new fields of growth arise for chemical companies, e.g. in the production of innovative battery materials. There could be further potential in battery recycling.

Lightweight vehicles

Quick view

- Weight reduction of vehicles
- Indirectly driven by regulation
- **Great potential for chemistry**

The construction of lightweight vehicles is of special importance in connection with electric mobility and for lower fuel consumption in conventional drive systems. This is highlighted by several forecasts: In the period from 2012 to 2020, the weight of vehicles is likely to be reduced by over 10% across all vehicle classes.[19] In particular, this is enabled by plastics substituting metals and glass. According to one forecast, the share of plastics in vehicles will rise to 18% to 2020 – from only 14% back in 2000 and 16% in 2010.[20] Carbon composite materials are on the advance too. Previously, they were used only in niches like sports car construction while they are now entering the mass market within electro mobility. Carbon composite materials are estimated to bring an average weight reduction of ca. 200 kg. This corresponds to roughly 13 % of the average weight of a passenger car.[21]

Thus, innovative and costly (composite) materials for electric vehicles mean growth chances for chemistry. Between 2015 and 2023, the share of technical and high-performance polymers in vehicles is thought to increase at an average annual rate of 2.8%.[22]

Alongside the lower weight of materials, new production processes like additive manufacturing (3D printing) contribute to reducing the material input and weight in the construction of complex plastic and metal components (see section on additive manufacturing in this chapter). Tier 1 automotive suppliers[iii] are expecting, according to a survey by Deloitte[23], that stronger and lighter materials as well as new manufacturing methods like 3D printing will strongly influence their business. This means that electro mobility has a major influence on chemistry in Germany, both in the existing core business (lightweight construction) and beyond (battery materials, additive manufacturing).

New mobility concepts

Quick view

- Car sharing, intermodal transport, autonomous driving
- Revolution in mobility
- **Impacts unfold increasingly after 2030**

The trend of new mobility concepts comprises elements like intermodal transport (changing between modes of transport depending on necessity and existing infrastructure), the use of car sharing facilities and autonomous driving. Here, the automobile industry is faced with a potentially disruptive trend that could fundamentally change the products in demand and customer structures: The new mobility concepts are competing with the existing business model of vehicles with features according to customer specification, which are driven and owned individually.

Intermodal transport and car sharing are a reality already today. In January 2017, 1.7 million persons in Germany were using car sharing facilities.[24] Until 2021, over 2 million users are expected in Germany and 35 million users worldwide.[25] Autonomous driving is currently still in a pilot phase. The federal government wants Germany to remain the "lead provider of automated and connected vehicles" and to become a "lead market". Against this backdrop, German Parliament (Bundestag) paved the way in March 2017 for level 3 "highly automated" and level 4 "fully automated" (see fig.) for German roads. According to draft legislation, in the future it will also be allowed to deploy vehicles that take over driving control for certain periods of time and in certain situations. But in principle, the driver has the final responsibility for the vehicle; i.e. the vehicle is not driverless like at level 5.[26]

The new mobility concepts impact the demand for chemicals. In such systems, vehicles are likely to be more standardized (less premium, probably smaller) with a changing customer structure (fleet managers instead of private persons). The heavy strain on vehicles tends to reduce their lifespan. Overall, a stagnating or even slightly lower demand for vehicles is expected. More customer power for professional large customers like fleet managers can bring stronger price pressure on suppliers and, consequently, on the chemical industry.

[iii] direct suppliers to carmakers

Five levels to autonomous driving

Advanced driver assistance systems → **Autonomous driving**

1: Assistant
- Individual control functions are automated
- Driver delegates tasks but remains in control
- Cruise control, automatic brakes
- Lane departure warning system

2: Partly automated
- Multiple control functions are automated
- Accessible at any time
- Adaptive cruise control and lane departure warning system

3: Highly automated
- Automatic action in most sequences
- Straightforward occasional taking of control and comfortable transitional phases
- Expected in 2018-2020

4: Fully automated
- Full autonomy at most times
- Not expected to have control at all times
- Expected: 2020-2025 (at low speed) and 2025-2030 (with higher complexity)

5: Driverless
- System can automatically cope with all situations during the ride: no driver needed

However, the change in mobility also opens up chances for chemistry. These come from the demand for robust, resilient and durable materials for a high utilization of vehicles by changing users. Furthermore, new applications will be needed for autonomous vehicles with higher passenger comfort when on the road, e.g. in the entertainment segment. Applications for flexible seating systems and entertainment offers are some examples. This potential is tied to the market penetration of autonomous vehicles which is likely to reach a significant volume only after 2030.

Additive manufacturing

Quick view

- Objects are printed on-site, based on digital models
- Enabling new digital business models
- **Huge potential for chemistry**

Additive manufacturing (AM; also: 3D printing) enables the production of three-dimensional objects in sequential layers from various materials, based on digital models. Beside the individual and decentralized production also of complex forms, AM can reduce the materials input and bring efficiency gains. For example, General Electric has designed a fuel nozzle that is five times as stable as conventional nozzles and, furthermore, allows optimal fuel flow. Using the possibilities of AM, the weight of the nozzle is reduced by 25% and its design is simplified from 20 individual components to just one part.[27]

In other applications, e.g. 3D printing for buildings, material savings of up to 60% can be realized.[28]

Over the past years, sales achieved with additive manufacturing methods have risen by ca. 30% annually. Many processes are ready for serial production. In 2015, global sales of 3D printed products amounted to 5.2 billion US dollars.[29]

AM impacts production, design and supply chains in a wide range of industries. For example, in principle AM can enable next generation engineering with rapid prototyping and short investment cycles and personalize products with customer involvement. One example is the "Shapeways" platform for 3D printing of customer-designed products.[30] With just-in-time production and favourably priced manufacture close to customers, AM can also contribute to optimized supply chains.

This has already brought a situation where industries that relocated from the USA or Europe to Asia (e.g. the textile industry) are returning to their original locations. Reebok is manufacturing (high-priced) parts of its product portfolio via 3D printing in the USA.[31] But this decentralization can adversely affect export-oriented industries.

Even though introducing 3D printers for the manufacture of medicines in pharmacies or at home is still a vision of the future, such use of 3D printing by manufacturers is already a reality.[32] Back in 2015 the US Food and Drug Administration (FDA) approved the epilepsy drug "Spritam" as the first 3D-printed tablet worldwide. The tablet from Aprecia Pharmaceuticals is produced by alternate printing of different layers of power and liquid droplets, resulting in a high-dosed and fast-dissolving medicine. So far, this combination could not be realized with conventional production methods.[33]

3D printing opens up new possibilities for chemistry where materials are concerned. For example, the cost per quantity unit of high-quality plastics for 3D printing are partly 60 to 100 times higher than the cost of materials for other production methods, and the margins are higher. But new business models and distribution structures require considerable investments. Here, chemical companies can use their comprehensive material portfolios and their expertise and innovation power in materials development and processing for offering a wide range of applications for various industries.

Also beyond innovative materials, chemistry can make contributions by expanding its range of services by digital services and by assuming a central role in the newly forming economic networks. In strategic partnerships with other suppliers e.g. of printers and print software or printer farm operators, 3D printing has the potential for new business models where chemistry can use its competence and customer base.

Business-to-Consumer

Relevant trends for chemistry are emerging not only in business with industrial customers but also for end consumers. Firstly, this is about possibilities for personalizing products by manufacturing small lot sizes in more flexible production processes and by offering additional services as well as direct distribution on online platforms. But, secondly, the perception among consumers of products, transport, uses and disposal of chemical products is subject to change too.

Perception of chemistry

Quick view

- Non-fact based discussion about substances, intensified by social media
- **Risk of disruptive effects without winners**

This trend describes the overall perception of chemistry by consumers. There is a direct perception of chemical products by end consumers, especially in consumer-related fields like detergents and cleaning products, personal care products and cosmetics. Here, there is also a special sensitivity for possibly misleading, non-fact based information about chemical ingredients. This can be intensified by the dynamics in social networks or campaigns targeting end consumers. Most recent examples of such developments are the discussions about parabens as preservatives in the cosmetics industry and aluminium salts in deodorants.

Such issues mainly impact individual manufacturers (of branded products) but the effects indirectly affect chemistry as a whole too: through a negative image and the "delisting" of certain ingredients. The economic consequences can be massive for individual chemical companies, particularly where businesses have specialized and smaller product portfolios. At the same time, quite often existing regulation does not permit the development or testing of new (substitute) ingredients.

The chemical industry is called upon to respond to such developments in a timely and effective manner and to provide broad information about the advantages and potential risks of chemical ingredients and new technologies. Stakeholders need to be involved early, and their concerns must be heard and addressed. For this purpose, new involvement concepts have to be developed in the cooperation with stakeholders. The sustainability initiative Chemie[3] is a good example of this type of involvement concept.

Agriculture

Major technological developments are emerging in agriculture, plant breeding and the use of plant protectants and fertilizers. Moreover, customer preferences are changing and new fields of application are developing. The wish for nutrition of particularly strong environmental compatibility and changed consumer behaviour will enable new business models.

Urban farming describes concepts for the production of agricultural products in or around cities, using modern control and steering technologies intended to minimize the consumption of energy, water, fertilizers and plant protectants. Except for some conurbations, in the examined period to 2030 urban farming is likely to have only minor importance for agriculture overall and thus for the chemical industry.

The assessment is comparable for efforts by non-governmental organizations and the Green Party regarding the agricultural turnaround (Agrarwende). Such efforts have a growing role in the public debate in Germany and internationally. This trend describes the pursuit of an allegedly environmentally sounder, more sustainable production of agricultural products entirely without mineral fertilizers and chemical crop protectants. However, this means losses in productivity and quality as well as higher costs. This cannot be reconciled with the goal of adequate food suppliers for a growing world population.

A demonstrably more promising way is to increase productivity in agriculture, inter alia, through technologies that make crops more resistant or tolerant to pathogens and climate change (precision breeding) and an efficient use of high-quality crop protectants by applying digital technologies (digitalization of agriculture).

Genome editing as precision breeding

> **Quick view**
>
> - Molecular biology methods for targeted DNA modification
> - CRISPR/CAS9 are new methods
> - **Potential for chemistry depends on regulatory framework**

Genome editing enables the optimization of crops through molecular biology methods up to precision breeding. New techniques like CRISPR/CAS9 and the better precision and speed that come with them open up new fields of application in crop breeding and crop protection. For example, in a targeted manner genome editing inactivated certain wheat genes that help mildew fungi enter cells. Once these genes are inactivated, the crops are resistant to mildew. Whether this potential can be used in Germany will depend, inter alia, on the regulatory framework conditions. In particular, it is important whether organisms treated by using gene editing methods are generally classified as genetically modified mechanisms and regulated or not according to Directive 2001/18/EC. Depending on the application, a genome editing method can trigger a point mutation, which does not constitute a genetic modification, or introduce a gene from another species. Only the latter is a genetic modification according to the German genetic engineering act (GenTG) or EU Directive 2001/18.

For the chemical industry, a stronger resistance to diseases initially brings a falling demand for crop protectants. But it also enables the use of more innovative products specifically tailored to the remaining needs, e.g. crop varieties that are adapted to climate and resistant to pathogens.

Digitalization of agriculture

Quick view

- Interlinking and use of various data to optimize the entire cycle of plants
- Newly forming economic networks
- **Great chances and risks for chemistry**

The digitalization of agriculture (precision farming) describes the use and interlinking of data on soil, weather and crops as well as further relevant data, together with digital system technology for optimizing the entire cycle of plants (sowing time, fertilization, irrigation, crop protection and nutrition, harvest time) – in order to increase the yields on existing farmland while reducing the costs.

The thus achieved efficiency increase can help avoid future food crises: For example, the global demand for grain is expected to go up by altogether 600 million tonnes from 2015 to 2025 (average increase by 1.4% annually).[35] This rise in demand calls for clearly higher productivity, as agricultural areas can be extended only to a very low degree.

The past years have seen major technical progress in the digitalization of agriculture through an improved availability of data and new analytical options. Satellites, drones, sensors (e.g. in soil) and autonomous machines provide exact information on the condition of crops and soil and the development of yields. The fuel requirement of smart tractors is 10% lower[36], optical sensors open up a savings potential in fertilizer consumption, and the application of crop protectants to control weeds and grasses specifically on selected parts of farmland only requires clearly reduced volumes. According to estimates, the digitalization of agriculture can reduce input costs by 15% through better information, improved analytical methods and automation.[37] In total, the global market potential of digital agriculture is estimated at 10.7 billion US dollars in 2025.[38]

The digitalization of agriculture has various impacts on the chemical industry. Firstly, it reduces the volumes of agrochemicals required per unit area; secondly, the demand increases for highly efficient crop protectants for targeted use and for tailored crop varieties. This is an opportunity for companies to develop new business models in digital agriculture.

Here, changing business models constitute the greater challenge which is also more important in structural terms. In the future, various actors – like manufacturers of agricultural machinery, fertilizers and crop protectants as well as crop breeders, innovative start-ups and large technology companies – will form platforms offering products and services connected with fertilization, irrigation, crop protection and varieties.

Agrochemicals and biologicals (biological crop protection products), crop varieties and competence in application are key factors in these networks. This puts the chemical industry in a good position not only for participating in the new digital business models but for assuming a decisive role in them.

Pharmaceuticals & healthcare

The health sector is characterized to a particularly high degree by innovative medical and technical developments. The personalization of therapies, further developments in professional medical technology and new digital applications for doctors and patients are of special importance.

Personalized medicine

Quick view

- Specifically adapted use of drugs based on biomarkers
- Current focus on oncology, infectiology, metabolic disorders
- **Great potential for pharmaceuticals and chemistry**

Personalized medicine (also: stratified medicine) describes the trend to understand the causes of diseases at the molecular level, fast and comprehensively. Findings on the mechanisms and various subtypes of diseases, the different disease risks of persons and the different effects of drugs or other therapies on individual patients are reflected in personalized treatment strategies.[39]

Important prerequisites for and drivers of the development of personalized medicine are progress in data analysis, sequencing techniques and genomics, a further acceleration and cost reduction of gene sequencing and technological progress in genome editing. This enables a taking into account in prevention and healthcare of the different conditions and needs of various patient groups with very similar genetic predispositions or biomarkers – by way of tailored drugs. In so-called precision medicine, these parameters are extended by lifestyle, social factors and environmental influences.

The pharma industry in Germany is a strong innovator. For this industry, the described medical approach opens up new fields of growth through the personalization of existing drugs and active substances. Pharma companies can transfer the findings on underlying disease mechanisms into active substance research and development and bring research in a more targeted form. This can increase the success rate in clinical trials, as findings on patients falling in certain patient groups can improve the selection of trial subjects based on their genetic profiles. Also, the breakthrough in genome editing makes it easier to develop new active substances. Existing fields of application for personalized medicine are mainly oncology, infectiology like HIV therapies[40] or hepatitis C infections[41], as well as metabolic and musculoskeletal disorders.

A successful implementation of personalized medicine needs high investments in research and development of validated tests and drugs. Another major success factor is cost reimbursement by health funds. This trend is driven forward by the wish of society for a medically improved and economically more sustainable treatment of diseases.

E-health and new medical technology

Quick view

- Wireless health, telehealth, mobile health
- Combination products, miniaturization, 3D printed medical devices
- Strong growth in the coming years
- **Medium impacts on the pharma industry**

Meaning the use of digital technologies in the health sector, e-health comprises all aids and services where information and communication technologies are applied for the purposes of prevention, diagnosis, treatment, control and administration in healthcare. Thus, e-health includes topics like electronic patient file, wireless health, mobile health, telehealth, telematics infrastructure and software for hospitals and doctors' offices.

e-health and new medical technology also reflect the interest in stronger patient commitment: Additionally to consulting doctors, patients use alternative sources of information for orientation about health topics. According to a survey by the EU Commission, already today some 60% of all internet users resort to the web for health issues.[42] Further fast growth, both globally and nationally, of digital health information media can be expected in the future. Experts anticipate growth rates of up to 18% annually to 2020, leading to a global market volume of roughly 300 billion US dollars in 2022.[43]

Wireless health is the integration of wireless technology into traditional medical technology. Also in the years to come, wireless health will remain the largest sector of e-health. Building up this digital infrastructure creates the basis for a holistic gathering and use of medical data. New medical technology comprises new products like 3D printed, miniaturized and combination products. Already now, bio-sensors can be integrated in these products. Bio-sensors can continually control a large number of parameters (e.g. contact lenses capable of measuring blood glucose levels). In the next 5 to 10 years, various new products will reach market maturity; inter alia, permanently implantable bio-sensors are expected.[44]

Mobile health – i.e. rendering medical services by way of mobile communication – is another major aspect of e-health: It will be the strongest growth segment of e-health in the coming years, opening up further possibilities for patients to search for information, exchange experiences between themselves and with doctors, and actively participate in therapies.[45] However, e-health addresses not only consumers.

Additional digital offers are part of future business models of pharma companies in Germany.

In the future, e-health will also offer solutions for doctors to help them in their decisions, up to automated diagnosis. Innovative, research-based pharma companies in Germany are involved in this exchange of experiences and provide the various stakeholder groups with scientifically sound information.

Self-medication, i.e. the treatment of diseases by patients themselves and at their own responsibility with medicines not prescribed by doctors ("over-the-counter"/ OTC), will be facilitated by digital media too. This trend is supported by the possibility to have non-pharmacy-only products supplied to the patients' homes through online platforms.

Overall, e-health and new medical technology have noticeably effects on the pharma industry in Germany. For example, health information can be obtained from digital sources and undetected needs of patients can be identified. Gathering and evaluating comprehensive data volumes is a critical success factor, inter alia, for improving healthcare by analysing "real world data". These also form the basis for new business models. 93% of pharma companies surveyed by Germany's digital association Bitkom in 2015 state that additional digital offers (e.g. apps that help in the intake of medicines) will be a part of future business models.[50]

For the pharma and chemical industry, new medical technology also brings opportunities through combination products, i.e. combining a medical device with a drug. Combination products open up the chance of enhancing the therapy adherence of patients and improving their quality of life e.g. through therapy-accompanying measuring (blood glucose for insulin dosing). Thus, they can raise the quality of available therapies generally. This also includes new products from 3D (in future: 4D) printing. It will be possible for chemistry to develop and offer the materials for such products. Materials for 4D printing have a shape memory that can be activated at a certain moment in time. For example, implants can first be manufactured in an easily processable form and then take their stored shape at the desired location.

Interim conclusion

In the medium-term, many of the above-described trends have considerable impacts on the companies of the chemical industry. They differ not only regarding their underlying reasons but, above all, regarding their consequences. In particular, it can be differentiated according to whether the trends in their impacts on the chemical industry need to be seen rather as incremental or disruptive.

Incremental changes are characterized by continuous innovation and improvement processes that largely take place inside existing product portfolios and process technologies and established business models. The structure of value chains largely remains unchanged. Such incremental, continuous innovation processes are part of the existing business and success models of the chemical industry in Germany. Also in the future, they will offer significant growth opportunities for chemical and pharma companies.

The chemical industry in Germany is traditionally in a good position for coping with the challenges of incremental changes. But increasing competition intensity in the national and international environment means an ever faster erosion of thus gained competitive advantages. Also in the future, major efforts will need to be made in research and development. Here, the medium-sized chemical industry – as an innovative industry close to consumers – is an important driver. Especially this industry can and needs to deploy its strengths through cooperation across companies and sectors (see chapter "Recommendations for action to companies and their associations").

Disruptive changes in the chemical industry's environment profoundly influence product portfolios, value structures and new business models. This comprises both the chemical companies themselves and the entire structure of their customer and supplier relations. Frequently, disruptive changes are triggered by changing needs of society, regulatory changes or new technologies. On the one hand, this type of change brings changes for chemical and pharma companies in new fields of growth. On the other hand, it presents challenges for fundamentally adapting products, services and business models to the new framework conditions.

Disruptive changes come in two forms: disruptive product innovations and disruptive changes of business models.

- Disruptive product innovations describe technologies or products that are fundamentally different from those on the market or in demand. They offer great growth potential while competing with existing products. The above-described trends (e.g. in e-mobility and personalized medicine) can be subsumed here, as they can profoundly change the demand structures in the respective product segments. All the same, disruptive product innovations only have a limited impact on the structure of value chains – to the extent that products can continue to be manufactured and marketed within existing structures.

Change in the chemical industry's environment

Incremental changes	**Disruptive changes**
Customer requirements increase gradually	Fundamentally new / changing societal needs, regulatory framework or technologies

Optimization	**Offer**	**Customer relationships**	**Business models**
Products or manufacturing processes are further developed	Existing products are phased out (physically or digitally)	Roles in value chains are newly / re-defined	New business models emerge, linear value chains develop into (digital) economic networks

Examples

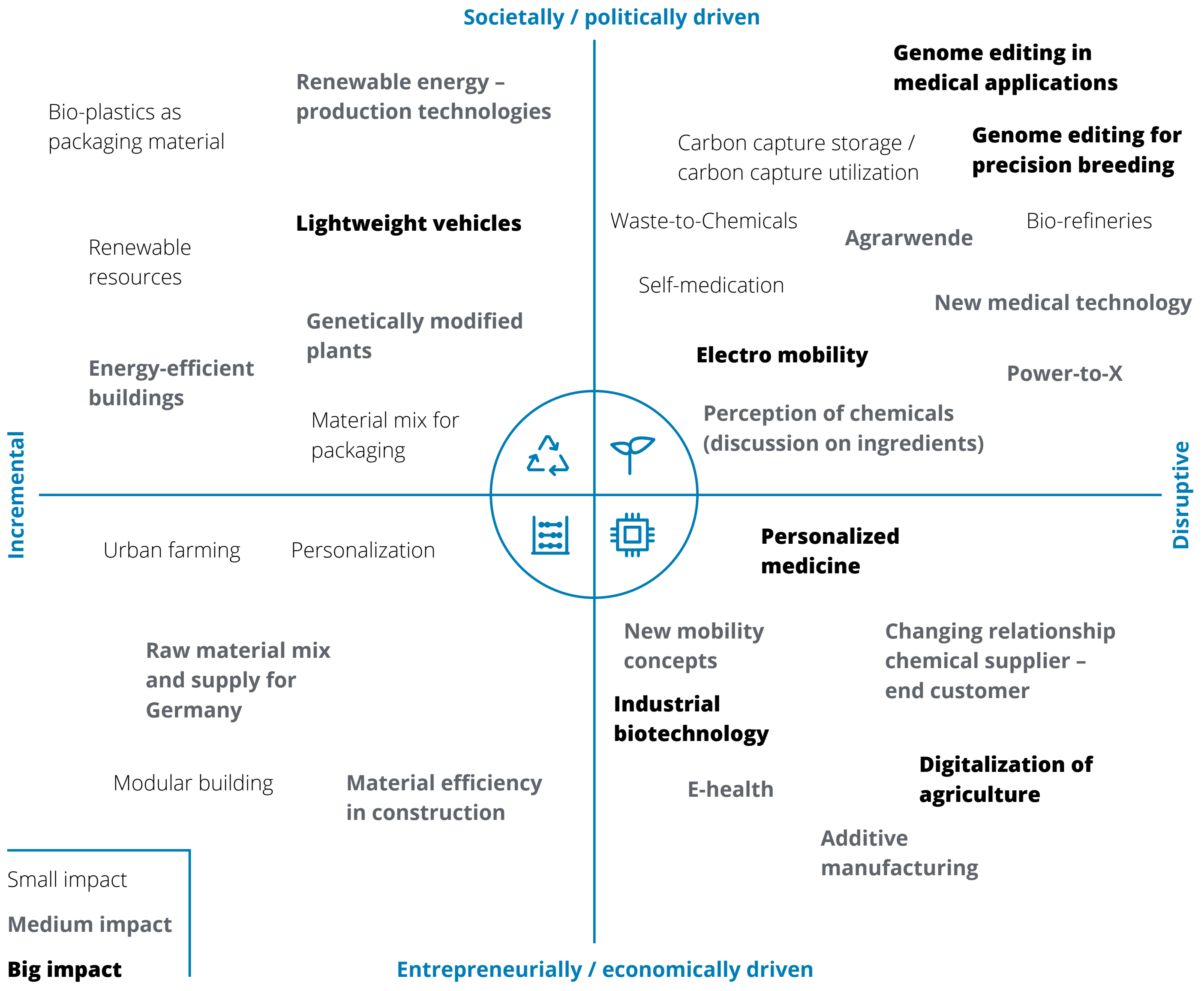
Optimization	Offer	Customer relationships	Business models
• Lightweight construction of vehicles • Efficient materials in the building sector	• Industrial biotechnology • Personalized medicine • Electro mobility • Perception of chemistry	• Changes in end customers of chemistry • E-health	• Digitalization of agricultur • Power-to-X • Additive manufacturing

- By contrast, disruptive changes of business models describe a new form of service rendering where several companies bundle various products and services and jointly offer them to customers. On the one hand, this gives the opportunity to chemistry to get closer to customers and to take over a larger share of value creation. On the other hand, there is the risk of chemistry being reduced purely to a supplier of materials and chemicals and of other, new market players establishing themselves between the customers and chemistry. Here, digital business platforms and value networks are gaining in importance, and the gathering, exchange and analysis of digital mass data are becoming ever more important. In this new environment, the above-described role as a chemical supplier – with a focus on a more efficient production of innovative chemicals – can pose a risk if other non-chemical competitors build market power and control value networks.

At a second level of differentiation, a distinction is possible according to whether the above-described trends and the connected decisions largely follow economic or business management calculations or whether societal and political criteria have a dominant role for the further development. This categorization is difficult and also depends on the development of societal and political dialogues. All the same, a distinction according to these criteria brings indications for the broadness of the connected societal debate and the involvement of political and civil society stakeholders in the development.

According to these distinction criteria, the following graph categorizes the 30 trends examined within this study into four different groups. This is based on a joint assessment from the viewpoint of the participants in the expert workshops where the framework analysis was performed. The type face of the trend names reflects the magnitude of the impacts on chemistry and pharmaceuticals in Germany to 2030.

Trends in the chemical industry up to 2030



It emerges that many innovations in important business fields of the chemical industry like the automobile, construction and packaging industries but also in production processes like industrial biotechnology will rather come about stepwise. But in fact, an unusually large share of the changes for the chemical industry, which can already be predicted for the coming years because of product and technology innovations, have a disruptive character.

A number of these developments are closely connected with the advancing digitalization of business models, as is highlighted by the examples of additive manufacturing, digitalization of agriculture and e-health. Furthermore, many developments – especially in the upper half of the graph – have an obvious reference to sustainability topics and circular economy concepts (e.g. renewable resources, renewable energies, carbon capture storage, carbon capture utilization, bio-refineries, bio-plastics). Many of these trends also point to an increasing "biologization" of the chemical industry.

Thus, the analysis of developments in the chemical industry's environment reveals two thematic focal points that can be subsumed under the headings circular economy and digitalization. Both topics will trigger transformation processes that will cover not only individual companies but the chemical industry and the economy as a whole. Business models and the role distribution in industrial networks will change considerably in the coming years.

At present, many industries are evaluating the potentials of digitalization. This tends to be linked with far-reaching changes in the structure of the industrial value chain. Therefore, digitalization is not only a trigger for fundamental change in the environment of chemistry, it also offers the opportunity to make a success of change in the chemical industry and, above all, to open up perfectly new business and service sectors. Society and politicians demand the further development of circular economy concepts, in order to achieve sustainability goals. From the viewpoint of companies, this brings growth potentials – as products and services from chemistry can play an important role in closing the material cycles of the chemical industry's customer industries. Furthermore, this tends to influence the perception of the chemical industry: Part of the general public still has an insufficient picture of the industry as a major innovation driver and problem solver for the main sustainability topics.

So far, the interplay between circular economy concepts and digitalization has largely gone unnoticed. The detailed analysis workshops have shown that there are significant parallels in the structures of digital and circular business models which result in similar requirements in the companies.

Moreover, the growing possibilities of digitalization can benefit the expansion of circular economy models. In the light of these interactions, it makes sense for the study to give emphasis on both focal points and to examine them as a whole with regard to their challenges and the ensuing recommendations for action.

The cumulative occurrence of many potentially disruptive developments, especially in the fields of digitalization and circular economy, is unusual and makes high demands to the chemical industry's ability to innovate. Many of the developments discussed in the framework analysis – particularly the intensive use of data as production input – open up further growth potentials if the companies make good use of the connected chances. At the same time, there are huge risks of non-chemical competitors building market power and trying to take away value creation shares from the chemical industry.

At present, the concurrent interaction between all these features suggests change towards a new development phase for the chemical industry – from Chemistry 3.0 as a phase of globalization and specialization to Chemistry 4.0 as a new stage of development with a focus on digitalization and circular economy.

Digitalization and circular economy trigger fundamental changes while offering the opportunity to make change in the chemical industry a success: by opening up new fields.

Survey among medium-sized enterprises: framework analysis

Medium-sized enterprises are a mainstay of the German chemical industry. Even though global business groups dominate the public perception, the chemical industry in this country is mainly characterized by medium-sized structures. Over 90% of chemical companies in Germany have under 500 staff, while the total number of employed in the industry amounts to ca. 165,000 persons. With an annual turnover of around 55 billion euros, medium-sized enterprises contribute just under 30% to the industry's total sales. This is made possible by a high degree of specialization and the opportunities of globalization.

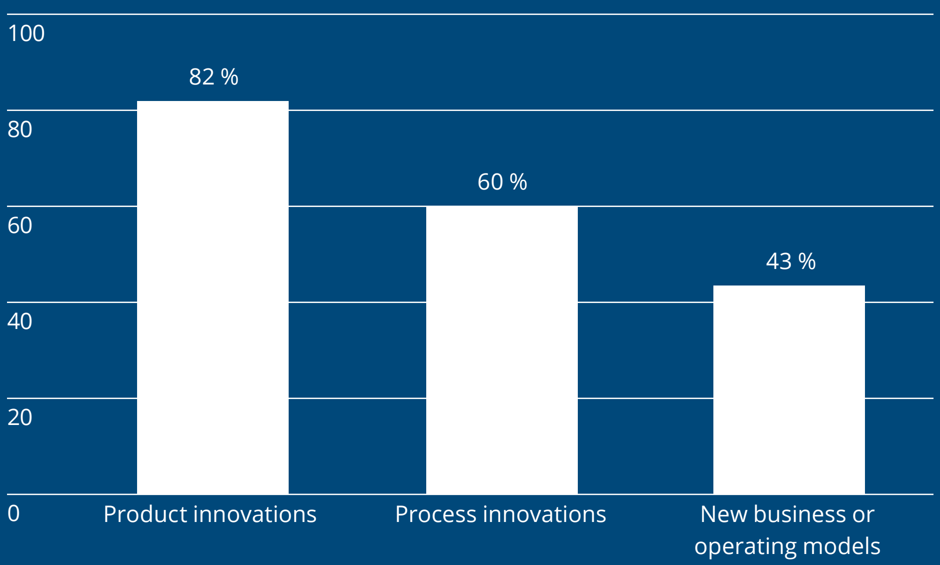
Small and medium-sized enterprises are successful in their strategy of opening up and filling niches; many of them are world market leaders in their respective fields. Medium-sized enterprises are not only important suppliers to large business groups: They are also – and this makes the chemical industry different from many other industries – major customers and quite often partners in research and development. They process chemical pre-products into specialty solutions for industrial customers, agriculture or consumers. Hardly any other chemical industry location worldwide has medium-sized enterprises of such high performance and specialization.

Medium-sized enterprises also use the opportunities of globalization. Roughly 45% of their sales are achieved abroad, half of this percentage outside Europe – while most production activities take place at the location Germany. Therefore, the strongly growing foreign markets in Asia, North America and Eastern Europe are mainly served by exports.

Medium-sized chemical enterprises in Germany are doing well. But the competitive pressure is high. Over 82% of enterprises rate the competition intensity as "high" or "very high". It is also worth noting that 42% of enterprises hold that the competitive pressure has increased considerably since the economic crisis of 2008.

Medium-sized chemical and pharmaceutical enterprises in Germany are under strong adjustment pressure. The environment trends examined in detail in this study as well as the digital revolution and the transformation towards a circular economy will trigger change processes in the future. Most companies are anticipating major incremental changes. Around 30% of enterprises are even expecting considerable disruptive changes in the chemical and pharmaceutical business. These include a comprehensive adaptation of product portfolios, the use of new process technologies and changes in value creation structures and business models. Only about 7% of enterprises are not expecting digitalization and circular economy to bring

Importance of various innovations to companies (multiple answers possible)
Shares of enterprises that attached high or very high importance to the respective innovation segments.



changes for their own undertakings. But all surveyed enterprises agree on one point: They see most developments as opportunities for their companies, and they want to use these opportunities mainly through investments. In order to strengthen their future viability, medium-sized chemical enterprises invest almost 5% of sales in innovations. Traditionally, product and process innovations have a high or very high importance. But the importance of new business and operating models is also high or very high for 43% of companies, so the membership survey (see chart). Due to the immense complexity of change in the environment of chemical business, the innovative ability of individual enterprises is often not enough. Therefore, companies resort to innovation cooperations. In their innovation projects, 75% of enterprises cooperate closely with suppliers, customers, universities or research institutes.

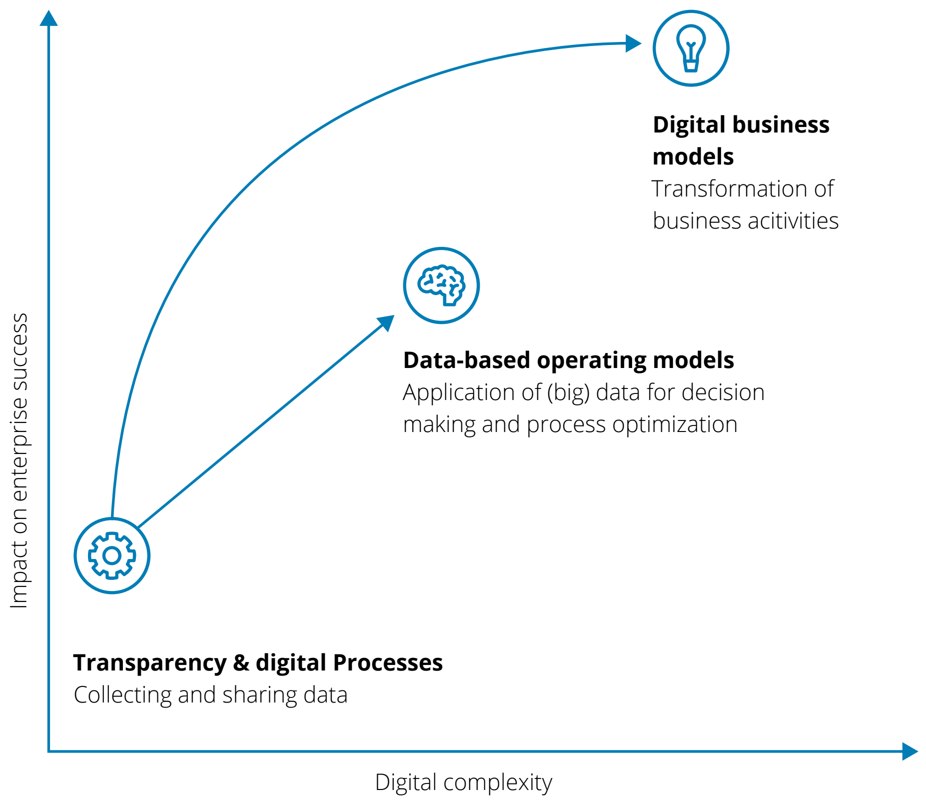
Digitalization in the chemical industry

This chapter describes the main fields for digitalization in the chemical industry, from efficiency increases to opening up new fields of business. The focus is on prerequisites for and possibilities of new, digital business models.

The developments summarized under the generic term “digitalization” have strong impacts. Their depth and scope should not be underestimated. Change is progressing much faster than was thought just a few years ago, and it is taking place at the same time globally. Almost 90% of over 3,200 executives in 131 countries and 27 industries, who were surveyed by Deloitte and MIT in 2016, agreed on these points.[46] A survey by Germany’s digital association Bitkom comes to the same conclusion. 80% of surveyed small and medium-sized enterprises think that digitalization is essential for the further existence of their companies.[47] Digitalization is changing the industry, particularly through a new quality and depth in the connection between the physical world (like plants and products) with the digital world (data). For the chemical industry, this interlinking – together with progress in computing capacities, intelligent software and the availability of technical systems (drones, robotics) – opens up many possibilities. These range from the optimization of core processes in the chemical industry to the option of seeking strategic growth through new business models.

But digitalization is a broad term. In principle, the various starting points of digitalization can be subdivided into three categories which have different (technical) focuses and assume an increasing degree of digital maturity in the companies. All digital aspects have in common that chemical companies recognize the value of data so that data need to be protected adequately. Therefore, the importance of cyber security is growing rapidly. Chemical companies need to deal intensively with this issue to protect themselves and their partners and customers.

The three categories of digitalization



Transparency & digital processes

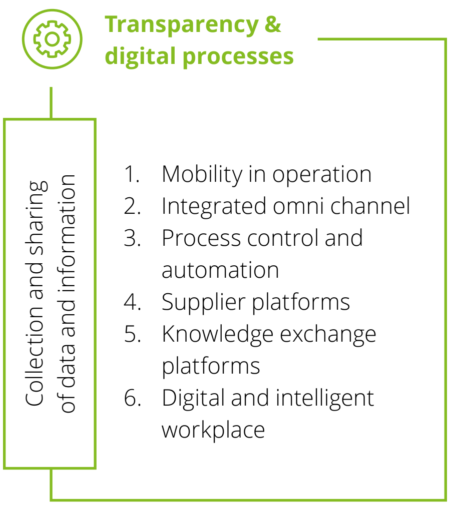
The category "Transparency & digital processes" comprises the collection and first use of digital data at the operational level of chemical companies. Efficiency potentials are utilized within production and business models that essentially remain unchanged. The digitalization of these operational processes also forms the basis for an efficient knowledge management. This is vital for successfully shaping the generation change in chemical company staff. Here, the chemical and pharmaceutical industry is comparatively advanced especially in its continuous and discontinuous production processes but also in business processes. The central and digitized control of plants and processes is often standard. But digitalization with the increasingly systematic collection of digital mass data by sensors and actuators enables yet more progress, e.g. a further automation of production processes.

The category "Transparency & digital processes" can be described by way of six different levers (see chart) two of which (mobility in operation and integrated omni channel) have the highest value creation potential for chemistry in the years to come.

Mobility in operation is the mobile retrieval and control e.g. of temperature and pressure data, the mobile handling of service processes like plant maintenance, and the exchange of relevant information in real time. Mobility allows a transparent, effective and efficient data management and the optimal use of on-site resources. Additionally, it enables the virtual deployment of decentralized experts.

Integrated omni channel is an instrument for enhancing the customer experience. 70% of chemical companies surveyed by Deloitte have already invested in this instrument within their digital initiatives.[48] This is about a seamless communication with customers across all distribution channels. Classic channels and digital channels are connected in such a way that all particulars about customers and their information and purchasing behaviour are available in their entirety and can be analysed – enabling the control and personalization of the customer experience across all channels and products.

Overview of digitalization levers for "Transparency & digital processes"



Data-based operating models

In data-based operating models – the second category of digitalization – the data collected in the category "Transparency & digital processes" are used more intensively and might be linked with other external data. This contributes to better decision-making and efficiency increases.

Data-based operating models want to benefit from the advanced possibilities for data collection and processing (e.g. mass data analysis) by linking both internal data (e.g. on stocks) and external data (e.g. on the behaviour of markets, customers and competitors), using them to optimize operational and operative business processes.[49] In the following, 8 digitalization levers are described. From the viewpoint of digitalization experts, in the coming years these levers will have the highest added value[50] for implementing and shaping the data-based operating models in the chemical industry.

Asset performance management & optimization

The continuous optimization of plant performance and utilization and relevant reliability are essential for the chemical industry.[51] The combination of recording and integrating real time information about performance, reliability and state of any type of operating resource with the visualization and analysis of such details takes optimization to a new level. Asset Performance Management – based on the systematic and automated analysis of mass data – can increase the lifespan of plants, reduce operating costs and minimize the risk of failure.

Overview of digitalization levers for "Data-based operating models"

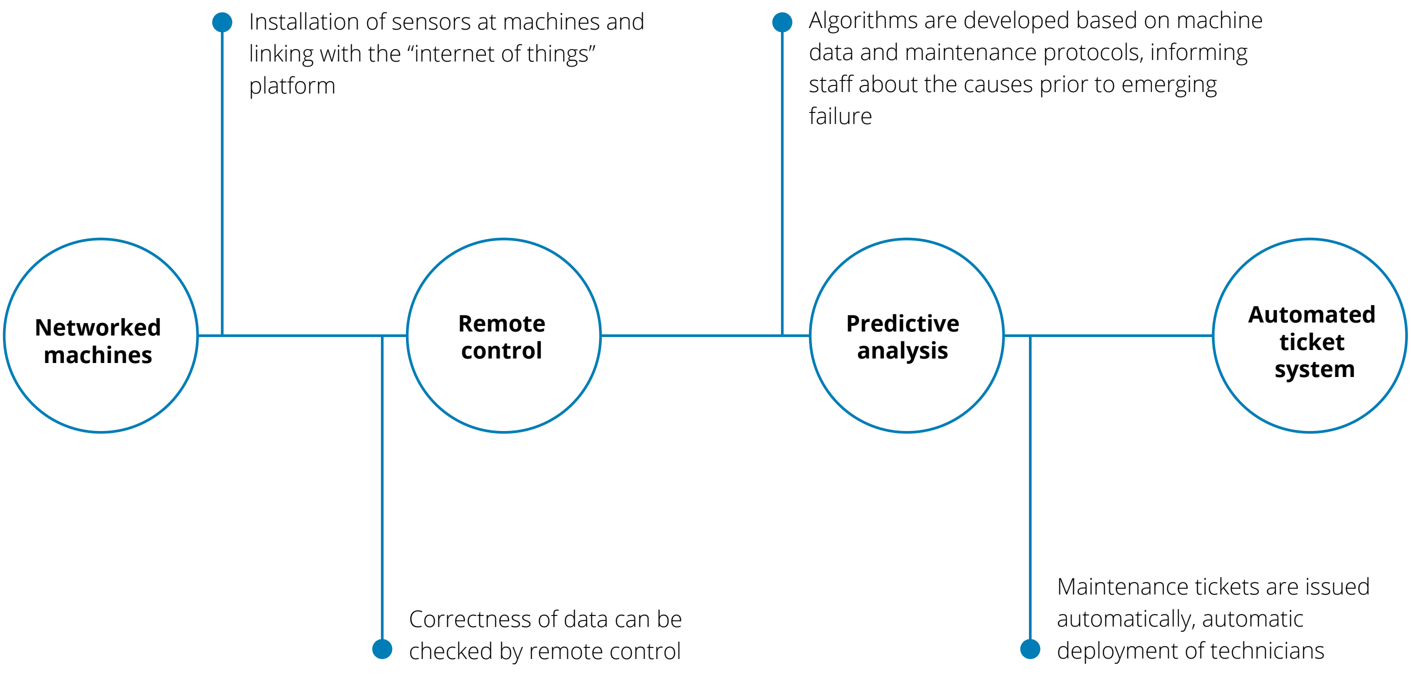
Data-based operating models

Use of data for smart decisions & optimized operation

1. Asset Performance Management & Optimization
2. Predictive maintenance
3. Demand-driven production & advanced forecasting
4. Advanced inventory management
5. Connected logistics
6. Smart & virtual plant
7. Direct distribution
8. Value-based pricing

Predictive maintenance
An (unplanned) plant failure can have far-reaching consequences for a chemical company. Predictive maintenance can minimize such failures and prolong the lifespan of components. Predictive maintenance can reduce the time for maintenance activities by 20% to 50%, increase the availability of plants by 10% to 20%, and reduce total maintenance costs by 10% to 55%.[52] Predictive maintenance is not a new topic for the chemical industry, but many companies have identified additional potential within digitalization and are investing in digital technologies for predictive maintenance. This includes e.g. sensors for collecting mass data about the condition of machinery, ticket systems for error messages, and the development of customized algorithms for predicting the maintenance needs. 41% of surveyed executives from the chemical industry confirm investment measures in this direction.[48]

Schematic description of predictive maintenance



Demand-driven production & advanced forecasting
Forecasting demand is becoming an ever greater challenge in times of increasing volatility and with a variety of fluctuating planning parameters. Chemical companies can optimize their production and capacity planning by adapting it as much as possible to the future demand and by making their production more flexible. In order to improve the quality of forecasts, previously unused or unlinked indicators are analysed and evaluated together in mass data-based forecasting. More classic indicators like historical customer data, current external data like economic indicators and other economic data on customer industries can be used for this purpose. However, also information about changes in legislation and company-internal information about strategies, expansions and acquisitions or spin-offs are relevant here. The automated analysis of contributions in social media brings further possibilities for sales forecasts.

This course of action is already widespread in chemistry close to end consumers. For example, after a pilot project in Europe reduced forecasting errors by 29% and the days of inventory held by several days, AkzoNobel introduced the software "Demand Sensing and Multi-Enterprise Inventory Optimization".[53]

Advanced inventory management
Additionally to better precision in demand forecasting and an optimized safety stock planning, the optimal management of outgoing warehouses is another major success factor for future inventory management. Rising requirements to the ability to deliver with broader product portfolios call for solutions that existing inventory management could not fully provide. Here, digitalization brings new possibilities with the digitally supported real-time optimization of the value chain. It enables manufacturing companies to reduce their storage costs by 20 to 50%[54] while coming up to the rising requirements to flexibility and delivery speed.

One implementation example is the analysis via sensors of real-time information on incoming and outgoing goods and their location, with a corresponding optimization of warehouses. The automation of warehouse logistics by robots and drones as well as support for warehouse staff in logistics processes through "augmented reality" opens up further efficiency potentials. In a pilot project, DHL clearly increased the efficiency of processes by supporting warehouse staff – through "augmented reality" – in in-store navigation and product selection.[55]

Connected logistics
The term "connected logistics" means the networking of all processes into an automated material flow inside and beyond the company. Such networking can be achieved e.g. by sensors or locating technologies in real time for products, means of transport or packaging whose virtual representation is realized with an "industrial internet of things" platform (IIOT). In this way, chemical companies can increase transparency in the value chain, with a better synchronization of their in-house logistics and customer logistics. At the same time, the transport of goods is optimized: Waiting and throughput times and the use of means of transport are reduced.[56]

These processes are complemented by new technical possibilities in goods transport, e.g. autonomous driving and platooning.[IV] Driverless vehicles become more important in in-plant transport too. Increasingly, companies rely on electric drive vehicles (e.g. fork-lift trucks). Operational logistics staff are supported by networked and portable smart devices (e.g. smart glasses to process checklists and orders, for identity checks, warehousing processes etc).

Smart & virtual plant
The smart & virtual plant concept comprises aspects like automation and modular production up to a virtual representation of whole plants. In modular production, small separate workstations enable workflows that are highly flexible in terms of time and space.[57] Modular and automated mixing and formulation of products is an important aspect to adapt products to customer-specific requirements fast and flexibly. Against the backdrop of faster innovation cycles with shorter product life cycles, this is increasingly gaining in importance.

The virtual plant concept describes a new, digital method of optimizing chemical production. Here, the entire production process is included in a 3D virtualization that can be called a "digital twin". This "digital twin" is an application/simulation that aggregates the operational and environment data of the physical processes in a plant and combines them with company data (e.g. bill of materials) into a digital real time model. In this model, different conditions and deviations in the plant can be simulated quickly, risk-free and comprehensively with the help of algorithms and analyzed regarding their impacts. The thus collected results show where costs (operating, warranty, product introduction costs) can be reduced. They also highlight where quality can be improved or where efficiency gains are possible in production facilitites.[58]

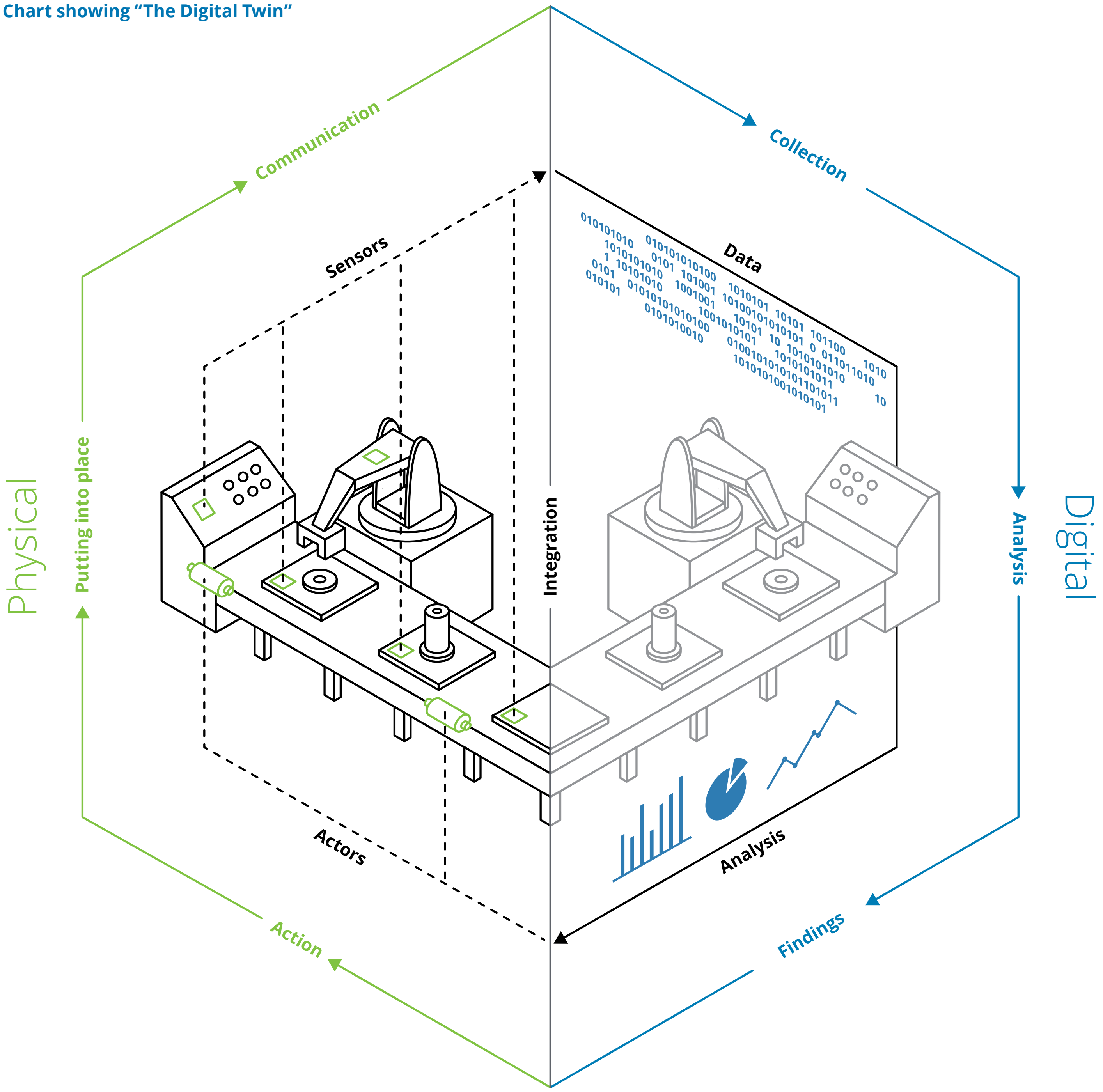
In this manner, smart factory can, firstly, comprehensively optimize the operation of existing production plants. Secondly, the collected data can be included in the training of staff and the construction of new plants.

Virtualization is not necessarily limited to production plants. It can also include upstream and downstream processes like logistics or even the application of the product as such, e.g. to simulate and analyze the use of the product in its future application.

In research into pharmaceutical active substances, simulating active substance molecules and their sites of action in the body has been an important instrument for many years for a faster screening and evaluation of potential active substances. Simulation does not replace clinical trials, but it speeds up the search for new medicines. Companies use the 3D VisBox™ technology so that chemists, neuroscientists and other researchers can visualize the human body at the molecular level and virtually explore it. In this way, information can be gathered and prioritized more quickly and assessed together with various colleagues.[59]

[IV] Vehicle system for road transport where trucks can closely follow one another on the motorway, with the help of technical drive support and control systems.

Chart showing "The Digital Twin"



The further development aims to simulate larger chemical systems in a quantitative, anticipatory and scalable manner. Higher computing capacities through progress in quantum computer technology, new analysis methods like the atomic force microscope and advances in mathematics and machine learning are to enable such "in silico" experiments in chemistry.

Based on these findings, companies can design materials with the desired chemical, electronic and physical properties. Furthermore, the described forward trends could lead to suggestions for an economically and ecologically efficient production route that does not necessitate a single laboratory experiment.[60] This can not only bring efficiency increases

"Digital twins" are a new, digital method to optimize chemical production.

in research and development; it can also result in the development of perfectly new products. The understanding of chemical reactions gained through this technology might also drive forward many chemical applications.[61]

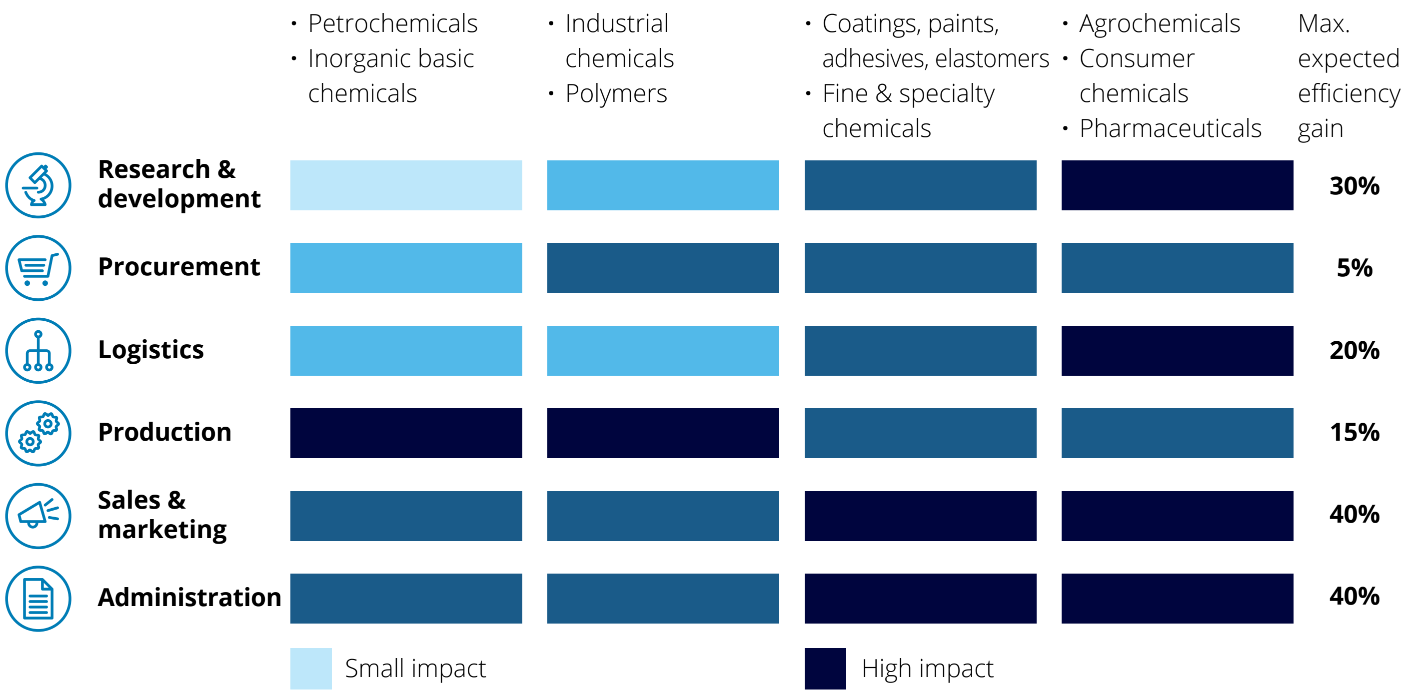
Direct distribution
A survey by Deloitte on digitalization in the chemical industry shows that executives see increasing the effectivity in distribution as the field with the best growth prospects. One way for this is direct distribution where customers purchase a product directly from the manufacturer, e.g. through a company-owned e-commerce platform. Digitalization facilitates direct (albeit impersonal) customer contact, customer information and communication as well as order processing become easier, and the transaction costs per unit of product are reduced. The latter applies particularly for low-volume customers. Furthermore, basic chemicals can be distributed at standardized conditions and favourable cost in a largely automated system (example: the Xiameter® platform for silicones of Dow Corning). Also, direct distribution makes it possible to collect more information about customers than would be the case if intermediaries (e.g. distributors) were involved. Such information can be used to offer other digital services like the personalization of a desired product (e.g. through an online configurator).

Using indirect platforms like Amazon4Business, Alibaba or MOLBASE is the alternative to digital direct distribution. For example, MOLBASE allows over 40,000 registered customers to compare details on more than 9 million basic chemicals and to purchase them from around 30,000 suppliers – in a straightforward, efficient and transparent manner. In addition, the company has built up an extensive database on chemicals for sale.[62] 15% of surveyed chemical executives believe that digital direct marketing has growth potentials for chemical companies.[54] But the loss of personal customer contact is a potential drawback.

Value-based pricing
A more differentiated pricing of chemicals is another field where digitalization can have a role. Manifold data are collected in both direct distribution and traditional distribution channels. The analysis of these data enables a better understanding of which aspects of a product, service or distribution channel are particularly important to customers. On this basis, a value-oriented price can be defined per customer or customer group, making the best possible use of their respective willingness to pay. Thus, companies can achieve additional margins of 1 to 3%.[63]

For the years to come, increasing the effectivity in distribution is seen as the field with the best growth prospects through digitalization.

Influence of digitalization on value creation areas



The potential of digitalization varies for the different parts of the chemical value chain.

Efficiency gains in production are most significant in raw material and energy-intensive chemical sectors. Remote, preventive and predictive maintenance and operation of plants, automation and the optimization of processes and plants through advanced data analysis have the strongest effect in this field.

The potential of digitalization across all business activities is particularly strong in consumer and application-related fields of chemistry. Comprehensive insights in the wishes of customers and product properties allow more focused research and development. R&D can also become more efficient through open innovation, new simulation techniques and the fast production of prototypes.

Furthermore, distribution and marketing can be strengthened by external aggregation platforms or direct customer contact, so that chemical companies can more cost-effectively serve also those customers with formerly lower contributions to earnings. In parallel, demand-driven production and advanced planning methods can ensure that customer demand is always met – while optimizing the warehousing costs. Administration is a non chemistry-specific field where digitalization has further potential for efficiency gains also for chemical companies, e.g. through a further automation of routine work in accounting.[64]

Regarding the digitalization categories, it is noted that the chemical industry in Germany is already very active in the first category ("Transparency & digital processes"). Potentials are seen by both large businesses and medium-sized enterprises, and many possibilities are already used. The second digitalization category ("Data based operating models") is also on the agenda of the German chemical-pharmaceutical industry and is being tackled actively, according to the Deloitte Digital Chemistry Survey 2016. Even though work is already ongoing on topics from both categories, these areas have yet more potential. Executives participating in the Deloitte Digital Chemistry Survey state their plans to prioritize in the near future on activating distribution, enhancing the customer experience and improving efficiency in logistics. In the medium term, they want to increasingly focus on business development through digital business models.[48]

While the potential of the first two categories is being increasingly exploited, the third category of digitalization ("Digital business models") is still at an early stage of development. However, this category is of major importance to the chemical and pharmaceutical industry in Germany to 2030.

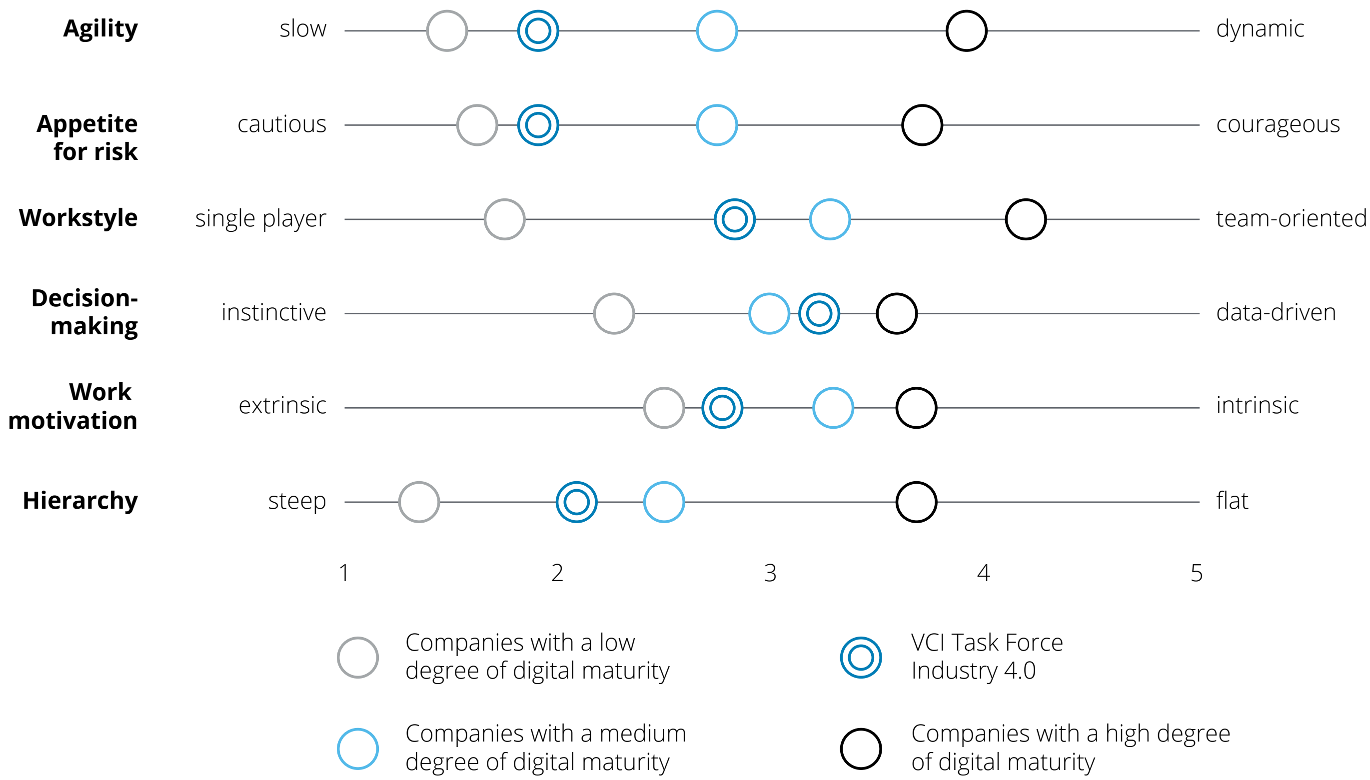
Digital business models

Digital business models – the third category – means value structures that are enabled by using digital technologies and data or that fundamentally change existing processes.[65] Outstanding features of digital business models are digital additions to products and services, in order to enhance customer benefit. In many cases, this is not done by just one single company but within digital networks (see chapter "The chemical industry's role in economic networks") where several suppliers offer joint solutions to customers. The customers are actively involved and flexibly specify their individual needs. Thus, digital business models comprise all approaches for a digital transformation of classic markets. In this connection, data are called "the new raw material" from which important information for new business models can be obtained. 40% of surveyed chemical executives state that they are already looking into new digital business models as described.[48]

For a material and substance-based industry like chemistry, the challenge is to adapt the advanced use of mass data as a raw material for new business models within the industry's understanding of business and to link such data with the perspective of materials and substances. Many digital business models are outside the existing core business and require both digital transformation skills and a different understanding of business, different indicators and a different corporate culture that is marked by more flexibility, a stronger willingness to take risks, and agility. Represented by the VCI's Task Force Industry 4.0[V], however, in some dimensions the chemical companies state in their self-assessments (see blue double circles in the figure) that they still hold attitudes that do not match the typical statements from companies with a high degree of digital maturity. The grouping of companies by high, medium and low digital maturity (grey and black markings in the illustration) was performed in 2015 by MIT and Deloitte within a survey among 3,700 executives, managers and analysts from 131 countries and 27 industries. The respondents were asked to think of their ideal of a digitally transformed company and to then rate their own company as compared with that ideal.

[V]Since autumn 2015, the VCI Task Force "Industry 4.0 in the chemical-pharmaceutical industry" has been accompanying the topics "Industry 4.0" and "Digitalization" in the industry, in order to support the VCI's development of positions and communication work in this field and to offer a platform for an exchange of experiences between the companies. For this purpose, the VCI Task Force informs about shortcomings in the legal and political environment as regards entrepreneurial implementation and provides practical examples for the chances and risks of industry digitalization 4.0. The Task Force consists of delegates from VCI member companies (large businesses and medium-sized enterprises) who either are in charge of the digital strategies in their companies or cover some of the manifold aspects of the topic "Industry 4.0".

Corporate culture and digitalization



Such business models must also be able to compete with existing business activities ("managed cannibalization"). Especially German executives see their own organizational processes as well as low agility and flexibility in their companies as obstacles to transformation.[48] According to a self-assessment by German executives from various sectors, the degree of the chemical industry's digital maturity is clearly below that of other industries, particularly of customer industries for chemistry.[66] But the future importance of digital business models makes it necessary for the German chemical industry to address the framework conditions and to create the prerequisites for an identification of "digital business models" and for evaluating and introducing them.

With a view to concretizing the digital business models, the study identifies 6 levers of digitalization that can serve as archetypes for developing new business models for chemistry in Germany.

Overview of digitalization levers for "digital business models"

Digital business models

Revolutionizing business activities

1. Hyper-personalization & customer integration
2. Process management as a service
3. Networked products and services
4. Open innovation
5. Additive manufacturing
6. Economic networks

Hyper personalization & customer integration

Customers increasingly demand more specific products tailored to their individual applications. This brings major challenges for chemistry, both in product development and production. Design – this term includes not only the external appearance but also the technical properties and the composition of products – needs to be adapted to customer wishes in an ever more individual way. This is facilitated by the systematic analysis of customer wishes, based on available customer data and direct interaction with customers on B2B platforms. Take the example of additives: Including the above-mentioned instruments, it can first be determined which functions are desired, next the chemical properties are defined, and then the product as such can be developed.

Researchers at the University of Illinois have developed a molecule synthesis method that initially breaks down the complex molecules into their building blocks and then reassembles them, enabling the production of new medicines and agrochemicals.[67]

Process management as a service

Chemical companies can expand their existing portfolios of services by marketing their comprehensive knowledge of chemicals and their behaviour in downstream processing: in the form of a service for customers. One example is the control and remote maintenance of the customers' production plants. Here, data can be viewed in real time and evaluated with algorithms, and suggestions can be made for optimizing the processes. In this setting, maintenance can be carried out or disruptions can be remedied by on-site staff of customers. They solve the problems live with the help of augmented reality – in a targeted and efficient manner as instructed by an expert.

This clearly goes beyond the established service business in some sectors where plants are operated at the customers. Instead, comprehensive customer data and real time information about processes and plants go into a real time optimization model. Ecolab already puts this business model into practice. Additionally to selling chemicals for water treatment, the company offers knowledge for recommending specific proposals for water use, reuse and recycling. These proposals are based on the analysis of real time information about the customers' processes and plants.[68]

The OASE® connect platform of BASE is another example of process management as a service. It is used, for example, to remove CO_2 and hydrogen sulphide from natural gases. Customers can benefit from this platform to optimize their gas scrubbing processes.

Networked products and services
The closed-loop management of product life cycles becomes more and more important. This is addressed in more detail in the following chapter "Circular economy and the chemical industry". Relevant concepts should include not only production or disposal but all phases of transport and consumption. Intelligent, networked products (keyword: "Internet of Things", IOT) which provide data on their state or location enable their tracking and administration as well the making available of product information in any phase of their life cycle – at any time and anywhere in the world.[69]

The chemical industry can provide its customers with such information for their own use or offer furthergoing analytical and other services – e.g. to improve product design with the goal of resource preservation, as hints for application in the use phase, or in the form of information for the best recovery option at the end of the life cycle.

Open innovation
Open innovation is the opening up of own innovation processes, in order to enable innovations jointly with other companies (competitors, suppliers or customers). This is to enhance the innovation potential through better access to external expertise, technologies and formulations and for an active marketing of innovations. For example, Eastman and Evonik already use the online platform "SpecialChem" to market their innovations.[70] In total, 39% of executives surveyed by Deloitte think that an innovation platform which fosters the collaboration and creativity among partners can make an important contribution to more sustainable and profitable business growth.[48]

Additive manufacturing
Additive manufacturing (3D printing) brings together various stakeholders with a wide range of different competencies (see chapter "Framework analysis"). Printer manufacturers with expertise in mechanical engineering, the chemical industry as a supplier of specific materials, and software companies that contribute the data for the design of the work piece and for operating the printer need to work together, so that they can offer one well-attuned overall package to customers. This new economic network brings growth opportunities for the chemical industry with its competency for materials – for assuming a decisive and economically attractive role (see chapter "The chemical industry's role in economic networks").

In the described setting, chemical companies can offer their innovative, printable materials to other network members – either through new channels (digital platforms), partnerships (e.g. with printer manufacturers) or company acquisitions that enable integrated solutions. Additive manufacturing no longer requires injection moulds, but chemical companies can benefit from it for product developments together with end product manufacturers (e.g. BASF with Reebok[71] or Henkel with DUS Architects[72]). Thus, the chemical industry can market its extensive portfolio of materials and its expertise on their uses in a new business structure and open up additional value creation potentials that have been utilized so far by other players along the value chain. This also contributes to innovative materials and design options in 3D printing providing a higher added value for customers.

Economic networks
More often than so far, digital business models require cooperation in network structures. These are also called "economic networks", as they often consist of different partners who are connected through a fast and networked exchange of data. In particular, this is the case where the requirements of customers and markets exceed the capacities or competencies of a single company and where combining specialized skills and resources creates added value for customers. The formation of digital economic networks is supported where common interests, goals and values make a basis and where the partners are willing to learn, adapt, cooperate and innovate with a long-term orientation. However, existing structures can be subject to structural change if new companies establish themselves inside such network structures and become, from the customers' viewpoint, the central contact points and providers of customer value. This is especially the case where entry barriers are low for new actors.

The chemical industry must more intensively look into the question how to identify early the potentials of such networks and how chemistry and pharma can concretely position themselves in them. Both the ability to influence a network and the ability to steer the cooperation and to create added value have key roles.

Chemical executives have ambitious goals in these respects. 30% state that they want to orchestrate the building of digital economic networks and run appertaining platforms at their own responsibility. Regarding the question how their organisations view the emergence of networks, another 23% respond that they are observing this matter and, should their organisations make a commitment, their focus would be on ownership of the most important resources inside the networks.[48]

More frequently than so far, digital business models necessitate a cooperation within economic networks.

Interim conclusion

Based on the systematic analysis of the various starting points and levers, it is noted that digital business models of the chemical industry offer considerable chances. Digital business models bring opportunities for companies to economically exploit in various ways the data they can access. Here, the data and information from interaction with (potential) customers in social networks have an increasing role for developing a deeper and faster understanding of customer wishes (or in the B2B sector: the wishes of customers' customers). For example, companies can even better orient their products to given market conditions and personalize the products, possibly without direct contributions from customers. Furthermore, by analyzing their data they can offer services that complement products (see "Networked products and services" in this chapter). Companies can also use data for customer segmentation, expanding cross- and upselling potentials and an even stronger orientation of pricing to customer benefit (see:"Value-based pricing" in this chapter). Moreover, digitally based information on products, customers and markets is more and more becoming a valuable asset in economic transactions.[73]

The strong network of industries in Germany provides particularly good conditions for developing digital business models and economic networks and thus for using the chances for the chemical industry and industry as a whole in Germany. However, for many companies these complex economic networks with new partners from other sectors are still uncharted territory with risks and uncertainties. For future new partners, learning platforms (see chapter "The chemical industry's role in economic networks) can make a basis for developing a shared understanding, launching partnerships, exchanging knowledge and experiences and establishing rules for cooperation. Not only the chemical industry can benefit in this way; this can also be a driver of growth and innovation for the entire German economy. Building up such (pre-competitive) platforms should be supported by the companies themselves and also by associations and politicians.

Digitalization brings significant change for the chemical industry, its customers, suppliers and partners. Many of the trends identified in the framework analysis (like digital developments in customer industries, e.g. new mobility concepts), new production methods (e.g. industrial biotechnology) and the networking of different partners in digital agriculture are either driven by digitalization, they are made possible by digitalization, or they open up new business opportunities for the chemical industry within digital business models. This makes digitalization and its effects an integral part of the chemical industry that permeates all areas.

Survey among medium-sized enterprises: Digitalization

Medium-sized chemical-pharmaceutical enterprises have come to see the topic of digitalization as a strategic challenge. Over 50% of executives who took part in the VCI membership survey state that they are intensively looking into the impacts of digitalization on their companies. 18% of companies already have a digitalization strategy, and further 32% are planning one. But there is still some way to go: While 25% of companies believe that they are well-prepared for the digital transformation, nearly 30% of companies see for themselves a need to take action.

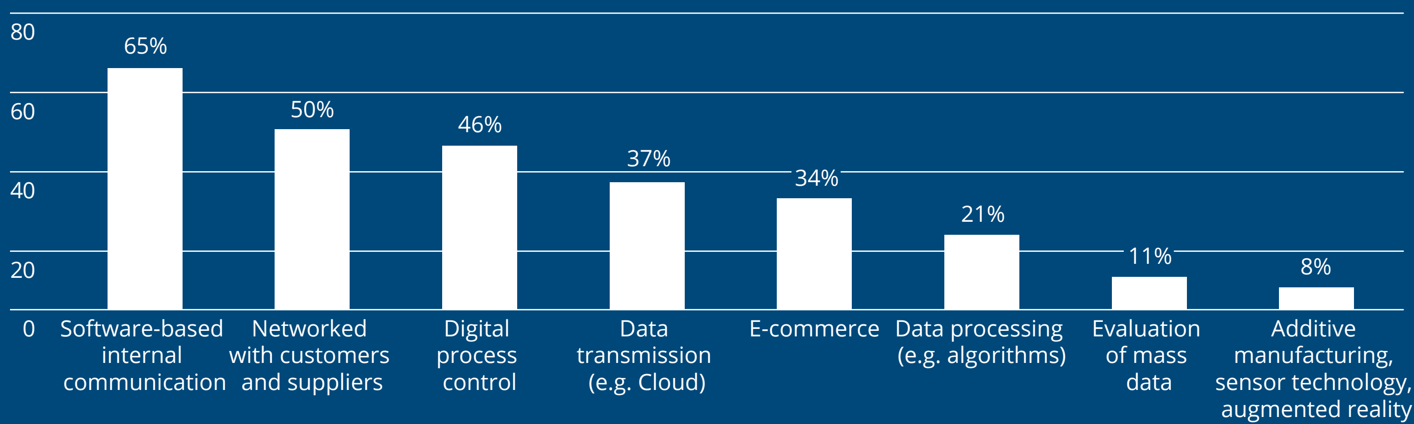
Overall, digitalization will leave a strong mark on the chemical business. Most companies see changes largely in existing product portfolios, process technologies and established business models. But almost 33% of companies are expecting for themselves disruptive changes within digitalization and the networking of the economy. However, the topic of digitalization has a positive connotation. There is a clearly stronger emphasis on opportunities – mainly for efficiency increases and also for the opening up of new markets and for establishing innovative business models.

Already now, digital processes and digital operating models are everyday practice for many medium-sized chemical and pharma enterprises. Some 40% of companies state that they have comprehensively digitized their production and business processes or that they are extensively using data to optimize their operating procedures – while the other companies (60%) have only partly implemented digital processes and data-based operating models. But this will change, as 50% of companies are planning major investments in digitizing their methods and business processes.

By contrast, so far digital business models are only of minor importance generally in medium-sized chemical-pharmaceutical enterprises. 70% of companies say that they do not have any digital business models. The remaining companies (30%) achieve, on average, around 5% of sales with the help of "digital business models". However, this topic is on the agenda of many medium-sized enterprises. After all, ca. 40% of them are planning to introduce "digital business models" in the coming years. But this is currently not yet under consideration in roughly 35% of the surveyed enterprises. At present, they see digital business models as unworkable or unsuitable for their companies.

Digitalization in medium-sized enterprises is hampered by high requirements to data protection but also by fears of being unable to adequately protect their own data (data security). A shortage of qualified IT staff and lacking IT skills of personnel additionally slow down the pace of digitalization. Insufficient technical infrastructures and missing technical standards are further obstacles to the development. This applies, in particular, to interfaces for a data exchange with partners. In contrast to this, the surveyed medium-sized enterprises think that a fast digitalization would not fail due to a lack of financial resources.

Share of enterprises that are using the mentioned instruments (multiple answers possible)



Circular economy and the chemical industry

This chapter highlights the main fields of application for a circular economy – from improved resource efficiency in customer applications and own production to the take-back and recovery of waste (recycling and energy recovery). Furthermore, this chapter describes the potential of connected business models for the chemical industry.

The demand for chemical products will further go up in the future. Contributing factors are the growing world population and the rising prosperity of emerging markets. Back in the 1980s and 1990s, the societal debate focused on the finiteness of fossil resources, especially oil and gas. Since then, technical progress in the production of shale oil and gas has brought a marked increase in the resources available to industry. At the same time, consumption grows more slowly because of improving resource efficiency – so that the discussion gives no longer as much emphasis on quantitative availability as it did 20 years ago. Instead, CO_2 emissions and the associated climate change have ever more room in the general public.[74] This led to an agreement between 195 countries at the Paris climate conference 2015 to reach as soon as possible the worldwide "watershed moment" of greenhouse gas emissions and to limit global warming to under 2oC.[75] Now, national action plans are needed to translate this goal into concrete measures. Beside CO_2 production in the combustion of fossil energy fuels for mobility and energy generation, chemical manufacture contributes to the consumption of fossil raw materials and, consequently, makes an indirect contribution to CO_2 production. For example, in Germany some 14% of crude oil and 4% of all fossil energy sources go into the conversion into chemicals and materials.[76]

50% of raw materials are used, for example, for the production of detergents and cleaning products, pharmaceutical active substances, paints, coatings and printing inks, plant protectants and fertilizers, and food additives[77] whose intended uses are for consumption. Consequently, they cannot be taken back and recycled. But the other 50% of raw materials could be managed in the sense of a circular economy which goes beyond cycles for fossil raw materials and includes the use of renewables (bio-economy).

The utilization of both reused and renewable raw materials can contribute to reducing CO_2 emissions and thus to reaching societal and political goals like the above-mentioned COP21 climate goals and the United Nations Sustainable Development Goals (Agenda 2030). For this reason, society and politicians are calling for a further development of circular economy concepts. With the climate action plan and the action plan for a circular economy, an ambitious goal has been set for Europe.[78] Other nations, too, see the need for a sustainable management style. For example, China has included first aspects of a circular economy in the 13th five-year plan (2016-2020).[79]

Circular economy not only contributes to achieving ecological goals; it also offers growth potentials for the chemical industry. Beside a reduced dependence on imports of fossil raw materials, the German chemical industry can use its strength in technology and innovation to assume an international pioneering role for circular chemical products, services and business models. Furthermore, circular economy is an opportunity to establish even more firmly a position as an essential driver of innovation and a problem solver for the major sustainability topics and to support customer industries in their new circular business models.

In the definition for the purposes of this study, the circular economy concept includes all contributions to resource preservation (e.g. the raw material base and eco-systems) Circular economy includes the following measures:

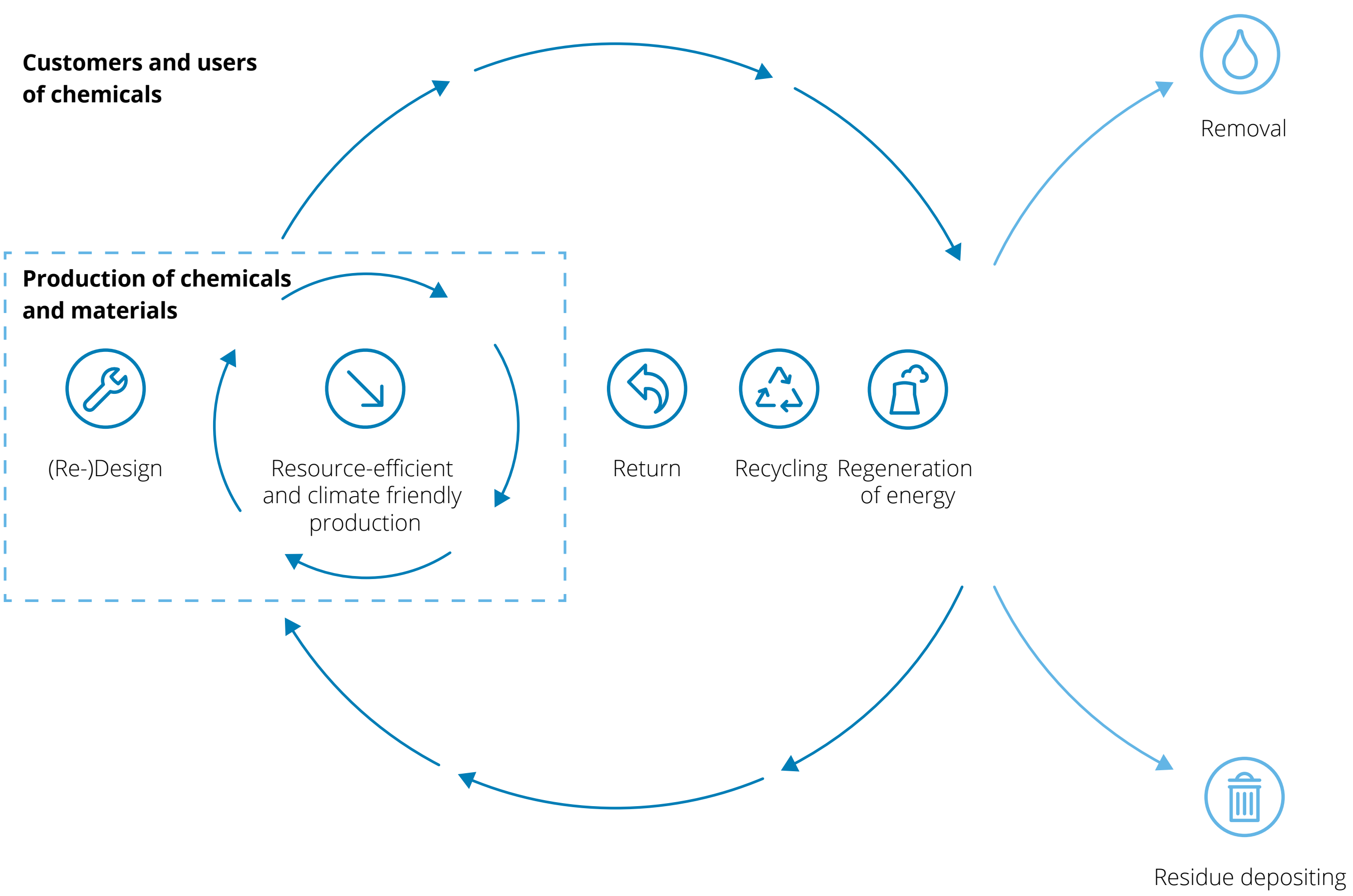
- Improve resource efficiency at all levels of value creation (suppliers, chemical industry, customers).
- Increase the lifespan of products and components and reduce resource consumption in application.
- Largely close cycles (i.a. by way of reuse, recycling, energy recovery or biodegradation), and use residual materials as efficiently as possible.

Only such a comprehensive understanding highlights the full value of the contribution from a circular economy and the contribution that the chemical industry can make for itself and its customers in this overall setting. It is a task, a challenge and an opportunity for chemical companies to examine and take into account all aspects of the circular economy throughout the entire product life cycles.

The circular economy concept includes all contributions to resource preservation.

The 7 levers of the circular economy in the chemical sector
It is distinguished between 7 levers to describe the holistic circular economy approach and to categorize the relevant activities (see illustration).

Circular economy model in the chemical sector (7Rs)



(Re-)Design

comprises all activities that ensure that all aspects of the circular economy are taken into account already in the development and design of products and that these aspects are optimized during the entire product life cycle – from production to application and potential reuse. This includes product composition and product design. Both need to consider the various aspects – like "design-to-recycling" as well as performance and lifespan of chemical products in the customers' production processes and also in their use by end customers ("design-to-performance") – and view them in a holistic manner.

Depending on product and application, different aspects can have priority for a holistic optimization. Carbon fibre reinforced composites in wind power plants are one example where "design-to-performance" (i.e. resource efficiency in application) is deemed more important than "design-to-recycling". The starting point is technical progress in the development of wind power plants. Since 1980, the diameter of wind rotors has increased more than eightfold from 15 to 126 meters. The length of rotor blades grows constantly in their design, because a blade that has doubled in length covers a surface that has quadrupled and, consequently, absorbs four times as much energy. In order to cope with the associated weight increase of the rotor blades, the chemical industry is developing carbon fibre reinforced composites that are four times lighter than steel but five times stronger.[80] Such innovative materials enable the design of longer rotor blades, contributing to an even more efficient production of renewable wind energy. Moreover, the described rotor blades have longer lifespans and additionally improve the sustainability balance of the overall system throughout the life cycle.

Weight reduction to cut fuel consumption across the lifespan of vehicles is another example of "design-to-performance". This development is driven not only by the demanded reduction in fleet consumption to an average of 96g CO_2/km from 2020[81]; another point is that weight reduction enables increases in the range of electric vehicles. Carbon fibre reinforced composites can reduce the amounts of steel and aluminium in various vehicle components and lower the weight of these components by up to 50%.

Thus, the overall picture is positive: Improved efficiency of wind power plants or the advantages of reduced fuel consumption and lower CO_2 emissions throughout the lifespan of vehicles outweigh the disadvantage of higher energy consumption in the production of composite materials and make up for the fact that some of these materials cannot yet be recycled optimally.[82]

The concept of (Re-)design can be put into practice in the pharmaceutical industry too. Some examples are improved pharmaceutical forms, e.g. through slow release systems for a more effective dosage, to increase adherence (the body more fully absorbs active substances) and personalized medicine where dosage and composition of drugs are improved or even individually adapted to the genetic disposition.

Furthermore, the chemical and pharmaceutical industry is working to improve the biodegradability of its products while maintaining the same level of efficiency and to reduce the use of poorly degradable ingredients.

From the chemical industry's viewpoint, this means that (Re-)design has a twofold meaning. Firstly, (Re-)design creates the basis for a circular economy or enables it in the first place (e.g. regarding the possibility to reuse the deployed resources). Secondly, the chemical industry with its competency for materials and chemicals can contribute to its customers' commitment to sustainability. In order to provide this form of added value also in the future, the German chemical industry needs to maintain and expand its strength for innovation and research. Additionally to technical expertise, chemical companies need to understand the requirements in application and the end customers' needs. For this purpose, they need to work closely with their customers. This cooperation goes beyond the well-known and established forms of joint product development and includes new, digital models for data collection and suitable concepts for data evaluation. This is looked into more closely in the following chapters.

Resource-efficient and climate-friendly production

describes how chemicals and materials can be manufactured with an efficient use of resources and in a climate-friendly manner – while largely avoiding waste. Resource-efficient production includes all aspects along the value chain, ranging from efficiency gains in plant management to optimized warehousing and transport and a more efficient management of waste and wastewater.

For example, at the European level the "E4Water" project wants to bring about an integrated and efficient water management in the chemical sector. 19 partners – including chemical companies, leading European water suppliers, research and technology development centres and users – were involved in the realization of this project. This new cross-sectoral approach with a networking of all relevant stakeholders achieved a reduction in water consumption by at least 40% (up to 80%), a decrease in water production by at least 20%, a drop in energy consumption by up to 20%, and a cut in costs by up to 30%.[83] In the next steps, the solutions from the "E4Water" project are to be transferred to other sectors.

In particular, the aspect of climate-friendly production includes all aspects of the use of renewable raw materials and energy. Renewable raw materials (the starting point for a "bio-economy") are an integral part of the circular economy for a climate-friendly manufacture of chemicals and materials. The raw material base consists of renewable raw materials of any kind (field crops, harvest residues from agriculture and forestry, organic household waste, algae or microorganisms).

Industrial biotechnology is a key technology for an effective and efficient processing of renewable raw materials into bio-based products. Especially in context with the circular economy, industrial biotechnology will further gain in importance for the chemical industry. For example, in a joint venture with POET (one of the largest producers worldwide of ethanol)[84], DSM has a developed a method to extract sugar molecules from maize residues. This is done with the help of an enzyme system that degrades lignocellulose into sugar components. Next, sugar is converted into bioethanol. According to the manufacturer, at full capacity utilization the plant can produce annually just under 76 million litres of bioethanol.[83]

BASF provides another example for the use of biomass. In the BASF biomass balance approach, renewable raw materials are used at the beginning of the value chain to produce basic chemicals which are then further processed in existing production plants. The shares of renewable raw materials are assigned to the thus obtained chemicals and materials.[85]

Climate-friendly production is also possible by using the greenhouse gas CO_2 as a raw material. For example, since 2016 Covestro has been replacing 20% of the crude oil normally needed in polyurethane production by CO_2 generated in other production processes. The current production capacity amounts to 5,000 tonnes of polyol per annum.[86]

However, the chemical industry uses not only CO_2 from own processes but is also engaged in research into possibilities of using emissions from other industries as raw materials. One initiative in this field is "Carbon2Chem" – an alliance of 17 partners of companies from the chemical and steel industries, research institutes and universities – who want to invest over 100 million euros by 2025. The goal is to utilize waste gases from steel production for the manufacture of fuels, plastics and fertilizers, using surplus electricity.[87]

Return

defines a lever of the circular economy where chemicals are not sold but supplied to customers and taken back after use. In chemistry, this is frequently connected with the term "chemical leasing". This lever is applied, in particular, for production auxiliaries such as solvents or coolants. In this service-oriented business model, the chemical industry can contribute its competency for materials and technical expertise, ensuring a safe and standardized reprocessing.

SafeChem is one example of a business model based on chemical leasing: Solvents are supplied to and collected from customers. The company works with producers of cleaning machinery, chemical traders and disposal businesses. Across the entire customer portfolio in surface and textile cleaning, SafeChem has been able to reduce the solvent share in waste water by up to 80% and volumes of newly needed solvent also by up to 80%. Risks in occupational health and safety have been reduced too.[88]

Take-back and chemical leasing models do not necessary involve volume-based billing; billing can also be based on performance. This means that e.g. cleaning chemicals are billed per square metre of cleaned product (see "Value-based pricing" in the chapter "Digitalization in the chemical industry"). In this form of pricing, the supplier benefits from the lowest possible consumption of materials and the longest possible use of materials and chemicals. This is an additional incentive for chemical manufacturers to activly contribute their know-how to optimizing the customers' production processes.

Recycling

as the fourth lever of the circular economy means recovery as mechanical and feedstock recycling. In mechanical recycling, materials are comminuted mechanically, cleaned, separated by fractions and returned into the material cycle, so that remelting – largely without changing the chemical composition – results in recyclates. Subsequently, the materials can be used for the same or other applications, possibly with lower requirements to materials. In feedstock recycling, organic materials are broken down into their basic materials while filtering out impurities. Thus, new organic basic materials are obtained for further processing by the chemical industry and its customers.

- Mechanical recycling is an established concept which has long been used for materials where recycling is relatively easy and for particularly valuable constituents (e.g. precious metals in catalysts).

  Traditional methods – e.g. separation by density – are not always suitable in the separation of waste plastics, as the differences are very small and electrical and magnetic properties are similar. However, sorting facilities with infrared technology, mass spectrometers and sensors enable the pure grade sorting of plastics as mono-materials from packaging waste. Today, modern sorting grades enable purity levels of up to 99.9.[89] However, this method is not yet suitable for composites. The method of Mtm plastics GmbH is an example for the recycling of mixed plastic wastes. In a first step, the pre-sorted wastes are comminuted mechanically; non-plastic constituents are largely removed. Next, the material goes into a combined washing and separation system with a pure-grade separation of plastics by density. In the following step, the plastic flakes are sorted by colour, washed and thermally dried. For the processing as granules, the flakes are compacted, melted, mixed with the necessary additives, kneaded, degassed and fully homogenized. Finally, the material is brought in a granular form and can be used as a drop-in raw material for high-quality applications (i.e. in existing plants).[90]

  A prerequisite for the success of the mechanical recycling of waste plastics are pure-grade substance streams in the collection or subsequent sorting or processing. Beside the problem of frequently mixed and soiled waste fractions, also the available technologies as well as available infrastructures and markets are essential criteria for an efficient waste management. In special cases, marker technologies or – for large components or end consumer products – also RFID chips[VI] can improve the treatment of substance streams.

  Similarly large challenges arise in the use of recycled waste paper in sensitive consumer products (e.g. food packaging). For reasons of consumer protection, foodstuffs need to be protected against potential, unacceptable substance migration from packaging materials. This is only possible with packaging technology solutions, e.g. barrier layers.

- Chemical recycling (also: feedstock recycling) can make an alternative where mechanical recycling is not possible or useful. Feedstock recycling means processes where mixed plastic wastes are recycled in various processes and converted into raw materials for the chemical industry. One option is the depolymerization to monomers by adding water, steam or oil. Pyrolysis or gasification to synthesis gas are other options. These processes are not yet mature. They require high specific investments and are rarely used at present. The essential reasons are technical problems and lacking economic efficiency in existing frames. Moreover, there are political reservations about the blurred borderline to energy recovery which is being criticized at EU level.

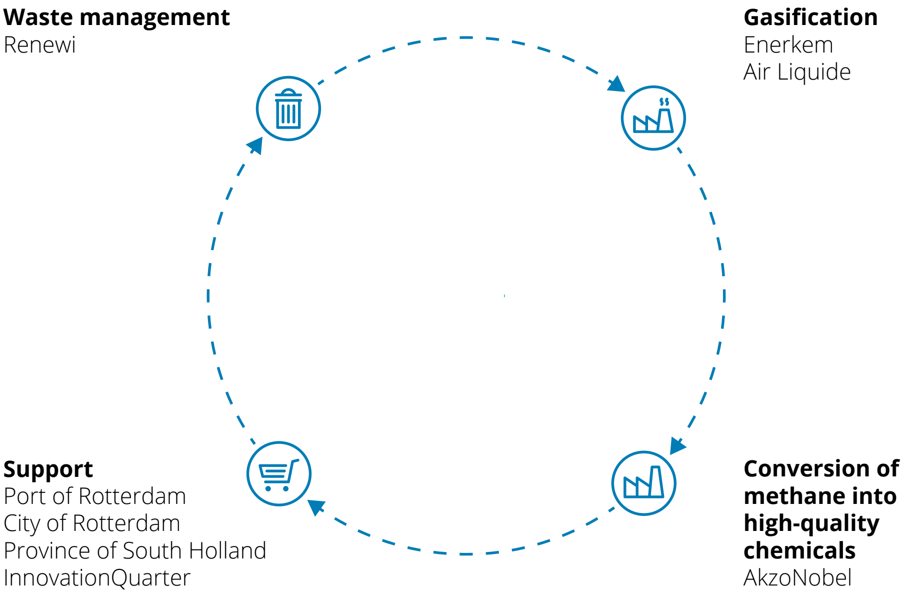
Irrespective of the above, from technical and economic aspects feedstock recycling is an alternative for waste streams where mechanical recycling does not make sense. Thus, feedstock recycling holds the perspective of becoming an important component of a circular economy.

Under the leadership of the "Waste2Chemistry" initiative, a pilot plant tailored to the relevant requirements is currently being built in the Netherlands. "Waste2Chemistry" is a consortium of 8 international companies, including Enerkern, Air Liquide and AkzoNobel. They want to produce jointly bio-based methanol and ethanol from municipal waste. The technology is compatible with the existing waste infrastructure; it wants to enable the conversion of non-mechanically recyclable waste – via synthesis gas – to fuels and

[VI] Technology for transmitter-receiver-systems high-quality chemicals. Such feedstock recycling closes cycles, diversifies the raw material base, and saves CO_2 and mineral oil.[91]

Both mechanical and feedstock recycling usually necessitate the formation of networks of partners who take over, for example, collection logistics and the disassembly and separation of the starting materials, distribute and use the obtained materials and jointly work on new processes and technologies. On the one hand, as a manufacturer of plastics and additives the chemical industry can provide mechanical recyclers with the technical expertise on materials. On the other hand, regarding feedstock recycling the chemical industry has the production know-how for processing the obtained inputs. In this way, the chemical industry can position itself as a successful actor and assume an important role in the newly forming economic networks of waste management companies and technology businesses.

Chart showing the process of the "Waste2Chemistry" initiative



Regeneration of energy

describes the use of waste for recovering energy (heat/steam or electricity). Thus, waste, which is used as energy, substitutes the fossil energy sources gas and oil that can be used instead as raw materials in chemical production. This is another important component of the circular economy.

An essential contribution from chemistry to recovering energy from waste is about hazardous wastes. Many wastes from the chemical industry contain hazardous substances that require particularly careful handling by the companies. Quite often, energy-efficient incineration is the best option for hazardous wastes, both ecologically and economically. The German chemical industry has numerous modern incineration plants for hazardous wastes. These optimally utilize the energy content of hazardous wastes by producing steam and partly also electricity with high efficiency. In this manner, the incineration of hazardous wastes in suitable plants makes a major contribution to saving resources. In Germany, the rated thermal input for the incineration of (hazardous) wastes by the chemical industry was ca. 650 MW in 2014[92], replacing a mid-sized coal-fired power plant. All organic pollutants are destroyed in incineration while ash and slag are safely disposed of. The associated emissions clearly keep below the relevant legal requirements. Furthermore, certain wastes classified as hazardous can be incinerated in specifically designed industrial facilities. The "co-incineration" of suitable wastes (e.g. in cement plants) enables the companies to reduce inputs of important primary resources and to contribute to a sustainable waste management.

Another example of the energy recovery of waste – that might be established in a similar form by chemical companies – is the "Ecluse" project in Belgium. This is a co-operation between environmental, waste management and energy companies. From 2018, steam will be obtained in thermal recovery from non-recyclable household waste, comparable industrial waste and sewage sludge, with a capacity of 250 MW per annum.[93] The plant supplies six companies with heat and energy. "Ecluse" also operates plants for electricity production where annually 1 million tonnes of non-recyclable waste and sewage sludge are incinerated, supplying 170,000 families.[94] According to the operator, the plant has the annual CO_2 savings potential of 50 standard wind turbines with a performance of 2.3 MWh each.

Reduction of environmental impacts

describes the minimization of the effects of chemicals that are released into the environment after their intended use. These can be medicines that are not absorbed or processed by the body, or even detergents. In this context, the biodegradation potential has an important role (see section "(Re-) Design" in this chapter). Here too, the chemical-pharmaceutical industry in Germany and Europe contributes to minimizing the negative impacts on the environment – e.g. with a decisive contribution to reducing poorly degradable ingredients of detergents.[95] Moreover, in a cooperation between pharmaceuticals, chemistry, industrial biotechnology and manufacturers and operators of purification plants, the cleaning performance can be improved and residual quantities can be reduced even further.

Residue depositing

With the existing technological possibilities, even a circular economy cannot guarantee that no residual materials are generated. Therefore, the elimination of residues – while ensuring the controlled and proper disposal of unavoidable "residual industrial wastes" (e.g. incineration residues) – is not an integral part but an aspect of the circular economy, and it will remain so until new and workable solutions are found jointly.

The question which of the above-mentioned methods is applied in detail in each individual case requires a full feasibility analysis which needs to take into account the technical options and weigh the ecological, economic and social aspects.

Irrespective of the lever, most circular solutions are characterized by their high complexity and a large number of required assets and skills. Therefore, in particular those business models are successful that work within economic networks and partnerships with competitors, companies from other sectors and further stakeholders (e.g. research institutes) and integrate the value chains of customers. This approach not only combines technical competences but also better coordinates innovation initiatives and facilitates the access to talent and resources.

Status of the circular economy in the German chemical industry

Publications on sustainability by 10 German chemical and pharmaceutical business groups were analyzed within this study.[96] The analysis focused on the aspect of a circular economy, regarding both the circular vision and its current implementation in the companies.

A grid was created for assessment purposes. The grid comprises 2 criteria for the circular vision and 6 criteria for the current implementation of the circular economy in existing organizational structures.

It was found that all analyzed companies formulate the topic of sustainability as an important aspect of their corporate strategies. The concept of the circular economy, too, is included in the corporate strategies through the various levers, however, usually not as a term itself.

Beside the formulation as part of the corporate strategy, the sustainability goals should be clearly formulated – as this is the only way to bring about just one uniform strategic direction throughout the entire company. All analyzed companies have set themselves such goals for a more resource-efficient production. For example, all companies have quantified goals for reducing CO_2 emissions, mostly supplemented by targets for reducing wastes or their increased use and for reducing water consumption. For example, Henkel wants to reduce water consumption by 30% by 2020 (base year 2010).[97] Many of the companies also emphasize the importance of alternative raw materials (e.g. CO_2) and of recyclates as raw materials. However, mostly no concrete targets are set in these respects.

The picture is similar for products. On the one hand, the intention is stressed to give products an even stronger orientation to the sustainability principle – while, on the other hand, wishing to increase resource efficiency in applications by customers. In some individual cases, this is concretely quantified too: For example, by 2020 BASF wants to achieve 28% of sales with products that substantially contribute to sustainability in their use.[98]

Analysis criteria for the circular status quo in the chemical industry

Circular vision	
Circular economy as an integral part of the business group's strategy	
Concrete targets for implementing the circular economy	
Circular economy in organization	
Resource-efficient production	
Innovation for a circular economy	
Circular products and business models	
Strategic partnerships for circular business models	
Circular requirements to suppliers	
Responsibility	

The circular economy is not only reflected in corporate strategies; already today, it is firmly embedded in the organizations. For example, the companies of the chemical industry are constantly working to improve the resource efficiency of their products. In 2015, the share of renewables in the total raw materials input of chemistry in Germany was already 13% (or 2.5 Mt).[99]

The public-private partnership initiative "Sustainable Process Industry through Resource and Energy Efficiency (SPIRE)" – with the European Chemical Industry Council (CEFIC) as a partner – has set itself the goal of reducing the consumption of non-renewable raw materials by 20% by 2030, as compared with 2016. This is to be achieved through improved chemical and physical conversion and by using renewables.[100]

The wider use of renewables presupposes targeted research and development. A global study in chemistry in 2016 shows that 61% of leading executives initiate research and development projects for the circular economy.[101] In Germany, 50% of analyzed business groups explicitly address sustainability in their innovation strategies.

All companies in the study offer resource-saving products. Most of them integrate the circular economy principles into product design and carry out comprehensive analyses across life cycles for this purpose. For example, the goal of Evonik is to perform sustainability analyses (including eco-balance considerations) for at least 99% of products with volumes over 1 tonne/year. With this in mind, Evonik has developed its own system that evaluates products based on a life cycle assessment.[102] Irrespective of the research and innovation strength of chemical companies, many circular business models can be successfully developed and established only by way of partnerships within the chemical industry and with partners from other industries. Through comprehensive mutual supply and service relationships, the chemical industry in Germany has a well-established network inside its own industry. However, for a circular economy this needs to be expanded to other industries, also beyond existing cooperations with customers.

Purchasing and supply management with an orientation to sustainability criteria is another major aspect of the circular economy. For example, all analyzed companies formulate sustainability expectations to their suppliers. By means of supplier audits, most companies ensure that these expectations are met. For instance, Bayer AG assesses all strategically relevant suppliers according to sustainability criteria – with the goal of introducing in 2020 a holistic sustainability standard for all suppliers.[103] This aim is also pursued by the "Together for Sustainability" initiative of several chemical companies like Bayer, BASF, Covestro, Merck, Wacker, Lanxess, Evonik and Henkel.[104]

There is no doubt that the circular economy concept needs to be firmly embedded in all areas of a company. Given the importance of this topic and its cross-functional character, all companies have assigned the responsibility for sustainability to the top management level. One organizational model is to appoint a chief sustainability officer or a business group coordinator environment. Another approach is to assign the responsibility to the head of human resources. Other chosen options are to commit the entire executive board (Vorstand) to the sustainability strategy or to set up a separate body or board that comprises executive board members and delegates from the different business units.

The chemical industry in Germany has already taken various measures to establish sustainability and circular economy as an element of its actions. Numerous sustainability initiatives have been launched by individual companies and in cooperation with other enterprises. In this connection, the Chemie³ sustainability initiative of the German chemical industry is certainly of special importance. The industry has set itself ambitious and concrete goals, particularly for meeting the sustainability aims of customers ((Re-)design) and for a more resource-efficient production. The examples from practice in this chapter also show that some chemical companies develop their own individual circular solutions and that they have also formed cooperations and partnerships. In the next step, the chemical industry should expand especially this partnership aspect and think in economic networks and new business models – in order to exploit for itself the opportunities of the circular economy.

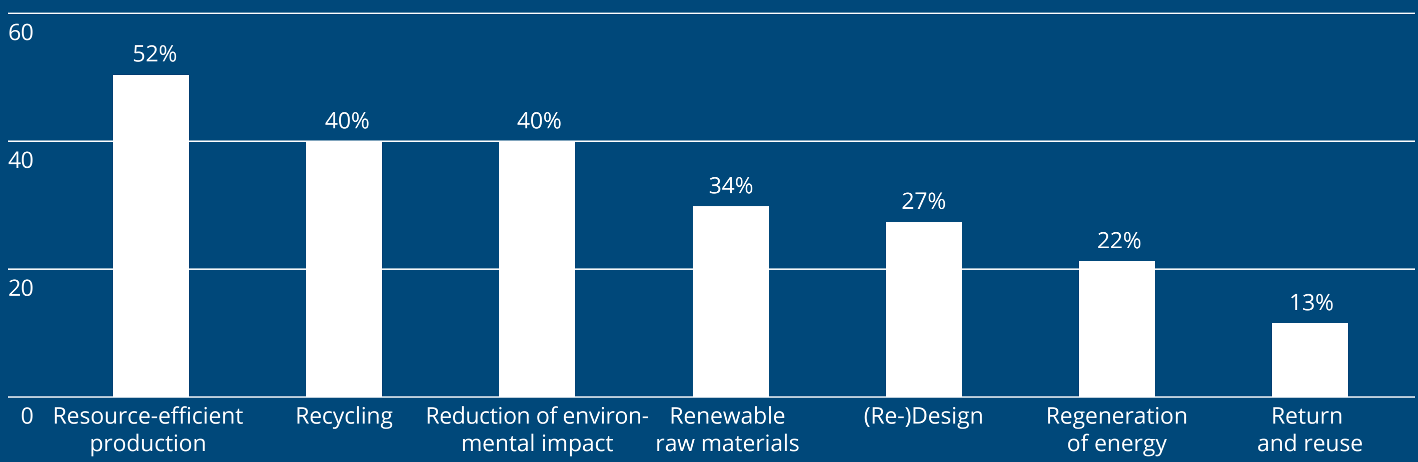
The chemical industry in Germany has established sustainability and circular economy as a central element of its actions.

Survey among medium-sized enterprises: circular economy

Sustainability and circular economy have long been highly important topics for medium-sized chemical and pharmaceutical companies in Germany. Over 20% of companies state that they are intensively looking into the impacts of a circular economy on their undertakings. 45% of companies have a person responsible or a steering body for sustainability at top management level. Nearly 40% of companies already have a sustainability strategy, and almost 25% of the remaining companies are planning to introduce one in the coming years. 20% of companies believe that they are well-prepared for the changes of a circular economy, while just under 30% see a need for action.

For medium-sized chemical and pharmaceutical companies, circular economy primarily means resource-efficient and climate-friendly production. The recycling and (Re-)design of products for resource preservation across entire life cycles also have major roles in corporate strategies – while the take-back and reuse of chemicals (chemical leasing) is not relevant for many businesses, because their products are not suitable for the latter. Many companies see potential for speeding up the expansion of circular business models or for making this expansion more efficient with the help of digitalization. But this development is still at its very beginning. At present, only 8% of companies have concrete projects.

Share of companies that already use the earlier mentioned circular levers (multiple answers possible)



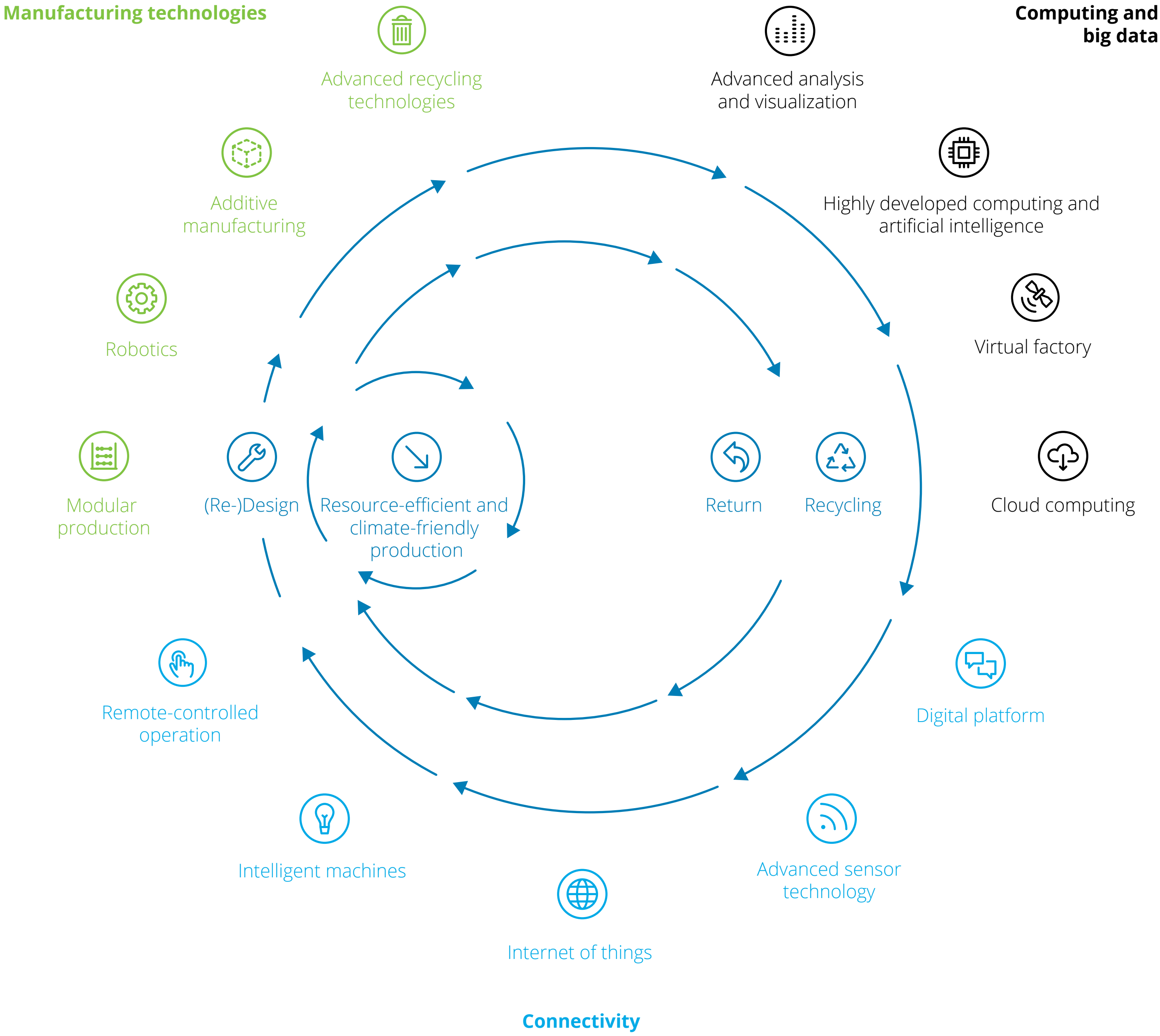
Interplay between digitalization and circular economy

This chapter is about the relationship between digitalization and circular economy. It highlights how digitalization can contribute to circular business models in the chemical industry.

The interplay between digitalization and circular economy concepts opens up special potential, but so far this has only a minor role in the current debate about the advantages of digitalization for national economies and business management. Existing analyses mainly focus on the improved resource efficiency of digitized production processes, reduced resource requirements in a "sharing economy", and better transparency regarding the location, condition and availability of resources.[105]

Up until now, the specific connections between digitalization, circular economy concepts and the chemical industry are addressed only marginally. One exception is the white paper of the World Economic Forum (WEF) which explicitly looks into improved resource efficiency in chemical production processes and better transparency of value chains in circular economy concepts.[106] But more and more attention is given to this issue; for example, the "European Composites, Plastics and Polymer Processing Platform (ECP4)" conference 2017 dealt with the mutual support between digitalization and circular economy.[107] As is shown in more detail below, digitalization in the chemical industry and the associated technical possibilities contribute in manifold ways to circular economy models becoming feasible in the first place and to improving their economic viability – thus helping to reach the UN sustainability goals. These technical possibilities include, for example, the use of sensors and the integration of simulations and data analyses in production, supply chain and business processes. Further important aspects are digital transparency and possibilities of digital coordination across the entire value chain. Various technologies – that can be summed up in the three clusters "Production technologies", "Computing & mass data" and "Connectivity" (see figure on the next page) – can act in many different ways at the interface between digitalization and circular economy. Both the circular economy and digital technologies are developing dynamically, so that only some examples are outlined here.

Technologies supporting the circular economy



In the following, this interplay is to be illustrated by four starting points for a circular economy:

(Re-)Design

In the interplay between digitalization and circular economy, the lever of (Re-)design focuses on improving products by way of detailed, digitally collected and evaluated information about their properties and use patterns. Firstly, this can make production more efficient; secondly, products can be better adapted for their intended uses.

The necessary items of information can be gathered e.g. through smart products (see networked products and services in the chapter "Digitalization in the chemical industry") or so-called digital twins (see section Smart & virtual plant in the chapter "Digitalization in the chemical industry"). Such information includes, for example, wear and tear in use or reactions to environmental influences. It can help improve the product design[60], and the digital twin can be used for virtual testing already in the development phase.

The chemical industry expects that the available information about chemicals and materials – also during the use phase – will increase significantly in the coming years. Such information can be used, for example, for the selection and composition of additives, in order to tailor them individually for their intended uses. Integrated electronics can turn plastics into functioning surfaces; e.g. in the automobile sector a plastic element can become much more than just a display. With integrated sensors it can also provide details about the condition of the material and the use of the element.[108]

Resource-efficient and climate-friendly production

In resource-efficient production, the focus is on the interfaces between digitalization and circular economy in the information transparency of production processes.

Here, digital simulation and the optimization of chemical-pharmaceutical production processes and biotechnological methods have the potential for huge efficiency gains, also in established processes. Furthermore, detailed insights into ongoing production processes bring possibilities for better process control and higher plant utilization and for minimizing the resource input and increasing the degree of automation. In these respects, the automated processing of mass data – collected through the Internet of Things (IoT) systems and sensors – can have a major role.

One example of such systems are IoT sensors which measure in real time the consumption of electricity, heat, gas, water and steam. The appertaining software collects, analyzes and visualizes the data, in order to identify deviations from the control status. In predictive maintenance (see chapter "Digitalization in the chemical industry"), faults can be corrected before the production process is interrupted. Moreover, such information contributes to optimizing the production process and to reducing resource consumption.

In digital business models, the chemical industry can improve not only its own resource efficiency but also that of its customers: by digitally supporting the use of products from chemical companies in the customers' production processes. A relevant example is the online platform OASE® connect where BASF helps its customers from the gas industry to optimize their gas scrubbing processes.[109]

Digitalization can automate and optimize chemical production, with a view to optimizing resource input.

Return

The possibilities of digitalization can benefit take-back business models in various ways. For example, the big data analysis of customer information from social networks, sales data and customer publications can identify the potential for such business models, e.g. by analyzing the consumption of chemicals over time and comparing with other customers and by setting these details in relation to further particulars. For deviations with increased consumption, this can be an opportunity to offer take-back business models with an integrated optimization of the consumption of chemicals (see chapter "Circular economy and the chemical industry"). The use of data from customers (e.g. through sensors in their productions) can enable chemical companies to draw conclusions regarding their own products and to see when these need to be replaced.

Another important aspect of take-back arises in the associated logistics where digitalization can help master complexity. In the waste sector, Rubicon exemplifies this with a digital platform where businesses can retain waste management companies to dispose their wastes properly. Bundling the demand, automated billing and optimized routes for waste management companies bring cost cuts of up to 20% compared with existing one-to-one solutions, i.e. one customer has an individual business relationship with one waste management company.[110]

Here, digitalization has an important role: collection is recorded by mobile end devices, disposal is documented centrally and billing is automated. For waste management companies, digitalization supports route planning and allows vehicle tracking using track-and-trace systems. Similar to the recycling of household waste, such digital solutions can reduce the costs and the organizational workload in chemical leasing business models by digitally recording and optimizing take-back logistics, billing and documentation.

Recycling

Digitalization also plays an important role in recycling, e.g. for mastering the complexity of logistics and creating transparency in information about materials.

For economically viable recycling, it is often a challenge to reach a critical mass of the material streams to be recycled. Here, digital marketplaces are an option where not only collection logistics but also transparency regarding volumes, availability and ingredients of the materials is an important aspect. One example is the cloud-based platform "Materials Marketplace". This is a project of the US Business Council for Sustainable Development, the World Business Council for Sustainable Development and the Corporate Eco Forum that wants to promote B2B materials reuse across companies. Surplus raw materials, industrial by-products and packaging can be offered through a cooperation platform and purchased by the participating companies. It is also possible to seek expert advice, e.g. on recycling. 23 companies from various industries, including 4 businesses from the fields of chemistry and advanced materials, took part in the pilot phase from June to August 2015 when 150 materials weighing 2.4 million tonnes were placed on the market. Building on this result, there are plans to expand the platform to more than 100 participating organizations in the United States and to transfer it to other regions.[111] Thus, digitalization brings about transparency, facilitates the exchange of materials and drives forward recycling.

Furthermore, digitalization can facilitate the recycling of plastics: In existing recycling solutions, individual material streams (e.g. plastics) can be sorted from packaging materials. The subsequent recycling of these plastics works the better, the more information about the constituents of the waste streams is available – because the homogeneity of the plastics is decisive for the quality of the recyclates. This can go beyond pure-grade materials so that the availability of further information seems advisable. With the possibility of fast information gathering and the analysis of comprehensive data streams, digitalization can significantly contribute to economic efficiency, e.g. in spectroscopic methods (infrared technology). Digitalization enables the adding of information about material streams (e.g. through innovative spectral analyses that can detect, for example, coloured plastics or bio-plastics etc). Sorting plants are conceivable that quickly and efficiently sort pure-grade plastics from packaging waste and then channel them into reuse, depending on their future applications. Further innovation steps are needed for non-separable plastics. Therefore, marker technologies could be developed for high-quality technical plastics in larger components, e.g. in electrical devices or carmaking. This could enable their sorting and mechanical recycling. Combined with science, the chemical industry, plastics producers and mechanical engineering have the required technical expertise for the above. In future recycling solutions, they could position themselves as essential players to steer the building up of a potential new economic network consisting of waste management companies, technology businesses and chemical enterprises.

Digitalization can also facilitate recycling in the construction industry. This industry is characterized by a complex supply chain and long product life cycles. Building information modelling (BIM) digitally models, combines and captures all relevant data on buildings and materials across the various partners and makes the information available in a 3D building model.[112] At the time when a building is demolished, the stored data provide details on what materials and chemicals are where in the building debris and, consequently, on how to optimize the recycling of the latter. This information can contribute to a higher recycling rate while lowering the costs for analyzing the rubble.

These examples highlight how digitalization can make the implementation of circular business models more cost-effective or enable them in the first place. However, they also show that the merger of both fields – digitalization and circular economy – has only just begun. The coming years will bring many opportunities for the chemical industry in Germany to start exploiting the added value of digitalization combined with a circular economy.

The role of the chemical industry in economic networks

This chapter describes the characteristics and the importance of economic networks for the chemical industry in Germany. Three potential roles for chemical companies are depicted, and the derived consequences are illustrated.

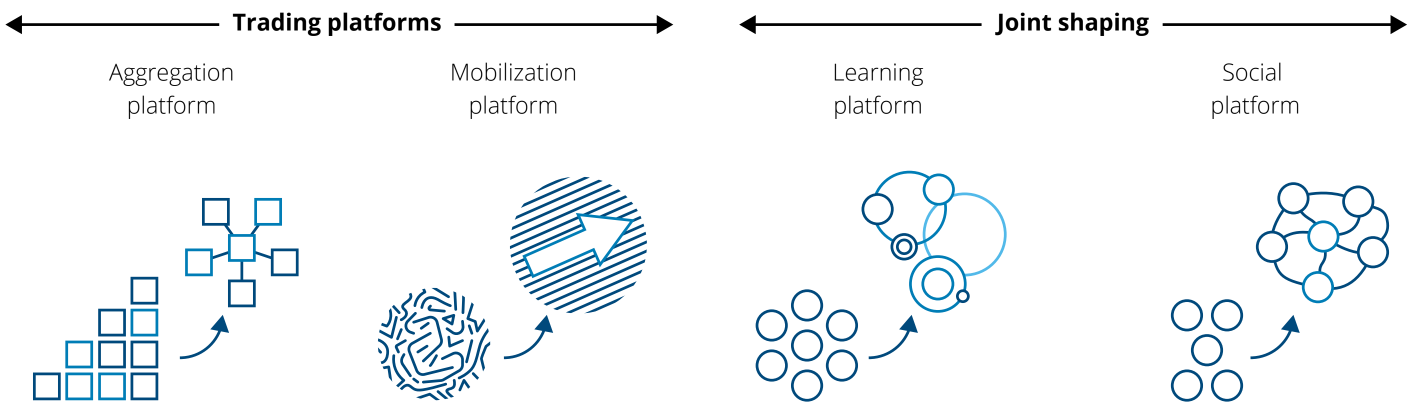
Economic networks

A sound and mature industrial network is traditionally an outstanding element of Germany's economic and innovation strength. This network links players from research and industry as well as companies from various sectors and of all sizes – down to start-ups. The diversity of network partners is a major reason for the strength of Germany as an industry location. Especially in the German industrial network, chemistry has a central role as an enabler for its partners. Changing customer requirements and new technical possibilities – also driven by digitalization and circular economy – are raising the importance of economic networks. Customers increasingly demand hybrid solutions that combine different products and services. Quite often, the complexity and the technical skills needed for all-round solutions cannot be mastered by a single company. This also holds true for innovation. In the past, this aspect was dominated by innovation chains which led sequentially from ideas to applications. In the future, innovation eco-systems will be needed where several partners of many different sizes cooperate. This is not new as such but more, new and different partners are involved – with a growing complexity of networking.

Digitalization changes the networking of industry, science and society. Therefore, special importance is attached to the formation of platforms that facilitate the exchange and active cooperation between different specialist or interest groups, established companies and start-ups.

Existing platforms can be divided in four categories: aggregation platforms, mobilization platforms, learning platforms and social platforms.

Four types of platforms for exchange and cooperation



Aggregation platforms, such as Amazon, facilitate for different players the trade in goods, services, ideas and data in a digital marketplace. They usually follow the "hub-and-spoke" model where transactions are made through platform operators.

Mobilization platforms link users with each other, in order to create transparency about common interests and needs and to exchange services. One example of such platforms is BlaBlaCar, the largest carpooling service in Europe.

Learning platforms facilitate the simplified exchange of knowledge. Based on a broader knowledge base, they contribute to a faster development and market maturity of innovations. A political-strategic example is the German National Platform for Electric Mobility which steps up the development and introduction of innovative technologies in a pre-competitive context. An operative example of learning platforms is the cooperation between science and industry in regional clusters, e.g. in biotechnology. A Deloitte analysis of 2016 shows that learning platforms are particularly important for companies, as they are conducive to product development. Product development was the driving force for digital partnerships and platforms.[112]

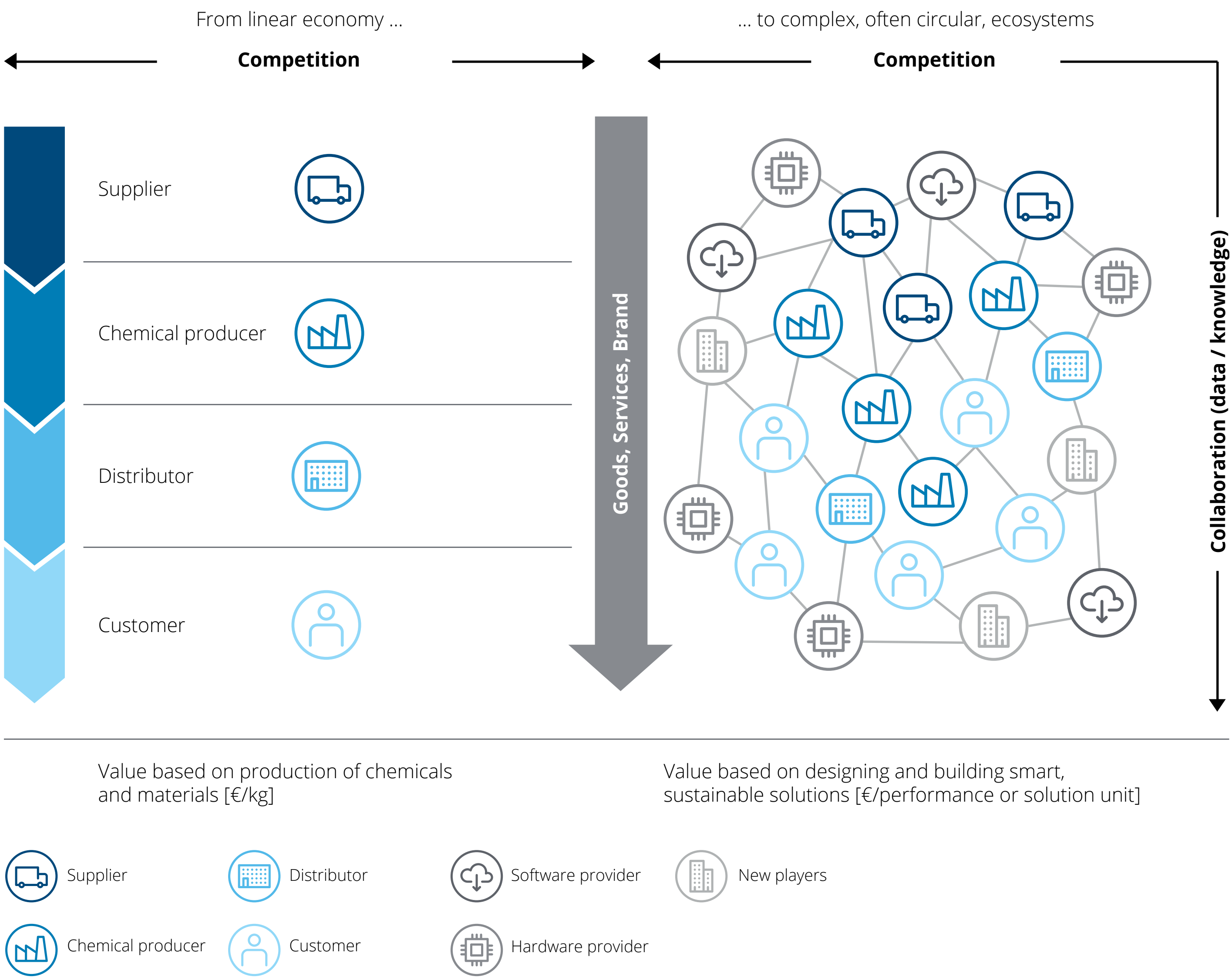
Social platforms like LinkedIn or Facebook bring together people in different ways. They serve to initiate and cultivate business and personal contacts. Social platforms have added value not only for individuals: Companies can use them for "social listening" where the trends on social platforms and the interaction with users are analyzed, in order to draw conclusions about the development of preferences and demand. Mainly by creating transparency and through falling transaction costs, the platforms of the mentioned categories – especially aggregation and mobilization platforms – contribute to simpler business transactions. However, there is a clear borderline between the above platforms and economic networks, regarding both goals and structures.

Economic networks are more than business cooperations between several companies; they also act as one unit vis-à-vis customers. They create added value for customers through new forms of cross-company networking and collaboration. Depending on the complexity of the problems at hand, such networks are often a meeting place for actors who had little interaction so far und must learn to understand the views of and the potential contributions from the other partners. In such networks, the innovation processes are cooperative and integrative and resort to expertise from many sectors and disciplines.[113] While companies were previously solely responsible for their performance, they can now become network partners who integrate other enterprises. Performances are rendered jointly and with joint responsibility.

It is worth noting that economic networks are not always the better solution. Networks presuppose trust and contracts; organizing networks requires input in terms of time. Inter alia, the network partners have to negotiate their shares in value creation. Therefore, it needs to be examined on a case-by-case basis whether networks are the optimal choice for customers and stakeholder companies.

Economic networks act as one unit vis-à-vis customers. Performances are rendered jointly and with joint responsibility.

Change of linear chains to complex economic networks



The competitiveness of its overall offer is the yardstick for the success of an economic network. Here, the network effects have an important role. The more customers, suppliers, consumers and manufacturers take part in an economic network, the larger, better and more favourably priced can the offer be for customers. Networks that quickly reach a critical mass can use economies of scale and successfully launch new offers and business models in the market. But for this, they also need to master greater complexity.[114]

Three roles inside economic networks
In an economic network, altogether three roles can be defined. They describe the function of and the contributions from the respective actors. These roles are called follower, partner and orchestrator. Companies can be economically successful in all three roles, but they need to orient their strategic positioning to their respective role as chosen.

Followers make contributions to networks that can be replaced relatively easily or with which they are only slightly different from other suppliers. They have little or no influence on the structure and the business model of the network. Therefore, followers – with their range of products or services – essentially compete based on low costs. Economic networks offer for followers (e.g. cost leaders in their product segment) the advantage of easy access to customers without own distribution network or the possibility of integrating themselves – with their range of products or services – in the full solution.

Partners are companies with more influence and higher shares in the value added inside the economic network. They make essential and specific contributions to value, e.g. in the form of a specific competency or a special product. However, such companies too are competing and can maintain their partner role only through better and more innovative products, as compared with their competitors.

But a distinction in competition cannot rely solely on products and services. Partners can distinguish themselves from others also through different competencies. Such a competency might be the access to customers. Here, digitalization has a role too. Mass data analyses, e.g. behaviourial or social analyses, are an instrument for identifying customer requirements and developing tailored offers on this basis.

Orchestrators are in charge of the central coordination of the various actors and their value contributions. This function is necessary in complex and multilayer networks. Additionally to delivering their own performance, orchestrators analyze both the customer requirements and the crucial success factors. They bring the network in such a shape that is offers a competitive product. This includes the constant evaluation of other network actors like partners and followers, in order to replace them if necessary and to achieve a better overall performance.

Even though aggregation platforms and economic networks differ in their outward appearance, the three roles described above are clearly illustrated on the example of an aggregation platform: Followers are suppliers that offer their products on the platform. A partner can be, for example, Paypal as a provider of an online payment system. The orchestrator is the provider of the trading platform such as e.g. Amazon.

Companies that want to be successful in such complex and dynamic economic networks need to demonstrate appropriate network competence: a combination of network willingness and network ability. The willingness to act as part of a network requires a culture that leaves room for collaboration, exchange and innovation. This includes the capability to integrate oneself and one's own work in changing structures. Network ability is a matter of organizational and technological competency. It presupposes digital skills and infrastructures. Network ability also needs reliable legal framework conditions, e.g. regarding data protection or copyright. Furthermore, it depends on fast, all area access to the internet and (attack) secure internet use (see chapter "Special aspects of the political regulatory framework of digitalization").[117]

The potential of chemical companies in economic networks
Generally speaking, chemical companies have always been moving in a complex environment. They manage complex integrated productions (Produktionsverbände) at integrated sites (Verbundstandorte) or chemical parks, and they are dealing with large numbers of suppliers and customers from a broad range of customer industries. Basically, this suggests good prerequisites for network willingness and ability. But the chemical industry does not yet fully exploit the opportunities of digital economic networks.[54] In order to better open up these chances, chemical companies should not only be early to identify the dynamics and the emergence of economic networks; they should also define their own role inside these structures and strategically shape this role. A strategic option for action might be a shift purely from the production of materials to offering system solutions.[115] Another potential option is to expand B2B approaches towards more B2C-oriented business models.

Assessment criteria for the role in economic networks
With manifold products and services, the chemical industry is part of the industrial value chain. Consequently, the industry can assume a diverse role in economic networks. The potential roles of chemical companies in various emerging economic networks can be determined by three factors:

- The possibility for chemical companies to influence the network;
- the likelihood of digital actors entering the network;
- capability of chemistry to create value inside networks.

The possibility for chemical companies to influence the shaping and composition of an economic network is largely determined by the concentration of customers and suppliers and the transparency of the offered products and services. A high customer and/or supplier concentration and the resulting strong influence of these actors narrow down the scope for chemical companies in the shaping process. Because of the great complexity of chemical-pharmaceutical products, their advantages are not always visible as first glance and require comprehensive explanations. This increases the capability to exert influence for chemistry.

The three factors for assessing the role in economic networks

Ability to exert influence
Buyer concentration
Supplier concentration
Complexity of products
Entry barriers for digital players
Profitability of the industry
Laws & regulations
Investment & availability of capital
Customer loyalty
Access to distribution
Network effects
Ability to create added value
Impact on costs and differentiation
Brand reputation
Providing solutions
Operational infrastructure for the eco-system

A special aspect in the formation and shaping of economic networks is the entry of new, digital companies that swiftly and nimbly take over the orchestrator role. Therefore, the entry barriers for digital businesses are a significant factor for the scope of action for chemical companies. The anticipated high profitability of an emerging economic network makes it a very interesting target for (digital) competitors. Entry barriers could be high investment costs, strict regulations and well-protected intellectual property like patents and production or product know-how. Also, close customer ties to established suppliers and distribution channels render access more difficult for new entrant enterprises. But digital trading platforms for chemicals like MOLBASE have shown that digital actors formerly unknown in the chemical industry can accept new business models and overcome the mentioned entry barriers.

The third determining factor for the scope of chemical companies in economic networks is the capability to contribute – with their products and services – a unique form of added value to a network. Only then can the companies assert themselves as orchestrators and attract and keep partners on a permanent basis. The scope of action for chemical companies is even wider if their products and services contribute such added value to the end product (and thus to the other partners). The added value of products and services is also determined by "soft" factors, e.g. customer confidence in a brand promise. Especially in the sensitive environment of the chemical industry, the trust in quality and safety can make a major contribution to the acceptance of offers from digital networks.

Taking into account the industry segment and the individual prerequisites of each company, the analysis of these three factors gives a good indication of what roles chemical companies could assume in which economic networks. But this analysis is not a static one: Framework conditions can be changed actively should a company find a different role more advantageous than the one allocated in the analysis. For example, 30% of chemical industry executives surveyed by Deloitte stated that their companies wanted to assume an active role as orchestrator in the building up of digital economic networks and as platform owners.[48]

Example: Digital agriculture

Digital agriculture ranks among the most advanced economic networks. Established companies like seed breeders, fertilizer and plant protectant producers, manufacturers of machinery and also food processing businesses cooperate with new players – e.g. providers of software and agricultural data or drone manufacturers – to offer a full package of products and services for farmers (see figure). Digitalization has a special role, as data on weather, soil, crops and machines are not only collected and evaluated: the results need to be put into practice in real time, e.g. to optimize fertilization during the fertilization process.

Next, three of the above-mentioned factors are examined in detail to give an example of a potential positioning of chemistry in this network.

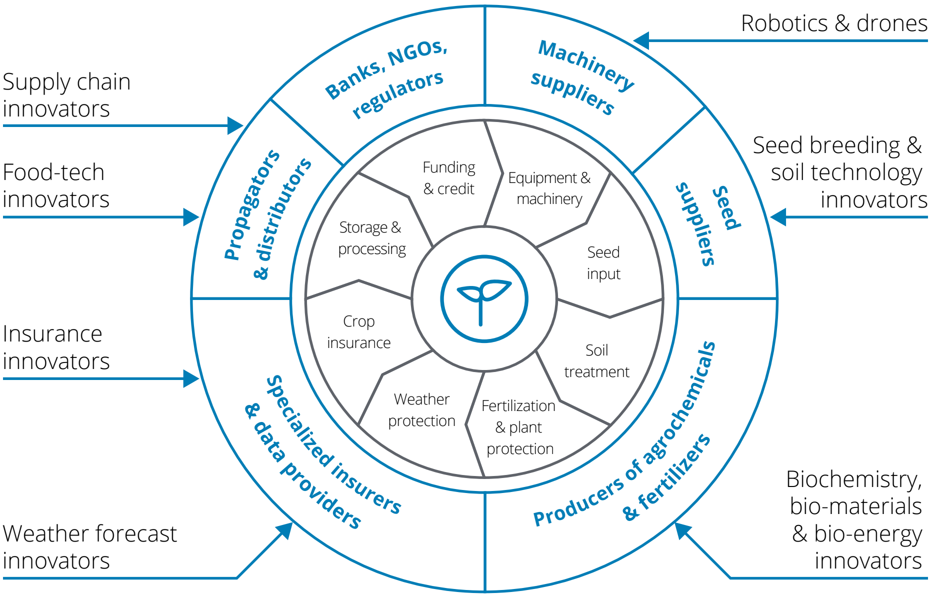
The first factor is about the chemical industry's ability to exert a significant influence on the shaping and composition of the economic network. With around 275,400 farms in Germany, the customer side is highly fragmented in 2016. Many of the 116 suppliers to agrochemical producers are globally consolidated manufacturers of organic base chemicals and intermediates. Their products are standardized and thus interchangeable. Therefore, the power of suppliers is not particularly strong. Given the variety of products and services and the difficult comparability, the product complexity is higher than for standard products.

The entry barriers for new digital companies are moderate to high. For example, high environmental standards and food industry regulations make it difficult to enter the economic network. Furthermore, strong customer loyalty, especially to agrochemicals and farm machinery manufacturers, is an entry barrier for new companies. Many farmers are loyal to established agrochemical brands, as agrochemicals – including biologicals – have significant effects on crop yields. Moreover, such effects become evident only after a certain time so that change constitutes a risk. Brand loyalty is also strong where investments have reached a significant level so that there is a potentially high risk, e.g. for farm machinery.

The barriers are high for new distribution partners; many farmers are loyal to their established partners. When buying farm machinery or agrochemicals, farmers expect expertise from established distributors and vendors. Also, manufacturers of agrochemicals and farm machinery have built up their own alternative distribution channels, e.g. online direct sales or integrated distribution through comprehensive analytical tools. Several agrochemical manufacturers have established new distribution concepts with supplementary offers and rely on their application competency. This relatively comprehensive existing digital distribution structure and application competency as key factors make it difficult for new digital businesses to establish themselves as aggregation platforms between end customers and network participants.

Active networking between established companies in the ecosystem[117] and the

New economic network in agriculture



orientation of products and services to new needs further reduce the business opportunities for new entrant companies. For example, the farm machinery manufacturer John Deere works with several software providers and other businesses from the agricultural industry to offer "MyJohnDeere" – where farmers can monitor and adjust, mobile and in real time, the performance of agricultural machines (e.g. spray pressure, application rate or ground speed). Farmers have also access to distributors, staff or experts from the John Deere network.[118]

On the other hand, the expected increases in profitability – and thus the potentially rising margins for suppliers – are incentives for new companies to overcome the above-described entry barriers. In 2015, the production of German farms was worth 52 billion euros.[119] Digitalization of agriculture (e.g. precision farming) could increase the sales of farmers by up to 18% while reducing input costs by an average of 15%.[120] Capital providers are aware of this business potential too. For example, in 2015/16 alone, venture capital funds invested nearly 8 billion US dollars in agtech.[121]

The third factor that defines the scope for suppliers is the ability to create added value for the network. Fertilizers, plant protection and crop varieties are essential for farmers. The use of high-quality plant protectants significantly increases yields by helping crops to better utilize their genetic yield potential. Add to this the innovation strength of established suppliers that gives them a lead in plant protection. The analysis of the above factors of influence suggests that the chemical industry has a good starting position for positioning itself as an orchestrator in digital networks in agriculture.

From the chemical industry's perspective: degree of fulfillment of the three factors in the economic network agriculture

	Situation for chemistry
Ability in chemistry to exert influence	
Buyer concentration from the chemical industry's perspective	advantageous
Supplier concentration from the chemical industry's perspective	neutral
Chemical product complexity	neutral - advantageous
Interim assessment	**neutral - advantageous**
Entry barriers for digital players	
Profitability of the industry	not advantageous
Laws & regulations	advantageous
Investment & availability of capital	neutral
Customer loyalty	advantageous
Access to distribution	neutral
Network effects	advantageous
Interim assessment	**neutral - advantageous**
Ability of chemistry to create added value	
Impact on costs and differentiation	advantageous
Brand reputation	advantageous
Providing solutions	advantageous
Operational infrastructure for the eco-system	neutral
Interim assessment	**advantageous**
Final assessment of potential	**Orchestrator**

Example: Additive manufacturing

Additive manufacturing processes (also: 3D printing) are ready for serial production. They will have manifold impacts on production, design and supply chains in a wide range of industries (see chapter "Framework analysis"). 3D printing holds growth opportunities in new economic networks where the production infrastructure has no advantage for established suppliers.

The concentration is low on the customer side, as 3D printing aims to serve a large number of end customers in a decentralized approach. At least for the time being, the chemical product complexity can be seen as neutral to advantageous. As in the previous example, therefore, the composition of networks can be influenced.

However, the entry barriers are low for new digital businesses because, firstly, investments are low due to the decentralized structure and, secondly, the share of digital value creation is high. For example, many innovative start-ups work in hardware manufacture and in the development of engineering software. They also offer services.

Chemical companies can add value to the economic network, as they have a comprehensive portfolio of materials and the knowledge for using them. They are also innovative and have a customer base across several industries. Production plants require high investments for many products. This open up the possibility to offer products from additive manufacturing for many different applications. Products can be development together with customers or directly with the suppliers of end products (e.g. Reebok and BASF[71] or Henkel and DUS Architects[72]).

From the chemical industry's perspective: degree of fulfillment of the three factors in economic networks additive manufacturing

	Situation for chemistry
Ability in chemistry to exert influence	
Buyer concentration from the chemical industry's perspective	advantageous
Supplier concentration from the chemical industry's perspective	neutral
Chemical product complexity	neutral - advantageous
Interim assessment	**neutral - advantageous**
Entry barriers for digital players	
Profitability of the industry	neutral
Laws & regulations	neutral
Investment & availability of capital	not advantageous
Customer loyalty	neutral
Access to distribution	not advantageous
Network effects	advantageous
Interim assessment	**not advantageous**
Ability of chemistry to create added value	
Impact on costs and differentiation	advantageous
Brand reputation	advantageous
Providing solutions	advantageous
Operational infrastructure for the eco-system	not advantageous
Interim assessment	**advantageous**
Final assessment of potential	**Partner - Orchestrator**

Especially with their expertise in the development and processing of materials, chemical companies can assume the role of a partner. They can cooperate closely with hardware (printer) manufacturers to optimize the development of printers for their own materials or build up their own production platforms. But regarding the positioning as an orchestrator within these networks, they are in strong competition with other network participants (e.g. the printer manufacturers themselves, suppliers of print software or printer farm operators).

Interim conclusion

Both examples show that chemistry, with its portfolio and compentencies, is well-prepared to position itself in the new economic networks. This requires the willingness and ability for networks, together with a continuous expansion of digital skills and the readiness to open up for further partnerships.

With its innovative products and services, chemistry can make a significant contribution and drive forward the creation of economic networks by developing new digital and circular business models. Thus, economic networks can become an important component of future profitable growth of chemistry and pharmaceuticals in Germany. This brings new chances for cooperation, especially for small and medium-sized enterprises.

With its innovative products and services, chemistry can make a significant contribution to the development of new digital and circular business models and drive forward the creation of economic networks.

Conclusions and recommendations for action

This study shows that the German chemical industry is faced with immense technical, economic and societal changes.

The existing portfolio of products and services must be put into question, and business models have to be adapted. The chemical industry should continue and accelerate the transformation process that has already set in – as an industry in its entirety and at company level. Politicians are called upon to support these efforts under the industrial policy and to bring about globally competitive framework conditions for the chemical industry in Germany. This is the only way for the chemical industry, in its position at the core of industry overall, to contribute to the long-term preservation and strengthening of the industry location Germany.

The following overview identifies the major fields of change. Initially, it outlines the recommendations for action to chemical companies and their associations. This is followed by the recommendations for action to politicians, both in an overarching approach and in more detail regarding the core topics of digitalization and circular economy.

Requirements to companies and associations

Digital and circular business models require technical and network competency. The chemical industry has a sound basis for this which, however, needs to be expanded and adapted in order to overcome the remaining obstacles and to fully exploit growth opportunities. These changes involve many risks and require high and targeted investments in education, capital in kind and software. Furthermore, there should be a change in corporate culture – for example, to create start-up niches within established organizational structures, expand the cooperation with external partners, possibly build up platforms and set up adequate decision-making and steering systems. All this needs entrepreneurial courage and the willingness to take risks as well as financial scope and persistence.

The relevant recommendations for chemical and pharmaceutical companies are divided into four categories. These highlight the most important elements of change: orientation of strategy, transformation of corporate culture, expansion of resources, and exploiting opportunities. It is worth noting that not only the companies themselves but also the associations and social partners of the chemical industry can support this transformation. Therefore, they are explicitly addressed in the recommendations for action.

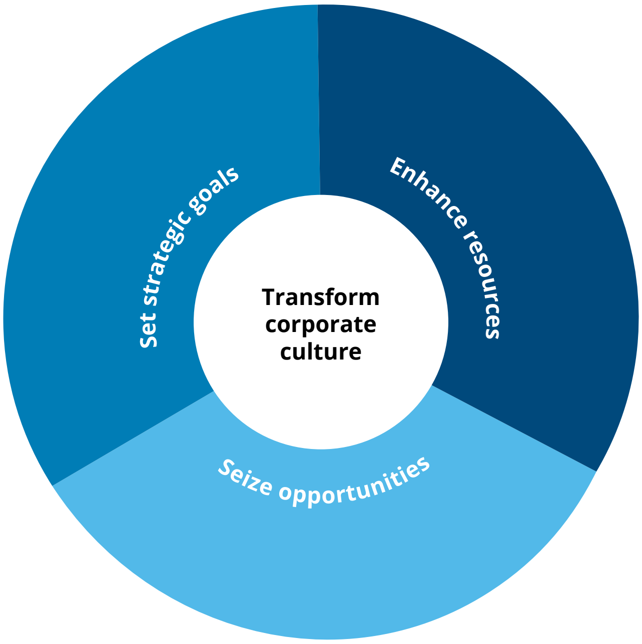
Recommendations for action for companies and associations

Set strategic goals

- Anticipate disruptions
- Make digital and circular an integral part of corporate strategy
- Amend decision criteria

Seize opportunities

- Ideate freely
- Utilize economic networks
- Establish co-operations and platforms
- Develop new concepts for participation



Enhance resources

- Company structure
- Competences
- Investments

Transform corporate culture

- Transparent and open
- Agile and tolerant
- Collaborative and communicative
- Act multi-modal

Orientation of strategy

For the future viability of companies, it is important that they become aware at an early stage of the technological, economic and societal disruptions and analyse them as regards the chances and risks for their businesses. Here, associations can support the companies through an exchange of information. On this basis, the companies can define a holistic strategy, develop offers for solutions and use the emerging chances. Companies need to define digitalization, circular economy and innovation as components of both their sustainability strategy and their corporate strategy as a whole. As is shown, digitalization and circular economy should also be examined in respect of potential synergies.

Derived from the strategy, the next steps are to determine detailed goals with clearly quantified targets and to communicate them inside the organization. For a sustainable embedding of digitalization and circular economy, both topics need to be firmly positioned strategically and steered from executive management level.

New assessment criteria need to be added to the classic success parameters of business administration. These new criteria should take into account the properties of new production and value chain structures (higher flexibility, smaller lot sizes/trend towards personalization, appraisal of existing and newly generated data).

Transformation of corporate culture
Additionally to defining strategic goals, it is important to adjust the corporate culture to the new requirements. The successful development and scaling of new business models for digitalization and circular economy, especially at the interface between these fields, needs corporate cultures with a start-up character.

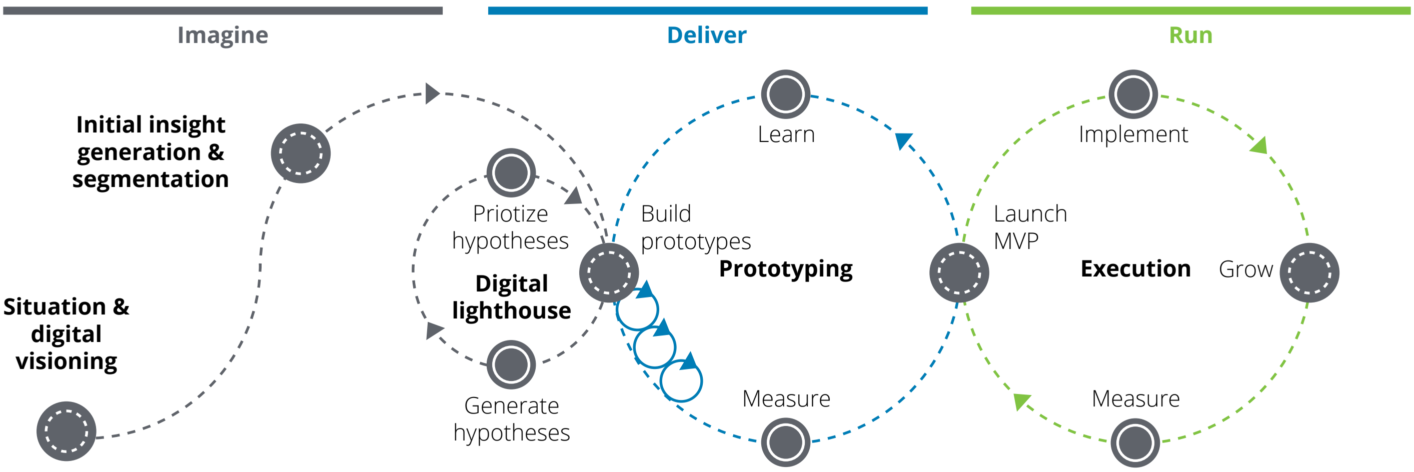
Important elements for this are transparency and openness, agility and tolerance as well as a culture of cooperation and communication, also beyond company boundaries. Quite often, especially digitalization is "merely" seen as a technological challenge. It is overlooked that digitalization has to come with a change in corporate culture.[122]

- Transparency and openness: Primarily, a transparent and open corporate culture is needed for a successful implementation of digital business models. Here, two aspects are important. Firstly, a leadership culture that is characterized by motivation and moderation where executives have rather steering tasks than controlling functions. Secondly, digital business models with their flexibility and dynamic changes require that processes and structures are constantly scrutinized and adapted. In this setting, staff need to work more independently and flexibly. Moreover, they should take on more responsibility. Studies show that the last-mentioned aspect is of great importance to employees.[127]

- Agility and fault tolerance: The fast pace of the digital age requires fast answers from companies. Innovation cycles are getting shorter; new products and business models need to become reality without delay. This presupposes a culture of fault tolerance[49] and great agility. More than ever before, companies need to accept the possibility that innovative ideas can fail. Alongside the established concept of a detailed weighing of chances and risks, also "trial and error" approaches and new concepts (example "Deloitte agile digital transformation concept", see below) are applied. Greater agility is an integral part of organizational development that aims to respond quickly to changing requirements: by way of changed operating and business models. There is a need to catch up in this respect: 55% of chemical industry executives surveyed by Deloitte in 2016 identified lacking agility in their organizations as a major barrier to the implementation of the digital economy.[48]

- Cooperation and communication: Digitalization and the associated changes in leadership culture and the way in which agile digital business models are implemented call for a new quality of cooperation and communication – externally and internally. On the one hand, new participation concepts need to be developed and put into practice for a stronger involvement of stakeholders. On the other hand, the work in project-oriented teams is gaining importance. Technologies such as video conferencing have long been established; they are complemented by new forms of information exchange (e.g. internal knowledge networks). These not only serve for a rapid exchange of information inside teams; they also boost the motivation of staff. The importance is reflected in surveys: 20% of executives see the lack of a culture that is both cooperative and encourages entrepreneurial action as one of the three major challenges in a successful implementation of digital initiatives.[48]

Deloitte Agile Digital Transformation method



Digital visioning	Implement target operating model	Execute & manage transformation
Where to play prioritization	Governance	Digital champions
Sense of urgency	Organization	Mobilization & communication
Digital Vision & objectives	Responsibilities	Implementation roadmap
Digital diagnosis	Processes	Program execution
Must do to win	Capabilities	Quick wins & success stories

Key step Sub step

The „Deloitte Agile Digital Transformation method" is an example of an agile cycle where ideas are rapidly translated into prototypes, these are tested on a small scale, and lessons can be learned from the results and errors (see figure).

The concept consists of three phases: In the first phase "Imagine", a digital vision is developed and – from the customer's perspective, taking into account this digital vision – an idea for a product or service is elaborated as an hypothesis. In the second phase "Deliver", cross-functional teams are formed. They define the prerequisites for implementation and create a prototype. The continuous review of results as to whether customer expectations are met and experiences are reflected is an integral part of the concept. In the third phase "Run", a first marketable product ("minimal viable product"/MVP) is placed on the market and optimized in application.

- Act in a multi-modal manner: Quite often, there is a marked difference between today's business and operating models in chemistry and innovative digital and circular models. Companies need to make sure that the processes and culture of their core business do not slow down such new solutions – while not neglecting their existing success factors. Therefore, companies should allow a scaling of business models that might run against their core business ("managed cannibalization"). The companies need to cope with this field of tension in their operative business and create suitable structures for putting into practice the different models in parallel.

The chemical industry associations can best support their member companies by developing catalogues of criteria (best practice analyses, toolboxes, guidance documents) for an adequate assessment of circular and digital business models and for depicting them in the companies. Here, the Chemie³ sustainability check is a good example.

Expansion of resources
Advancing digitalization and the introduction of circular economy models necessitate and enable an expansion of the range of services and products from chemical and pharmaceutical companies. These products and services require additional competencies for such operating and business models.

- Corporate structure: Companies need to adapt their organizational structures to facilitate the development of new business models. This can be brought about by separate innovation units or intrapreneurship concepts where staff act as entrepreneurs, e.g. in company-internal incubators.

- Competencies: Education, recruiting, work 4.0, cyber security – new business models in the chemical industry require one overall offer that comprises products and services partly from outside the core competencies of chemistry. This will lead to expanded skills being demanded from certain groups of staff. In the future, such skills will have to be extended increasingly in chemistry. But already today, finding suitably qualified personnel with digital competency is a major challenge for chemical and pharma companies.[123] As regards digitalization, 75% of chemical industry executives surveyed by the German business newspaper Handelsblatt fear a shortage of staff with the necessary skills in the next ten years.[121]

Therefore, continuous education and marketing initiatives in chemistry are needed to attract new staff and for vocational and advanced training. This will contribute to positioning the chemical industry as an attractive employer of talented people also in the future. Another success factor for utilizing the existing potential is a needs and target group-oriented teaching of digital skills in vocational and academic education. For example, complex data analysis is a topic that should be given more room in the curricula of universities. Furthermore, universities are increasingly called upon to open up to advanced training for persons already in employment, i.e. advanced training additionally to daily work. Alongside digital know-how, self-management and social competencies are crucial too. Such qualifications should be built and taught fast, in order not to leave staff behind and to address possible fears and reservations. To master the challenges of digitalization in the world of work, the chemical industry should continue the social partner dialogue WORK@industry 4.0 where the industry develops a common understanding of the challenges as well as recommendations for action in the shaping of the chemical industry's future world of work.

The progressing networking of production, products and services – and with partners, mainly inside economic networks – increases the risk of data being manipulated. Therefore, chemical companies should intensively look into the topic of cyber security and, together with their partners, define the security of the entire system as a common protection goal.

- Investment: The above-described changes call for additional investment in vocational and advanced training, capital in kind and software. Chemical companies should clearly allocate budgets to digitalization and circular economy. New business models in the digital and circular economy could require long start-up times before the anticipated business success materializes. Start-up costs might have to be funded over rather long periods. It is necessary to convince internal and external stakeholders (shareholders) of the need for such investment.

The chemical industry has a good starting position. However, the industry needs to expand and adapt its competencies and structures to fully utilize the opportunities for growth.

Exploiting opportunities

The companies have realized that digitalization and circular economy will fundamentally change chemistry in many business fields. The trends in the environment of the chemical industry, as described in this study, bring disruptive changes. New competitors are establishing themselves in new business models and economic networks. The chemical industry needs to actively shape these changes and use them for its own benefit. The following four topics are of special importance in this context:

- Shape freely: In order to develop innovative and competitive solutions for their customers, the companies need to focus on the customers' needs – without being influenced by familiar products and services. Digitalization and circular economy bring new, not yet established options that have to be identified, developed and assessed. Structured methods (e.g. the "Ten Types of Innovation")[124] are helpful for finding new ideas. In the shaping of business models too, the companies should break away from existing structures and assets and benefit from the new aspects of digital and circular business models. For example, the business model Canvas Method[125] offers a possible definition framework.

- Use economic networks:
Chemical industry companies already operate in complex value chains. However, economic networks will be getting ever more important in the future and require yet more networking between actors from different industries, universities and research institutes – and sometimes also with customers. This makes economic networks highly complex and calls for an open culture of cooperation and innovation with partners of different origins and sizes. Business models realized by networks require a comprehensive analysis of incentive structures, value contributions and remuneration structures. This means for chemical companies that they themselves identify independently their chances in emerging economic networks and define their roles.

The associations of the chemical industry can help, for example, with a "toolbox for economic networks" that remains to be developed. In this context, more attention should be given to supporting start-ups in chemistry, pharmaceuticals, biotechnology or life sciences, e.g. by way of own corporate venture capital.

- Build up cooperations and platforms:
Digital and circular business models require extensive cooperations within the chemical industry and beyond. Through its associations, the chemical industry can drive forward the building up of platforms for an exchange of knowledge and the search for partners (inside the industry), position itself as an open and attractive partner for start-ups and technology businesses, and expand research cooperations.

- Develop new participation concepts:
  The speed and complexity of change can fast cause a rejection of innovations. Beyond stronger communication, the associations and companies should open up their innovation development for a stronger participation of politicians and other interested groups in society. Thinking and acting in networks is necessary for the success of digitalization; this should also include the cooperation with societal stakeholders. For this purpose, companies and associations can jointly develop new participation concepts. The sustainability initiative Chemie[3] is a good example for such a concept.

Digital and circular business models require extensive cooperations and economic networks inside the chemical industry and beyond.

Special aspects of the political regulatory framework of digitalization

- Drive forward digital education: The needs and target group-oriented teaching of digital competencies in vocational and academic education is a success factor for the German economy. Politicians can support such knowledge building by creating suitable framework conditions and infrastructures for teaching digital know-how at schools and universities. Furthermore, universities are called upon to open up to advanced training for persons already in employment, i.e. advanced training additionally to daily work. Beside the teaching of digital competencies, also the STEM subjects (science, technology, engineering, mathematics) should be further strengthened in the German education system.

- Solve challenges in social partner style: Social partner agreements should be sought to solve the challenges of digitalization in the world of work. Such agreements should have preference over new regulation. With this in mind, the social partners of the chemical industry have launched the dialogue process WORK@industry 4.0 where they want to develop a common understanding of the challenges as well as recommendations for action for shaping the future world of work in the chemical-pharmaceutical industry.

- Expand the technical infrastructure: The German economy needs a digital network that is fast and stable and connects companies, suppliers, customers and staff in an all-area approach. Broadband expansion needs to be driven forward faster. It is imperative to expand the telecommunications infrastructure with full regional coverage by 2025; the next mobile phone generation 5G should become reality as fast as possible. Other countries are investing far more in their telecommunications technology. If Germany does not increase its pace, this country might fall behind, so the IMD World Competitiveness Center in Lausanne in May 2017.[126]

- Further develop the institutional infrastructure: Technical infrastructure expansion should be accompanied by creating a high-performance security network between public authorities, companies and research in Germany and Europe. This network should provide the necessary advice and services in encryption and other security technologies and ensure security at the interface between information technology and production plants. Thus, cyber and IT security should be a focus in the German high-tech strategy.

  Public authorities too must meet the prerequisite security standards. Efforts should be accompanied by a fast and secure expansion of e-government, e.g. in the electronic filing of applications: All signature boxes should be removed fast from electronic forms where signatures are not required by law. Flagship projects for e-government at selected public agencies could support this process.

- Align personal data protection and innovation benefits: The responsible citizen should be the yardstick for the regulatory framework in data protection. It should be examined to what extent the data protection rules can obstruct the development of end customer-oriented, individualized business models and whether it is possible and necessary to make adaptations to data protection law. Harmonized European approaches and agreements that enable a secure international data exchange would be desirable. In this connection, the national localization obligations in the EU should be reviewed to find out whether they might stand in the way of implementing the "free flow of data" principle.

- Make machine and company data usable while safeguarding IPR (intellectual property rights) and know-how protection: Machine data must be usable in such a way that innovations are not impaired in the development of products and services. Regarding data use and the safe handling of data, preference should be given to contractual agreements over legal (ownership) regulations. Industry should show ways for successfully solving the issue of data ownership and make potential solutions available to political decision-makers. A rapid transposition of the Trade Secrets Directive (EU) 2016/943 into national law should be ensured to protect company data and business and trade secrets. Disclosure obligations for company data must not adversely affect security and, therefore, should be limited accordingly. Moreover, the existing liability privileges for platform operators should be reconsidered in the fight against product and brand piracy and to strengthen IPR.

- Promote cooperation and a non-bureaucratic development of platforms: Networks, cooperations and the strengthened work between industry and science within integrated projects (Verbundprojekte) and networks take into account an increasingly dynamic business environment. This is particularly important for small and medium-sized enterprises. The public sector should support the development of the necessary network structures and the establishment of cross-industry platforms and innovation clusters for knowledge exchange. Here, it is important to give equal consideration to all sectors, in order to identify and use all synergies as comprehensively as possible.

- Dialogue on the necessity of and perspective for digitalization: Politicians should take fears about changes through digitalization seriously and initiate dialogues with citizens (Bürgerdialoge). This should be supplemented with online forums and accompanying media work on the topic of digitalization. Although digitalization means a continuous process of change and adaptation, it is important to show that it can also increase the productivity of the overall economy, support a self-determined life and enable more sustainable living. Moreover, the connection should be made to Germany's demographic problems: Digitalization is an important component for resolving the economic problems of an aging population in Germany. However, there is no need for new rights for public authorities to take up relevant issues in connection with consumer protection, as regards fair trade law and regulation on general terms and conditions.

- Open borders in the digital world: The digital world is networked globally. Europe's digital economy needs to be strengthened. Therefore, European approaches and harmonisation are needed inside Europe. Beyond that, an international framework is desirable too. Here, national or European go-it-alone actions towards digital technological sovereignty are unsuitable starting points. Digital sovereignty for Europe must lead neither to protectionism and special ways nor to incentives for using inferior technologies.

Special aspects of the political regulatory framework of the circular economy

- Understand circular economy as a holistic and open approach: According to the definition in this study, the term "circular economy" must not be narrowed down to mechanical recycling. It comprises efficiency gains at all levels of value creation and in entire product life cycles, starting with the production of basic materials and subsequent processing stages to the use phase of (end) products. Waste avoidance through multiple use, improved efficiency through the use of by-products and wastes as raw materials, energy recovery of wastes, use of renewables as CO_2 cycle and use of CO_2 as raw material, feedstock recycling: All these are options for a development away from elimination and towards a more efficient use of resources through effective recovery. Technical feasibility and cost-effectiveness are vital prerequisites. Furthermore, (end) products make their efficiency contributions essentially in the use phase, e.g. energy-efficient insulation of buildings or construction of lightweight vehicles.

- Strive for sustainability: The customers' needs regarding cost, quality, benefit and sustainability of products must be met. A sole focus on the recyclability of products is not enough. Circular approaches should not rely exclusively on a one-dimensional "design for recycling" approach. Instead, they should take up the idea of "design for sustainability" which also includes the aspect "design for performance" and possibilities for using secondary raw materials in production development.

  An "across-the-board" orientation of material design to mechanical recycling can be counterproductive to the development of innovative materials, for example, modern composites. Not all of them are optimal to recycle, but they have important properties e.g. for resource efficiency and climate protection. Therefore, sustainability assessments should give emphasis on the entire life cycle of a product instead of focusing only on recyclability at its end.

- Better regulation: The composition of wastes should be the decisive criterion for the most sustainable disposal method. Waste legislation should not give a one-sided and non-differentiated focus on the mechanical recycling of waste. Specifications and quality are decisive for recycling, in order to maintain the functionalities of chemical building blocks where this makes sense and to reuse them as raw materials in new products. Generally raising recycling targets or introducing new ones can put limits to recycling efforts.

  Existing recycling targets need to refer to end consumer waste as it is generated in practice. Regarding industrial waste streams unsuitable for further recovery (e.g. incineration residues from energy recovery) landfilling must remain possible so long as this is the only feasible disposal option.

The respective scope of the chemicals and waste legislation should be duly taken into account. Chemicals are adequately regulated under chemicals law which also applies to products from mechanical recycling, e.g. regranulates. Product safety is ensured through the existing European regulations REACH (Registration, Evaluation, Authorisation & Restriction of Chemicals) and CLP (Classification, Labelling and Packaging) and general and specific product safety directives in conjunction with the Waste Framework Directive. For this reason, there is no need to enshrine aspects of chemicals law in the waste legislation. Applying practical guidance on reuse (e.g. from the German Federal Environment Agency/UBA) regarding REACH and plastics recycling should be supported both in Germany and at European level.

- Review the existing regulatory framework as to obstacles to a circular economy: The existing regulatory framework should be reviewed as to obstacles to expanding circular economy concepts. One example is the use of electricity from renewable energies and CO_2 in the production of chemicals and synthetic fuels (Power-to-X and carbon capture utilization). These approaches hold great promise for the future in technological terms but they make sense economically only if their high electricity requirement can be covered at competitive conditions. Due to the high state-induced levies on the electricity price in Germany, this prerequisite is not fulfilled at present.

- Create societal awareness for circular economy: Circular economy cannot be successfully established without the joint efforts of all sectors and consumers. Therefore, the political side should foster a fundamental understanding. This should be done by way of suitable dialogues and educational offers at a societal level, in order to bring about transparency about objectives and costs.

Support by improving the general political framework conditions

- Expand support for innovation: The environment trends identified in this study show a considerable potential for innovation with positive external effects, together with a high degree of technological uncertainty and corresponding investment risks. Examples are Power-to-X technologies which can drive forward the greenhouse gas neutrality in German industry, genome editing which can bring progress in human medicine/pharmacology, crop protection and crop breeding – and chemical feedstock recycling that enables an efficient use of secondary raw materials in a circular economy. Suitable deployment of digitalization in circular economy systems is a promising field of research.

  In view of the anticipated positive external effects of R&D investment, public innovation promotion is efficient for the overall economy if it is open to a wide range of technologies and non-bureaucratic. Such promotion is also needed to achieve an increase in R&D spending to 3.5% of GDP, as is recommended by the Commission of Experts for Research and Innovation (EFI) and adopted by the German federal government. Typically and in particular in the digital economy, investments come about in networks of companies of different origins and characteristics. Quite often, larger companies are the leaders of innovation consortia and contribute the lion's share to R&D spending. Therefore, companies of all sizes should benefit from fiscal incentives for innovation.

  Depending on whether the field of a topic can be seen within clear-cut borderlines, both extended project funding and supplementary fiscal incentives are possible options. However, introducing fiscal incentives for innovation must not be to the detriment of project funding; the latter can still be expanded under the high-tech strategy. Tailored and non-bureaucratic programmes should facilitate access to project funding and venture capital for small and medium-sized enterprises. Publicly supported start-up programmes and guidelines for project funding should address in a targeted manner also interested parties with projects in the chemical, pharma and life science industries. Regarding new projects for the use of renewable electricity and CO_2, time-limited support for pilot plants can make sense for the overall economy.

- Review of the regulatory framework: Given the dynamics and openness of current developments in the digital and circular economy, is it important to allow scope for own action and to bet on industry initiatives (e.g. within the sustainability initiative Chemie[3]). Therefore, accompanying legislation needs to be oriented to an equal degree to the principles of "product stewardship", precaution, economic efficiency and innovation – i.e. to the sustainability principle overall (equal consideration of ecological, economic and social aspects). Therefore, in an "innovation check" new and existing pieces of legislation should be reviewed, in particular, as to whether and to what extent they drive forward or even impair innovation (including new business models). One example is industrial biotechnology: For future regulation, it should be borne in mind that such regulation needs to keep up with scientific and technical progress in biotechnology, so that large and small companies can use it.

Regarding future plans for regulation, it should be ensured that they do not conflict with other pieces of legislation. Also, duplicate regulation should be avoided. Inconsistencies would make it more difficult to keep the location Europe competitive and render a scaling of solutions impossible. Therefore, politicians should strive to create a consistent and reliable regulatory framework and harmonize laws and regulations throughout Europe and – in combination with other sectors – strengthening the competitiveness of the chemical industry in this manner.

Companies should be informed early about planned reviews of existing legislation and new regulatory initiatives, and they should be adequately involved in an accompanying process (e.g. in consultations, workshops etc). According to the "better regulation" principle of the EU, impact assessments should be performed generally for relevant amendments to regulatory framework conditions.

Regulatory planning security should be made possible by consistent, holistic legislation with good transparency for future framework conditions, e.g. through regulatory roadmaps. It should be examined whether regulation needs to be adapted in order to facilitate the cooperation on platforms. Furthermore, it should be evaluated whether it is possible for the political side to support – together with industry – the putting into place of standards for products and data: for establishing networks in a straightforward manner and fast.

Survey among medium-sized enterprises: Recommendations for action of special relevance to medium-sized enterprises

Almost all medium-sized enterprises respond with the tried-and-tested strategy mix to rising competitive pressure and changing customer requirements: expand innovations, drive forward specialization, get established in niches, and use the chances of globalization.

However, in many cases the disruptive changes in value creation structures necessitate a readjustment of the corporate strategy and a review of existing business models. This is the only way for companies to use growth chances and remain successful in the long term. Many medium-sized enterprises have recognized this need for action and implemented a digitalization and sustainability strategy.

But available potentials are not always fully identified. For example, so far the chances of digitalization are seen mainly for "digital processes" and "digital operating models". By contrast, many executives currently still see no potential for innovations in "digital business models" – ignoring the new extra opportunities that open up especially for small and medium-sized enterprises in "digital models" where not the company size but flexibility and speed are decisive. Many chances are missed also regarding circular economy, which is predominantly perceived as a regulatory issue. With the help of innovations, many medium-sized enterprises adapt their strategies to changing customer requirements and existing regulation – whereas it would be more promising to anticipate at an early stage the changes in the customer's needs or future legislation. Quite often, personnel and financial resources are lacking for such an "early warning system". Against this backdrop, many medium-sized enterprises expect support from their associations in the form of information events, benchmark studies or exchanges of experience – up to concrete guidance documents and regulatory roadmaps. Such support should be given primarily through sector and regional associations. Economic-political framework conditions are mainly rated positively by the companies. However, the regulatory environment became slightly less favourable lately. Current problems in regulation are mostly about implementation and enforcement. 67% of companies hold that licensing procedures are "slow and bureaucratic". Consequently, politicians and public administration can provide concrete support by further reducing bureaucracy, bringing regulation in a more cost-efficient shape and speeding up licensing procedures.

Glossary – Environment trends

Energy & raw materials

Reliable raw material supplies / supply security for raw materials in Germany: Describes the change in the mix of raw materials (e.g. towards a higher share of renewables) and the development of supply security for naphtha-based chemistry in this country.

Power-to-X: A possibility for converting electricity into synthetic raw materials and heat by producing hydrogen from water by electrolysis and optionally converting the hydrogen into syngas and methane by reaction with CO_2.

Carbon capture storage/utilization: Storage (e.g. subterranean) and use of CO_2 from processes or air as a raw material.

Renewable raw materials: The use of renewables (e.g. oil crops, cereals and other types of biomass) for the manufacture of chemicals and materials. This trend includes the use of both crops/fruits and agricultural residues.

Waste-to-chemicals: The use of biomass in municipal waste as a raw material for chemical production. Methods and processes need to be robust, as biomass is usually difficult to separate from other wastes.

Bio-refineries: The processing of biomass through thermal treatment, biological processes or enzymatic conversion into basic or fine chemicals and foods and feeds.

Industrial biotechnology: Biotechnology methods in industrial production with which biomass can be processed more effectively and efficiently into bio-based chemical and pharmaceutical products.

Business-to-Business

Material-efficient building: Overall optimization of the properties of building materials with the resulting efficiency increase in construction. One driver is the more efficient processing of materials; this reduces either the input of materials as such or the labour time (e.g. through faster drying). Another driver is the longer durability of materials where repairs become necessary only after prolonged periods, e.g. through self-healing materials.

Energy-efficient building: Trend towards a higher energy efficiency of buildings as a result of societal and regulatory requirements. This is enabled, firstly, by better insulation systems and, secondly, by modern building technology.

Modern building: Modular construction of buildings from prefabricated components; these are produced in factories and assembled on site. Combined with a high level of standardization, this can cut costs.

Electro mobility: Trend towards a further market penetration of electric vehicles and plug-in hybrids (EVs).

Lightweight construction in the automobile industry: Weight reduction through a higher share of plastics (substitution of glass and metal), composites and additive manufacturing. This trend is driven by the needs of electro mobility and a more stringent environmental legislation.

New mobility concepts: Include car sharing, autonomous driving and intermodal transport, the mutually strengthening effect of these concepts and their impacts on the automobile industry (drive, equipment and fittings, customer structure).

Additive manufacturing: A manufacturing process – also called 3D printing –

which enables the production of a three-dimensional object in sequential layers from various materials, based on a digital model.

Material mix in packaging: Development of a changing mix of materials (glass, metal, paper and board, plastics) in packaging, which is mainly driven by urbanization, demographic change, trend towards convenience (including smart packaging) and increasing (mail order) trading.

Bio-plastics in packaging: The trend towards biodegradable plastics or plastics from renewable resources, in order to take into account the growing environmental awareness of consumers or regulatory regulations and targets.

Renewable energies – production technologies: Describes the growing number of photovoltaic, wind and other plants to generate renewable energies and the rising requirements to their efficiency.

Business-to-Consumer

Personalization of consumer products: Development towards a targeted adaptation of consumer products to the consumers' wishes – up to individual products for individual consumers. This requires flexible production and small lot sizes.

Perception of chemistry: The way the chemical industry is perceived by consumers: in production, transport and use of chemicals and their disposal. Chemistry is directly perceived by end consumers, especially in consumer-related fields like detergents and cleaning products, personal care and cosmetics. Here, there is also a special sensitivity for possibly misleading, non-fact based information about chemical ingredients. This can be intensified by the dynamics in social networks.

Change in the relationship between the chemical industry and end customers: The shift from the classic relationship between the chemical industry and end customers, which is characterized by numerous intermediate stages, towards more direct relations. The increase in e-commerce offers more possibilities for direct contact with end customers.

Agriculture

Urban farming: Various concepts for producing agricultural products (especially cash crops) in or near cities, using the latest control technologies that minimize or partly fully avoid the consumption of energy, water, fertilizers and plant protectants.

Agricultural turnaround (Agrarwende): The trend towards a greening of agriculture and the pursuit of an environmentally sounder, more sustainable production of agricultural products without synthetic fertilizers and chemical crop protectants. This involves yield losses and cost increases.

Genetically modified crops: Possibility to modify the genetic make-up of crops by inserting genes.

Genome editing as precision breeding: The use of molecular biological processes to optimize crops. New methods such as CRISPR/CAS9 – and the better precision, speed and cost reduction that come with them – open up new applications in crop protection and plant breeding, e.g. making crops more resistant to plant diseases by improving their own immune response or improving the yields per crop.

Digitalization of agriculture: The use and linking of all data on soil, weather, crops and further relevant aspects combined with digital system technology (including drones) to optimize the entire cycle of plants (fertilization, irrigation, crop protection and nutrition, sowing and harvest time). The goal is to increase yields on existing farmland while reducing the costs.

Pharmaceuticals and healthcare

Personalized medicine: The effort to understand fast and comprehensively the causes of diseases at the molecular level and to reflect the following in personalized treatment strategies: findings on mechanisms and various subtypes of diseases, different health risks of persons, different effects of drugs and other therapies on individual patients.

Genome editing in medical applications: Application of molecular biological methods (e.g. ZNF, TALEN and CRISPR-Cas) in medicine. With the help of these methods, the genome is changed in a targeted manner. The methods of genome editing are similar to a microsurgical intervention where genes can be switched on or off, inserted or removed. Thus, defective genes can be repaired or changed and mutated genes can be switched off. The special feature of genome editing methods is that genetic material can be edited more precisely, better targeted and at lower cost than ever before. Together with the insights gained through omics technologies, genome editing opens up extraordinary possibilities to sequence diseases and to decisively improve prevention, treatment and cure or to make them possible in the first place.

E-Health: All aids and services where information and communication technologies are used for prevention, diagnosis, treatment, monitoring and administration in the health sector. These include, for example, electronic patient files, wireless health, mobile health, telehealth, telematics infrastructure and software for hospitals and doctors’ offices.

New medical technology: Innovative medical devices with digitalization, miniaturization, combination products and 3D-printing as the main drivers. These trends lead to various new fields of research such as medical informatics and biosensors.

Self-medication: The treatment of diseases by the patients themselves and at their own responsibility with medicines not prescribed by doctors (“over-the-counter”/OTC), Main drivers are comfort in purchasing, more responsible and better informed patients, innovations and high acceptance.

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