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Aim and Scope

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

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Letter from the Editors

Navigating in a VUCA world

Describing today's world by VUCA (volatility, uncertainty, complexity, and ambiguity) seems to be more appropriate than ever. Leaving aside the question whether or not the acronym could always be used to characterize the prevalent situation because in retrospect the past was easier to manage than the future. Over the last years, we have witnessed VUCA in many forms. The political context is becoming more uncertain than ever. While presidents neglect climate change, we recognize the success of right-wing political parties and increasing protectionism all over the world. The global economy is shaped by low-interest rates and high stock valuations. Technology is changing rapidly just as customer preferences do. Accordingly, VUCA is both, a driver and an outcome of disruptive innovation. In this VUCA world, companies in the process industry gain sustainable competitive advantages through innovation, digitalization, and the right collaborations. The Journal of Business Chemistry aims to provide insights on these topics. Therefore, we are proud to present the following articles.

In his Commentary "The long term survival through innovation" John Bessant describes what companies from different sectors have had in common in order to survive and prosper for over one hundred years. He emphasizes that firms need to focus on some key themes around competence, networking, strategy, and innovation management.

In our Practitioner's Section Martin Geissdoerfer and Ron Weerdmeester present in their article "Managing business model innovation for relocalization in the process and manufacturing industry" the main results from the INSPIRE Project. In the Horizon 2020 funded INSPIRE project, tools for helping companies to integrate flexibility into their business models have been developed.

In their article "Implementation of sustainability in innovation management: The Idea to People, Planet and Profit (I2P3®) Process" Aurélie Wojciechowski, Beatrix Becker, Martin Kirchner and Burkard Kreidler demonstrate how sustainability can be integrated into the innovation process of a specialty chemical company. The process is based on a holistic approach with respect to the three dimensions of sustainability. The paper presents a detailed description of each stage of the process as well as the used assessment categories and criteria.

The first research paper in this issue comes from Marius Stoffels, Tim Smolink and Christin Hedtke. Their article "Artificial Intelligence in the process industries - technology overview, case studies, and success factors" provides an overview of promising Artificial Intelligence (AI) technologies and their potential application along the value chain in the process industry. Furthermore, the authors describe two cases and discuss potential barriers and pitfalls that companies might encounter while integrating AI into their business processes.

Magdalena Kohut's article "Collaboration in the context of industry convergence - an overview" deals with the biopharmaceutical sector as a convergent industry over the 20-year period from 1996 to 2016. Additionally, the article provides theoretical background on industry convergence and introduces a classification framework for competence transfer in cross-company collaborations.

Please enjoy reading the first issue of the sixteenth volume of the Journal of Business Chemistry. We are grateful for the support of all authors and reviewers for this new issue. If you have any comments or suggestions, please do not hesitate to contact us at contact@businesschemistry.org.

Thomas Kopel (Executive Editor)
Bernd Winters (Executive Editor)

Commentary

The long term survival through innovation

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1 Introduction

Next time you switch on your TV or computer display spare a thought for the company who probably produced the liquid crystal display. With over 60% of the global market, the German company Merck is probably not one which would instantly come to mind. Nevertheless, they dominate this and a wide spread of other activity in the chemical and pharmaceutical world (Bessant, 2017).

Or think about the headlights in the car you are driving – there's a pretty good chance that they will be made by another hidden champion, the German company Hella. They are a major international player in this market with an increasingly significant role in the expanding world of automotive electronics.

Turn on your air conditioner or your heating system and the chances are the pump driving it is made by the German company Wilo. Founded in 1872 it has evolved into one of Europe's most successful manufacturers of pumps for a wide range of domestic and industrial applications.

And if you ever need your aircraft, car or truck modified, upgraded or configured for some special application there's a good chance you might approach the Marshall Group in the UK. Once again a major global player in the specialized area of adaptive engineering.

Even something as basic as eating breakfast offers an interesting story. There's a good chance that you are in the company of around one billion people who like you have consumed cheese, perhaps a yogurt, or some delicately colored juice drink, all products enabled by the Danish company Christian Hansen. They have spent the last two hundred years developing and supplying a huge range of live bacterial cultures to the food industry around the world. These days they also dominate the world of food coloring and have a growing presence in the field of healthcare via probiotics.

Visiting your supermarket to buy your breakfast goodies you might still be paying in cash. And if you did there's a good chance that the banknotes you exchanged were made by another company, De La Rue. Like the others, they have been doing this a long time, specializing in high precision printing for the past two hundred years. Their track record of world first includes inventing the modern playing card in 1831 and diversifying through postage stamps, identity documents and high security products.

2 The 'one-hundred club'

These are all examples of the 'Hundred Club' – companies which have survived and prospered for over a hundred years. (In the case of Merck they will need a very big cake to take all the candles for their celebrations – the company was founded back in 1668 and is the world's oldest pharmaceutical and chemical company!)

Needless to say not many organizations manage to do this over an extended period. Anyone might get lucky once - but whilst we hear a lot about start-ups as the exciting 'sharp end' of innovation, the reality is that most of them do not stay the distance. Growing a business from these early seeds is not simply a matter of time – there is no guarantee of survival. It's a process fraught with challenge and based on crisis – riding the waves of change and being able to stay on top (even if its' a rough ride) rather than being drawn under.

Those organizations, which do survive over the long-term, may come from many different sectors. But they share the ability to ride out the waves of change which a turbulent and uncertain environment creates. They may find themselves blown a long way from their original course – for example the German firm of Preussag began life as the (public sector) state lead mining and smelting company in Prussia, back in 1917 (Francis et al., 2003). These days it still trades very effectively but now as one of the world's major players in the tourism and transportation sector. Corning began life as glassmaker back in the 1850s; these days its world is more concerned with life sciences and communications technology. Moreover, there is the well-known example of Nokia, beginning its hundred year plus journey as a paper and pulp producer in the Swedish forests, moving through the world of mobile phone handsets and currently dominant in the cellular network technologies behind telecommunications. Rather like its slightly older cousin, the Stora company which began as a paper-maker in the thirteenth century and is now a key player in the energy industry.

Riding out these waves of change also involves being prepared to refit and sometimes redesign the ship. Long-term survivors also change the ways in which they work, especially in the underlying innovation processes, that they use. For example Procter and Gamble spent over a century working very well to bring a steady stream of household product innovations to market using a model based on internal R&D and extensive market research. But in 1999 they shifted the whole basis of their innovation approach form this rather closed system to a new model, called 'Connect and develop', which embraced the idea of openness and connectivity with a wider external world. Or Philips, closing its vast Eindhoven R&D complex and repopulating it with a wide range of small and start-up firms, creating its version of an innovation ecosystem.

There are others for whom a long period of success is followed by a sudden violent storm that threatens to destroy the whole business, outstripping its ability to stay afloat. Kodak dominated the imaging world, innovated successfully from George Eastman's start-up through generations of change – but nearly crashed on the rocks of trying to make new sense of the digital imaging world. It survives but in a slimmer form, working now to reuse its deep knowledge base in new directions, rather like the survivors of a near shipwreck lashing together a new vessel from the wreckage of the old.

Importantly size is not the issue; survival is not about scale. In this field big is not necessarily beautiful; while it might mean organizations have extra resources to draw upon when times get difficult this alone does not guarantee survival. The statistics on membership of the Dow Jones index give a sobering reminder of that – of the large corporations which were present in 1900 only General Electric made it through to the year 2000 and they eventually fell out in 2018 (Foster and Kaplan, 2002).

3 Innovation at the heart of long-term survival

Survival depends on taking an approach which by its nature is agile and resilient. These might be 'buzz' words today but essentially, they characterize what these players have been doing for an extended period of time. They have grown through an ability to navigate stormy waters and to weather often difficult external market and technological conditions.

At its heart, this requires a commitment to innovation – being prepared to change what the company offers and how it creates and delivers that offering. Such innovation behavior is not about having a lucky new product or service at the right time, or a magic machine, which enhances productivity. It is about a sustained organized commitment and the underlying structures and processes to enable it to happen. In addition, a key part of this commitment is recognizing the need for 'dynamic capability', constantly reviewing the ways they innovate and being prepared to change or adapt the fundamental model underneath.

Each of our examples from earlier began as a start-up – an entrepreneur spotting an opportunity. For David Marshall it was the idea of using the new idea of motor cars to provide an early chauffeur-driven taxi service in the town of Cambridge in 1909. And for Sally Windmüller it was the chance to take his business selling whips, horns and lights as accessories for the horse-drawn vehicles of his time and apply these skills to the newly emerging world of motor cars, founding his company (Hella) in 1899. For Christian Hansen it was the research he was doing on digestive enzymes, which gave him a clue about the need for a business to produce products like rennet – his was a very early example of a science-based university spinoff. For Thomas de la Rue it was adapting the emerging science of typography to specialist stationery production – including inventing the modern playing card.

Caspar Opländer's original factory in 1872 was set up to produce copper and brass distillation equipment for the drinks industry. Wilo developed from this primarily through a commitment to innovation, developing the world's first heating pump in 1928.

However, for each of them the bright idea that got them started was just the beginning. Growing through innovation requires a different approach, putting structures and processes in place where there was once fluidity and informal exchange. Striking the balance between creativity and control, between exploration and exploitation, between do better and do different – these are the day-to-day challenges of organizations moving from entrepreneurial start-up mode to long-term large-scale activity.

Their success lies in understanding and managing innovation for the long haul – and this is not an accident. Extensive research suggests that five core themes are involved (Tidd and Bessant, 2018):

- Build competence – grow through what you know.
- Build via networking – organizations don't have to know it all but they do need the ability to find, form and build high performance networks of knowledge.
- Build a capability for innovation, embedding key behavior patterns into routines which can be repeated and form the underlying structure and process.
- Focus innovation in key strategic directions, fully exploring and exploiting innovation space.
- Build dynamic capability – the ability to review, reconfigure and change their innovation models and approaches to suit a constantly changing external environment.

We will look in more detail at each of these in the following section.

4 Five core themes for managing innovation

4.1 Competence - building on knowledge

Innovation relies on new knowledge. Characteristic of all our examples is a story of investing in building a knowledge base, providing the wellsprings from which new opportunities could flow. Marshall's began life in the earliest days of the car industry – they had to learn to repair and maintain their vehicles by themselves, building a deep understanding of how to modify things. This opened up new opportunities; for example, they took a standard Austin saloon car and, using the skills and equipment learned from years of repairing this model in their limousine business, developed an open top sports car. Later on, these skills were transferred to the newly emerging world of airplane maintenance and repair as the next generation of the family moved into this business.

For Sally Windmuller the early days of horns and simple lights drew on a simple knowledge base, one grounded in making and repairing horse drawn buggy equipment. But soon came the need to specialize and learn to understand and control. He had seen the need to invest in what we would now call R&D; for example, early on he saw a key development was going to be the new acetylene lamp – a big move forward compared to the old oil or even candle powered lights. Recognizing the importance of technology led to the award of their first patent, in 1901; this also gave them valuable experience in the process of assembling and protecting intellectual property. In 1906 German light bulb manufacturer, Osram invented the first light bulb suitable for use in automobiles. Because of their early commitment to R&D Sally's company was able to capitalize on this development, making battery-powered electric lamps for cars, including sidelights, rear lights with a red glass cover, and license plate lights.

The same pattern runs through Merck's early history – not just selling pharmaceutical products but also developing a deep understanding of formulations and of the manufacturing techniques needed to make them safely and to high quality. On his gravestone in Darmstadt the tribute to Johann Franz Merck (the 3rd generation of the family) says he was a man who "made great contributions to the pharmaceutical arts" while Emanuel Merck's

1826 work on opium and morphine published in the 'Magazin für Pharmacie' represented a milestone in the transformation from pharmacy handcraft to a research-based industrial company. By 1895, Merck had established a department of bacteriology producing smallpox vaccines, diagnostics for tuberculosis and typhus, as well as sera for anthrax, streptococci, pneumococci and diphtheria.

Christian Hansen's painstaking laboratory work gave him an appreciation of the power of a strong science base from which to grow a business. Developing a deep understanding of enzymes and their properties was part of the story but so too was the underlying process technology needed – understanding how to grow, how to stabilize, how to transport them. These skills embedded in his product technology enabled the company to become a major supplier in the world of cheese making and to build a strong applications base out from that. Their continued investment in understanding the science of microbiology enabled them to enter increasingly sophisticated markets in food and healthcare sectors.

In similar fashion, Wilo's early days as a specialist foundry gave them a deep understanding of how to work complex shapes in metal and maintain precision and quality. De la Rue can trace its technological competence back through a long history of learning about and applying key specialist knowledge in the printing and stationery world.

This is not about making occasional and lucky investments; it is about a sustained commitment to knowledge creation. For example back in 1980 Hella was an early entrant into the emerging world of intelligent electronics – a move which was high risk at the time, costing a great deal with little apparent short-term payoff. However, the seeds sown then have blossomed forty years later with the electronics side of their business now the main driver and likely to grow further with the explosion of applications of intelligent electronics in driverless cars.

Similarly, Christian Hansen's sustained investment in understanding and learning to work with the underlying science of microbiology has made it an essential player in many markets, able to configure solutions based on this deep long-standing knowledge resource. Wilo's pump technology is underpinned by decades of investment in learning by doing coupled with R&D-based scientific understanding. Companies of this kind spend a significant proportion of their turnover on design, research and development activities. For example, Wilo spends around 5% whilst De La Rue recently announced a commitment to double their R&D commitment by 2020.

4.2 Competence is not enough – developing innovation capability

However, knowledge is not enough – we also need to learn how to create value from it. Innovation is not a magical event like the cartoons, where a light bulb magically flashes on above someone's head. It is about turning those ideas – knowledge – into value and that involves a long and uncertain journey. We might manage to get to our destination once by sheer good fortune, but being able to make the journey repeatedly needs much more in the way of a map, provisions, experience.

Successful innovation requires careful management, organizing key behaviors into embedded routines which define the way we approach the challenges of searching for opportunities, selecting the right ones and implementing innovation against a background of uncertainty (Tidd and Bessant, 2018).

Extensive research on innovation management capability over a long period consistently points to the same themes. Innovation does not happen by accident. Successful organizations develop 'routines' – patterns of behavior which become embedded in core processes, structures and policies – they become 'the way we do things around here' (Nelson and Winter, 1982). They put in place processes, which enable search, selection, implementation and the capture of value from their ideas, and they learn from that experience, gradually reinforcing and building innovation management capability.

Of course, the reality of the journey is never as simple as the linear map offered in most textbooks. It is a messy process of stops and starts, dead ends and blocked roads, diversions and hold-ups. On many occasions, we may need to abandon the journey, dust ourselves off and start again in a different direction. But a wide range of studies suggest that there is an underlying journey and there are consistent lessons about the kinds of thing we can do to improve the ways we make it (Van de Ven, 1999).

4.3 Networking – building an ecosystem of innovation

Building a core knowledge base is important – but it can also represent a significant cost to small organizations. This has often been used in the past as an explanation of their lack of innovativeness, but the reality is that it is not an issue of knowledge ownership so much as knowledge acquisition and deployment. Innovation is increasingly recognized as a multi-player game, one in which the ability to connect to complementary resources is the key (Birkinshhaw et al., 2007).

This concept of 'open innovation' was memorably expressed by a comment made by Bill Joy of Sun Microsystems. He observed that in a knowledge-rich environment of the kind in which we now operate even the largest company has to recognize that 'not all the smart guys work for us'. This has huge implications for the way the innovation game gets played – essentially it flattens the landscape and creates conditions which are more favorable for smaller enterprises. It is not a problem of being small but rather of ensuring that they are connected – and building networks for innovation has become a key success factor in the 21st century (Bessant and Venables, 2008).

'Open innovation' as a formal term was coined by Henry Chesbrough in an influential article and book back in 2003 (Chesbrough, 2003). Since then there has been an explosion of interest in the concept and extensive experimentation with new models for managing innovation more effectively based in increasing the flow of knowledge, both into and out from organizations. The somewhat static picture of the last century where knowledge production and ownership were seen as important has given way to more of a trading environment where managing knowledge flows is the key skill.

Although fashionable now open innovation is not a new message. Our 'hundred club' members have long had an appreciation of this principle and have developed successful growth models, which build on a networked approach to innovation, assembling and managing knowledge partnerships. This has meant they have been able to leverage their own knowledge base and also to take advantage of complementary skills and resources held by others through various forms of collaboration.

The widespread availability of knowledge 'out there' does not mean that organizations can abdicate their own responsibility to develop a knowledge base. Instead it is the presence of that knowledge base which gives them the ability to assess and evaluate external knowledge and to deploy it to advantage – a concept termed 'absorptive capacity' (Cohen and Levinthal, 1990). This is the ability of an organization to identify, acquire, absorb and deploy new knowledge in order to grow. If there is no understanding of the core content then such organizations won't be able to assess what might be relevant to them and they won't have the ability to adapt and configure new knowledge to work for their advantage (Zahra and Georg, 2002).

Track each of our example companies back and we can see that there is a pattern – consistent investment in acquiring knowledge and deploying it in a series of successful new products and processes. For example during the 1990s Hella recognized that the world of the automobile was changing and that trying to compete along such a complex technological frontier required developing networks and partnerships. They began to put these in place via a mixture of acquisitions, mergers and joint ventures, steered by a deliberate 'network strategy' which helped fuel knowledge-led growth across the business (Bessant, 2017).

This move anticipated what was to become an increasingly important shift in the role of automotive suppliers, moving from being simply shops where components could be purchased towards players with strategic knowledge and capability to put together whole systems. Today's elaboration of that network strategy involves strategic partnerships and joint ventures with dozens of companies supporting along the knowledge frontier and feeding into lighting, electronics, aftermarket and special applications fields. A good example is the current ability to work in the strategically important field of camera-based driver-assistance systems. Hella's ability to work in this space comes from their acquisition in 2006 of a small Berlin-based specialist for visual sensor systems.

Open innovation as a principle involves networking widely outside and inside the organization to leverage a broad knowledge base. Companies like Wilo work with customers in close fashion, with many of their projects essentially a result of co-creation amongst partners, and Marshalls have long recognized the value of such user input in their design work. Nor is the networking confined to external sources; Wilo also operates an internal collaborative platform on which all of its 7000 employees can contribute ideas and build and share these to help mobilize their innovation capacity.

4.4 Strategy – direction and distance

Having the capability to innovate and a strong internal and external knowledge base on which to draw is important, but another key element is making sure innovation is strategically directed. Successful innovators recognize that there is a wide field of opportunity and build a portfolio covering and exploring all the innovation space.

In particular, there is the need to balance exploitation and exploration – doing what we already do but better and occasionally doing something completely different. Innovation inevitably involves risk and a balanced portfolio would seek to have a range of projects distributed along this incremental/radical spectrum with the majority around 'do better' improvement agenda but with others pushing the frontiers of radical innovation.

But there is a second challenge in innovation strategy – making sure that the full space available for innovation is explored. It is helpful to think of this space as being mapped by an 'innovation compass' (Francis, D. and Bessant, J., 2005). Essentially innovation can take place in a number of directions but principally we can think about:

- The product or service – what we offer the world.
- The process – the way we create and deliver that offering.
- The position – who we offer it to and the story we tell about it.
- The 'business model' – the way we think about what our organization does and who we do it for.

Most organizations begin life as start-ups with a core product or service offering. But over time innovation needs to move along other directions as well. For example, Christian Hansen's pioneering science in the laboratory would have remained there without the underlying process innovation able to enable reproduce ability, scale, transportation, etc. Wilo's early work as a specialist foundry was customer -led application of process technology and skill; only later did their core product work around pumps come into the equation.

Marshalls demonstrates what happens when companies develop capabilities along both product and process innovation directions – they can configure and create new products through the interplay of these complementary capabilities.

But whilst product/process innovation remains a key axis along which considerable activity can take place a key characteristic of hidden champions is their exploration of innovation space enabled by position innovation. By entering new markets, especially internationalizing at an early stage, they confront key challenges which require very different configurations to solve. Drawing on their product and process innovation skills but also learning with the new marketplaces stretches and extends their capacity as innovators, expanding their markets in the process.

Relationships with key customers matter because they enable a flow of key knowledge between the players – for example, Christian Hansen's ability to configure bacterial strains for different environments owes much to its close links with cheese makers around the world, established and worked on over decades. Marshall's business has been built on close partnerships with customers, learning from and with them in what is essentially joint problem-solving activity.

Of growing significance in todays' environment is the ability to innovate the underlying core business model, which drives the business – 'paradigm innovation'. We can see this willingness to reframe in our examples; each of them has had episodes in their history where they have redefined themselves, letting go of some of their original core and identifying new ways in which the business will create value in the future. For example, Marshall's moved in the post-war years from a contractor model, relying on its close links with key customers to one in which they increasingly became a design and knowledge partner. Rethinking that business model anticipated in many ways the move towards 'servitization'; which characterizes and increasing number of project-based manufacturing organizations today.

For De La Rue the shift was from working with advanced and specialized printing technologies to reframing the business as one in which security was the defining feature. It had the effect of moving them out of certain markets but also towards close relationships of trust with key agencies for whom high security documentation is of central importance. As their business moves increasingly into the digital world, so this business model has to adapt again.

Christian Hansen's business moved, like Marshalls, from supplying products to increasingly delivering a science-based service, customizing and configuring to suit highly specific needs. And Hella is now in the position of adapting and extending its business model as it moves from a role as an automotive component supplier to a high technology provider of intelligent electronics with potentially wider application possibilities in the emerging markets created by the 'Internet of Things'.

4.5 Dynamic capability - modifying the DNA of innovation

As if innovation was not already a tough enough order there is one final element which comes into play. We also need the capability to step back from time to time and reflect on how well we are managing it. In a changing world are our recipes, our organizational structures and processes still the right ones? Do we to keep on, cut back or develop new routines? Does our approach to managing innovation still fit the world in which we are trying to operate? So as well as the capability to turn knowledge into value we need a second order capability to reflect and learn, constantly tuning our approach. What we could term dynamic capability.

In 1962 the Nobel Prize for Medicine was awarded to Frances Crick, James Watson and Maurice Wilkins for their work unravelling the structure of the DNA molecule. Together with others in the team like Rosalind Franklin they were able to open the door to our better understanding of genetics – how characteristics are passed on from generation to generation.

Strands of DNA make up genes and these provide the carriers for what makes an individual in terms of their make-up and behavior – blue eyes, long legs, stronger heart, etc. Genes encode the programs for the future and being able to carry forward key characteristics enables us to survive in hostile and complex environments.

Understanding the building blocks through which genetics operates moved us to a new world where we can now engage in genetic engineering – removing troublesome genes or switching them off, splicing in new ones with additional capabilities, improving the health of existing ones.

We often use the metaphor of DNA when talking about organizations. Their routines for innovation are effectively the expressions of 'genetic coding' around how we tackle the day-to-day challenges of creating value from knowledge. How we search, how we choose projects, how we allocate resources, how we build teams, and so on.

The big difference between an organizational model and the wider world of evolutionary genetics is that we do not have to wait for random mutations to modify the genes. Within organizations, we can carry out 'genetic engineering' to revise and reshape the genes in more active ways. That is the role of innovation leadership, trying to create organizations, which are well adapted for their current and future environments.

So over time if an organization is to survive and continue to innovate it needs to find some way of passing on its genes – continuity. And it also needs to have the capacity to review, revise and modify its genetic make-up for innovation – changing some and splicing in others, adding to the overall capability.

'Dynamic capability' of this kind is the third key to innovation longevity (Teece and Pisano, 1994). Being able to step back and review routines, asking key questions like:

- More of - of the routines we have in place which ones do we need to strengthen, build on?
- Less of – of our routines which ones should we change, or perhaps eliminate, since they are no longer appropriate?
- Different – which new tricks do we need to learn, which new behavior patterns do we need to rehearse and embed?

Once again, we can see this ability – to review and to reconfigure innovation routines –

at the heart of organizations with long-term aspirations. Businesses like 3M are renowned for their reflection, their ability to look at their routines and change them – for example modifying their Six Sigma efforts when those seemed to be stifling the flow of breakthrough ideas within the business. Or companies like Philips and Procter and Gamble, radically reconfiguring the way they worked with knowledge and moving from an emphasis on knowledge production and ownership towards more open fluid approaches involving rich external linkages.

This willingness to challenge and revise approaches, which have worked in the past, is another feature of our long-term survivors. In the case of Hella we can see innovation move from a fairly ad hoc informal process to one which is at the heart of their success. Their history has been one of reviewing and adapting innovation capability, adding new elements, adapting others, letting others go. Their early commitment to R&D led to increasing formalization, to recruitment of specialist staff and establishment of departments within which they could operate. That commitment remains today with around 10% of turnover being ploughed back into knowledge creation – but the structures to enable the work of those scientists and engineers have changed. At key points in their history, we can see this kind of strategic reflection at work.

For example in the 1980s there was an explosion of product development, new ideas flaring up everywhere, some customer-led, some opportunistic deployment of new technologies. What was clear was an increasing lack of focus or control – one review suggested that of around 4000 projects a small number – less than a hundred) made up the main contribution to sales, accounting for around 80%. A further 300 delivered around 15% of sales and the remainder – 3000 plus – delivered less than 5% of sales whilst consuming over 30% of the R&D investment. Rethinking product development and putting in place disciplines and structures for portfolio management was a key intervention, a major reconfiguration of the innovation model.

Or the move towards networking – the foundations of the open innovation approach discussed earlier. Once again, there was a key reflection point and a recognition that the model, which had brought the company through much of its early life, needed to give way to a newer model based far more on building knowledge networks with others.

More recent activity has focused on how to deal with disruptive innovation. In an industry which has suddenly become much more fluid and uncertain there is great risk but also opportunity for entrepreneurs. For an established player like Hella this implies the need to build a very different kind of innovation capability, one geared much less to the 'do what we already do but better' agenda and instead focusing on doing something completely different. At the limit, this may require letting go of core parts of the company to replace them with new businesses. Building such a capacity for corporate entrepreneurship has involved some fundamental rethinking of the innovation model, letting go some old approaches and adding new capabilities with new operating tools and processes more linked to entrepreneurial start-up culture.

5 Conclusion

Innovation matters today more than ever. Managed effectively it can provide the underpinning resilience and agility to enable organizations to weather the storms of a turbulent and uncertain environment. However, this requires much more than wishful thinking around the desire to be innovative. As our examples and others show there is a need to focus on some key themes around competence, networking, strategy and innovation management. And there is a need to underpin all of this with a willingness and capacity to step back, reflect and retune the overall approach – dynamic capability.

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Practitioner`s Section

Managing business model innovation for relocalization in the process and manufacturing industry

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More and more industrial activities are performed outside of Europe. INSPIRE is a project, that is driven by the European process industry in order to facilitate the relocalization of process industry value chain activities to Europe. Within the project four business model archetypes (BMA) that facilitate this relocalization were identified: decentralization and modularization, mass customization, servitization and product service systems (PSS), circular business model, by name Re-use, Recycle and Sustainability (RR&S). For companies that want to adopt these business models, we have developed four INSPIRE Tools to integrate flexibilization into process industry business models concepts: Technologies Dashboard for the 5 INSPIRE BMA's[1], Business Model Innovation (BMI) Game, BMI Decision Support Tool for each BMA, and Business Model Archetype Revenue Pattern Map. This article presents the main results and partly reprints other relevant aspects from the INSPIRE deliverable D 4.4. It aims to provide recommendations for decision makers to choose the right business model given their specific context and key parameter.

1 Introduction

Traditionally, innovation is perceived as a result of R&D department's activities carried out by engineers, chemists or material researcher. However, findings from e.g. the Boston Consulting Group (2008) have shown that "business model innovators have been found to be more profitable by an average of 6% compared to pure product or process innovators" (Gassmann et al., 2014).

For many managers and decision makers the concept of business model and its innovation is still vaguely defined and its application to their own business remains difficult. The INSPIRE project examined over the course of two years trends for Business Model Innovation (BMI) in the process and manufacturing industry. The specific background for the INSPIRE project has been the request from the European Commission Horizon 2020 call for proposals to look at "Business models for flexible and delocalized approaches for intensified processing." INSPIRE has hence focused on those BMI trends that contribute to flexibilization of the process and manufacturing value chain, which according to previous studies, is amongst the main drivers to keep industry (or bring back to) in Europe (INSPIRE Deliverable, 2017). This contribution provides interested stakeholders related to the process and manufacturing industry a summary overview of these practical learnings and tools in the context of BMI processes. It guides the BMI practitioner from these stakeholders in the steps to take towards possible business model innova-

[1] The Emerging Energy Carriers business model archetype is not part of this article.

tion. In doing so, it provides a framework for the dynamic evaluation of the proposed business models as opposed to static evaluation:

- paving the way for dynamic monitoring of key supply chain parameters and factors (e.g. labor costs, production costs, raw material availability, market attractiveness, financial stability of suppliers, etc.) and analyzing the long-term impact of the novel business model proposed;
- considering the possibility of switching from one business model to an alternative in the medium term.

This article equips the reader with guidelines on how specific business solutions that INSPIRE developed could be implemented in order to assess and decide about BMI that are relevant for the process industry.

The topic of BMI has gained a lot of interest over the past years from practitioners and researchers alike. The article starts with a brief recap of the business model concept on how it was defined in the INSPIRE project.

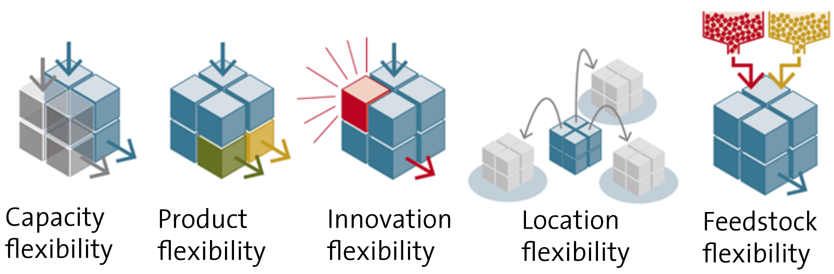
Thus, a business model consists of the (1) value proposition (product-market combination), (2) value creation and delivery (configuration and implementation of value creation activities) and (3) value capture (the revenue model) and the interaction of these elements (Geissdoerfer, 2018a). Other frameworks following a similar logic are, for instance, Osterwalder and Pigneur (2010) and Gassmann et al. (2014).

INSPIRE has taken this business model concept to study business model innovation in the process and manufacturing industry with regard to flexibilization. In rapidly changing and volatile markets, flexibility is a key factor to strengthen the position of Europe (Ecorys, 2009).

Figure 1 illustrates the different types of flexibility for companies in the process and manufacturing industry. In order to react to fluctuations in terms of demand or feedstock/ energy prices, companies should be able to adapt production accordingly while being cost efficient at the same time (capacity flexibility). Likewise, companies should be able to switch to another product (product flexibility). In this context the innovation flexibility denotes the ability to carry out R&D and pilot settings at production sites. Another aspect relates to the location. Either the place of the production or the production plant itself should be easily moveable (location flexibility). Furthermore, companies should be able to handle different kinds of feedstock (feedstock flexibility). The INSPIRE project has identified and defined four business model archetypes[2] (BMA) that respond to major societal trends, and contribute to five types of flexibility.

In a previous publication we described these archetypes, identified the main enabling technologies, their maturity levels, related research needs, besides defining a number of decision factors, possible bottlenecks/challenges and solutions (INSPIRE Deliverable D3.2., 2018). These technologies, decision factors, bottlenecks/challenges, and solutions for the different archetypes

Figure 1 Different types of flexibility (source: own representation).



[2] We follow the established terminology of Bocken et al. (2014), which uses the term archetypes for more or less generic strategies or templates.

are mostly concerned with types of the products/services to be offered, the availability/capability of the suppliers locally in Europe or globally to provide such products/services, the supply chain structures considering the characteristics of the partners and competition, demand profiles and customer needs. Therefore, together these may be used to assess if a specific business model archetype is relevant for a sector or an industry, or how they could be made relevant.

This article therefore provides BMI guidelines with relevant information and a BMI process to be followed. The four tools developed by the INSPIRE project related to these business model archetypes are:

1. **Technology Dashboard for each Business Model Archetype**, indicating which cluster of technologies enable this BMA and what their maturity level is.
2. **Business Model Innovation Game**, for each BMA, that allows multiple stakeholders to reason about their value chain, based on the available enabling technologies and a number of objectives.
3. **Decision Support Tool**, that enable decision makers to score decision factors for each BMA to assess if its industry is "BMI ready" based on a calculated "BMI index". The Decision support Tool also provides for each BMA insights in the ke y challenges, and which possible solutions are available in the market to overcome those.
4. INSPIRE **Business Model Archetype Patterns**, that matches the INSPIRE BMAs against the 55 St. Gallen Business Model Patterns and serves as an inspirational tool to consider innovative value propositions and revenue models for the INSPIRE archetypes.

This article is organized the following way. After giving a short introduction, we will provide a summary of the academic background on BMI to create a common understanding of the underlying theory. Then, we will provide a more practical insight on how BMI in general takes place in industries, more particularly which tools are available to support the main steps in BMI from business model ideation, through conceptual design, experimentation up to the launch of new business models and their fine-tuning. We will then explain new BMI support tools that INSPIRE adds to this portfolio of BMI instruments, and provide guidelines and suggestions on how to use these tools in a BMI process.

2 Theoretical background

Parts of this chapter are taken from Geissdoerfer et al. (2016, 2017, 2018a).

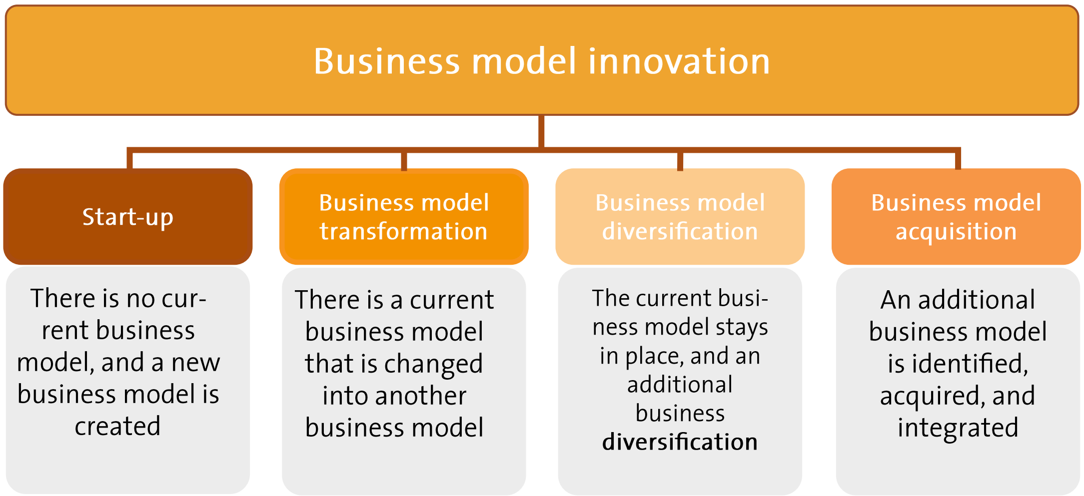
2.1 A new form of innovation: Business model innovation

Research on business models has increased significantly in the period from 1980-2015 (Foss and Saebi, 2017). The concept gained wider popularity during the dotcom boom of the 1990's. As new, innovative revenue mechanisms were introduced the business model concept came into wider use as a means for communicating

Table 1 The four Business Model Archetypes with regard to flexibilization (source: own representation).

	Impact based on flexibility type				
Business Model Archetypes	Capacity	Product	Innovation	Location	Feedstock
Decentralized/ Modular	Medium	Medium	Medium	High	High
Mass Customization	Medium	High	High	High	Medium
PSS/Servitization	Medium	Medium	Medium	Low	High
Reuse, Recycle and Sustainability	Medium	Low	Medium	Low	High

Figure 2 Dimensions of business model innovation (source: Geissdoerfer et al. 2018a).



complex business ideas to potential investors within a short time frame (Zott et al., 2011). From there, the concept has developed into a tool for the systemic analysis, mapping, planning and communication in face of organisational complexity (Doleski, 2015; Knyphausen-Aufsess and Meinhardt, 2002).

Different authors conceive the business model concept either as a model of an organisational system (e.g. BaBaden-Fuller and Morgan, 2010; Knyphausen-Aufsess and Meinhardt, 2002), as an abstract characteristic of an organisational unit, (e.g. Osterwalder and Pfigneur, 2010; Teece, 2010), or with a reduced scope that equates the term with individual elements of other authors' definitions or reduce it to achieve certain means (e.g. Doganova and Eyquem-Renault, 2009).

Most definitions of this concept emphasise the role of value creation, more or less following the categorization of Richardson (2008), value proposition, value creation and delivery, and value capture, while some authors also add the value network (e.g. Zott and Amitt, 2010). For this research, we define business models as, "simplified representation of the value proposition, value creation and delivery, and value capture elements and the interactions between these elements within an organizational unit." (Geissdoerfer et al., 2018a, p.402)).

The creation or adaption of business models is referred to as business model innovation. Most authors refer to business model innovation as a change in the configuration of either the entire business model or individual elements. Consequently, companies align the elements as a reaction to opportunities or challenges in the environment or as a vehicle for diversification and innovation. In this regard, the concept mainly has been applied in corporate diversification (Ansoff, 1957), business venturing and start-up contexts .

Figure 3 The Cambridge Business Model Innovation Process (source: Geissdoerfer et al. 2017).

For this research, we define business model innovation as, "the conceptualisation and implementation of new business models. This can comprise the development of entirely new business models, the diversification into additional business models, the acquisition of new business models, or the transformation from one business model to another. The transformation can affect the entire business model or individual or a combination of its value proposition, value creation and deliver, and value capture elements, the interrelations between the elements." (Geissderfer et al. 2018a, p.405f.)

2.2 The Cambridge Business Model Innovation Process

The Cambridge Business Model Innovation Process, as depicted in Figure 3, describes the different steps, key activities, and challenges of business model innovation.

According to the framework, the phases of business model innovation are:

1. **Ideation:** The purpose of the business model innovation and its key stakeholders are defined, and the value proposition and first conceptual ideas are ideated.
2. **Concept design:** A first rough conceptualization of the key business model elements is developed and documented.
3. **Virtual prototyping:** A range of prototypes is generated and revised to refine and communicate the business model concept. The phase also comprises benchmarking with solutions and concepts from other parties.
4. **Experimenting:** Key assumptions and variables of the concept are tested in simulations and field experiments, ideally through randomized controlled trials.
5. **Detail design:** An in-depth analysis and detailing of all the elements of the business model and interactions between these elements is conducted.
6. **Piloting:** The entire concept is tested by running a first limited version of the business model in a subsection of the target market.
7. **Launch:** The business model is rolled out across all responsible organizational units and the target market.
8. **Adjustment and diversification:** The business model is revised according to initial plans, expectations, and strategic fit. Based on this evaluation, adjustments and diversifications are made and, depending on the comprehensiveness of the necessary changes, the entire business model innovation process may be repeated.

However, not all business model innovation processes will go through each of the steps. For example, a business model project team might decide to skip experimentation and launch a new product or service without testing whether the underlying assumptions of market acceptance and willingness to pay actually apply.

Furthermore, the process is not linear but iterative and repetitive, the business model team might go back and forth between phases, sometimes omitting one or several, learning from mistakes and pivoting towards a solution that gets traction with a viable customer segment. Once the business model is launched it might go through the entire process again to adapt to a change in its ecosystem and the macro environment. This process obviously has some overlaps with concepts like the Lean Start-up (Ries, 2011) and Design Thinking (Plattner et al., 2011). While it was conceptualized in order to integrate these concepts advantages, like instant and meaningful customer feedback, it is a more comprehensive approach that addresses a range of these concepts' disadvantages.

3 Tools for Business Model Innovation

3.1 Review of existing tools

In order to translate insights on business model and its innovation from academic research into business practice several tools can help organizations to guide the process. Geissdoerfer et al. (2018) refer to a design-implementation gap of business model innovation as the accumulated challenges along the business model innovation process that lead to failures and non-implementation (Geissdoerfer et al., 2018a).

The review and brief description of seven tools are summarized in Table 1: (1) Value Mapping Tool (Bocken et al., 2013), (2) Value Proposition Design Tool (Osterwalder et al., 2014), (3) Value Ideation Tool (Geissdoerfer et al., 2016), (4) Business Model Canvas (Osterwalder and Pigneur, 2010), (5) Business Model (Gassmann et al., 2014), (6) Business Model Archetypes (Bocken et al., 2014), (7) Cambridge Business Model Innovation Process (Geissdoerfer et al., 2017).

3.2 Dedicated tools for BMI for flexibilization in the process industry

The different tools for BMI proved to be effective for guiding companies in the BMI process. However, all support tools are rather generic and don't explicitly focus on the process industry and its characteristics. So, while harnessing the aforementioned tools, we added specific "flexibility in process industry" elements for the purpose of INSPIRE's project objectives.

INSPIRE has developed practical results that can provide these elements for the five Business Model Archetypes (BMAs), and can as such be integrated and combined with the existing toolset described in section 2 and the general BMI value system as inspired by the Business Model Canvas. These tools are the following:

1. Technologies Dashboard for the 4 INSPIRE BMA's
2. Business Model Innovation Game
3. BMI Decision Support Tool for each BMA
4. Business Model Archetype Revenue Patterns Map

These INSPIRE tools provide specific and complementary added value with respect to the existing generic tools:

1. They provide dedicated support tools for **business model innovation (BMI) towards 5 key trends** in the process industry (modularisation of the value chain; (mass) customisation of products, processes and services; servitization; recycling, re-use and sustainability, and digitization of the value chain), so being more specific than general tools.
2. They provide support to reason about **specific technologies, that are relevant for these BMA's** and the extent to which they are mature enough or if further research is recommended. Existing BMI tools are more general, and do not take a "technology view".
3. They provide a **"serious game approach" towards value chain Business Model Innovation**, potentially involving multiple value chain partners. One of the learnings of the INSPIRE project is that for all of the Business Model Archetypes a systems approach, value chain collaboration and even aligned business cases between the value chain partners maybe a critical success factor. The INSPIRE BMI game provides a **dynamic "out of the box" but guided process to take a value chain view as input to the BMI (ideation) process**.
4. They **introduce the concept of BMI readiness for the four BMAs**, as well as an index which could be used to benchmark the

Figure 4 INSPIRE support tools for BMI towards flexible process industries (source: own representation).

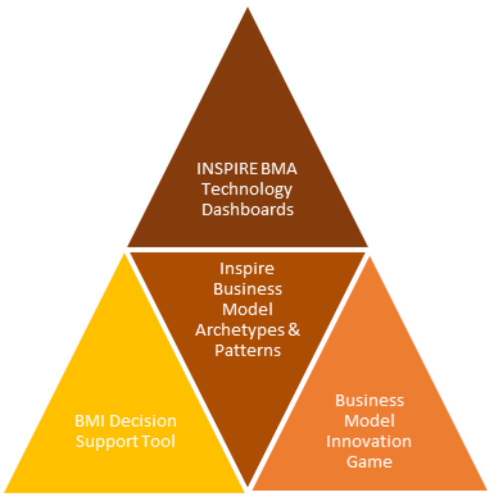
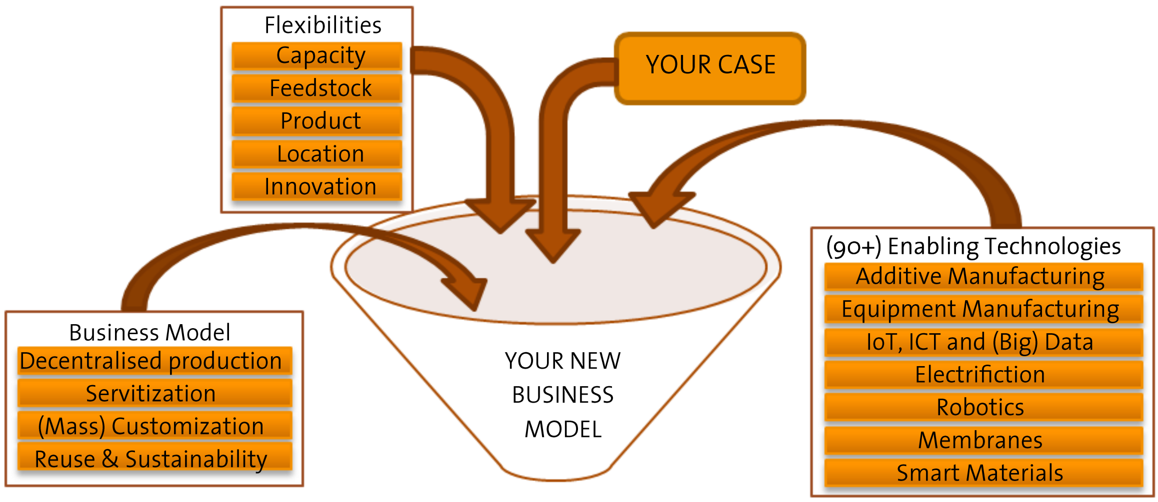


Figure 5 The INSPIRE Business Modelling Approach (source: own representation).



BMI readiness of one company, in the future possibly against the sector baseline. The INSPIRE project only made a limited number of test surveys to calibrate and prioritize the scoring factors. But in the future we could use this concept to do a broad sector specific survey with a large number of industries, which would lead to a general BMI readiness index per sector per BMA, as a baseline against which companies could benchmark themselves. In the meantime, the **Business Model Decision Support tool**, can be used by **managers to reason about the "fitness" of a specific Business Model Archetype for their company or business eco-system**.

5. They provide **practical solutions** to think about, when **designing the new Business Model** for the value chain, to overcome concrete challenges/bottlenecks and improve the BMI index as initially calculated.
6. They provide **inspirational suggestions for Revenue Model innovation**, by mapping specific process industry relevant Business Model Archetypes, against 55 revenue model patterns based on academic research carried out by the University of St. Gallen.

Like depicted in Figure 4 the INSPIRE tools hence add value to the existing tool system, by adding a specific layer dedicated to flexibilization in the process industry, interacting and enriching the current support systems (Cambridge Business Model Innovation Framework & support tools and the Business Model Innovation Value System).

The support tools can be used separately and in random order, within the iterative Business Model Innovation process. However, it is advised to start with the Business Model Innovation Game, as it provides a higher-level value chain view using the enabling technologies Dashboards as input. In a second moment the business models of individual value chain stakeholders can be used for a detailed business model design, also using the other more general support tools.

3.2.1 Technology Dashboard

Technology innovation is accelerating every year, and continuously offering new opportunities (as well as threats) for business model innovation. Particularly, INSPIRE technologies are enabling new Business Model Archetypes:

1. **Process intensification** enables process industries to develop smaller, modular or even mobile ("containerized") production processes, that open-up the opportunity for modular flexible distributed production and related **"from central-to-distributed" business models**;
2. **New production technologies** such as 3D printing, open-up opportunities for more (mass) customization and new **"from push-to-pull" business models**;

3. **New sensors and monitoring technologies** facilitate the emergence of Servitization concepts moving **"from product to service"** business models, where performance-based contracts substitute traditional product or materials sales agreements;
4. New **lower-cost selective separation and recycling technologies**, open-up new opportunities for stakeholders to innovate business models and grasp novel market opportunities by valorizing resources that were previously considered waste, **"from linear to circular business models".**
5. **New energy technologies** such as solar, wind or biomass, open-up new opportunities for novel business relationships between energy consuming industry and electricity supplier in a synergetic way. New energy carriers such as hydrogen, ammonia, methanol and formic acid can be used to store and release energy where needed facilitating **"from on-directional to open business models"** where collaboration with partners in the ecosystem becomes a central source of value creation.[3]

It is expected by the INSPIRE consortium that these types of Business Model innovation will further proliferate in the market, leveraging on continued technology innovations. INSPIRE therefore identified for each of the four Business Model Archetypes, the key technology clusters that may enable breakthrough Business Model Innovation in the near future.

We summarize the main technologies and their Dashboard for each BMA. The detailed description and analysis can be found at INSPIRE deliverable 4.4 (2018). We recommend stakeholders in the process and manufacturing value chains to consider those clusters as enablers for their BMI process.

3.2.2 Business Model Innovation Game

The Business Model Innovation Process starts with the ideation phase, in which the purpose of the business model innovation and its key stakeholders are defined, and the value proposition and first conceptual ideas are ideated. One of the learnings of the INSPIRE project is that for all of the INSPIRE Business Model Archetypes a systems approach, value chain collaboration and even aligned business cases between the value chain partners maybe a critical success factor. The INSPIRE BMI game provides a **dynamic "out of the box" but guided process to take a value chain view as input to the BMI (ideation) process.** It provides a **"serious game approach" towards value chain Business Model Innovation**, potentially involving multiple value chain partners. It leverages and integrates the key INSPIRE results:

1. The 4[4] process industry Business Model Archetypes (dedicated playing cards to design relevant supply chains – looking at the key Business Canvas elements Supply, Demand, Cost, Revenues and Eco-system).
2. The technology Dashboards (different technology playing cards for each BMA).
3. The INSPIRE objectives to stimulate flexibility, resilience, business model innovation and EU reshoring (playing cards integrating flexibilities and assess cards for each objective).

The INSPIRE Business Model Innovation Game is an infotainment tool, to be played in a workshop. It helps individual companies or multiple stakeholders and decision makers reason about how to innovate their business model in the supply chain.

3.2.3 INSPIRE Decision Support Tool

Once the ideation process generated a specific interest in a Business Model Archetype, the **INSPIRE BMI Decision Support tool**, provides an instrument to test the industry on its "fitness" for the specific Business Model Archetype.

We have designed the tool as an Excel Tool that guides an industrial manager or decision maker in his process to assess key decision factors, which have been validated by the INSPIRE project with industries and experts in the market. Key factors that determine whether an industry decides to develop a new business model vary per Business Model Archetype. Based on the weights and scores obtained from the industry stakeholders through surveys, this decision support tool enables the managers to focus on a "few critical factors" that are most influential on the fitness of the business model

[3] As indicated before, the Emerging Energy Carrier Business Model Archetype is not part of this article, but mentioned here for the sake of completeness.
[4] Would be 5 when including the Emerging Energy Carrier Business Model Archetype.

archetype for a particular company. The parameters (e.g., labor cost, production cost, network structure, capacity, etc.) related to these few important factors could be monitored over time to be responsive to changes in the business environment.

The Excel tool is composed by different spreadsheets on which, a set of instructions on how to complete the highlighted cells is presented. There is the "Current Situation" tab, which allows an easy comparison between the results from the surveys and the internal view from the company. The tool also helps companies to review how their future situation will be, under different scenarios. This analysis is made in the "Future Scenario" tab, where the new Scenario Impact is added, aiming to help companies understand the future impact of the factors. Additionally, a benchmarking tool is also included in the tool, aiming to help companies to compare their performance on each factor versus the average performance for each archetype. It allows an easy overview in which factor the company is ahead or lagging behind, compared to the average performance of companies within the archetype. Currently, the tool is in a conceptual stage and will require a sector to take up the task to create a statistically meaningful benchmark tool. Until then, the tool can be used as a support to reason about the individual and combined factors that need to be taken into account when deciding about BMI.

3.2.4 INSPIRE Business Model Archetype Patterns

90 % of innovations emerge from recombinations of previously existing concepts. The INSPIRE toolbox leverages on the work of the University of St. Gallen that analyzed 250 business models from over the last decennia, resulting in 55 business model patterns. Applying those patterns to the INSPIRE Business Model Archetypes, offers an inspiring map for industry stakeholders that wish to engage in business model innovation within the process industry (Gassmann et al., 2014). We found that at least 15 of the 55 business model patterns, have potential applications within the INSPIRE BMA's, providing particular inspirational ideas for novel Revenue and Value proposition innovations in the process industry (see Table 2).

4 Integration of the INSPIRE tools in the Cambridge Business Model Innovation Framework

In this section we first discuss how the INSPIRE toolkit can complement existing tools to provide a comprehensive toolkit for conceptualizing new relocalization business models. In this section, we illustrate how the newly developed INSPIRE tools can be combined with other existing tools to have comprehensive tool support along the business model innovation process. We explain how this can help managers to make choices in BMI based on the specific characteristics of their organization and the particular context of their BMI project (type of business, customer segment, company size, market trends, etc.).

While the tools presented in section 2 and 3 can be combined at the discretion of the manager in charge with regard to the specific context of the business model innovation project, we want to suggest one comprehensive path to combine different tools along the Cambridge Business Model Innovation framework that integrates the INSPIRE toolkit with a deliberate focus on relocalization models. To use this path for your relocalization focused business model innovation project, just follow these 11 steps; as indicated this is not a purely sequential but deliberately iterative exercise:

1. We start with the **Cambridge Business Model Innovation Process***[5]. We use a poster without the entries to plan the process with the responsible executives. The participants individually put sticky notes with proposed content for key activities and challenges to each of the phases and discuss and add to them afterwards. The resulting poster can be kept as a communication tool and a constant reminder of the initial plan in the working space of the business model innovation team. (Geissdoerfer et al., 2017)
2. We use the **INSPIRE Business Model Innovation Game*** to take a higher-level value chain view of Business Model Innovation, with the 4 INSPIRE Business Model Archetypes and related Technology Dashboards as inputs. You may use the INSPIRE Business Model Archetype Templates* that summarize the BMAs and technology Dashboards to

[5] All tools indicated with a * can be downloaded from http://www.inspire-eu-project.eu/downloads/.

support Game. This allows you to explore value chain collaboration opportunities and align business cases with your value chain partners. If you are considering modularization BMI, you may need to consider what that does to the full value chain, and how it changes your relations with transporters, regional clients etc. If you have potential partners and suppliers in place, invite them to joint workshops, if not, start with your project team and affected executives and identify and include partners based on the outcome.

3. We use the **INSPIRE Decision Support Tool*** to get an impression of which business model best fits the current resources and capabilities of the participants' organization or involved organizational units and objectives. The tools can be used in a workshop setting by discussing each factor with the participating executives or as a survey by asking a target audience to individually filling out the tool's questionnaire and sending it back. The results can then be aggregated and communicated back to the participants. It will provide the users with valuable guidance on which decision factors to consider for a specific BM Archetype, which are the main challenges and potential bottlenecks and what solutions can be considered to increase success chances for the Business Model Innovation.
4. With the most appropriate business model in mind, we are engaging in the **Value Ideation*** process. The workshop is facilitated with key executives and representatives or proxies of key stakeholder groups, e.g. a sales person from a supplier or – if they are not available – a procurement manager from the organization. After a value mapping exercise, the generated value proposition ideas are prioritized and prototyped. The resulting prototypes are discussed and improved and key insights are documented for dissemination within the organizations and as an input for the next steps (Geissdoerfer et al., 2016).
5. In this phase of the process, the **Business Model Patterns** from the **Business Model Navigator** can be used to reason about the most appropriate revenue model for the Value proposition. We have selected the most adequate of the 55 revenue mechanism templates and associated them to the 4 INSPIRE Business Model Archetypes for relocalisation. The resulting (see **INSPIRE Business Model Archetype Value Patterns tool***) can be used to select and combine the most adequate revenue mechanisms. Please do also quickly check the remaining 40 revenue models; if you aim for a social or environmentally friendly model (especially if you go for the RR&D archetype), you can also find inspiration in the Sustainable Business Model Archetypes (Gassmann et al., 2014, Chapter 1, Bocken et al., 2014).
6. The created value proposition from (4) and revenue mechanism from (5) are now transferred to the respective fields of the **Business Model Canvas*.** Based on this, all other fields are ideated in a workshop setting. First, every participant ideates on sticky notes and put them to a poster of the canvas. Subsequently, the post-its are discussed within the group and additional ideas are added. Once completed the result is prototyped and discussed following the respective steps of the **Value Ideation tool*** used in (4). The results of this are transferred back to the canvas, which serves as a means for dissemination and as an input for the next steps (Geissdoerfer et al., 2017; Osterwalder and Pigneur, 2010).
7. The **INSPIRE Technology Dashboards*** can be used again to identify and research the key technologies to realize the business model concept documented in the business model canvas (6). The technologies are discussed in a group meeting and the key technologies to realize the business model in the specific context of the organization are selected. These technologies are the investigated in desk research and the results are discussed and documented. Also, the INSPIRE Deliverable regarding research needs (D4.3) may be consulted for further input in the discussion on the technology aspects.
8. Based on the findings of (4), (5), (6) and (7), **hypotheses of key enablers and barriers** are formulated. For example, for the RR&S model, it might be essential that customers are willing to pay a certain amount for a remanufactured product. Based on the hypotheses an experiment is designed to test it. For example, the remanufactured product is offered in a certain region and the revenues from this product are compared to the expected sales. If the test reveal that necessary conditions for the business model are not

fulfilled, start again at the step where the underlying business model element was conceptualized, e.g. if the value proposition is to solve a certain customer problem and the customer seem to not appreciate this solution go back to (3) where the value proposition was defined (Geissdoerfer et al. 2017, 2018b).

9. If the hypotheses are confirmed, refine the business model concept and develop a **minimum viable product** (MVP) of your product or service. Form a team to sell this MVP to real customers. Give them freedom to go beyond the customer segments initially defined. If you cannot find a viable number of customers, analyze what could be the problem. Either tweak the MVP or go back to the step where the problem was caused. E.g. if customers repeatedly tell you that they would buy your product if you add a certain functionality, add it and see what happens; if your customers do not seem to be willing to pay for the solution you provide for their problem go back to (3) where the value proposition was defined. Address new customer segments once you found a viable one (Ries, 2011).
10. Once you are confident that you found a viable customer segment, i.e. they are buying your product and are a large enough group to sustain your business, **pilot**. Launch your offering in part of the target market. For example, if you are planning to sell all over Europe, you can start in an important geographical area in Europe e.g. the North of Italy or the greater Paris region. If you are successful expand it to other parts until you have reached your entire target market. If you encounter problems, analyze them, tweak your offering, try another part of your market, or go back to the step that caused the problem (Geissdoerfer et al., 2017, 2018b).
11. Keep analyzing how your new business model performs and constantly adapt it to changes in its ecosystem. Do A/B testing to optimize your offering. Diversify into similar markets or business models using parts of or the entire process described here. In the latter case, start again at (1) (Geissdoerfer et al., 2017).

5 Conclusion and next steps

As next steps we would propose to implement the INSPIRE tools with companies and conduct the business model innovation process described above. The use and outcomes of this can be investigated and tracked over time. Based on this research, we can improve the process and the involved tools and build confidence in their use. Different assumptions on their efficacy can be tracked and improvement potentials enquired. Tweaks in the toolkit should be attempted and successful changes adopted until a saturation in improvement potentials is reached. For this an approach analogue to the methodology of (Geissdoerfer et al., 2016) can be used.

Also, we would recommend developing a web-based INSPIRE decision support tool. We are discussing with a UK company Britest, to integrate our Decision Support Factors in their web-based “chemdecide” tool, which we already jointly used in a Dinner Workshop at the Achema 2018 in Frankfurt. Other tools described here could follow to provide a comprehensive, easily access - and disseminatable toolkit that fosters business model development for relocalization.

Another potential avenue is to concentrate on the simulation of business model options. As outlined in Vladimirova et al. (2017), a business model simulation tool that allows to run different business model configuration through a simulation model based on identical assumptions on its elements and the interactions between these elements would allow data driven decision making in the configuration phase. Different concepts could be experimented with virtually before being taken forward to the next stages. This would add a third fourth phase besides prototyping, experimentation and piloting.

Finally, measuring business model success is still in its infancy. Further research on what are the most adequate KPIs for evaluation and controlling is necessary. An adequate toolbox of metrics would support the approach presented here and would allow more effective steering of the process and decision-making at key milestones.

Table 2 Mapping of INSPIRE Business Model Archtypes and St. Gallen Business Model Patterns (source: own representation).

INSPIRE BMA	St. Gallen BM Pattern	Description of the BM Pattern	Explanation
Modularization and distributed manufacturing	Mass-customization	Customizing products through mass production once seemed to be an impossible endeavor. The approach of modular products and production systems has enabled the efficient individualization of products. As a consequence, individual customer needs can be met within mass production circumstances and at competitive prices.	Industrial processes can be easier customized to local needs due to increased flexibility.
	From push-to-pull	This pattern describes the strategy of a company to decentralize and thus add flexibility to the company's processes in order to be more customer focused. To quickly and flexibly respond to new customer needs, any part of the value chain - including production or even research and development - can be affected.	Production processes can be designed more based on the demand of the customer.
	Fractional Ownership	Fractional ownership describes the sharing of a certain asset class amongst a group of owners. Typically, the asset is capital intensive but only required on an occasional basis. While the customer benefits from the rights as an owner, the entire capital does not have to be provided alone.	Local modular production plants/assets can be jointly owned with clients.
	License or rent or buy	Efforts are focused on developing intellectual property that can be licensed to other manufacturers. This model, therefore, relies not on the realization and utilization of knowledge in the form of products but attempts to transform these intangible goods into money. This allows a company to focus on research and development. It also allows the provision of knowledge, which would otherwise be left unused and potentially be valuable to third parties.	IP owner of the modular production technology can license to clients or other local industries in the concept of distributed manufacturing. Or can rent the facility.
	Orchestration	Within this model, the company's focus is on the core competencies in the value chain. The other value chain segments are outsourced and actively coordinated. This allows the company to reduce costs and benefit from the suppliers' economies of scale. Furthermore, the focus on core competencies can increase performance.	The central IP owner of the modular production technology could orchestrate a network of distributed production facilities (not necessarily owned by him).
Customization	From push-to-pull	See above.	Customers customize individual products and manufacturing + process industries react with tailored manufacturing.
	Mass-customization	See above.	
Servitization	Pay per use	In this model, the actual usage of a service or product is metered. The customer pays on the basis of what he or she effectively consumes. The company is able to attract customers who wish to benefit from the additional flexibility, which might be priced higher.	Materials and chemicals can be paid based on their use or function.
	Performance based	Product's price is not based upon the physical value, but on the performance or valuable outcome, it delivers in the form of a service. Performance based contractors are often strongly integrated into the value creation process of their customers. Special expertise and economies of scale result in lower production and maintenance costs of a product, which can be forwarded to the customer. Extreme variants of this model are represented by different operation schemes in which the product remains the property of the company and is operated by it.	Instead of materials or chemicals, the producer takes responsibility and gets remunerated for the function of the material (e.g. the de-icing of airplane wings, instead of supplying the chemical).

Table 2 (continued) Mapping of INSPIRE Business Model Archtype and St. Gallen Business Model Pattern (source: own representation)

INSPIRE BMA	St. Gallen BM Pattern	Description of the BM Pattern	Explanation
Servitization	Rent instead of buy	The customer does not buy a product, but instead rents it. This lowers the capital typically needed to gain access to the product. The company itself benefits from higher profits on each product, as it is paid for the duration of the rental period. Both parties benefit from higher efficiency in product utilization as time of non-usage, which unnecessarily binds capital, is reduced on each product.	Similar (chemical leasing).
	Revenue sharing	Revenue sharing refers to firms' practice of sharing revenues with their stakeholders, such as complementors or even rivals. Thus, in this business model, advantageous properties are merged to create symbiotic effects in which additional profits are shared with partners participating in the extended value creation. One party is able to obtain a share of revenue from another that benefits from increased value for its customer base.	Revenues can be shared with another service provider (e.g. the de-icing company) or even with the customer itself depending on the current business model and value chain configuration.
Re-use, Recycle, Sustainability	Digitize	This pattern relies on the ability to turn existing products or services into digital variants, and thus offer advantages over tangible products, e.g., easier and faster distribution. Ideally, the digitization of a product or service is realized without harnessing the value proposition which is offered to the customer. In other words: efficiency and multiplication by means of digitization does not reduce the perceived customer value.	Regional and interregional on-line platforms for information about and trade of waste streams or industrial side streams.
	Crowd-sourcing	The solution of a task or problem is adopted by an anonymous crowd, typically via the Internet. Contributors receive a small reward or have the chance to win a prize if their solution is chosen for production or sale. Customer interaction and inclusion can foster a positive relationship with a company, and subsequently increase sales and revenue.	Similar: demand from an industry for a specific waste stream can be "sourced" on an on-line platform (similar to innocentive concept) but then for industrial symbiosis.
	Crowd-funding	A product, project or entire start-up is financed by a crowd of investors who wish to support the underlying idea, typically via the Internet. If the critical mass is achieved, the idea will be realized and investors receive special benefits, usually proportionate to the amount of money they provided.	Investments in joint infrastructures to facilitate industrial symbiosis can be jointly funded by industries in an industrial park (e.g. ESCO concept).
	Customer Loyalty	Customers are retained and loyalty assured by providing value beyond the actual product or service itself, i.e., through incentive-based programs. The goal is to increase loyalty by creating an emotional connection or simply rewarding it with special offers. Customers are voluntarily bound to the company, which protects future revenue.	Customer loyalty programmes can be used as an incentive for consumers (or even industrial customers) to collect and return waste to generate a critical mass of waste for the business case.
	Fractional ownership	See above.	Similar to crowd funding above.

Table 2 (continued) Mapping of INSPIRE Business Model Archtype and St. Gallen Business Model Pattern (source: own representation)

INSPIRE BMA	St. Gallen	Description of the BM Pattern	Explanation
Re-use, Recycle, Sustainability	Orchestrators (+ performance based)	Within this model, the company's focus is on the core competencies in the value chain. The other value chain segments are outsourced and actively coordinated. This allows the company to reduce costs and benefit from the suppliers' economies of scale. Furthermore, the focus on core competencies can increase performance. + see	Intermediate organizations can be created to orchestrate the collection, (pre) treatment and re-use or recycling of waste or industrial side streams (already used in Industrial Symbiosis in industrial parks), and be paid by the result.

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Practitioner`s Section

Implementation of sustainability in innovation management: The Idea to People, Planet and Profit (I2P³®) Process

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Assessing the sustainability of the innovation portfolio is a particular challenge for industries. The two main issues are the lack of data at the early stage of project development and the high number of ideas and projects that are developed. This paper provides an overview of the I2P³® process (Idea to People, Planet and Profit®) which was developed by Evonik Creavis GmbH, the strategic innovation unit of Evonik Industries AG, in order to integrate sustainability into its innovation process. This process is based on a holistic approach to assess the three dimensions of sustainability (economical, environmental, and societal). The paper includes a detailed description of each stage of the process, with the categories and criteria used to assess these three dimensions, from idea generation to market launch. Following this, difficulties faced in the implementation process and improvement options are discussed.

1 Introduction

There is widespread agreement on the claim that an enterprise can survive and prosper in the long run only if it is able to innovate every now and then (Drucker, 2014). Innovation is the key to a company's long-term success. New product offerings, process improvements, new market applications, or business models are the drivers for future cash flows.

Hence, every innovative company needs to ask itself two crucial questions: How do we find the right innovations? How do we innovate the right way? A trend that can be observed in many industries is a shift towards environmentally or societally benign and hence "sustainable" solutions. There is abundant evidence that companies offering solutions that are more sustainable than competing offerings also perform financially better, for example, in terms of share price development or product lifespan (Nidumulou et al., 2009; Hart and Dowell, 2011; Pogutz and Winn, 2013; Shrivastava and Kennelly, 2013). Reasons for this are – among others – environmental and societal pressure groups, responsible investors, environmental scandals, informed and responsible customers, and legislative activity.

The latter becomes particularly visible in the United Nations (UN) Sustainable Development Goals (SDGs) (United Nations (UN), 2016). These goals were adopted by 193 countries during the 2015 UN General Assembly.

Therefore, many companies need to somehow systematically combine economy, ecology, and societal impact in their ideation and innovation processes. A pivotal role is played by the specialty chemical industry, as their products often have an important influence on the innovation processes of other industrial sectors, such as the food, textile, automotive, and electrical industries.

The following is a brief description of the involved parties. **Evonik Industries AG** (short: Evonik) is one of the world leaders in specialty chemicals. The focus on high-margin specialty businesses, customer-orientated innovative processes, and a trustful and performance-oriented corporate culture form the heart of Evonik corporate strategy. **Evonik Creavis GmbH** (short: Creavis) is the strategic innovation unit of EVONIK, focusing on medium to long-term innovation projects that support growth and the sustainability strategy of EVONIK and open up new business options. CREAVIS carries out research into transformative innovations while taking economic, ecological, and societal aspects into account in its portfolio management. With respect to the assessment of ecological and societal aspects, Creavis works closely with the Evonik internal Life Cycle Management (LCM) team, which acts as a competence center for Life Cycle Assessments (LCA) and sustainability related topics.

1.1 Problems and Challenges

The commitment of Creavis to focus on sustainable innovation poses the challenge to predominantly develop new offerings that are profitable, environmentally benign, and beneficial for society. This means that the 3 dimensions of sustainability need to be addressed at some point during the innovation process. But what is the right time to consider the effects of an innovation on society (i.e. on the people dimension) and on the environment (i.e. on the planet dimension)? At which maturity stage should sustainability issues be taken into account? From our perspective, the answer is: as early as possible. The earlier any environmental or societal effects are evaluated, the easier it is to take countermeasures if the effects turn out to be negative or – in the positive case – the easier it is to translate such effects into a compelling value proposition (Bednarz et al., 2017).
However, this "as early as possible" statement creates two challenges. First, uncertainties at the early stage of innovation make any assessment extremely challenging. Then the practicability due to the high amount of innovative ideas that are being developed at Creavis.

There is abundant literature on structured appraisal of ideas and fruitful innovation processes but so far only a few publications have addressed approaches and indicators for sustainable development (e.g. Kralisch et al. (2018), Stock et al. (2017)). For the chemical industry in particular, some initial approaches have been developed, which address a sustainability assessment for their innovation (VCI, 2017). To the best of our knowledge, none of these approaches has been adopted by any other but the originators' company. This is mainly due to insufficient disclosure of the respective method and because at least one of the challenges mentioned above had not been sufficiently resolved.

1.2 Aim of this paper

In this paper, we introduce and fully disclose the I2P³® (Idea to People, Planet and Profit®) process, which was developed by Creavis to incorporate sustainability into the DNA of the innovation process while overcoming the two challenges of uncertainty and practicability.

With this process, effective management and control of sustainable innovations within a company is possible. This process was introduced in 2013 and has been successfully implemented in the innovation landscape of Creavis. In the further course of this article, a detailed description of the I2P3® process is provided with the assessment method in each stage of the process. This is followed by a discussion about possible improvements to the process and its further development.

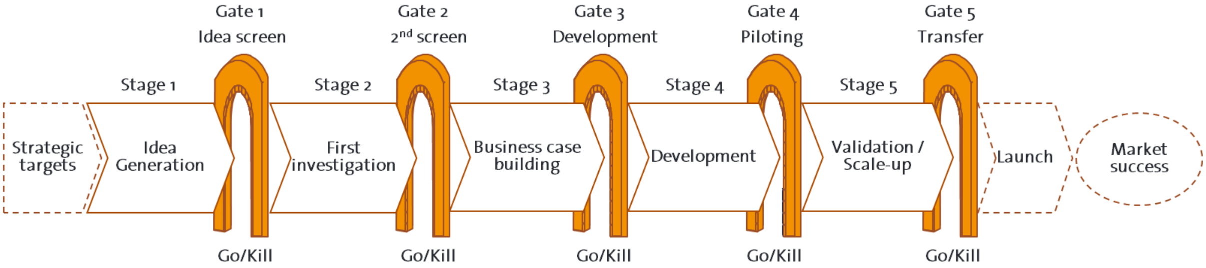
2 I2P³® Process

2.1 Structure of the I2P³® process

In general, I2P³® is a management process that starts with idea generation and ends with the market launch of the innovation. Within this process, impacts of the idea/project on all three dimensions of sustainability are taken into account: People (societal aspects), Planet (ecological aspects) and Profit (economic aspects). Like Cooper's Stage-Gate® model (Cooper et al., 2002), the I2P³® process comprises six stages (see Figure 1).

A stage is a phase during which a cross-functional and/or cross-regional team works on the realization of stage-specific deliverables. For a sound decision, a set of categories and criteria for all the three dimensions of sustainability is assessed by the respective project man-

Figure 1 Structure of the I2P3® process (source: own representation).



ager and discussed during the gatekeeper meeting.

The nomenclature of the I2P3® process is shown in Table 1. **Dimensions** are the highest level of aggregation for the analysis; they represent the three dimensions of sustainability. Within each dimension, **categories** have been selected to describe as holistically as possible the landscape of each dimension. Finally, **criteria** have been defined to further specify each category (e.g. Global Warming Potential using a 100-year timeframe within the category "Greenhouse gases" or Acidification Potential as one criterion within the category "Other emissions").

During stages 1 and 2, the assessment is carried out qualitatively on the dimension and category levels. From stage 3, a quantitative assessment is performed at the criterion level. The full set of criteria is described in the section 2.3.3. The goal is to increase both quality and validity of the assessment throughout the stage-gate process. All assessments provide scores between −2 and +2 in comparison to a benchmark, which makes the assessment a comparative one (Table 2). The benchmark represents the most established technology on the market at the (future) time of market entry, in other words, the direct competitive product on the market (more details in section 2.2).

First, this allows qualitative analyses to be semi-quantified in stages where knowledge about the development and therefore the data quality for a quantitative analysis is poor. Second, it enables the effects of a project on different criteria to be compared. This comparability was shown to be a major issue within the establishment of the I2P3® process: What if a particular innovation project promises to yield a fantastic net present value (NPV) within the profit dimension and, in addition to that, saves 200,000 tons of CO_2 equivalents per year but at

Table 1 Dimensions of and categories of the I2P3® (source: own representation).

Stage 1: Dimensions	Stage 2: Categories
People	Societal value added
Planet	Ecosystem risk potential
	Greenhouse gases
	Other emissions
	Waste
	Raw material use
	Energy
	Land use
	Water use
Profit	*Not addressed in this paper*

Table 2 Scoring System (source: own representation).

−2	−1	0	+1	+2
Significant deterioration	Deterioration	No impact	Improvement	Significant improvement

the same time causes 100 tons of additional SO_2 emissions?

Therefore, a set of scoring rules for each criterion was derived and classified within the scale [−2; +2], allowing a translation of different numbers and units into one consistent assessment scheme (Table 3).These criteria allow the performance of the innovation idea/project to be (semi-) quantified in each stage of its development. Each project is expected to yield a significant improvement (i.e. +2) in at least one of the three dimensions. If a project shows a significant deterioration in one category (score = −2), it should usually not be continued. However, despite a score of −2 in a certain category, a project may still be pursued (e.g. if the project manager provides a credible idea on how to improve that category while exhibiting a significant improvement for any other category). To express the quality of the assessment of each criterion, a score between 0% and 100% is assigned to each of them. This is selected according to the data availability and quality at the time of the assessment.

Nevertheless, the problem of defining the right scoring rules remains. Unfortunately, scientific literature does not provide any guidance or methods on how to classify such effects in a comparable manner. For example, the question "*what amount of avoided acidification potential needs to be reached in order to deserve the label 'significant'?"* has not yet been answered. In order to set ambitious but realistic scoring rules, Creavis analyzed its current innovation project portfolio at that time and determined the top 5% of projects for each sustainability criterion. The threshold for a +2 score for each criterion was then set right below this group of top performers. A score of +1 is awarded if 10% of the threshold for a score of +2 is reached. The same applies for negative scoring rules, which have the same absolute values as the positive ones but the opposite sign (see Table 3).

This approach allows for regular and transparent sustainability reporting of the Creavis innovation pipeline as well as simple target setting on a portfolio level (e.g. "*next year x additional +2 projects and no more −2*"). Since the initial introduction of I2P³®, some categories have undergone slight alterations – mostly

Table 3 Scoring rules, exemplified for Global Warming Potential (GWP100) and Acidification Potential (AP) (source: own representation).[1]

−2	−1	0	+1	+2
Significant deterioration	Deterioration	No impact	Improvement	Significant improvement
		GWP100 [ton/a CO_2eq]		
<−1,000,000	<−100,000	+/− 100,000	>100,000	>1,000,000
		AP [ton/a SO_2eq]		
<−1,000	<−100	+/− 100	>100	>1,000

[1] Ranges might be modified according to current innovation portfolio and company's targets. The ranges presented in this publication are the ones used at the time of the study (2018).

due to scientific progress. For instance, in 2016, it was decided to apply AWaRe characterization factors (Boulay et al., 2017) instead of water stress indices (Pfister et al., 2009).

Special attention is paid to describing the People and Planet dimensions because they represent the specificities of the I2P³® process. The assessment of the different categories and criteria from the People and Planet dimensions is conducted by in-house Life Cycle Management (LCM) experts with the support of the manager in charge of the innovative idea. This activity is called SusCHEQ and is explained in more detail in Section 2.2. An assessment of the profit dimension is not part of this paper.

2.2 SusCHEQ in practice

The assessment of the sustainability performance of innovation ideas or projects is called 'SusCHEQ' (Sustainability performance of innovation ideas and projects by means of a Comparative and Holistic Evaluation that is based on Quantitative and Qualitative data). To conduct a SusCHEQ in the most efficient way, a workflow is defined that consists of four steps (Figure 2).

SusCHEQ Introduction: This first step aims to produce a common understanding of the SusCHEQ methodology and to answer some general questions about the I2P³® process. Generally, this step is carried out only if it is the project manager's first SusCHEQ.

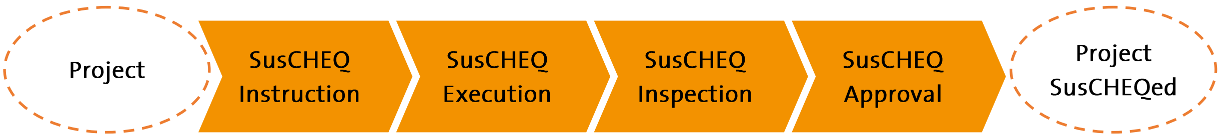
SusCHEQ Execution: The second step, "Execution", is the heart of the SusCHEQ. First, the project manager presents his/her idea or project to an LCM expert with all the relevant technical aspects (application, markets, expected benefits). Following this, the goal and scope of the analysis are defined together with system boundaries and a functional unit is selected. Choosing the benchmark is also an important aspect in this stage. The SusCHEQ is a comparative approach. This means that impacts on the People and Planet dimensions are assessed for the new idea or project (also called 'New Solution') in comparison to a benchmark (also called 'Existing Solution'), which is the most established technology on the market at the time of market entry (direct competitive product on the market). The choice of the benchmark may be a particular challenge, for example, for an entirely new offering that creates a completely new market (e.g. printable batteries). Sometimes, more than one benchmark, representing several possible applications for the new product, may be considered in the business case. Benchmark selection should be supported by a proper market study that each project manager carries out for the assessment in the profit dimension. This benchmark solution is usually the product that the future Evonik product will compete with most fiercely. We deliberately decided to select the benchmark in this manner rather than choosing a possibly better-than-standard solution if this solution is used only in niche applications and hence is not the main competition for our product.

During the execution step, a specific set of categories and criteria, described in Section 2.3, is assessed in relation to the stage of the project. The assessment level (dimension level, category level or criteria level, *vide supra*) and hence the detail level and time effort of the execution depends on the stage of the project.

At the end of the execution step, the LCM expert presents the results to the project manager, as well as the scores obtained in each category or for each criterion. Additionally, relevant conclusions (e.g. potential for optimization or aspects that could be used for further differentiation) are drawn and discussed.

LCM experts must check the completeness of the SusCHEQ (e.g. that all categories or criteria have been assessed, results have been documented, etc.), the consistency and transparency of data and results, and a valid interpretation

Figure 2 SusCHEQ workflow (source: own representation).



has been made. When the execution is completed, a different LCM expert takes over for the inspection step.

SusCHEQ Inspection: The inspection is intended to ensure a certain level of quality by applying the principle of dual control. The inspector has to check the relevance of the SusCHEQ (e.g. benchmark selection), its completeness, consistency, transparency, use of conservative assumptions, as well as a valid interpretation. A checklist is available for the inspector in order to ensure a correct and reproducible process.

SusCHEQ Approval: Once the inspection is finished, the result needs to be approved by the project manager's line manager. This supervisor also needs to check for relevance, completeness, and consistency of the SusCHEQ.

This complete 4-step process for the assessment of an innovation project's effects on planet and people is carried out from I2P³® stage 3 onwards. For stages 1 and 2, a shorter and purely qualitative version is applied to deal with the uncertainty and practicability challenges mentioned above. These shorter versions are described in Sections 2.3.1 and 2.3.2.

2.3 Assessment of the People, Planet and Profit Dimensions

When a new idea for an innovative product is developed and has just been entered into stage 1 of the I2P³® process, in general, very little is known about it. Consequently, the quantitative assessment of some categories and criteria can be very challenging and the data quality will be poor. However, data availability usually increases during the process development so that the data quality also improves.

2.3.1 Stage 1 (Gate 1 assessment)

The initial point of the I2P³® innovation process is when a new idea for a new product or an improved process is created. The idea generator files his idea in the Creavis I2P³® database, which is followed by an initial qualitative assessment regarding the positive, neutral, or negative impact on the People and Planet dimensions. No differentiation into different categories takes place within this first, rough assessment. Nor is the evaluation team required to consult with LCM experts in this stage. In a sense, the only purpose of the assessment in this stage is to make sure the evaluation team pays attention to potential ecological or societal impacts of the idea. The evaluation of these two dimensions in stage 1 is shown in Table 4. At gate 1, the evaluation team also acts as gatekeeper. In the case of a positive gate decision, an investigator is chosen to carry out the stage 2 assessment described in the following section.

2.3.2 Stage 2 (Gate 2 assessment)

In stage 2, the assessment of the planet dimension takes place on a category level, i.e. one level of more details. The result of this assessment is also more refined than in stage 1 as it uses a 5-step Likert scale. Based on the information provided by the investigator, a score between −2 and +2 is attributed to the categories presented in Table 5. While the Planet dimension is further substantiated by eight categories, the People dimension only contains one category, which is called Societal Value Added (SVA). This category reflects the contribution of the idea to topics that are relevant for society, such as housing, health, nutrition, energy supply, communication, safety, water supply, and

Table 4 Evaluation of planet and people dimensions in stage 1 (source: own representation).

Score	General ecological attractiveness in year 5 after market launch	General societal attractiveness in year 5 after market launch
+2	Large opportunities for very positive ecological impact	Large opportunities for very positive societal impact
0	Nearly no opportunities for positive ecological impact	Nearly no opportunities for positive societal impact
−2	Large opportunities for very negative ecological impact	Large opportunities for very negative societal impact

education.

The question asked in common for all of these categories is: do we expect a (significant) deterioration or a (significant) improvement in the respective category in comparison to the benchmark, taking the entire life cycle of the future product into account?

To answer that question for all categories, short researches (e.g. using LCA software, scientific articles, etc.) can be conducted or the investigator can consult with LCM experts in order to gain some insights into the potential environmental impacts of some raw materials or processes.

This assessment usually requires some minor effort (<1 day). For most ideas, in this stage, the project manager is still not able to provide quantitative data (i.e. mass or energy balances) for the production of the new product but is able to give some information about the most likely production route, raw materials and performance in the application (e.g. energy savings

Table 5 Criteria considered for the assessment in stages 3, 4 and 5 (source: own representation).

Dimension	Category	Criteria	Sources
Planet	Ecosystem Risk Potential	Substance criticality and Exposure Potential	Own method disclosed in section 1
	Greenhouse gases	Global Warming Potential 100 (GWP100)	CML 2001 impact assessment method (Guinée et al., 2002)
	Other emissions	Acidification Potential (AP), Eutrophication Potential (EP), Ozone Depletion Potential (ODP), Photochemical Ozone Creation Potential (POCP) and Freshwater Aquatic Ecotoxicity Potential (FAETP)	
	Raw material use	Abiotic Depletion Potential (ADP)	
	Energy	Primary Energy demand (PED) from renewable and non-renewable	PE International AG (2014) thinstep AG (2017)
	Land use	Agricultural Land Occupation and Land Transformation	ReCiPe impact assessment method (Goedkoop et al., 2013) and own method for land transformation
	Waste	Waste quantity and waste treatment	Own method disclosed in section 2
	Water use	Water Scarcity Footprint based on Blue Water Consumption and the characterization factors from the AWaRe method	Blue Water consumption according to Hoekstra et al. (2011) and AWaRE characterization factors from Boulay et al. (2017)
People	Societal Value Added (SVA)	Nutrition, health, education, etc.	Own method disclosed in section 4

in the targeted market or longer lifetime). Based on this semi-quantitative information, system boundaries, functional unit and the benchmark according to ISO 14040 and 14040 standard requirements (ISO, 2006) can be defined.

This approach allows positive or negative impacts of the innovation idea to be identified without going too much into the details of a full LCA. The latter would be impossible in this stage, anyway, due to poor data availability and the high resource requirement for such an analysis.

Based on the assessment in all three dimensions, the gatekeepers decide whether the idea should advance to stage 3.

2.3.3 Stages 3, 4, and 5 (Gate 3, 4, and 5 assessment)

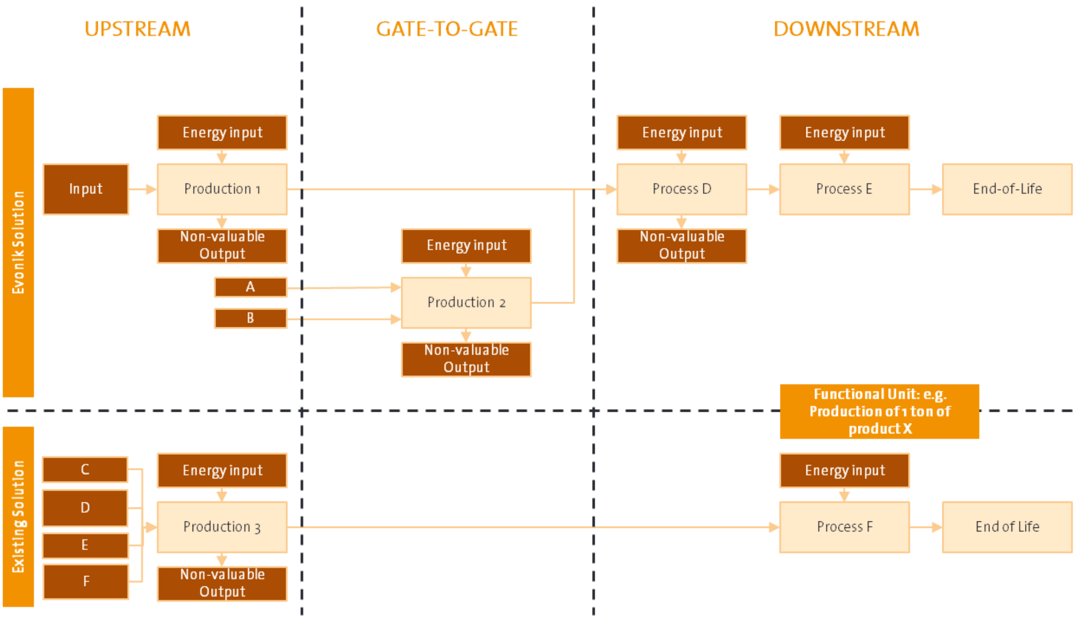
The assessment of People and Planet dimensions in stages 3 to 5 is conducted on the criteria level, i.e. a set of specific criteria is assessed for each category defined in Table 1. Consequently, the SusCHEQ requires more time and resources for both parts compared to the previous assessment. The same SusCHEQ method (in terms of criteria used) is used for these stages (3, 4 and 5) but the analysis is refined: the data quality increases together with the data availability.

Starting with stage 3, the assessment of the Planet dimension is similar to an LCA and meets the requirements in terms of life cycle perspective, functional unit, transparency, comprehensiveness, workflow, and data quality according to (ISO, 2006). Criteria used are, as far as possible, widely accepted LCA impact categories (i.e. current best practices). However, some criteria are not derived from typical LCA impact categories but have been selected due to their relevance for chemical industries. Consequently, we developed our own methodology within the scope of the I2P³® process development and had it reviewed by the Wuppertal Institute. The criteria considered for stages 3, 4 and 5 are described in Table 5.

Like for any LCA, system boundaries have to be identified and a model representing the different steps of the life cycle (process overview) has to be established both for the innovation project and for the benchmark (see Figure 3). Based on this process overview, the next step is to prepare a Life Cycle Inventory (LCI), in other words, mass and energy balances, in order to quantify all inputs and outputs of each process unit. It should be noted that the innovation project may still be years away from commercialization and hence the I2P³® process allows significantly more assumptions and uncertainties than a classic LCA.

Gathering data about the benchmark may be very challenging and often requires more effort. As far as possible, data from established

Figure 3 Process overview (source: own representation).



LCA databases are used, supplemented by literature data.

From stage 3 onwards, the assessment is mostly quantitative. In order to quantify the overall impact of the innovative Evonik solution over the identified benchmark, the difference in, for example, GWP 100 per functional unit is multiplied by the volume scenario that represents the amount of sales expected in 10 years from today. Consequently, the project manager needs to estimate the volume of sales from stage 3 onwards.

Criteria used for assessing the People and Planet dimensions are described in the next sections, with the focus on the methodological approach and scoring system.

Ecosystem Risk Potential (ESRP)

Responsible care has been a paradigm for the chemical industry for more than 20 years and it has been implemented within I2P³® in order to avoid or safely manage hazardous chemicals (International Council of Chemical Associations (ICCA), 2014) even though ESRP is not a classic environmental impact category. ESRP is currently not included in LCA software. For this reason, the assessment is semi-quantitative and with limited system boundaries. All substances (inputs and outputs) mentioned in the process overview (Figure 3) have to be assessed regarding their ESRP. This assessment method has been developed based on the "Guide on sustainable chemicals" from the German Environmental Agency (Reihlen et al., 2016).

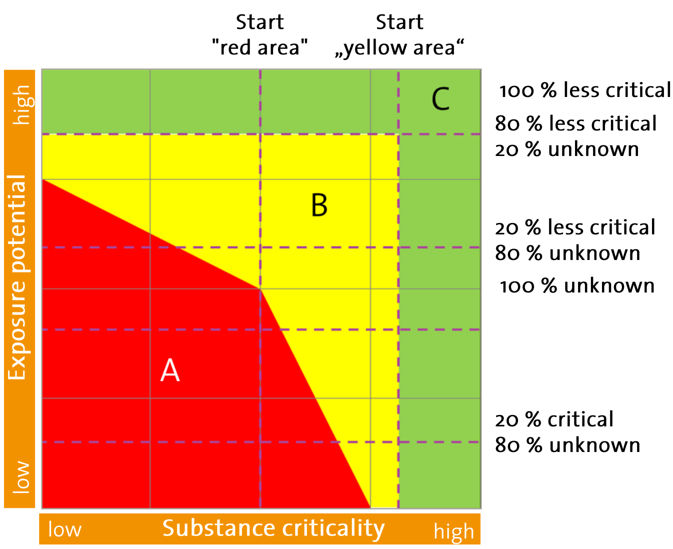
Substance Criticality

Substance criticality (= hazardousness) is assessed based on the material safety data sheets of the respective substances. A classification (red, yellow, green or white) is attributed to each substance according to its criticality, which corresponds to a specific value (see brackets):

- Red: Substance may cause severe health and/or environmental damage (8)
- Yellow: Substance may damage health and/or the environment (2)
- Green: Substance is not dangerous to human health or environment (0)
- White: Substance properties are unknown (6)

This assessment covers the criticality regarding explosion risk and human and environmental toxicity. An interim value is attributed that reflects properties of the most critical substance. This interim value is multiplied by a second value representing the risk of dispersion of the substance in order to obtain a final substance criticality. Substance risk of dispersion is also assessed based on the material safety data sheets of the respective substances (solubility, vapor pressures, etc.) and the following classification:

Figure 4 Ecosystem Risk Potential classification (source: own representation).



- Red: Substance has a high risk of dispersion (2)
- Yellow: Substance has a medium risk of dispersion (1,5)
- Green: Substance has a low risk of dispersion (1)
- White: Substance risk of dispersion is unknown (2)

Exposure Potential

Secondly, each substance's exposure potential is assessed. A hazardous substance may be exposed to the environment (e.g. containment of installation, water emissions), to the workplace (e.g. processing at low or high temperature and pressure, safety management system for workers) and to customers (e.g. type of application, disposal). For each risk, a classification as “critical” or “less critical” can be made.

- A value of 1 is given to the classification as “less critical”, a value of 2 is given to “unknown” and a value of 3 is given to “critical”
- Finally, the average value is calculated for all the exposure potential

Substance Ecosystem Risk Potential

The ESRP is produced from the combination of substance criticality and exposure potential. The substance is either classified as Red (A = Highly critical), Yellow (B = critical) or Green (C = not critical) according to the matrix shown in Figure 4.

All substances involved in the innovative New Solution and in the benchmark Solution are assessed on the basis of this method, cradle-to-grave, as far as possible. Then the most critical substance is identified for either solution, which gives the final classifications (A, B, C).

As the assessment is comparative, the final score of the category ESRP is obtained by comparing the classifications of either solution. Table 6 describes the rules to be followed in order to assign the score to the category.

Waste category

The most important question when discussing waste is whether it is

- hazardous or
- non-hazardous

and what its disposal route is:

- Waste to dispose of,
- Waste to incinerate with or without energy recovery,
- Waste for recycling and
- Waste for reuse.

Table 6 Scoring rules for the category Ecosystem Risk Potential (source: own representation).

Score	Change in classification between the benchmark and the new solution
+2	A -> C or A -> B
+1	B -> C or C -> C
0	B -> B
−1	C -> B or A -> A
−2	C -> A or B -> A

Table 7 Characterization Factors (CFa) for the waste category (source: own representation).

End of life option / Criticality of the treatment option	CFa for hazardous waste	CFa for non-hazardous waste
Disposed of or incinerated without energy recovery	1	0.71
Incineration with energy recovery	0.86	0.57
Recycling	0.43	0.14
Preparation for reuse	0.29	0

With the help of the LCA software GaBi (thinkstep AG, 2017), the quantity of waste generated per functional unit can be calculated (hazardous and non-hazardous going to disposal). If other wastes are disposed of by other routes, they have to be calculated manually according to the data available and based on the Life Cycle Inventory. The amount of waste is then multiplied by a characterization factor (CFa) that represents the criticality of the waste treatment (Table 7), whereby a CFa of 1 represents the worst waste treatment option and a CFa of 0 the best one. Within the classification, hazardous wastes have a higher CF than non-hazardous wastes within the same waste treatment option. The CFa values are based on the

Table 8 Scoring rules for the Waste category (source: own representation).[2]

Description	Score	Change in waste eq. [t waste equivalent]
Significant improvement	+2	> 3,000
Improvement	+1	> 300
Neutral/unknown	0	+/−300
Deterioration	−1	< −300
Significant deterioration	−2	< −3,000

Table 9 Scoring rules for other criteria (source: own representation).[3]

Category	Criterion	Unit	Scores +2	+1	0	−1	−2
Greenhouse gases	GWP 100	kt CO_2eq	>1,000	>100	+/−100	<−100	<−1,000
Raw material use	ADP	t Sbeq	>10	>1	+/−1	<−1	<−10
Other emissions	AP	t SO_2eq	> 1,000	>100	+/−10	<−100	<−1,000
	EP	t PO_4eq	>500	>50	+/−50	<−50	<−500
	FAETP	t 1,4-DCBeq	>50,000	>5,000	+/−5,000	<−5,000	<−50,000
	ODP	t R11eq	>1	>0.1	+/−0.1	<−0.1	<−1
	POCP	t C_2H_4eq	>100	>10	+/−10	<−10	<−100
Energy	PED	TJ	>5,000	>500	+/−500	<−500	<−5,000
Land use	Agricultural Land Occupation	km^2	>100	>10	+/−10	<−10	<−100
Water	Water Scarcity Footprint	1,000 m^3 Water eq	>4,000	>400	+/−400	<−400	<−4,000

[2] Positive values indicate savings compared to the benchmark Solution.

waste hierarchy developed in the German law on Closed Cycle Management and Waste (KrWG, 2012), as no scientifically substantiated CFa are available so far.

For the assessment, all waste streams occurring in both the Evonik solution as well as the benchmark solution are multiplied with the respective CFa, resulting in waste equivalents. Finally, the difference in waste equivalents between both solutions is multiplied by the production volume in 10 years from now in order to obtain the absolute impact and the score for the waste category (see Table 8).

Other criteria

All remaining criteria related to the categories greenhouse gases, other emissions, raw material use, agricultural land occupation, energy and water can be directly assessed with the GaBi software. Again, criteria are calculated for both the New Solution and the benchmark, and the difference is multiplied by the production volume in 10 years from now. The following scoring rules (see Table 9) are used to define a score between −2 and +2.

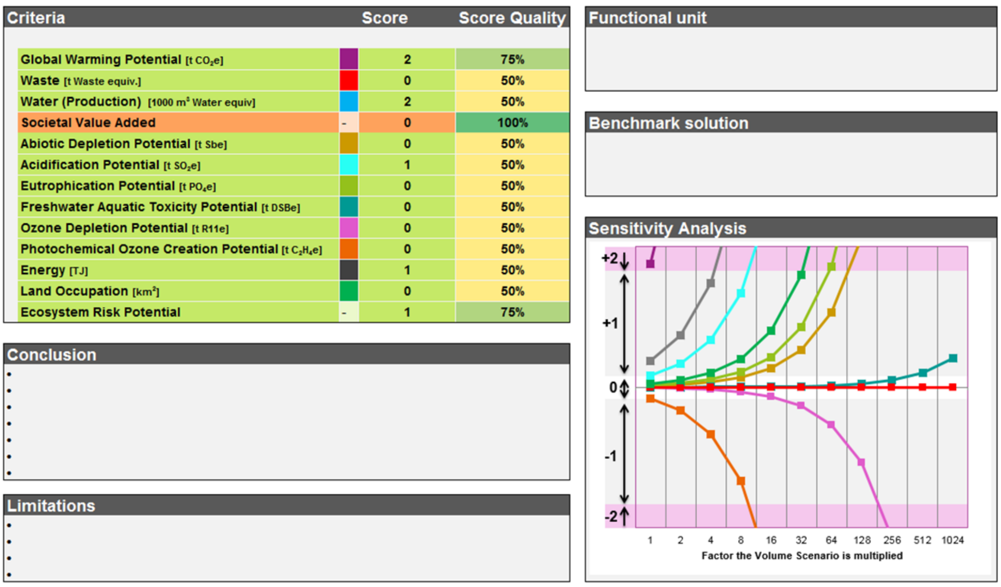
Societal Value Added (SVA)

Due to a lack of methodological approaches to assess societal aspects of sustainability quantitatively and due to the requirement of having a pragmatic approach within the scope of I2P3®, a qualitative approach was developed to cover this dimension. The goal was to focus on the societal value added, i.e. the societal benefits that the New Solution might have compared to the benchmark in its application. While the assessment of the societal value added remains the same from stage 2 onwards, the analysis becomes more detailed for the different criteria. The following societal value-added criteria have been selected, as they are particularly relevant for Evonik business:

- Nutrition: malnutrition, hunger, obesity, etc.
- Health: life expectancy, human diseases, infant mortality rate, etc.
- Education: access to education, graduation rate, etc.
- Energy supply: access to energy, security of supply, etc.
- Housing: living conditions, etc.
- Mobility: transport infrastructure, access to mobility, etc.
- Water supply: access to clean drinking water, etc.
- Communication: access to communication systems, etc.
- Safety: safety and security conditions, protection against natural catastrophes, etc.

These criteria are mainly derived from

Figure 5 Presentation of results during the gatekeeper meeting (source: own representation).



Schaltegger et al. (2007), Schmidt et al. (2004), UBA (2016) and UNDP (2016).

Due to the subjectivity of this assessment, it is hard to distinguish between "significant improvement" and "improvement". Therefore, only scores of +2, 0 and −2 are attributed. The project manager and LCM expert discuss the range of criteria and prepare a detailed documentation of the expected impact.

2.3.4 Communication and presentation of results at the gatekeeper meeting

SusCHEQ results are presented in a decision meeting (gatekeeper meeting). No weighting is applied between criteria from a category and between categories from a specific dimension. In fact, all criteria are presented as stand-alone criteria without giving more or less importance to any of them. In order to present the results clearly, pragmatically, and transparently, a chart (Figure 5) is used to present the results for the individual criteria. A graphic is also provided showing the scores obtained if the volume scenario were to be increased.

3 Discussion and Outlook

I2P³® is the innovation process of Creavis. It has, to date, not been used extensively in the innovation processes of other Evonik departments. Therefore, not all innovations of Evonik are yet assessed on the basis of the I2P³® process.

Several improvement possibilities have already been identified to make I2P³® more efficient and holistic. First of all, due to recent improvements in assessing societal aspects of sustainability, the category SVA might be revised in the coming years. A first improvement could be to consider societal aspects in the full life cycle and regard impacts on different stakeholder groups, as recommended by the UNEP SETAC (workers, local community, society and consumer) (UNEP/SETAC, 2009). For each stakeholder group, a qualitative assessment could be performed for a set of criteria as described by the Roundtable for Product Social Metrics (Fontes, 2016) and WBCSD (WBCSD, 2016). This quantitative approach would be a first step to improve the assessment of societal aspects within I2P³®.

The assessment of biodiversity and aspects related to the impact of land transformation is currently a bottleneck in LCAs. When the I2P³® process was developed, a qualitative method was implemented in order to include land transformation due to its high relevance, especially for bio-based chemicals. However, implementing I2P³® and conducting SusCHEQs showed that this method is currently not practicable and needs to be revised (qualitative assessment too generic to lead to any meaningful conclusions). Within the scope of optimizing I2P³®, a new method was proposed in order to include quantitative impacts from land occupation and transformation. A set of criteria has been chosen based on the LANCA impact assessment method (Bos et al., 2016) and is currently being tested in some projects. Aspects such as biotic production, erosion resistance, groundwater replenishment and mechanical filtration will be included in the assessment.

Due to the high number of ideas and projects that have to be assessed (the number of SusCHEQs carried out so far is in the three-digit range), the method needs to be pragmatic. An important aspect is the integration of the I2P³® criteria in LCA software. For example, the integration of societal criteria would accelerate the successful implementation of a quantitative assessment of the People dimension. The integration of an Ecosystem Risk Potential assessment method in LCA software would also increase the quality of the assessment: in the current method, the assessment of the substances used upstream is very limited due to data availability (i.e. knowledge of the substances used upstream).

The I2P³® process is currently based on the consideration of absolute improvements in the Planet and People dimensions, as it is the intention to provide significant benefits for environment and society which relative approaches might not provide. The consequence is that, compared to bulk chemicals, specialty chemical projects with a low expected production volume often result in a score of 0 in various categories and criteria, even if they result in a high *relative* improvement compared to the selected benchmark. Thus, adding relative data to the absolute data might assist the decision-making process.

Moreover, an important improvement of the current I2P³® process would be achieved if an approach or recommendations were to be developed in the scientific community to define absolute scoring rules (i.e. what is a significant improvement e.g. for greenhouse gases emissions?). The I2P³® process could easily be adapted to these new scoring rules.

Last but not least, the large number of criteria assessed within the I2P³® process and the associated complexity raised questions regarding whether it would not be more valuable to reduce the number of criteria and instead focus on the criteria that are considered relevant for the respective innovation project. In consequence, this means that for each innovation project an analysis regarding relevant sustainability criteria along the whole value chain needs to be performed first. This step requires a good understanding of the sustainability requirements of the customers and the market. By doing so, some positive side effects might occur:

- Methodological connectivity to recent developments with regard to product portfolio assessment is ensured (WBCSD, 2018). This aspect is very important, as innovation projects might eventually become part of the product portfolio in the future.
- Improved customer communication, as the focus is on sustainability-related topics that matter.

However, in order to avoid greenwashing, it is very important, that criteria that are not identified as being relevant for the respective innovation project do not lead to a significant deterioration.

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Research Paper

Artificial Intelligence in the process industries – technology overview, case studies, and success factors

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This article explores the role of artificial intelligence (AI) in the process industries such as the chemical and pharmaceutical industry. We start by classifying the most prominent technologies comprised under the generic term of AI, define them, and delineate their applicability in various functions along the organizational value chain. Further, we illustrate the boundary conditions for AI application by describing what data are required to initiate and sustain the "intelligence" of algorithms. We continue with thought-provoking case studies that exemplify the status quo and possible future applications of AI in the chemical and pharmaceutical industry. Based on academic insights, we discuss potential barriers and pitfalls that firms might face while integrating AI into their business processes and present remedies.

1 Introduction

As the internet of things gains traction, new opportunities for value creation arise in the process industries through the availability of connectivity, data, and cloud computing. Recent estimates attribute artificial intelligence (AI) an annual value creation potential of over $100 billion in the chemical and pharmaceutical industry, respectively (Chui et al., 2018). Taking off on the physical infrastructure, new business models in the process industries increasingly place intangible assets like software, services, and data analysis on the center stage (Stoffels and Ziemer, 2017; Yoo et al., 2010). This constitutes a stark shift for companies operating in the process industries that are coined by high asset-intensity, integration into physical locations, and complex value chains (Lager et al., 2013). In order to gain a competitive edge over their competitors and realize the full technological potential of AI, companies are recommended to intertwine their business strategy with the use of new technologies (Bharadwaj et al., 2013), and then pervasively exploit the emerging opportunities in the company. The latter involves the kind of activity that is wired into the DNA of most companies in the process industries, which is innovation. Therefore, the goal of this paper is to support innovative applications and overall acceptance of AI in the process industries by pursuing two measures. First, we unravel the major strands of technologies comprised under the notion of AI and second, we draw on academic insights to discuss the applicability of AI in the context of two case studies. In the following, we focus on technologies that are either already extensively used or are likely to become major technology components in the future. Thus, the list of AI technologies is not complete but presents a snapshot of the most relevant technologies.

2 Technology overview of AI

Under the umbrella of AI, we identified four main technologies that appeared particularly important in the process industries, namely expert systems, neural networks, intelligent agents, and case-based reasoning. In the following, each methodology will be outlined in more detail.

Starting with an overview of how AI is used for different functions along the value chain in research-intensive industries, Table 1 maps four AI technologies against major functions in companies.

2.1 Expert Systems

Expert systems (ES) are among the oldest and most widely used AI technologies (Negnevitsky, 2005). Their decision-making operates based on rules that are codified by the user in advance into the software that eventually presents a conclusion for a problem that otherwise needs expert reasoning. The coded rules serve as the knowledge base of the algorithms. On a technical level, the user feeds the algorithm with knowledge, which is commonly encoded in the form of If (antecedent) – Then (consequence) clauses. Take, for example, chess computers. Rules that account for the “smart” might look like these: *If* the pawn is on front of a competitor´s figure, *Then* it can neither walk forward nor capture the opponent’s figure because it can merely capture figures diagonal forward. Programming a rule-based ES for a specific application conventionally requires an expert in the respective field of application to collaborate with a programmer who translates the expert knowledge into code. However, the usefulness of this type of AI not only depends on the quality of the hard-coded rules but also on the newly fed data and facts that constitute the foundation of the reasoning process (Negnevitsky, 2005).

After the knowledge base has been filled with rules, new facts that capture the user’s problem can be filed into the expert system. Figure 1 presents the architecture of rule-based ES, including i) a knowledge base (comprising rules), ii) a database (comprising the facts), iii)

Table 1 AI methodologies and some major applications along the organizational value chain (source: own representation).

AI technologies	Functions in the value chain			
	Procurement	Research & Development	Production & Manufacturing	Sales & Marketing
Expert systems	Supplier evaluation and selection Resource planning	Modelling and simulation	Reactor steering Failure detection Process control	
Artificial neural networks	Demand forecasting Inventory optimization Price prediction Supplier classification	Drug discovery DNA-based disease prediction Protein folding prediction Personalized treatments	Reaction design Yield optimization Waste stream management Predictive maintenance Fault detection Compliance with regulation	Dynamic pricing Personalized marketing Repeat purchase modelling Next product to buy
Intelligent agents	Storage observation Self-ordering	Automation and robotics Co-working humans and robots	Process control Reactor steering Detection of rejects Compliance with regulations	
Case-based reasoning	Order management		Production plant design Chemical process planning	

an inference engine, iv) explanation facilities, v) and a user interface. When mimicking expert reasoning, these components interfere in the ways described in the following.

The inference engine is where the “intelligent” work takes place. Here, the rules that are encoded via If-Then relationships in the knowledge base are applied to the data or facts of the respective situation for which reasoning is required. When the “If” condition in the rule is fulfilled by the data, the “Then” i.e. the action is executed and the inference engine eventually delivers a result based on the given facts. In order to make the reasoning process more transparent, explanation facilities are embedded between the inference engine and the user. They enable users to ask *how* a result was produced and *why* specific facts are needed (Negnevitsky, 2005). Explanation facilities therefore bridge the gap between the rules and the outcome so that the result presented to the human user is comprehensible. Finally, the user interface needs to be designed in a way that suits the IT-skills of common users. Conventionally, interfaces are designed to be simple and intuitive, so that even non-experts have easy access to the knowledge condensed in the rule-based ES.

In terms of their application, rule-based ES are able to deliver value in situations where expert knowledge is available and can be purposefully captured in a system that then applies it to specific problems. The capabilities of ES include expressing relations, making recommendations, suggesting directives, strategies, and heuristics (Mohd Ali et al., 2015). Due to these abilities, rule-based ES have been applied in the context of strategic goal setting, planning, designing, scheduling, fault monitoring and diagnosis applications (Abraham, 2005). A major advantage of rule-base ES over novel methodologies such as deep learning with artificial neural networks is that their reasoning process is comprehensible for humans (Giarratano and Riley, 1989). This is especially important in situations where the AI’s decisions might have legal consequences such as in medical contexts. Table 2 presents some major advantages and disadvantages of rule-based ES.

Figure 1 Architecture of a simple rule-based expert system (source: Negnevitsky, 2005).

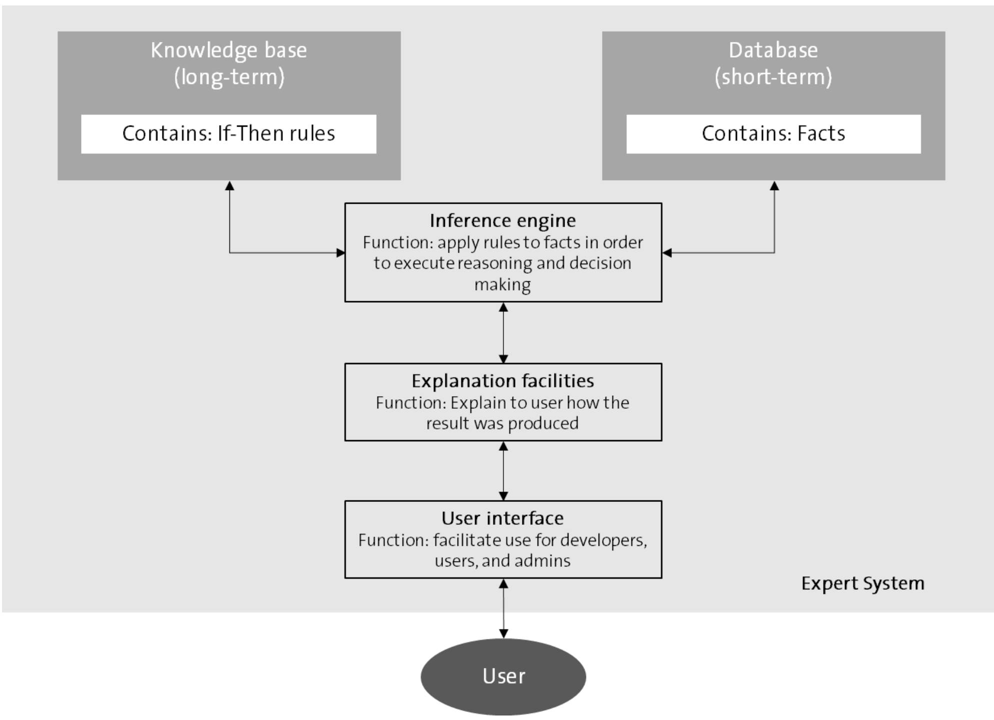


Table 2 Characteristics of rule-based ES (source: Negnevitsky, 2005).

Advantages of rule-based ES	
The ability to capture and preserve human knowledge	The ability to develop solutions faster than human experts
High consistency throughout a large number of decisions	The ability to apply human expertise coherently across several situations
The comprehensibility of how the solution was produced as opposed to other AI technologies	In the past, the low required computing power was an advantage of ES. However, in times of potent and flexible cloud computing suppliers this advantage diminishes
Limitations of rule-based ES	
Experts can only express relationships in form of If-Then rules that they are actively aware of (no tacit knowledge)	The basic algorithm needs to be changed when the knowledge base changes because all reasoning is hard-coded
Becomes slower with larger numbers of rules	Ambiguity of human reasoning might be hard to be encoded in IF-Then rules
Experts must be available	Inability to learn

2.2 Artificial neural networks

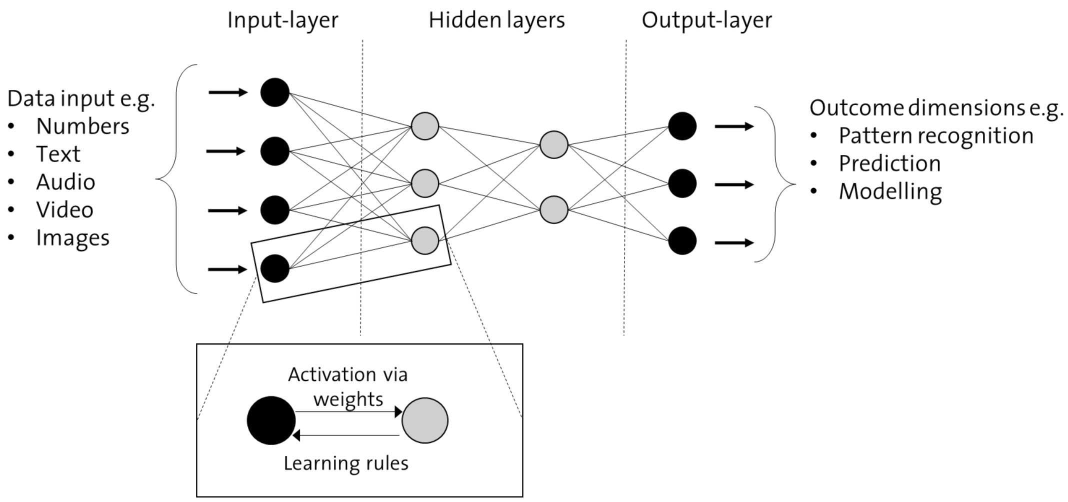
According to recent estimations, artificial neural networks (ANNs) have the potential to create an additional annual value of $100-200 billion in the chemical industry and around $100 billion in pharmaceuticals (Chui et al., 2018). Although ANNs have been around for several decades, they have long been unable to unfold their potential for pervasive application. Complementary forces that render ANNs more widely applicable today include the exponentially increasing computing power following Moore's law[1], cheap and small sensors, the resulting availability of data, and cloud computing (McAfee and Brynjolfsson, 2017). These mutually reinforcing elements have multiplied the applicability of ANNs, so that widespread application is reported in the chemical (Mohd Ali et al., 2015) and pharmaceutical industry (Agatonovic-Kustrin and Beresford, 2000; Zhavoronkov, 2018).

The technological architecture of ANNs is inspired by the nervous system of the human brain. ANNs adopt the idea of neurons as the smallest operating unit, which if interlinked in a network, can perform complex tasks. A schematic representation of such a network is shown in figure 2. The main constituents of ANNs are the different types of layers of neurons that are interconnected in a network. These include an input-layer, a problem-specific amount of hidden layers, and an output-layer. The input layer receives all information to be included in the reasoning process of the ANN. One of ANN's major advantages in comparison with established technologies such as regression analysis is its ability to incorporate largely heterogeneous sources of information (Backhaus et al., 2016). For example, a neural net for predictive maintenance might include a database with numbers, images, and audio input from microphones in the plant. The hidden layers serve to extract patterns in the data that are then used to generate the outcome. Regarding the number of hidden layers, practitioners face a trade-off between using enough hidden layers to reach a fair level of accuracy on the one side and "overfitting" the network at the cost of the results' generalizability on the other (Srivastava et al., 2014). Finally, the output -layer returns the intended outcome dimension.

At the level of the inter-neuron relationship

[1] Moore's law states that the number of transistor's per integrated circuit doubles every 18-24 months. In consequence, smaller and faster devices are affordable for the same amount of money. Note that the continuous doubling follows a logarithmic function.

Figure 2 Architecture of artificial neural networks (ANNs). Neurons are displayed as circles. Activation via weights: The intensity with which one neuron passes information to the next. Learning rules: The way in which the weights are adjusted during the training of the neural net. (source: Backhaus, Erichson, Plinke, & Weiber, 2018).



depicted in figure 2, the activation of a focal neuron is contingent on the signals it receives from the neurons in the preceding layer. Most commonly, the weighted sum over all inputs signals is used to determine in how far the neuron is activated and consequently passes on its signal to the following layer (Backhaus et al., 2016). During the setup of the neural net, the input data determines the initial weights that the connections between neurons have. At the end of the training phase, the value of these weights represent the memory of the neural net (Agatonovic-Kustrin and Beresford, 2000). Due to the forward-oriented flow of information between neurons, this mode of training the network is referred to as “feedforward”. In order to optimize ANNs for their application, they are exposed to feedback and learning in subsequent iterations. For this means, learning rules are responsible for slightly readjusting the weights between neurons from the output backwards to the input layer, until the neural network has reached the intended level of accuracy. The iteration of this so-called backpropagation mechanism is the actual training of the neural net. After a satisfactory level of precision has been achieved through training, the ANN can be fed with new data and fulfil its actual purpose.

According to a study from McKinsey including several hundred use-cases, ANNs have large potential to generate additional value in areas where IT tools such as regression, estimation, and clustering are already in place (Chui et al., 2018). They further estimate that in 69% of their use cases ANNs provide incremental improvements over the technologies already used, while only 16% are applications in which no other analytics technique could deliver value. Although 16% appear small in comparison, there is considerable potential for industry disruption immanent in these digits. Additionally, in the remaining 15% of the cases ANNs cannot beat conventional analytics, since the application of ANNs is inextricably tied to the existence of sufficient training data. If the cost of gathering these data exceeds the value to be extracted from it, then, for example, a regression analysis or an expert system might be superior choices. However, because of the recent availability of data for training ANNs, the importance of rule-based ES is likely to fade and ANNs will take their place because of their superior capabilities (McAfee and Brynjolfsson, 2017).

A recent example of the power of ANNs to solve vastly complex problems is its performance in predicting the folding of a protein based on its DNA sequence. A team of Googleaffiliated researchers created a neural net the called AlphaFold, which predicted the folding of complex proteins starting from scratch and significantly outperformed renowned teams in a worldwide prediction tournament (Evans et al., 2018).

2.3 Intelligent agents

Intelligent agents are referred to as autonomous components of a larger system, e.g. a production process in a chemical plant. They pursue their own agenda or goal but simultaneously interoperate with the other components in the systems (Franklin and Graesser, 1996). In many cases, multiple intelligent agents are connected in so-called multi-agent systems. For example, these include industrial process control systems or robots, where sensors feed information from the outside world into the system that then decides whether it should act on the situation or not. However, different agents might have conflicting goals about what actions to take in a specific situation, which is why a coordinating unit that aligns the various interests stemming from the individual agents might be useful (Bellifemine et al., 2007). Part of the agent system are effectors such as speakers, screens, stirrers, pumps, etc. through which the desired actions can be performed. In sum, intelligent agents feature the following characteristics (Wooldridge and Jennings, 1994):

- Autonomy: Intelligent agents operate without human intervention and supervise their own actions.
- Collaboration: Intelligent agents cooperate with other agents or humans to achieve its goals.
- Reactivity: Intelligent agents perceive the environment and react to environmental changes.
- Pro-Activity: Intelligent agents show goal -orientated behavior by taking initiative risks.

The interaction process of intelligent agents with their environment is presented in figure 3. The agent is programmed to independently identify an effective way to act upon its environment to achieve its goals. The sensor-based perception in combination and the effectors are the physical backbone of the system (Bellifemine et al., 2007). On the level of the algorithms, the agent evaluates possible actions in terms of whether they manipulate the environment in direction of the agent's goals. As a result of this reasoning process, the agent will use its effectors to execute the action that will move it towards fulfilling its objectives (Russell and Norvig, 2010).

A powerful way to multiply the capabilities of individual agents is to connect them in a system. In these multi-agent systems (MAS), numerous agents with restricted capabilities cooperate in order to pursue the goals of a larger system (Franklin and Graesser, 1996). To this means, data processing and decision making is centralized to gain a larger picture of the environmental status quo, which, in turn, determines what actions shall be performed (Russell and Norvig, 2010). Take, for example, the process control system of a chemical plant. A variety of sensors is used to observe the reactions and all information is gathered and supervised in the process control centre. The overarching goal is to optimize the reaction parameters, which resolves potentially conflicting microgoals of individual agent units. As becomes evident from this example, multiple agent systems often include an interface to connect to human experts in order to harness their knowledge and give them the opportunity to interfere in special situations.

However, as intelligent agents can be coupled with neural networks that are able to store experts' 'intuition' of how to conduct a chemical process, the window of opportunity for human intervention is narrowing. As Porter and Heppelmann (2014) argue, the applicability of smart connected systems such as multiple agent systems are gradually shifting from mere monitoring over to control, optimization and eventually towards fully autonomous systems with high degrees of proactive behaviour.

2.4 Case-based reasoning

Case based reasoning (CBR) builds on the notion that 'similar problems have similar solutions'. It is therefore related to how humans learn from experience. The foundation of this methodology is a database with previous cases that include a description of a problem and the respective solution. Figure 4 shows the most common framework for performing CBR, which is known as the CBR cycle (Aamodt and Plaza, 1994).

Figure 3 Procedure of intelligent agents, their interplay, and connection to the environment (source: Russell & Norvig, 2010).

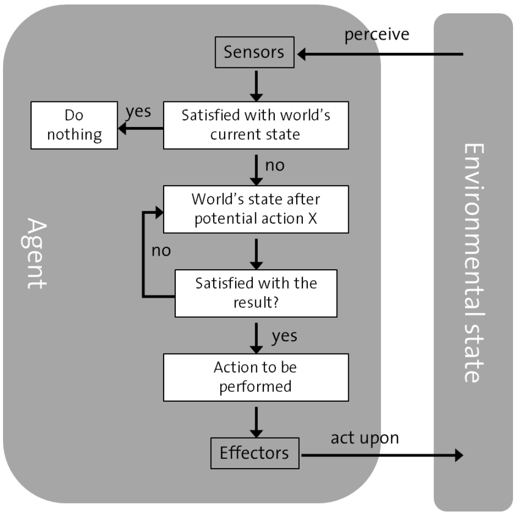
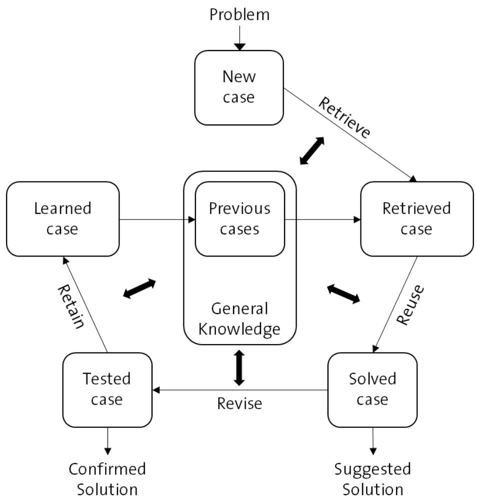


Figure 4 CBR cycle (source: Aamodt & Plaza, 1994).



In CBR, every problem to be solved is treated as a new case. Initially, the relevant parameters that characterize the case like e.g. feed components and product purity requirements need to be filed into the system. In order to find a suitable solution, the characteristics of the new case are matched against those from previous cases and the ones with the highest overlap are retrieved. The collection of similar cases subsequently constitutes the foundation for solving the new case. After a solution for the new problem has been proposed by the algorithm, the newly solved case is revised and eventually added to the database so that the knowledge repository expands over time (Aamodt and Plaza, 1994).

CBR systems are often used in combination with ANNs, since they have complementary capabilities. While CBRs can make a purposeful preselection of cases that will be considered for the reasoning process, ANNs are good at encoding the distinct characteristics into complex patterns stored in their hidden layers. Together, the two systems represent an efficient means for solving complex problems based on a history of relevant cases without sacrificing the comprehensibility of the outcome (Li et al., 2018).

3 Case studies

3.1 AI in drug discovery – The case of Deep Genomics

The application of AI in medicine has matured and now offers capabilities that are particularly useful for the design of medical treatments (Patel et al., 2009; Wainberg et al., 2018). In this regard, harnessing the pattern-recognition capacity of artificial neural networks is the most common approach. Based on this technology, numerous startups strive to complement the resource-rich incumbent firms with an AI-based approach to make research for new treatments more efficient. Take the example of Deep genomics, a Toronto-based startup founded in 2015. Their aim is to create personally tailored genetic medicine by utilizing AI to determine how DNA variations might produce specific diseases.

Recent advances in cell biology, automation, and AI enable treatments that are individualized at the level of the DNA. Despite the vast amount of data that is available for creating neural nets that deduce disease risks directly from the DNA, these direct prediction models turned out to be nontransparent and therefore not very useful in this highly regulated context. Due to the complex and interlinked processes in the body, researchers use so-called *cell variables* as mediators that bridge the wide logical gap between DNA sequences and disease risks (Leung et al., 2016), as figure 5 presents. These *cell variables* are factors that represent the processes in the cell such as the quantities of key molecules and interaction predictions (Leung et al., 2016). Based on information gained from high-throughput screening under various conditions, DEEP GENOMICS uses the data on DNA sequences and related cell variables to train a neural net, therefore teaching it a general-purpose model. In the next step, deviations in *cell variables* are related to disease risks, creating a mediated link to the DNA sequence that accounts for the biological complexity of the cell. Thus, the algorithms is taught which DNA sequences are connected to what kind of circumstances in the cell, which in turn relates to the resulting diseases. In combination with newly developed gene editing technology such as CRISPR/Cas (Cong et al., 2013), unprecedented opportunities for personalized medicine arise.

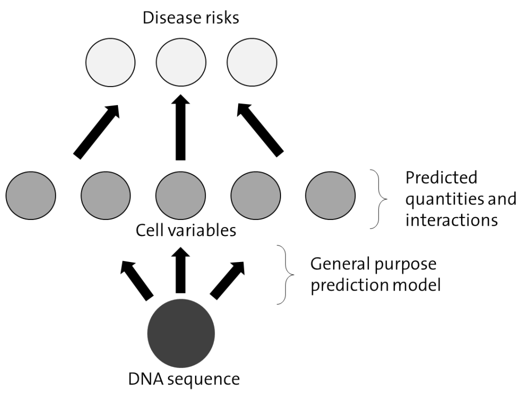
In order to preselect promising target molecules that can eventually be tested in the lab, DEEP GENOMICS has set up a platform database including over 69 billion molecules and tested them against 1 million targets in silico. This approach yielded 1000 promising compounds that delivered the intended effect on the biology of the cell. These molecules have effects on the *cell variables* used as mediators in the learning model. As a result of their *in silico* expertise, DEEP GENOMICS scheduled first clinical trials in 2020 (Lohr, 2018). Thus, neural networks can guide the selection of potential treatment candidates but they cannot fully rule out the need for extensive practical testing in clinical trials.

3.2 AI in the laboratory – The case of *Clever!Lab*

Despite the value that artificial intelligence already delivers in scientific R&D, the wet chemistry routinely done in many laboratories is still performed in a mostly analogue manner. Insofar, laboratories as the cradle of innovation might hold large innovation potential that pioneering companies now strive to exploit using AI. Intelligent agents in combination with ANNs seem to be the most suitable combination for creating value with AI in the laboratory. Combining these two approaches, the enterprise *Clever!Lab* offers a smart assistant for upgrading everyday work in the laboratory with AI. Using cameras and microphones as agents and building on IBM Watson, the clever digital assistant strives to excel the capabilities of a digital laboratory journal and connects data on an overarching level, potentially augmenting efficiency and enabling innovation. The combination of a multiple agent system with an artificial neural network is a classic example of a *hybrid* AI system.

Clever!Lab conceptualizes their value proposition based on five pillars (Gressling, 2017), as depicted in figure 6. First, their solution comprises a digital lab journal that stores results in a coherent manner across all staff, thus, standardizing the results from routine analyses so

Figure 5 Cell variables are used as mediators for predicting disease risks from DNA sequences, because cell biology is too complex to allow a direct deduction of diseases from DNA (source: Leung et al. 2016).



that deep learning with ANNs can find hidden patterns in the data. To communicate findings to the clever assistant, employees may comfortably dictate their results via microphone, while personal accounts for all employees keep track of their time accounts, making individual notation obsolete. Second, the clever agent might assist in augmenting lab safety. For instance, cameras with infrared function can readily alert employees if a reaction overheats or when they forgot to put on their safety glasses. The third pillar is concerned with planning the reaction schedule and experiment setup. The hybrid AI might not only prevent bottlenecks on popular laboratory devices and therefore contribute to higher efficiency, but also directly assist by projecting reaction setups directly into the fume hood if needed. Fourth, implementing AI in the laboratory offers considerable opportunities for training and education. For example, employees could be supervised when trying new analyses and receive immediate feedback. Simulations of special events such as emergency alerts are also conceivable in this domain. Finally, having an interface to the firm's supply chain management would allow the AI to keep account of all resources needed for the scheduled experiments and initiate timely purchases if any material runs short. Immediate orders via voice might also be possible. In addition, a useful feature might be to ensure and document that workflows comply with relevant regulation.

Regarding the technological requirements of smart laboratories, figure 7 illustrates the basic setup of how agent-based neural networks might interact with lab workers. The interface with the user is managed by the intelligent agent system that comprises sensors to receive information from the environment and effectors to interact with it. These sensors might include audio, video, temperature, humidity, etc. and potential effectors such as monitors, speakers, heating, among many other conceivable functionalities. A central position in the system is taken by the data lake that is ideally nurtured by the sensors and many other sources of knowledge such as scientific publication databanks and molecular libraries. The data lake constitutes the knowledge repository that underlies the reasoning processes of the system. Coupling the agent system with a neural network introduces the capability to analyze complex relationships in the data lake. For example, neural networks have made striking contribution in domains as complex as retrosynthesis planning, where hybrid approaches including neural networks have recently made a huge leap forward, as has been reported in Nature (Segler et al., 2018). Neural networks can extract patterns from noisy and heterogeneous types of data such as audio, video, and images. In congruence with the hybrid system's goals, the neural net provides information and decisions that flow to the effectors for being transmitted to the user.

AI has the potential to deliver considerable value in the laboratory, but nothing comes without costs. In order to enable hybrid AI sys-

Figure 6 Key value propositions of Clever!Lab (based on: Gressling 2017).

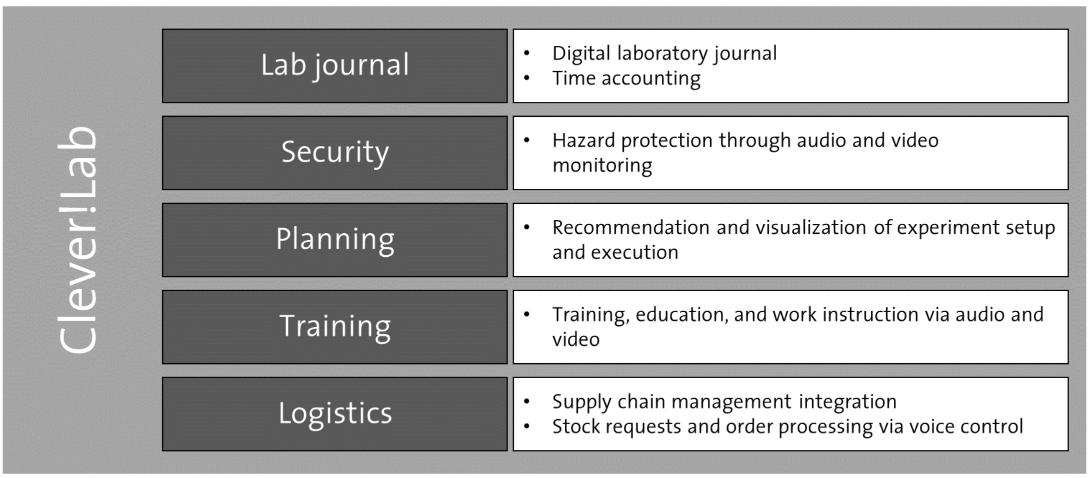
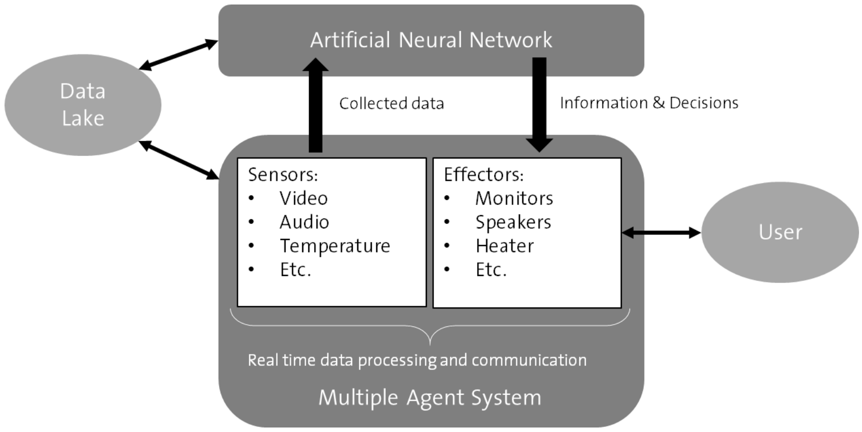


Figure 7 Schematic representation of the hybrid AI underlying Clever!Lab (based on: Gressling 2017).



tems to unfold its more advanced functionalities, some major technical preconditions need to be met. At the center of the collaboration between lab workers and intelligent agent lies their communication. However, our human language is hard to understand for machines because it is ambiguous and work environments are often complex (Xiong et al., 2018). For this means, *Clever!Lab* builds on IBM Watson as the backbone of the intelligent agent, which readily enables sense-making from conversation. The analytical power of the neural net increases with the amount of information it gets from its environment. Although the internet of things is a strong driver of pervasive connectedness between devices, the longevity of old analogous machinery may currently hinder the exchange of relevant information between analytical devices such as chromatography systems and the digital assistant. In addition to necessary technological conditions, new technology needs to be adopted by employees in order to unfold its value, a topic that we discuss in the following chapter.

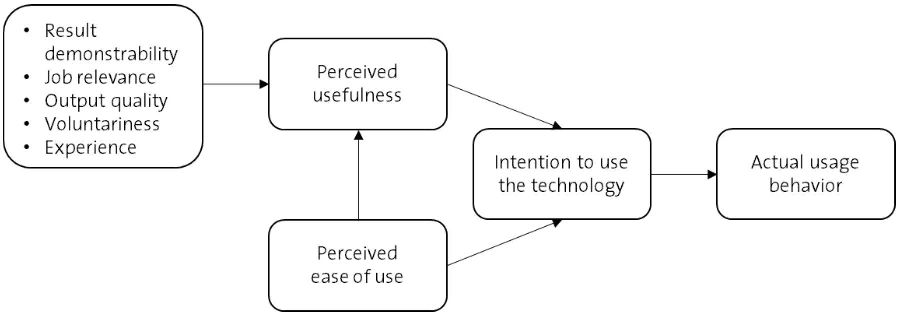
4 AI adoption in incumbent firms -- The technology acceptance model

In the following, we discuss the potential organizational challenges of AI application, suggest remedies, and derive implications for firms operating in the process industries. For this means, we introduce and discuss the technology acceptance model (TAM) in order to deduce success factors for firms that strive to create value by applying AI throughout their businesses.

The implementation of new information systems is often not only costly, but might even fail (Legris et al., 2003). Therefore, research on the adoption of information technology in organizations has received considerable academic and managerial attention. Among others, academic researchers have developed and extensively tested a framework briefly termed TAM (Venkatesh and Davis, 2000). The goal of this framework lies in explaining the employees' usage behavior regarding novel information technology. Beyond the application of AI in the case studies presented above, AI is argued to be a general purpose technology such as the steam engine, electricity, or computers that has the potential to create profound value throughout all industries (Brynjolfsson at al., 2018). In order to leverage the 100-200 billion dollars of potential annual value creation projected by McKinsey for the use of neural networks in the chemical industry alone (Chui et al., 2018), employees must be willing to embrace new AI-based solutions at the sacrifice of some of their old working habits. Figure 8 illustrates the relationships between major factors that drive technology adoption in form of actual usage behavior in firms.

The employees' actual usage behavior is largely driven by their individual intention to use a given technology. The intention to use a technology does not directly translate into actual usage because old habits and routines might drive employees to proceed in the old manner. The intention to use a technology can

Figure 8 Outtake from the technology acceptance model (TAM); arrows represent significant relationships (source: Davis et al., 1989; Venkatesh & Davis, 2000).



itself be predicted to a considerable degree by the perceived usefulness and the perceived ease of use of that technology (Davis et al., 1989). While perceived usefulness describes the individual employee´s cognition that utilizing the new technology would improve their job performance, perceived ease of use is defined as the employee´s perception that the IT system can be used effortlessly (Davis et al., 1989). On the left-hand side, figure 8 shows factors that increase the perceived usefulness of a technology (Venkatesh and Davis, 2000). Table 3 explains these factors in more detail.

In brief, high result demonstrability, job relevance, and output quality all contribute to higher technology adoption levels (Venkatesh and Davis, 2000). Furthermore, some users are unwilling to comply with mandatory usage of new technologies, so that compliance-based introduction should be avoided (Venkatesh and Davis, 2000). Therefore, the usage of new technologies should be voluntary and adoption might be encouraged through social influence, for example by engaging in dialogue with the actual users about how the result demonstrability, job relevance, and output quality might be improved from their perspective. In addition, communicating the advantages of the new technology through a direct comparison with the old systems might increase the technology's adoption level (Venkatesh and Davis, 2000).

In context of the case studies presented in the previous section, the technology acceptance model is applicable to different degrees. While Deep Genomics does not face issues regarding the technology adoption because they primarily employ AI experts, several established companies from the process industry might face significant barriers during the adoption process of AI. For example, implementing an AI-based *Clever!Lab* approach to routine lab work might provoke scepticism regarding the advantages of the technology in comparison to the costs of underlying steady audio and video surveillance, while data security concerns remain high. Insofar, managers responsible for the introduction of new technologies might bear in mind the dimensions that drive the employees' perceived usefulness of technologies and incorporate them into the design of the system as well as clearly communicate them to potential users. Decision makers might consider nurturing a corporate culture that rewards experimentation and does not punish failure. Investments in technology are never self-sufficient and only pay off if courageous organizational employees use it as a means to take hold on the emerging opportunities (Stoffels and Leker, 2018). As all of us will inevitably become more experienced with hybrid systems combining intelligent agents with artificial neural networks e.g. in cars, smart homes, and with our mobile phones, the willingness to adopt AI at work will successively increase. However, those who vividly explore the new technological opportunities and purposefully design their applications will gain a competitive edge.

5 Conclusion

In times of declining returns from R&D in the process industries, AI not only holds the potential to incrementally improve data analysis in many cases, but might also spark new innovation by unlocking unprecedented insights into data. Going forward, researchers

Table 3 Dimensions that improve the perceived usefulness of technologies (source: Venkatesh & Davis, 2000).

Dimension of perceived usefulness	Description
Result demonstrability	The tangibility of the positive results produced with the new technology.
Job relevance	An individual's perception of how relevant the new technology is for performing a current job.
Output quality	The user's perception of the quality of the results that the technology enables.
Voluntariness	The extent to which potential adopters perceive the usage to be voluntary and not mandatory.
Experience	The more experience users have with a given technology, the more they are willing and confident to use it in new situations.

and practitioners need to join forces to overcome the barriers that prevent firms from leveraging the value creation potential of AI. This article therefore strives to demonstrate when specific AI methodologies are useful, discusses two case studies, and explicates how potential adoption barriers might be tackled in incumbent firms based on academic literature dedicated to the acceptance of technologies.

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Research Paper

Collaboration in the context of industry convergence - an overview

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Recent literature on organizational features and activities along the phases of convergent value chains is gathered in a classification framework. It is emphasized that within convergent value chains organizations lack certain competences and hence need to collaborate in order to close their competence gaps. These collaborations are also discussed in regard to the intensity of resource and competence integration, ranging from licensing agreements to mergers and acquisitions. Strategic alliances, joint ventures as well as mergers and acquisitions in the biotechnology sector undergoing convergent processes are analyzed over the 20-year period, 1997-2016. Subsequently, the biopharmaceutical sector is chosen as a convergent industry case example and its value chain analyzed using the classification framework developed. The position of the incumbent firms is shown to shift from spanning the entire value chain in a fully-integrated business model, to being pushed towards the market end of the value chain by the industry new entrants, to finally trying to regain a stronger position by adapting a coordinating hub business model.

1 Introduction

In recent years more and more often we observe industries overlapping and merging. This convergence process has been witnessed in a range of high technology environments, initially in computing and telecommunication systems, and more recently also in the field of natural sciences. With a growing number of inter-industry fields, the relevance of cross-industry innovation and collaboration has increased. There is growing literature detailing the stages of the industry convergence. What is currently missing however is a framework for classification of organizational features and activities along the stages of the value chain. Having such a framework will allow the positioning of organizations along the value chain and subsequently the examination of the changing structure of the value chain during its disintegration process. Furthermore, the framework will allow the investigation of changes in business models of the organizations involved. Hence it will provide a tool to track industry development not only on the level of technology, but also on the level of business model innovation. This framework will be of high strategic value, enabling firms to analyze convergent processes in greater depth and hence to adapt earlier to changes in technologies, markets, customers and competitors.

In this work a cross-section is cut through the life cycle curve of a convergent R&D-intense industry and the types of collaborations formed by different institutions along the value chain are analyzed. The work focuses on biotechnologies, which are defined as “new technologies of genetic, protein, cell and tissue engineering that enable significant advancements in human and veterinary health, agriculture, industrial processing and other application areas” (OECD, 2006). Such technologies include genomics, pharmacogenomics, genetic engineering, gene editing, protein engineering, cell/tissue/embryo culture and manipulation, bioinformatics and bioleaching. The biotechnology industry shows tendencies to converge with adjacent industry and market segments both on technology and market levels (Aaldering et al., 2018).

2 Theoretical background

2.1 Industry convergence

Industry convergence is recognized as the blurring of boundaries between formerly distinct industries and can be described as a sequential process starting with converging scientific fields followed by a convergence of formerly distinct technologies and markets, finally leading to converging industries (Curran and Leker, 2011). Industry convergence can either be driven by developments on a technological level (technology-driven input-side convergence) or market level (market-driven output-side convergence) (Bröring, 2010). In most cases technology convergence, reinforced by market convergence, triggers industry convergence. Industry convergence can be either substitutive or complementary: technology substitution tends to be driven by radical innovation, whereas technology integration by more incremental innovation (Rikkiev and Mäkinen, 2013). Converging technologies and markets lead the firms involved to identify competence gaps which they close through collaborations with firms of complementary competence.

The convergence process follows a life cycle pattern where science convergence is superseded by technology convergence and then by market convergence over time, as the new industry goes through introduction, growth and maturity phases (Bornkessel et al., 2016). The types of collaborations formed will differ depending on the stage of the life cycle the industry is currently at (Marks et al., 1999). Furthermore, the innovativeness of the entrepreneurial activities will also differ based on the stage of the industry life cycle. High technological opportunities stimulate entry early in the industry life cycle. As the industry matures, entry barriers rise, entry falls off, concentration increases and innovation becomes more incremental.

Industry convergence is distinguished from fusion (Curran and Leker, 2011). While in convergence the converging area is formed between the two converging sectors, in fusion the resulting segment is formed at the spot where one of the two former sectors was located. The resulting sector therefore does not create any new application domain. One or both of the old sectors may either remain as independent technology segments, giving birth to new fusion in the future, or they may disappear as a result of the fusion of its applications.

2.2 Types of collaborations formed with respect to the intensity of resource and competence integration

Within convergent fields, owing to their interdisciplinary nature institutions collaborate with each other in order to gain critical resources and competences and to share costs and risks (Parmigiani and Rivera-Santos, 2011). Resources can be classified into financial resources and intellectual resources. Intellectual resources include technology knowledge and market knowledge, which are otherwise called technology and market competences. Types of collaborations range from forms such as licensing agreements, strategic alliances and joint ventures to mergers and acquisitions (M&A). Each of these collaboration types integrates the resources and competences of another institution to a different degree. A licensing agreement is an agreement between two companies to use resources and competences of the other firm for a payment of a licensing fee (Gallini et al., 1985), which demonstrates the lowest level of resource and competence integration. A strategic alliance is a contract between two partners, which exists for a set time and task (Parmigiani and Rivera-Santos, 2011) and which shows a slightly higher level of resource and competence integration. A joint venture is a jointly-owned entity created by two companies that stay separate, resulting in risks and rewards for each company (Parmigiani and Rivera -Santos, 2011), where resources and competences of the involved institutions merge due to the establishment of a new entity (i.e. a further increase in resource and competence integration). Lastly, M&A result in a fusion of companies (Hennart and Reddy, 1997), where resource and competences of the involved institutions merge completely resulting in the highest level of resource and competence integration.

The early stage of complementary industry convergence is characterized by more flexible collaboration forms such as strategic alliances or joint ventures owing to the high level of uncertainty caused by the dynamic and fast changing technological environment (Sick et al., 2018). These are collaborations on the technology level formed in order to close technology competence gaps. In the substitutive convergence more technology-based M&A collaborations are observed even in highly uncertain environments as the company´s core business is threatened. The medium stage of the complementary industry convergence is characterized by market-oriented strategic alliances and joint ventures to close the market competence gaps during the period of slower technological change and emerging industry standards. In the substitutive case, market-oriented M&A collaborations are formed. As the industry proceeds into the late stage, uncertainty decreases even further as more regulations and standards are becoming established. In the case of complementary convergence the companies will now engage in M&A, whereas in substitutive convergence the companies reshape their business units and respective business areas.

2.3. Framework for classification of collaborations based on closing resource and competence gaps

Apart from classifying the types of collaborations with respect to the intensity of resource and competence integration, a further classification is proposed based on the types of competences transferred.

Collaborations are based on different factors, which are needed for competence transfer. One such factor is the strategic type of the partner. Strategic types include technology developers, technology-intense product developers and product developers using existing technologies (Bröring and Cloutier, 2008). It can be seen that the technology developers will collaborate to gain market competences and the product developers to gain technology competences, with the technology-intense product developers lying in between. Therefore, collaborations can also be distinguished as technology - or market- based: technological agreements include joint development agreements, research joint ventures, technology transfer and technology sharing, whereas commercial agreements include licenses, joint distribution agreements or customer-supplier relationships (Colombo et al., 2006).

Similarly, collaborations are based on value creation, which again is associated with competence transfer. Value can be either indirect and intangible, or direct and tangible (Bröring and Cloutier, 2008). The indirect, intangible value is associated with the earlier stages of ideation, technology development through to product development, whereas direct, tangible value is obtained going from the product development to commercialization and sale.

The nature of the motivation for collaboration is also influenced by the competences that each partner can offer. The motivation for collaborations include explorative and exploitative types (March, 1991). Exploration aims to investigate new opportunities and focuses on long-term competitive advantage, while exploitation aims to execute existing knowledge and focuses on short-term commercialization. The intensity of collaboration differs between the two types (Parmigiani and Rivera-Santos, 2011). Exploration shows reciprocal interdependence between the two institutions, where they have a joint development using resources and competences from both partners. Exploitation shows discrete interdependence, where decisions are made independently by the two partners. Building on the distinction between the exploration and exploitation, alliances can also be distinguished between ones which acquire knowledge and ones which access knowledge (Grant and Baden-Fuller, 2004). In a knowledge acquiring alliance each firm transfers and absorbs the partner´s knowledge base. On the other hand, in knowledge accessing alliances each firm accesses its partner´s knowledge in order to exploit complementarities but maintains its own specialized knowledge.

The way competences are transferred between companies can be viewed in terms of organization modes in open innovation (Bianchi et al., 2011). Through inbound open innovation companies can be brought into the collaboration with others through in-licensing, acquisitions, joint ventures, R&D contracts and research funding, or purchase of technical and scientific services. Looking from the perspective of outbound open innovation, the possibilities include licensing out, spinning out of new ventures, sale of innovation projects, joint venture for technology commercialization and supply of technical and scientific services.

The competence transfer may also vary based on the industry sector the company is a part of (Enkel et al., 2009). The outside-in collaboration describes the integration of resources and competences from other industry sectors. The inside-out collaboration describes the externalization of assets towards other industry sectors. The coupled process describes a simultaneous internationalization of external assets and externalization of internal assets.

Furthermore, the alliance management capability, defined as “a firm´s ability to effectively manage multiple alliances” will differ for different firms and in different collaborations (Rothaermel and Deeds, 2006). The alliance management capability is dependent on the type of knowledge transferred in a collaboration, where greater alliance management capability is needed when more tacit, ambiguous and complex knowledge is concerned. This more tacit, ambiguous and complex knowledge is also associated with a higher degree of uncertainty in the alliance.

The classification of collaborations in terms of the transfer of the science, the technology and the market competences, along the value chain starting with basic research, through technology transfer up to commercialization is summarized (Figure 1).

Knowledge-based collaborations benefit from the economies of scope (Grant and Baden-Fuller, 2004). Economies of scope are prevalent in sectors where knowledge requirements are broad and where a lot of knowledge is not product-specific, such as in medicines and pharmaceuticals. This trend is further emphasized during convergence, where knowledge requirements are broadened and the importance of knowledge not specific to particular products and sectors increases e.g. incorporating digital

Figure 1 Classification framework for cross-company collaborations along the value chain with respect to competence transfer (source: own representation).

Competences	Science	Technology	Market	
Activity	Basic research	Technology transfer	Commercialisation	
Strategic type	Technology developer	Technology-intense product developer	Product developer	(Bröring and Cloutier, 2008)
Value creation	Indirect and intangible		Direct and tangible	(Bröring and Cloutier, 2008)
Motivation	Exploration		Exploitation	(March, 1991); (Bornkessel et al., 2016)
Open innovation structure	Outbound innovation	Inbound/Outbound	Inbound innovation	(Bianchi et al., 2011)
Industry scope	Inside-out integration	Inside-out/Outside-in	Outside-in integration	(Enkel et al., 2009); (Bornkessel et al., 2016)
Alliance management capability required	Higher		Lower	(Rothaermel and Deeds, 2006)
Knowledge transferred	Tacit, ambiguous, complex		More explicit and hence codifiable	(Rothaermel and Deeds, 2006)
Uncertainty	Higher		Lower	(Rothaermel and Deeds, 2006)

technologies or management sciences into other sectors.

Collaborations can also provide early-mover advantage during convergence. While knowledge is rapidly advancing during the convergence process, appropriating its returns often depends on achieving early-mover advantage. Collaborations allow firms to quickly identify, access and integrate across new knowledge combinations to recombine knowledge into innovative products, and hence greatly increase the speed with which a company can bring new products to the market.

Opposing the many benefits, forming a collaboration also incurs transaction and management costs (Colombo et al., 2006). Transaction costs include the costs of the search for suitable partners, the costs of partner assessment and selection, negotiation and other contractual costs, and the appropriability hazards endangered by the alliance, while management costs are the opportunity costs of time and effort devoted to the alliance management over other activities.

3 Data collection and analysis

3.1 Data Collection

In order to perform an analysis of strategic alliances, joint venture, mergers and acquisitions in convergent biotechnology industry, data on collaboration of biotechnology sector firms were compiled. The data differentiates between collaborations of firms within the biotechnology sector and with firms from other sectors. The number of strategic alliance and joint venture formations between the years 1997 –2016 was assessed through the Thomson Reuters database, whereas the number of M&A between the years 1997 – 2016 was assessed through the Securities Data Corporation (SDC) Platinum database. Since there is not one Standard Industrial Classification (SIC) code for the biotechnology sector in the SDC Platinum database, five SIC codes for either the acquirer or the target were searched for to represent the biotechnology sector as closely as possible (Aaldering et al., 2018). These were: 2834, 2835, 2836, 8731, 8734, which stand for Pharmaceutical Preparations, In Vitro and In Vivo Diagnostic Substances, Biological Products except Diagnostic Substances, Commercial Physical and Biological Research, and Testing Laboratories respectively. Acquisitions deals were defined as these where the acquirer previously owned <50% of the target´s voting shares and increased the ownership to at least 50% as a result of the takeover.

3.2. Analysis

3.2.1 Strategic alliances and joint ventures

The twenty-year period was divided into five -year segments to investigate how the sectors interacting with the biotechnology sector changed over time. For strategic alliances and joint ventures the sectors of joint activity were investigated. 8436 strategic alliances and joint ventures were identified over the specified time period (Table 1). The most prominent sectors over the twenty-year period were shown to be: exclusive licensing services, health and medical services, licensing services, manufacturing services, marketing services, research and development services, retail and wholesale services, and supply services (Table 2, Figure 2).

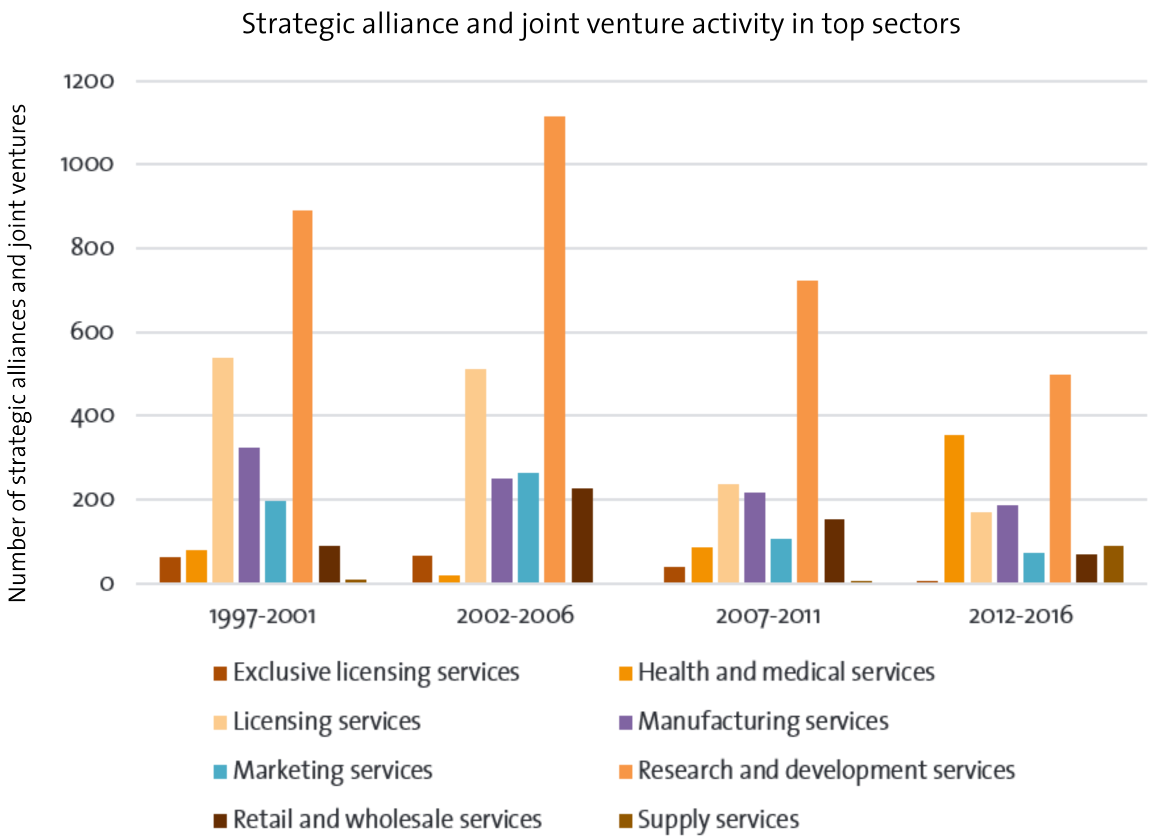
Table 1 The total number of strategic alliance and joint venture activity within four time periods (source: own representation).

Period	Frequency	Percentage
1997-2001	2443	29,0
2002-2006	2600	30,8
2007-2011	1675	19,8
2012-2016	1718	20,4

Table 2 The number of strategic alliance and joint venture activities within the eight top sectors (source: own representation).

Top sectors	1997-2001	2002-2006	2007-2011	2012-2016
Exclusive licensing services	62	66	40	6
Health and medical services	80	18	87	355
Licensing services	540	511	237	171
Manufacturing services	323	250	218	187
Marketing services	198	265	107	74
Research and development services	890	1116	722	499
Retail and wholesale services	89	226	153	68
Supply services	10	3	6	90

Figure 2 The number of strategic alliance and joint venture activities in the eight top sectors within four time periods (source: own representation).



3.2.2. Mergers and acquisitions

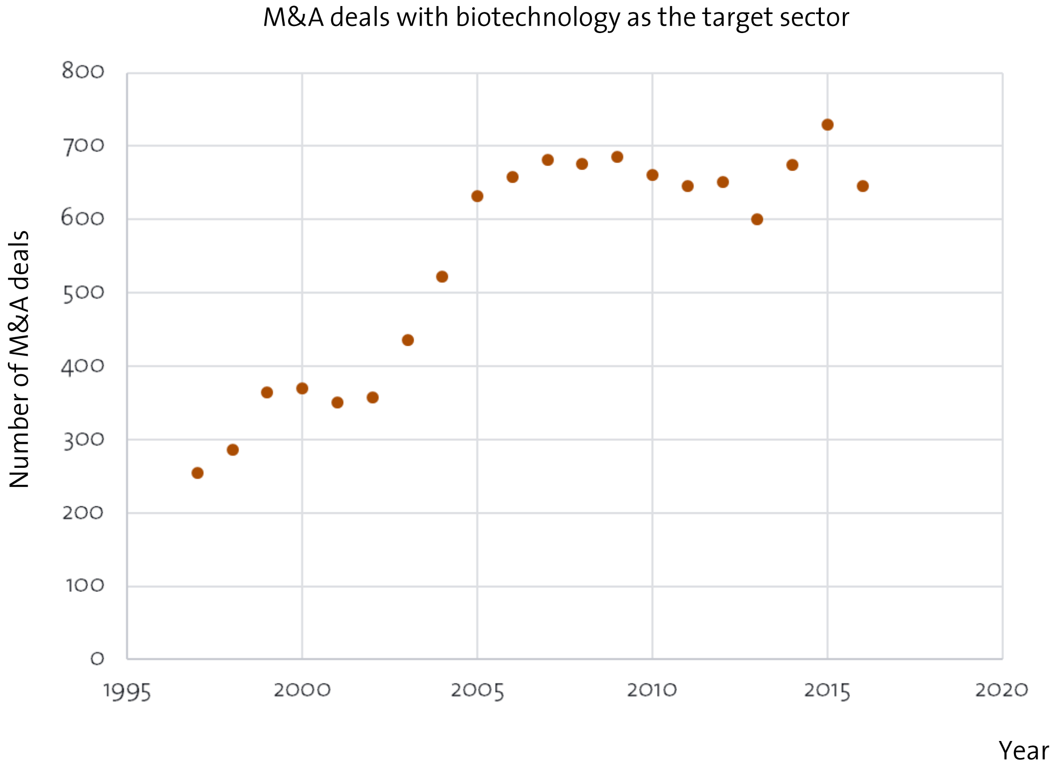
The development in mergers and acquisitions was investigated over the 20-year period, 1997-2016. The analysis was done on five dimensions. Firstly, the study looked at the biotechnology sector as the target for M&A of firms from all sectors. Secondly, it examined the biotechnology sector as the acquirer in M&A of firms from all sectors. Subsequently, the biotechnology-biotechnology transactions were removed to get a more in-depth picture of transactions only between the biotechnology sector and other sectors. Lastly, only transactions within the biotechnology sector were shown for completeness.

The number of M&A with biotechnology as the target sector over the 20 years was investigated (Table 3, Figure 3). 10880 M&A transactions were found. This data includes transactions between biotechnology firms.

Table 3 The number of M&A with biotechnology as the target sector (source: own representation).

Period	Frequency	Percentage
1997-2001	1626	15,0
2002-2006	2604	23,9
2007-2011	3350	30,8
2012-2016	3300	30,3

Figure 3: M&A deals per year with biotechnology as the target sector (source: own representation).

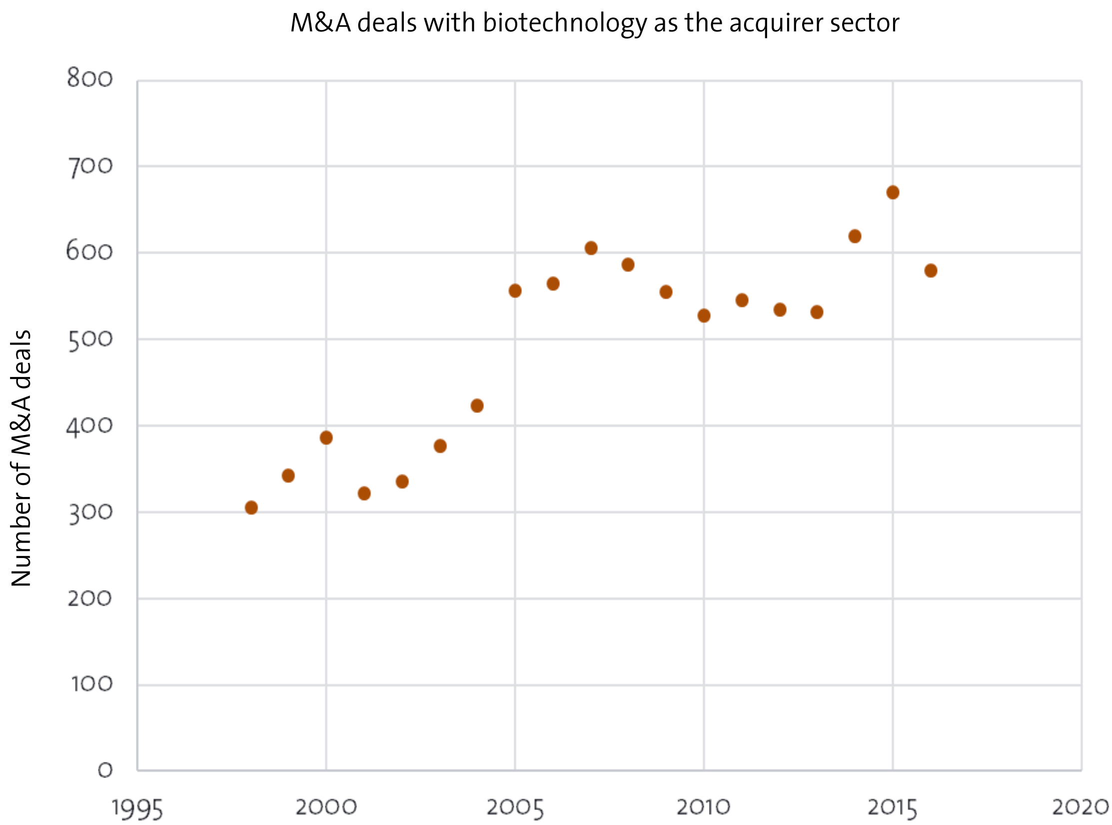


Furthermore, the number of M&A with biotechnology as the acquirer sector over the 20 years was investigated (Table 4, Figure 4). 9621 transactions were found. This data includes transactions between biotechnology firms.

Table 4 The number of M&A with biotechnology as the acquirer sector (source: own representation).

Period	Frequency	Percentage
1997-2001	1608	16,7
2002-2006	2255	23,5
2007-2011	2821	29,3
2012-2016	2937	30,5

Figure 4 M&A deals per year with biotechnology as the acquirer sector (source: own representation).

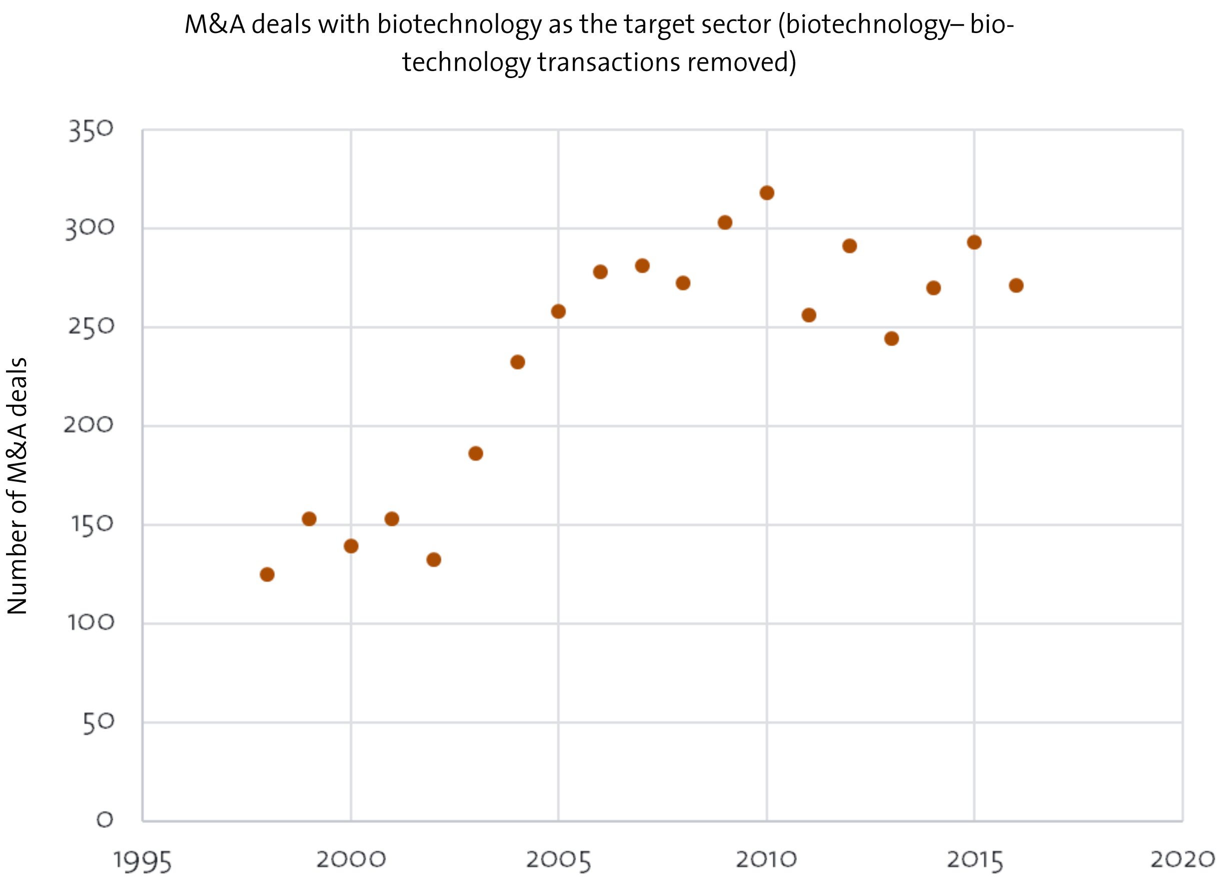


Subsequently, the number of M&A with biotechnology as the target sector was investigated, where biotechnology firms were the target for firms from other sectors (i.e. biotechnology to biotechnology transactions were removed) (Table 5, Figure 5). 4577 transactions were identified.

Table 5 The number of M&A with biotechnology as the target sector for firms from other sectors (source: own representation).

Period	Frequency	Percentage
1997-2001	692	15,1
2002-2006	1086	23,7
2007-2011	1430	31,3
2012-2016	1369	29,9

Figure 5 M&A deals per year with biotechnology as the target sector for firms from other sectors (source: own representation).

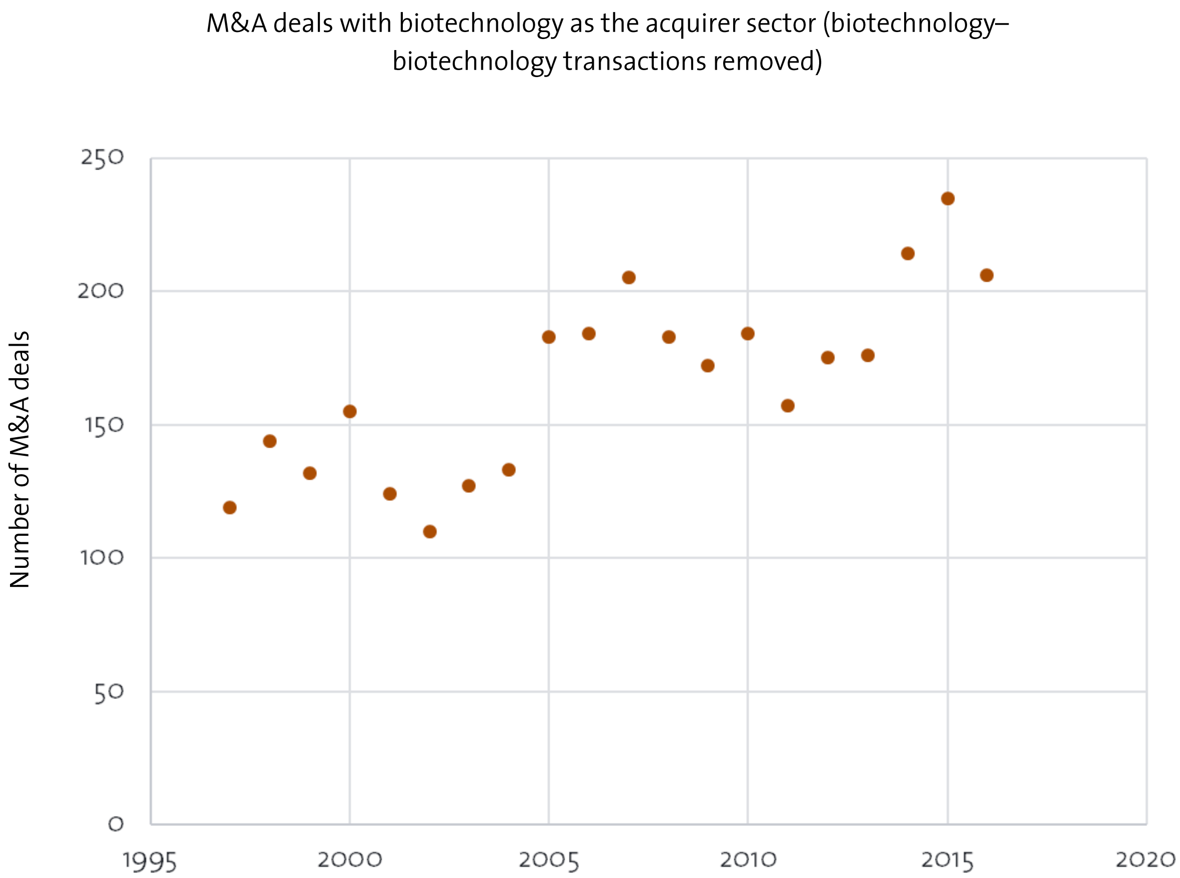


Moreover, the number of M&A with biotechnology as the acquirer sector was investigated, where biotechnology firms were the acquirer of firms from other sectors (i.e. biotechnology to biotechnology transactions are removed) (Table 6, Figure 6). 3318 such transactions were identified.

Table 6 The number of M&A with biotechnology as the acquirer sector of firms from other sectors (source: own representation).

Period	Frequency	Percentage
1997-2001	674	20,3
2002-2006	737	22,2
2007-2011	901	27,2
2012-2016	1006	30,3

Figure 6 M&A deals per year with biotechnology as the acquirer sector of firms from other sectors (source: own representation).

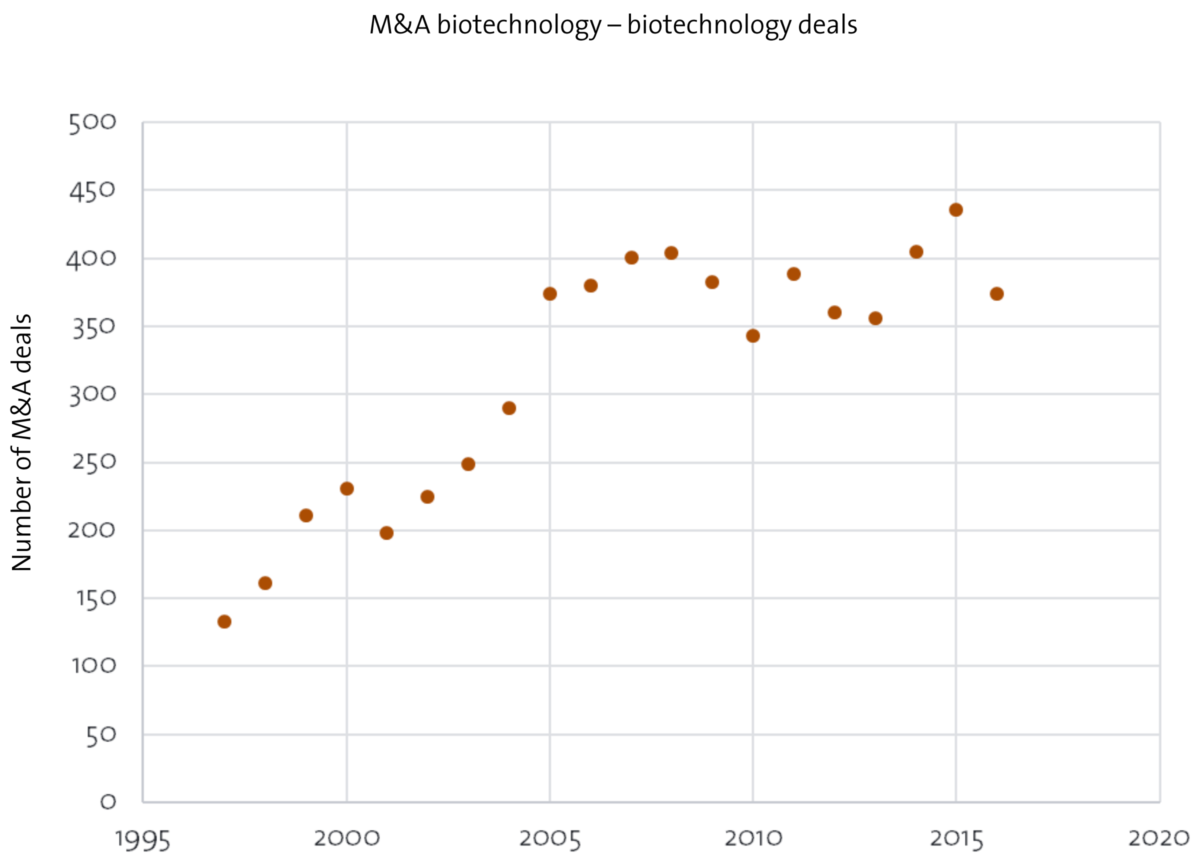


Finally, M&A transactions within the biotechnology sector were investigated (Table 7, Figure 7). 6303 such transactions were found.

Table 7 The number of M&A within the biotechnology sector only (source: own representation).

Period	Frequency	Percentage
1997-2001	934	14,8
2002-2006	1518	24,1
2007-2011	1920	30,5
2012-2016	1931	30,6

Figure 7 M&A deals per year within the biotechnology sector only (source: own representation).



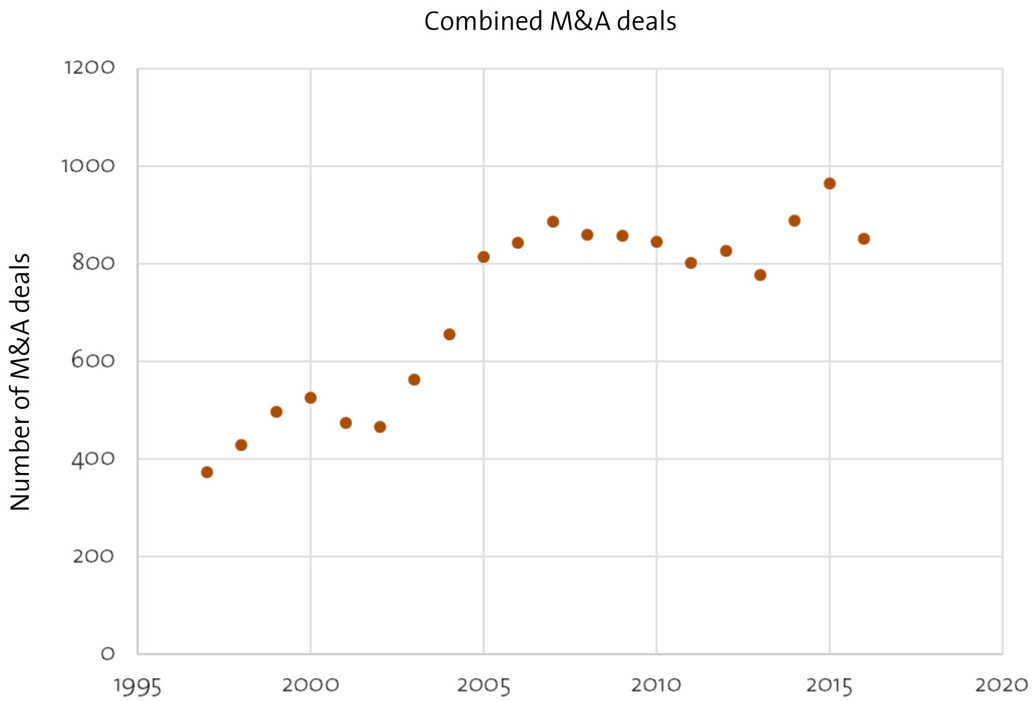
Aaldering et al., 2018 report a dataset, which includes biotechnology sector as the acquirer of firms from other sectors, other sectors as the acquirer of biotechnology firms, as well as biotechnology firms acquiring within its own sector. 14198 transactions were found. This data is shown in the table and graph below for completeness (Table 8, Figure 8).

An increase in the number of M&A is observed over the 20-year period. It is interesting to compare the trends in the number of M&A deals against strategic alliances and joint ventures during the years post 2008 Global Financial Crisis. The Financial Crisis affected both pharmaceutical and biotechnology industries. Small biotechnology companies were weakened by investment shortages during the time of the crisis, which caused them to scale down their activities. At the same time many major pharmaceutical companies strengthened their

Table 8 The number of M&A with biotechnology as both the acquirer and the target sectors (source: own representation).

Period	Number	Percentage
1997-2001	2300	16,20
2002-2006	1518	24,1
2007-2011	1920	30,5
2012-2016	1931	30,6

Figure 8 M&A deals per year with biotechnology as both the acquirer and the target sectors (source: own representation).



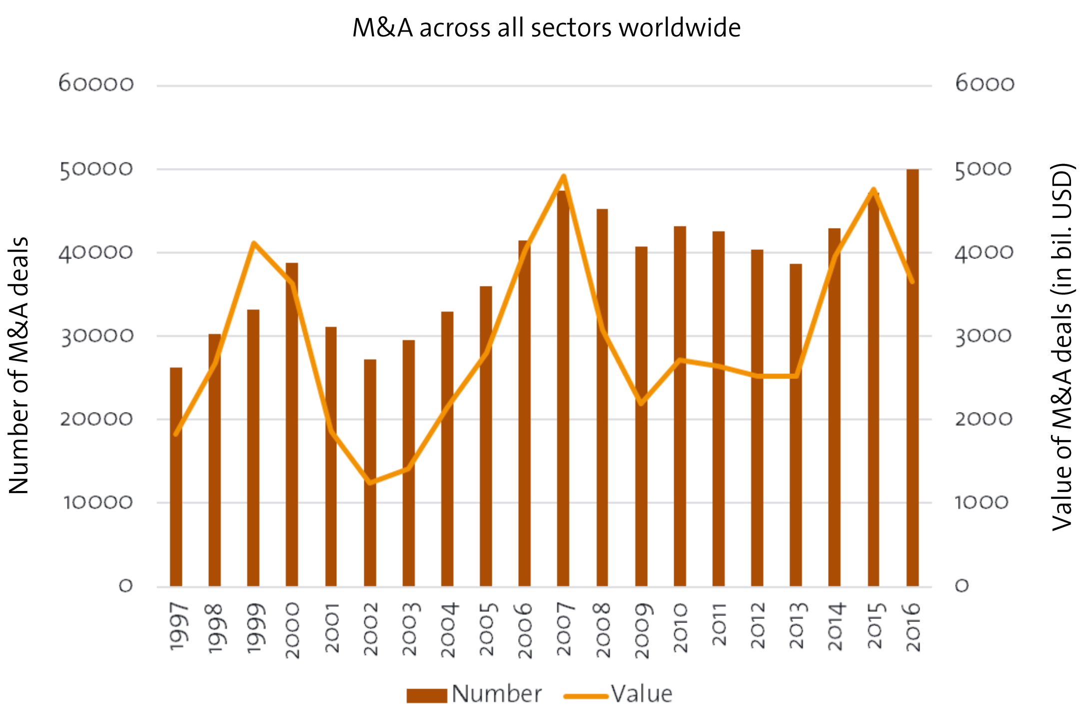
capabilities and focused on improving efficiency, cost-effectiveness and productivity; many companies significantly restructured. The number of mergers between large companies and acquisitions of smaller companies by larger ones stayed high during the financial crisis. The high number of acquisitions of drug candidates from biotech companies took place because the large companies retained significant cash reserves, whereas smaller biotech companies became financially unstable and lost their bargaining power. Similarly, a high number of mergers could be explained by the fact that mergers allow for greater control over the partner at a time where trust between partners is uncertain. On the other hand, a decrease in the number of acquisitions by biotechnology companies of firms from other sectors was observed, which can be explained by the weaker position of the biotechnology companies, which are heavily reliant on capital investments. Moreover, a steep decrease was observed in the number of strategic alliances and joint ventures, in part since companies were focused on merger and acquisition activities and because such forms of collaboration provide the acquirer with less control over the partner, which might be considered to be more risky in uncertain times of the financial crisis.

To further demonstrate how the biotechnology sector fits within the global, cross-industry M&A trends around the time of the financial crisis, a graph by the Institute for Mergers, Acquisitions and Alliances (IMAA) is included below (Figure 9) (based on: https://imaa-institute.org/mergers-and-acquisitions-statistics/, accessed 21.12.2018). A drop by 6745 transactions (14.2%) is observed in the years 2007 – 2009, a 2728.5 billion USD (55.5%) drop in cash terms. It is interesting to observe that biotechnology industries do not adhere to this generally observed pattern.

3.2.3 M&A – convergence triggering and receiving sectors

Apart from the changing trends in the number of M&A transactions over the years, it is important to show which sectors converge with biotechnology. Aaldering et al., 2018 report the

Figure 9 M&A deals across all sectors worldwide (source: own representation).



impact that different sectors have on convergence with biotechnology and whether they act as a trigger or a receiver in the convergence process. Their data was divided over four time periods: 1997-2001, 2002-2006, 2007-2011 and 2012-2016. The data included industries converging with the biotechnology sector (72, 78, 78 and 80 industries respectively over the four intervals) as well as more specific converging groups (249, 280, 298 and 304 groups respectively over the four time intervals). They showed that in the industry category all ten industry sectors stayed within the same given top ten bracket throughout all four time periods (Figure 10). There were more convergence triggering industries than convergence receiving industries in the top ten. For convergence receiving industries, seven out of ten kept their top positions throughout the entire time period. Two convergence triggering industries that only appeared in the top ten in the final interval were “Security and commodity brokers, dealers, exchanges and services” as well as “Real estate”. Regarding convergence receiving industries only two, namely “Biotechnology” itself and “Health services” were present consistently

Figure 10 Ten most impactful industries convergent with biotechnology over the period 1997 – 2016 (source: own representation).

Top ten industries with respect to impact
Biotechnology
Chemicals And Allied Products
Wholesale Trade-non-durable Goods
Engineering, Accounting, Research, Management, And Related Services
Health Services
Holding And Other Investment Offices
Measuring, Analyzing, And Controlling Instruments; Photographic, Medical And Optical Goods; Watches And Clocks
Business Services
Wholesale Trade-durable Goods
Food And Kindred Products

Figure 11 Eight most impactful groups convergent with biotechnology, which stayed in the top ten groups over the period 1997 – 2016 (source: own representation).

Top eight groups with respect to impact
Biotechnology
Drugs
Drugs, Drug Proprietaries, And Druggists' Sundries
Medical And Dental Laboratories
Research, Development, And Testing Services
Surgical, Medical, And Dental Instruments And Supplies
Professional And Commercial Equipment And Supplies
Computer Programming, Data Processing, And Other Computer Related Services

over all time intervals. “Stone, clay, glass and concrete products” as well as “Rubber and miscellaneous plastics products” were two industries which entered the top ten convergence receiving industries category in the final interval. In the group category, eight group sectors stayed within the top ten bracket throughout all four periods (Figure 11).

4 Convergent biotechnology industry case example: biopharmaceuticals

As shown in the analysis of the strategic alliances and the M&A, one of the major sectors of convergence with the biotechnology industry is the pharmaceutical sector. Therefore, in this section the convergence between biotechnology, pharmaceuticals and information technology is analyzed, and the change in the biopharmaceutical business models over time is illustrated. Lastly, the position of the incumbent firms in the collaboration framework along the value chain is shown to change over time.

4.1 The changing scene of the biopharmaceutical industry

In the recent years technology firms, wellness companies and other non-traditional players have started to enter the traditional biopharmaceutical space (Campbell, 2017). These competitors face new regulatory hurdles, timelines and risks of therapeutic R&D, but they show advantage in their in-depth expertise in understanding customer behavior, brand building, big data analysis, IT and short-cycle innovation – areas which form the healthcare scene of today and where many biopharma companies have limited skills. The dominant industry logic is challenged not only by technological discontinuities but also by disruptive business models that the new entrants employ (Sabatier et al., 2012).

In future digital tools might help improve patient outcomes as well as traditional drug therapies (Campbell, 2017). This could pose a large threat to current biopharma business models, especially if the service is offered at a much lower price and without concerns regarding unwanted side effects or drug-drug interactions.

Biopharma is already starting to incorporate digitalization, driven by cost pressures and the urgent need for product differentiation. Currently the research focuses on incorporation of digital technologies into clinical trials and the gathering of real world evidence. Further work is being done on consumer-facing digital technologies to augment drug value. This product-focused side of digital technologies is still in early stage. Some biopharmaceutical companies, however, try to see digital tools as a way to increase profits, while these may in fact cause exactly the opposite effect.

The new sources of competition can also provide a new source of partnerships and external innovation for the incumbents. Over time digital health and technology companies have evolved to work closer with regulators in the pharmaceutical sector, which is necessary in a highly regulated health system. The narrowing cultural divide with biopharma is making collaborations between the sectors easier. Currently biopharmaceutical companies do not have the data infrastructure to properly exploit digital tools, hence they rely on partners for data analysis and software vending.

The major threats to the biopharma sector are costs. The pricing pressure and the declining number of blockbuster drugs continue to challenge revenue growth while the costs of developing a drug remain high. The ongoing decline in the return on investment (ROI) of biopharma R&D is unsustainable. There has to therefore occur a change in the biopharma business models since otherwise the falling ROI will threaten the sector´s viability.

4.2. The development of new biopharmaceutical business models

The changes that the biopharmaceutical industry is undergoing will have a huge impact on the type of business models the companies in the sector will have to employ (Pisani and Arlington, 2009). The companies need to improve R&D productivity, reduce costs, exploit the potential of emerging economies and switch from selling medicines to managing outcomes. These are difficult for a company to achieve on its own. Biopharmaceutical companies must change their business models more rapidly as otherwise they may get displaced by prominent players entering from other sectors.

Two main business models – federated and fully diversified are proposed as potentially effective models for the biopharmaceutical industry (Pisani and Arlington, 2009). The payer pressure and the opportunities to build or buy the required networks will accelerate the shift to these new models. The traditional business model, where one company focuses on the entire value chain no longer suffices and will no longer meet the market´s needs. It has been shown that disruptive innovation in various industries dismantles the prevailing business model, where new players initially target the least profitable customer segment and gradually move upstream to satisfy the needs of other customers, and the old business model collapses. The biopharmaceutical industry is currently undergoing a period of innovation with the talks of shifting the payment system to be based on the results that drugs deliver.

All trends point towards the need for greater collaboration. New business models emerge to account for the social, economic and technological changes taking place in the biopharmaceutical and healthcare landscape. These focus on the development of multinational, multidisciplinary networks which incorporate more competences than are present in the biopharmaceutical sector alone. The value chains of the three parties involved, namely pharma, payers and providers are highly interdependent. These currently linear value chains are starting to form a single, circular value chain, where feedback loops are being created.

In the federated model a company creates a network of separate entities with a common supporting infrastructure and goals. It draws on the in-house as well as the external assets, and balances size with flexibility. The federated model has two variants: virtual and venture. In the virtual model some or all of the company´s operations are outsourced and the company forms a management hub coordinating activities of its partners. Advantages of this model include: lower initial capital outlay, more variable costs, more efficient use of resources, greater flexibility, greater opportunities for expansion into new product or service areas and into new geographical markets. A major disadvantage is a shift in the balance of power towards suppliers. The venture variant of the federated model involves investing in a portfolio of companies in return for a share of their intellectual assets or capital growth they generate instead of outsourcing specific tasks. This model is beneficial to the biotech sector as it reduces the funding challenges and allows smaller companies to learn from the established ones without restraining their working culture. It allows biopharmaceutical companies to make strategic, long-term investments, explore new avenues of R&D, and expand global manufacturing and marketing. Challenges include gaining investment skills, which are different to the core skills of the biopharmaceutical companies.

In a fully diversified model a company expands from its core business into the provision of related products and services such as diagnostics, devices, generics, nutraceuticals or health management. The disadvantages of this model include a substantial investment in new equipment, premises, personnel and major cultural changes. This model may be best adopted progressively – starting from opportunistic alliances, through more strategic, longer-lasting coalitions, and finally creating a fully federated network of long-term partners.

4.3. The illustration of the changing position of the incumbent firms in the biopharmaceutical value chain

In Figure 12 the position of the incumbent pharmaceutical firms with a fully-integrated pharmaceutical company business model is shown in orange. The incumbent firms formerly covered the entire value chain with their internal competences spanning from science to market competences.

In Figure 13 the position of incumbent pharmaceutical firms in the initial convergence process with biotechnology and information technology firms is shown. The incumbent pharmaceutical firms have moved to the market end of the value chain providing primarily market competences, while science and technology competences have been supplied by the biotechnology and information technology firms.

In line with our framework for the classification of collaborations, with the advent of new business models the incumbent firms would no longer just sit at a particular place in the framework but would instead form hubs coordinating the collaborations within the value chain network (Figure 14). Through the management hub model the transfer of knowledge competences within the network would be coordinated. Financial resources within the network would be coordinated through the investment hub. Lastly, through the diversified hub model the convergence process would be coordinated with partners coming from other sectors.

5 Summary and outlook

In summary, an overview of collaborations in the context of industry convergence has been provided. Collaborations have been discussed with regards to competence gaps that organizations seek to close during the convergence process, as well as with regards to the intensity of the resource and competence integration. The conceptual framework developed is illustrated by the example of the biopharmaceutical industry. The changes in the position of the incumbent firms within the value chain during the convergence process between the pharmaceutical industry, biotechnology and information technology are exemplified. The study provides a new perspective on the disintegration of the pharmaceutical industry value chain and on the development of new business models, which may lead to the disintegration of the dominant industry logic on a level beyond

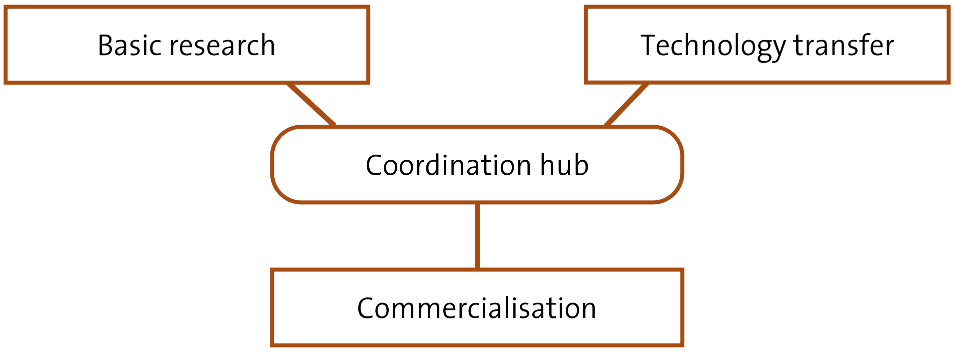
Figure 12 The position of the incumbent firms with a fully-integrated business model in the value chain (source: own representation).

Competences	Science	Technology	Market
Activity	Basic research	Technology transfer	Commercialisation
Strategic type	Technology developer	Technology-intense product developer	Product developer

Figure 13 The position of the incumbent firms in the value chain early on in the convergence process with biotechnology and information technology sectors (source: own representation).

Competences	Science	Technology	Market
Activity	Basic research	Technology transfer	Commercialisation
Strategic type	Technology developer	Technology-intense product developer	Product developer
Value creation	Indirect and intangible		Direct and tangible
Motivation	Exploration		Exploitation
Open innovation structure	Outbound innovation	Inbound/Outbound	Inbound innovation
Industry scope	Inside-out integration	Inside-out/Outside-in	Outside-in integration
Alliance management capability required	Higher		Lower
Knowledge transferred	Tacit, ambiguous, complex		More explicit and hence codifiable
Uncertainty	Higher		Lower

Figure 14 The new model of a coordinating hub (source: own representation).



technological disruption. Future research could include applying the classification framework to investigation of the position of other types of organizations in the value chain – e.g. start-ups or small and medium enterprises, and their influence on the value chain disintegration. A further study could also look to apply the classification framework to another convergent industry.

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