World class patents in cutting-edge technologies

The innovation power of East Asia, North America, and Europe

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English translation of the German original text

A cooperation of projects
Global Economic Dynamics (GED)
Fostering Innovation. Unlocking Potential.

Scientific analysis
EconSight GmbH

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SUMMARY

Our approach

The patent portfolio of an economy forms an important basis for its innovation, and, as a result, competitiveness. In this study, we look at how this portfolio of individual countries and regions has developed since the turn of the millennium. We focus on 58 important cutting-edge technologies, sorted into ten subject fields. In contrast to most other studies on this subject, we focus on the world class patents, i.e. the most important 10 percent among all patents, instead of considering all patent applications. We hope to contribute to a better assessment of the innovation capacity of large economies, which has become even more important during the coronavirus crisis.

Our most important results

North America (USA, Canada) and Europe (EU-27) still show the highest patent efficiencies: A strict view of all patent applications exaggerates the strength of East Asia (China, Japan, South Korea). A great many patent applications are filed there, but the share of world class patents as compared to all patents in the three economies with the greatest patent power in East Asia – China, Japan, and South Korea – remains clearly below 10 percent in most years. In contrast, the countries with the greatest patent power in North America – Canada and the USA – and in Europe – Germany, France, and the United Kingdom – reach more than 15 percent.

East Asia is catching up in leaps and bounds: South Korea and China in particular have developed enormously in terms of patent quality in the last ten years. In 2019, China ranked among the three countries with the largest numbers of top patents in 42 of the 58 examined technologies. In 2010, the country hadn't even been able to make the top 3 at all, and in 2000 it didn't even reach any of the top 5 places. In light of growing prosperity and high population numbers, China's strength in the field of nutrition does not come as a surprise. South Korea did not reach the top 5 in any cutting-edge technology in 2000. In 2010, it already held 14 places there, and in 2019 as many as 29. That means South Korea is among the five leading countries in half of all technologies where world class patents are concerned.

The United States remains the unchallenged "patent superpower": There is barely any field left in which China's dynamic does not slowly bring down the USA's share in world class patents. However, the United States' head start is so large, and its strength so broadly based, that it will remain the greatest patent power in the medium term. In 50 out of 58 cutting-edge technologies, the USA holds the largest number of world class patents. It is particularly far ahead in the fields of health and security. The United States still shows a high growth dynamic in central cross-sectional technologies around the subject of digitalization. They are the only industrial nation able to keep up with China in entirely new technologies.

While still the strongest European patent power, Germany is losing ground worldwide: Measured by population, Germany's results are still impressive nearly across the entire bandwidth of technologies. Its claim to the status of a leading technology nation is, however, increasingly challenged. In 2010, Germany was among the top 3 nations worldwide in terms of world class patent numbers in 47 out of 58

technologies, its share had more than halved to 22 technologies by 2019. This development also concerns Germany's traditional strength in the fields of industry and mobility. The image of a "green" Germany is not living up to scrutiny either: In the field of environment, as well as in the alternative fuels that are so very important for the energy revolution, focus is increasingly shifting to East Asia.

Europe as a whole can put far more weight on the balance than any of the EU-27 alone: No European country holds the largest number of world class patents alone on its own in any of the 58 technologies. The EU-27 together manage to hold two top positions: In wind energy and functional food. Without Brexit, they could even call five first places their own. United Kingdom's relative strength in digitalization is particularly relevant here. Europe is threatening to fall behind in new developments such as 5G or blockchain. Adding up the patents from all European states in a strictly geographic analysis, Europe would be holding the largest number of world class patents in twelve out of 58 technologies. In light of the coronavirus crisis, it stands out positively that health – and in particular vaccines – continue to be a very strong field for Europe.

Our recommendations

Development of European and international cooperation: Societies do not become more innovative by separation. Exchange of ideas helps all countries strengthen their innovation power. This is particularly important for Europe, which can profit greatly from the dynamics and strength in other world regions. At the same time, Europe – if possible going beyond the EU-27 – should try even more to bundle and use its strengths and to actively tackle its increasing weakness in a field as important as digitalization. Quick action is needed in order to keep up. Rather than happening on a national level, it should follow a more ambitious European digital strategy.

Better application and commercialization: In spite of their weaknesses as pointed out in this study, Germany and Europe still maintain outstanding research sites and a vibrant science scene. They produce many good ideas, though application and commercialization are often lacking. In particular the USA, but increasingly also China, are often faster to develop successful products and companies from new ideas. In order to bring more promising approaches to market maturity, one needs to be open and bold about business ideas. This requires a positive attitude towards entrepreneurship.

Combining innovation and societal progress: Germany and its neighbors are connected by more than just commercial economic interests. Europe is more than just an economic area. Innovations also must be aligned with the needs arising in our societies. From this point of view, innovation is more than just a competition to reach a pre-defined target. Innovation also means that our society is working out the path that we want to follow with the help of research and development. A modern, ambitious innovation politics should, therefore, aim not only missions and targets desirable for the economy, but also for society.

East Asia is catching up in leaps and bounds: South Korea and China in particular have developed enormously in terms of patent quality in the last ten years.

1. INTRODUCTION

China and its East-Asian neighbors, headed by South Korea, have exhibited an unparalleled inventive spirit in the last 20 years. China, which did not exist as a developer in most technologies at the beginning of this millennium, spectacularly launched itself onto the higher ranks. In many cutting-edge technologies, East Asia is increasing its innovation power with a dynamic that leaves not only Europeans, but at times even the USA, which dominated that area with a great head start for a long time, behind in some cases. North America may still be leading in the most important innovation fields, but is far less dynamic than its competitors from East Asia. Europe and Germany are stagnating or falling back. They can only hold their own in a few fields, in particular where they set out strongly to begin with. Those niches are also where they stand the best chances of keeping up internationally in future. This allows them to be cautiously optimistic in spite of all Asian strength. Beyond this, it stands out that countries outside of the three world regions of East Asia, North America, and Europe have barely managed to gain ground at all in the last 20 years. We define East Asia simply as China, Japan and South Korea, North America includes the USA as well as Canada, and Europe generally refers to the EU-27.

This summarizes the study results in a nutshell. It reflects the strong shift of international powers in the field of intellectual property that is of central importance for the success of knowledge societies. This allows us to close a knowledge gap: In which countries and regions can we find the most meaningful patents, the "world class patents", in central cutting-edge technologies? Which countries and regions have a particularly great potential – assuming that the political framework conditions are met – to contribute to value creation with their own high-performance products and innovative societal solutions in future? In which economic fields can they stand out the most, and where is their development less promising? Patent development is particularly relevant because copyright and innovation power are moving increasingly to the focus in the international race for trading strength and economic power.

Our study is not the first one that analyses patents in more detail as an indicator for societal innovation capacity. Our approach differs from previous ones in considering the great quality differences between patents (see box "Patents vs. world class patents"). A strictly quantitative analysis of the countries where most patents are registered is not sufficient to determine indicative results on a country's patent power. Therefore, we use an approach focused on world class patents in cutting-edge technologies: In the period from 2000 to 2019, we look only at those patents that were particularly often cited in other patent applications and for which applications were filed in many markets. These also only concern relevant technologies with a potential for changing the economy and society, and helping master major challenges. This approach is particularly indicative in light of the innovation power of countries and regions. Since the number of patents is increasing in all countries around the world, and in all cutting-edge technologies under consideration, the attempt of

In which countries and regions can we find the most meaningful patents, the "world class patents", in central cutting-edge technologies?

BOX 1

Patents vs. world class patents

China has made targeted investments in its technology development and, consequently, it has managed a huge leap in patent applications. In absolute patent numbers, China is indeed soaring, leaving Europe and even the USA far behind. Often, however, the total number of registered patents is cited without further analysis when describing the new Chinese strength, although it has little meaning on its own. Many of those patents have little value. Their inclusion distorts the image.

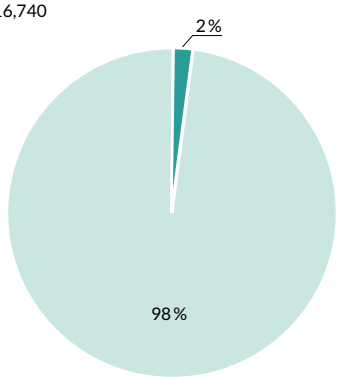
The situation is different for those patents that are the most important in their respective technologies around the world. Such patents are characterized by the fact that they are particularly technologically relevant, cover a wide range of markets, and are often cited when filing applications for other patents. This makes these world class patents especially indicative of a country's or region's innovation power.

Wind energy technology is a good example when explaining the discrepancy between the great mass of patents and the elite of world class patents: All in all, 2019 saw 40,011 wind energy patents worldwide until September 9th. 16,740 of these were from China. Out of these, however, only 300 are world class patents if measured by quality and relevance. In 2019, China held about 40 percent of the global wind energy patents, but much less, or specifically 6.6 percent, of the world class patents. When putting those world class patents in relation to patents as a whole, China has a research efficiency of 1.8 percent in that technology. Vice versa, 16,440 out of China's impressive total of 16,740 wind energy patents are negligible. By comparison, Germany holds 958, world class patents in wind energy, out of a total 3,829 patents in that technology as of September 9th, 2019.

CHINA'S PATENTS

In the wind energy technology (2019)

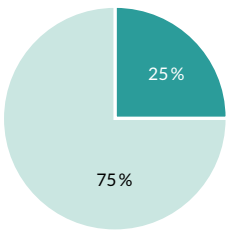
Total: 16,740



GERMANY'S PATENTS

In the wind energy technology (2019)

Total: 3,829



World class patents No world class patents

comparing absolute patent numbers is not useful. As a result, this analysis focuses on the development and comparison of the global shares of individual countries and country groups. The annual data reflect a country's patent portfolio on December 31st (2019: September 9th). Further details regarding the determination of such patents and the study methodology can be found in the annex.

Analysis of the patent system has been criticized because filing an application, with the resulting disclosure of an innovation, brings about competitive disadvantages in particularly fast-moving technologies, and therefore renders it unreasonable. However, this does not consider the fact that patents grant a temporary monopoly and are first and foremost a prevention right: They prevent potential competitors from operating in certain technology fields. Entrepreneurs may commit negligence if they dispense with patent protection while competitors claim it for themselves. Apart from this, patent intensity increases the fastest in extremely dynamic technology fields such as digitalization.

Our focus permits sober assessment of the major economies, which are competing more and more fiercely with each other.

Our focus permits sober assessment of the major economies, which are competing more and more fiercely with each other: What are the strengths and weaknesses of their technology portfolios? Only if they are known can existing innovation potential be discovered and exploited. This knowledge is also needed to create potentials where they do not exist yet. We understand a country's innovation capacity as a driving force for the prosperity of its economy and the development of its society. First and foremost, innovations in the high-tech field are elementary when trying to remain competitive and solving urgent societal challenges. This is more than ever before the case now that the coronavirus crisis is demanding gigantic innovative solutions from us. Countries with great innovation potential, even beyond the field of health, are much better equipped for this.

On the one hand, we will look at East Asia, North America, and Europe as the three world regions that excel in innovations in the most important cutting-edge technologies. We define East Asia simply as China, Japan and South Korea, North America includes the USA as well as Canada, and Europe generally refers to the EU-27. Where has East Asia caught up the farthest, where can North America, and especially the USA, maintain its dominant position, and where can the European Union and Germany find a platform for starting future success? On the other hand, we will use central key technologies in order to describe the development of innovations. We have sorted technologies roughly by relevance for the respective world regions. The first set comprises the fields that are particularly good examples for the Asian ascent, followed by technologies where American leadership in particular is barely challenged. Finally, we present the development of technologies that offer the greatest potential for the EU and for Germany. Of course, these dividing lines cannot be drawn neatly. We will address outliers and nuances, which can be found in all technologies, among other things in the profiles of economies with particularly powerful patent portfolios that we insert in the form of country pages where appropriate.

This study is guided by two motives in particular: Firstly, we aim to produce a detailed analysis of the global innovation scene to highlight the current positions of Germany and Europe in particular in this international competition, along with way for them to maintain or improve their positions. Secondly, we will focus on political decision-makers actors in society and economy, and mechanisms that drive innovations with special success. Two Bertelsmann Stiftung projects that were essential in preparing this study represent this as well:

I. Global Economic Dynamics (GED)
The "Global Economic Dynamics" (GED) project is targeted at the identification and analysis of relevant international economic developments. It strives to develop options to take action for their sustainable and inclusive design. We want to close existing knowledge gaps regarding the multilayered variations and complex effects of globalization with a mixture of tried-and-tested and innovative scientific methods, using qualitative and quantitative approaches. To this end, we cooperate with strong partners from research and consulting. We use traditional and social media, workshops, and sets of events to contribute our proposals for action that are derived from our results to the national, European, and international societal debates.

We focus on those trends with a particularly high potential impact on competitiveness and participation opportunities in Germany and Europe that are not considered sufficiently in the public discourse so far. In particular, this includes developments that could either further accelerate the structural change towards a service and knowledge society with a closely interconnected global network (e. g. increasing global data exchange or trade in services), or decelerate it abruptly, even to the point of reversal (e. g. acerbating economic conflicts, macroeconomic shocks, or an international trading system that has lost efficiency or is becoming increasingly fragmented).

II. Fostering Innovation. Unlocking Potential.
In the scope of the project "Fostering Innovation. Unlocking Potential.", we are looking for exemplary initiatives, mechanisms, and strategies that help promote innovative strength in Germany and Europe in connection with the Reinhard Mohn Prize. One goal is to remain technologically – and thereby economically – competitive. The other is designing our economic development in a humane, equitable, and democratic fashion. We assume that the two paradigms of "strengthening innovation and technological competitiveness" as well as "solving societal problems through innovation" can amplify each other in combination.

While Germany regularly comes out with good scores in international rankings on competitiveness and innovation ability, a closer look reveals a declining degree of innovation in Germany, just as in Europe as a whole, in the last years, no matter its strengths and economic indicators. This applies in particular to the field of key digital technologies. Moreover, Germany brings about barely any disruptive innovations, which are those that fundamentally change the market rules or consumer usage behavior. This causes issues both from an economic and from a societal point of view. After all, (disruptive) technology innovations in particular could solve many of the societal challenges of our time. Within our project, we bring these potentials to light to make them accessible.

EA STA SIA

2. EAST ASIA

One image will come up frequently in this study: The speed of research and development in East Asia, and in China most of all, has reached a point where the dominant USA and stable Europe have gone from being challenged to being left far behind in some cutting-edge technologies. East Asia is writing not just one, but at least three stories here: Those of China, South Korea, and Japan.

First, we have the story of dynamic China, long known as the "workbench of the world". Beyond that, it was at best known for quick, cheap, and sometimes artful imitation of the innovations brought to the market from the USA and Europe. That is firmly in the past now. China no longer produces at such low prices. While imitation and mass production still exist, of course, the Chinese government strives to lead its country elsewhere. In 2015, it launched the "Made in China 2025" innovation project, an ambitious plan subsidized with the equivalent of around 270 billion euros: The goal is to raise China to the top of the world rankings through targeted research and development in key economic sectors such as aircraft construction, electric vehicles, or computer chip production (Bertelsmann Stiftung 2018).

Years ago, China managed to overtake all other countries by sheer number of innovations for which patent applications had been filed. However, many of these were mass patents of little value. No applications were filed for them outside of China and they hardly gained any significance on a global level. Of course, sheer mass by necessity also increases the number of highlights. Much of China's research has been initiated through cooperation with Western companies. The figures in this study show that China has made enormous progress in world class patents. It is catching up quickly in almost every single technology since these patents were not only registered in their own country but also in important foreign markets. They are so relevant for the respective industries that they are often cited in other patents as well.

China not only managed to catch up in the most important environmental technologies, but has now left the previously leading USA behind. China holds slightly more than a quarter of all world class patents in recycling, with the USA in second place at about 21 percent. In water treatment, China has acquired

Research and development in East Asia is fast-paced – especially in China.

a patent share of 36 percent, leaving the USA behind again at just over 22 percent. China leads in the waste management industry as well, holding more than 23 percent of all patents there. This is one full percentage point ahead of the USA. What stands out is that China had virtually no relevant patents in this area when the observation period commenced in 2000. The same holds true for many other technology fields. Since 2010, however, the number of Chinese world class patents has clearly grown. In some instances, the annual average growth rate exceeds 50 percent. All in all, East Asia has taken the position of innovation leader and absorbed the share once held by the USA, with a current 46 percent share of world class patents in the environmental industry.

China is on a similarly steep rise in most other technologies, though not usually quite at the point yet where it could dethrone the USA. Most of these immense advances have happened in fields where the technical challenge remains manageable. In the case of fertilizer, for example, China ended up with 61.7 percent in 2019, leaving the USA far behind with only 12.6 percent. In pest control, China has also moved slightly beyond the USA, holding a quarter of all patents. Further success is achieved in relatively young fields where competitors cannot depend on their old strengths. For example, China holds 33.5 percent in blockchain technology, with the USA only slightly ahead at 35.6 percent. China has left Germany behind in a number of fields where the latter used to be among the leaders or was at least poised to become one before its share either stagnated or reduced. Photovoltaics and thermal solar energy are some indicative examples of this.

Companies in China have learned to value research and development as much as they do today partly due to their early co-operation with German companies.

Chinese companies place great value in research and development today, among other things due to their early cooperation with German companies. Chinese battery manufacturer CATL, for example, produced batteries for a joint venture of the Chinese car manufacturer Brilliance and German BMW group in 2012. They had to secure high quality standards through continuous inspections. One fifth of the group's workforce are assigned to research and development now. Quality has improved throughout, bringing CATL close to Panasonic, Samsung, and LG, three major competitors from Japan and South Korea. CATL is in the process of setting up its first European site in Thuringia in order to produce batteries close to German customers, such as BMW, starting in early 2022. We have come full circle now: While China is no longer the "world's workbench", a Chinese company is moving one of its workbenches to Germany, bringing back a technology where Germany and Europe have been left behind. According to a 2017 EU Commission survey, 85 percent of the lithium-ion battery cells produced world-wide for use in electric cars come from Asia. Only 3 percent are made in Europe. The European share could, therefore, rise to a still-low 5 percent in 2021 (Eisenring 2019).

The field of energy technology is interesting as well. Just like the mobility industry and digital infrastructure, this field reflects the second story East Asia has to tell. It deals with global dominance in interaction with its regional neighbors, and South Korea first among them. That country experienced a growth with dynamics comparable to those in China in many technologies, though it is still clearly short of the latter's level. Batterytech accounts for around half of the energy industry volume at hand and, therefore, constitutes its most vital factor. South Korea holds 11.8 percent of all patents in this fields, placing it one percentage point above China. In digital infrastructure technologies, South Korea scores particularly well in the new 5G mobile radio standard and, at a bit more than 19 percent, comes in second behind the USA, and well ahead of China. The East Asian countries have taken the lead in innovations in the technology fields of energy, nutrition, infrastructure, industry, and environment as a group.

The energy industry also serves as an example of East Asia's third story: The ambivalent role of Japan. Japan has traditionally been strong, e. g. in batterytech; in spite of modest growth, it holds the world's largest share of world class patents in that field, at a bit more than 30 percent. It stands out, however, that the country that used to be one of the world's most research-intense business locations still scores best where it can continue to use its old strength. On the other hand, Japan has seen a decline in other technology fields by losing an entire business decade. As a result, it shares the same fate as Europe, which once occupied important positions in many technologies but is now largely left behind. Japan, once in second only to the USA in key digitalization technologies such as artificial intelligence and big data, has widely lost its position, while falling behind as compared to its competitors from the region as well.

South Korea experiences growth with similar dynamics as China in many technologies.

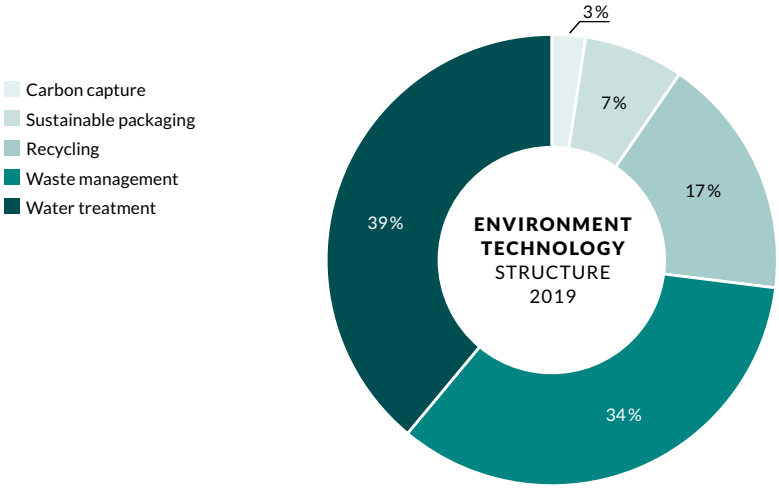
There is some hope for Japan yet, as it seems to have passed the trough. The country has already been able to build on its good foundations and is in the process of recovering in some fields. Electric vehicles are one of Japan's strengths. This is a field in which it even managed to combine more than half of all patents around 2010. In 2019, it held 41 percent of all patents and was the clear international leader there. In spite of some loss, Japan still stands out with a good second place in the field of smart traffic, reaching about 15 percent. The USA's numbers are nearly twice as high. Japan continues in a strong second place in the industrial technologies of smart factory, robotics, and process automation as well, even though its market share has seen a sharp decline as compared with other countries.

DEFINITION

Environmental technologies include circular economy and recycling as such, as well as approaches to adapt to climate change. Issues such as water treatment, waste management, and recycling profit from a longer-term focus. In contrast, newer topics such as carbon capture, as well as sustainable packaging, have not moved beyond their early stages yet.

Important patents of the last two decades in the environmental technology field:

- US2005031514.A1 – Emission treatment system
- US2008072762.A1 – Industrial CO_2 filter



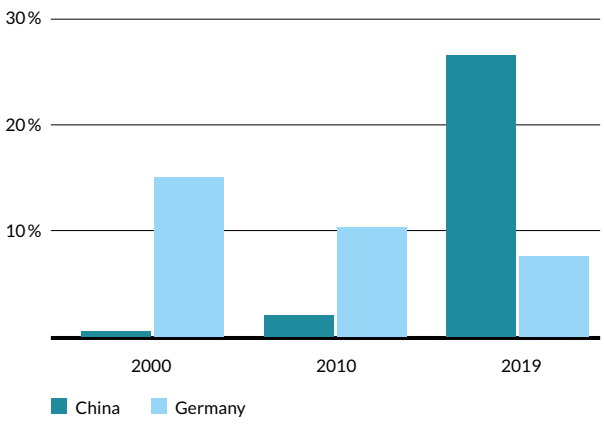
2.1 ENVIRONMENT

Recycling, climate change, and sustainability subject to agitated debate in our country. Germany and Europe will likely claim a leading role in environmental issues at least on a moral level. A closer look at everyday matters such as our handling of waste shows that this positive self-image is not necessarily true. Critics warn that Germany is far from holding a top spot in recycling, as some industry representatives like to claim (Eisenring 2019). Germany certainly is not making the best use of its technical progress to improve treatment of nature, water, the climate, or our waste either: Innovation dynamics in environmental technologies mainly happen in East Asia, and above all in China. North America and the EU have been left behind.

Environmental technologies are connected to the circular economy, recycling, and our reaction to climate change. Water treatment and waste management are the largest fields here, followed by recycling. Changes in the latter industry in particular are immense and pose enormous challenges to Europe and the USA. German companies are increasingly concerned about the rapid growth of Chinese patent numbers in recycling and waste management technologies (BDE 2018). While China held only 0.4 percent of the world-leading patents in 2000, and continued at a modest share of 2.1 percent as much as a decade later, figures climbed steeply to 26 percent thereafter. In 2019, East Asia as a whole holds 44.3 percent, and therefore almost half, of the top patents in this industry. The region has now replaced the former North American share in the world market. Germany's share of innovations in recycling halved during the period under review, dropping from 15.1 to 7.7 percent (Fig. 1).

This is a politically, economically, and societally risky development. China not only drives its innovations, but also re-defines its role as prosperity increases. For many years, the country was the larg-

FIGURE 1
RECYCLING
Shares of world class patents



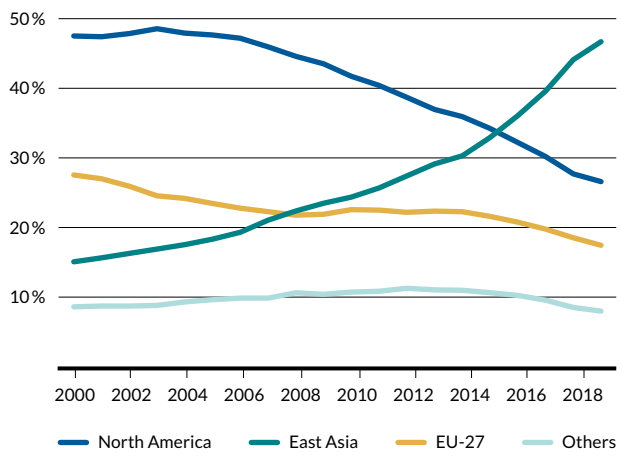
est purchaser of western plastic waste. Then Beijing stopped imports for a total of 24 materials starting in 2018. Our local waste management industry was barely prepared for this. After all, its high recycling rate also depended on being able to export part of the plastic waste in particular. For example, the German Environment Agency states that just under 40 percent of all packaging waste in Germany is recycled. However, the Heinrich Böll Stiftung and BUND come to far more less exuberant figures if deducting, among other things, the exported waste: According to their "Plastic Atlas 2019", the actual recycling rate for plastic waste is just above 15 percent (Heinrich Böll Stiftung and BUND 2019).

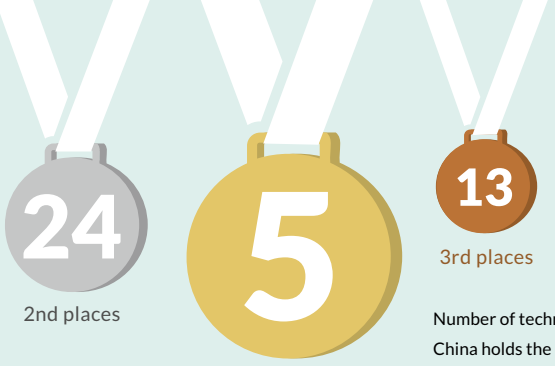
Pressure is growing in the western industrialized countries for developing recycling alternatives as a result of China's increased awareness of environmental matters and the circular economy, along with Beijing's new view of its own role, while the dynamics for this are mainly found in East Asia. China benefits from the fact that comparatively low-level innovations are concerned, at least in the recycling industry. Innovations in sorting and separating plants and collection bins are easier to develop than innovations in complicated high-tech fields. The idea of decentralized organization of recycling, for example by using smaller mobile recycling facilities, is another innovation of the industry.

A similar change to that in recycling has taken place in environmental technologies as a whole. Patent developments are particularly dynamic in East Asia, where the growth rate is 16.4 percent, but much lower in North America and Europe. The trend all around is that China is in the lead and has increased the number of its patents almost tenfold. In the meantime, Japan has achieved strong innovation growth in all major environmental technologies. However, it established roughly in the position previously occupied at the beginning of the period under review in 2019. As this shows, Japan may not be very dynamic, but contributes to the strong position of East Asia with its solid patent shares in environmental technology – amounting to 19 percent in waste management, 12.5 percent in recycling and 10 percent in water treatment.

The number of globally relevant patents from the environmental area among the 27 EU member states increased by 5.7 percent per year from 2010 to 2019. North America only saw a corresponding growth by 3.5 percent. This comparatively weak growth has reduced North America's global share severely. In 2000, that share dropped to less than half, at 46.9 percent. In 2019, it had sunk to 26.8 percent. The slightly higher growth in the EU slowed the proportional decline from 27.9 to 18 percent a little. In contrast, East Asia had replaced North America with a share of 46.2 percent by 2019, taking the technology leader's position in that area (Fig. 2).

FIGURE 2
ENVIRONMENT
Shares of world class patents





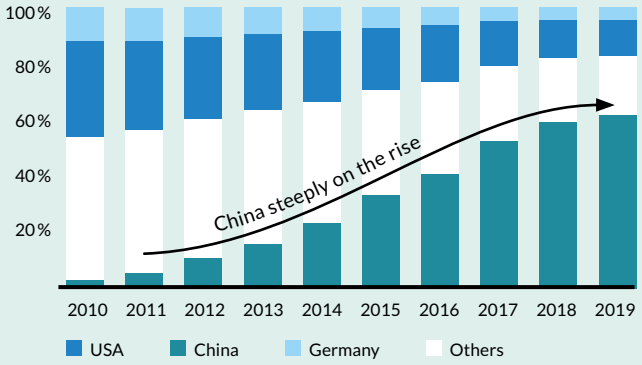
Number of technologies in which China holds the most, second-most, and third-most world class patents.

CHINA

LEADER IN ENVIRONMENT AND NUTRITION

Recycling, water treatment, and waste management are three environmental technologies where China has outperformed its competitors, now holding the largest number of world class patents. China also leads in the two nutritional technologies of biocides and fertilizer. In fertilizer, China is considerably ahead of all other countries.

FIGURE 3
FERTILIZER
Shares of world class patents



WEAKNESSES IN THE FIELD OF HEALTH

In this field, China only makes it into the top 3 once among the seven technologies (precision medicine).

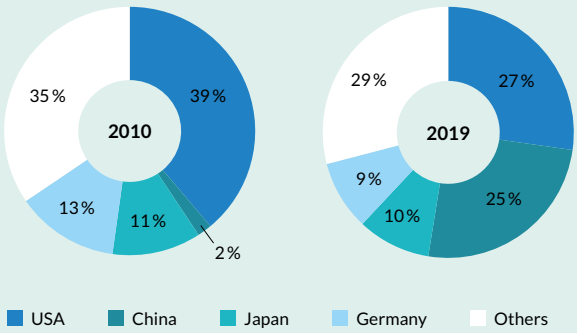
STRONG GROWTH SINCE 2010

In 2019, China ranked among the three countries with the largest numbers of top patents in 42 of the 58 examined technologies. In 2010, it was not even among the top 3, and in 2000 not even among the top 5.

GREAT POTENTIAL IN THE FIELDS OF ENERGY, DIGITALIZATION, AND INFRASTRUCTURE

If growth continued at the current rates, China could soon challenge the USA's top position in this area. China already holds second place in six of the nine energy technologies under examination. It ranks second in four out of six digitalization technologies, and makes second place in five out of six infrastructure technologies.

FIGURE 4
CONSTRUCTION
Shares of world class patents

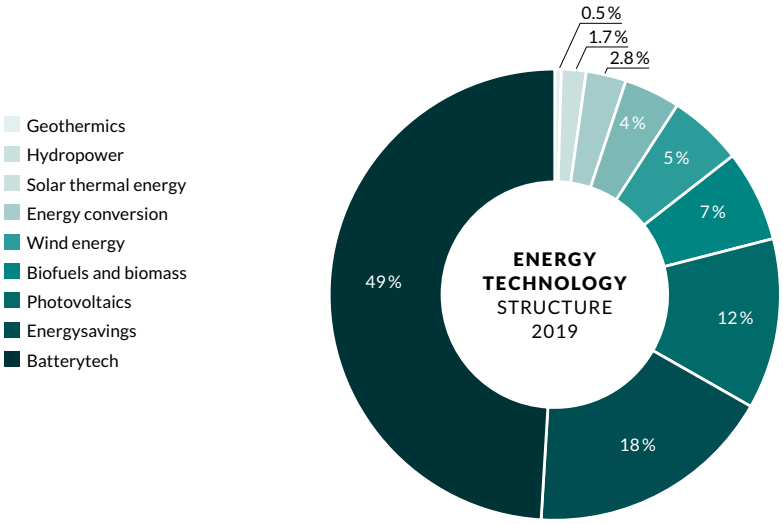


DEFINITION

The move away from fossil fuels shifts the technology focus in the field of energy to renewable technologies. Energy generation comprises wind energy, hydropower, geothermics, solar energy, and photovoltaics. Energy-saving technologies and energy conversion technologies in the fields of solar and wind energy, as well as energy storage, are added to this.

Important patents of the last two decades in the environmental technology field:

- US2009096413.A1– Inductive charging technology for portable electronic devices
- US2010071979.A1 – Battery system for electric vehicles

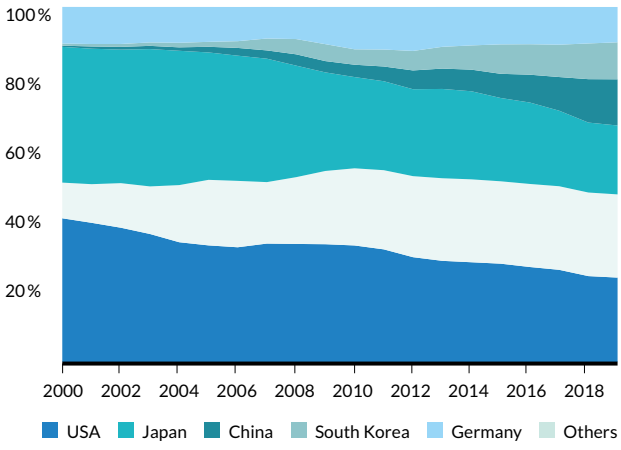


2.2 ENERGY

Solar energy, more than any other industry, shows how Germany has surrendered its top position. From 2005 to 2008, German companies produced more solar cells than any others (Haffert 2019). When the last factory of the formerly exemplary company SolarWorld was closed in the fall of 2018, the country's production virtually ceased, while the industry continued to set one record after the other around the world. Experts name German companies, in contrast to Chinese ones, not specifically investing in expansion of silicon photovoltaics as a reason for the Germany's decline (ibid.). The opposite development between the two countries is also reflected by the patent figures. Germany's soaring trend around 2010 correlated with the success in the German solar industry. 2012 was a peak year in which nearly 8,000 megawatts were newly connected to the grid in Germany. This was about four times the current number (ibid.). By 2019, however, Germany's share in the top patents had dropped to the 2000 level of 10 percent.

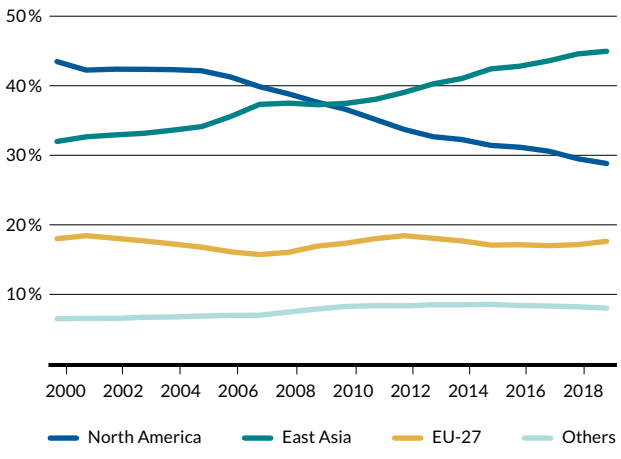
China, on the other hand, started out with only a small number of world class patents in photovoltaics in 2000. It has left Germany clearly behind now with its global share of 13 percent. South Korea also exhibits remarkable growth. After holding less than ten patents in 2000, the country has just managed to overtake Germany. With a share of the top patents that has been cut in half from 38.2 to 19.4 percent, Japan shares the fate of Germany and the USA where growth rate and dynamics are concerned. Nevertheless, it still comes in second behind the USA with its share just under 24 percent when comparing individual countries (Fig. 5). Comparing the world regions, however, East Asia has clearly outperformed North America – not least thanks to Japan's continuing strong position.

FIGURE 5
PHOTOVOLTAICS
Shares of world class patents



Energy is one of the industries most vitally dependent on innovations. Efficient energy sources are essential for the energy revolution to succeed. For example, a survey of the European Parliament showed that the energy industry accounted for 80 percent of the 2017 greenhouse gas emissions in the EU (Europäisches Parlament 2018). Sustainable energy sources that emit no pollutants or greenhouse gases can remedy this. These are wind, water, geothermal energy, solar thermal energy, and photovoltaics. Moreover, switching to electric vehicles as an alternative to the combustion engine can only succeed if batterytech is developed further. About half of all energy patents concern batteries. Batterytech is, therefore, the most important segment of the energy technology field in terms of innovation capacity. The total number of patents in energy technologies has tripled in the last decade. They represent East Asia's innovation power, with about 45 percent of all world class patents held by that region in 2019, while North America's share has developed almost precisely in the opposite direction, dropping to around 29 percent in 2019. The European Union has kept its share largely unchanged over the years, at around 17.5 percent (Fig. 6).

FIGURE 6
ENERGY
Shares of world class patents



East Asia's strength, especially in the field of energy technologies, is a success story that goes beyond China. Japan and South Korea stand out specifically in the particularly innovation-driven battery industry. Japan had started out on a high level here, increased its worldwide patent share to around 30 percent and managed to maintain this figure, which puts it ahead of the declining USA with approximately 23 percent in 2019. South Korea developed steeply to a global share of 11.8 percent. China is just behind it at 10.7 percent. However, China started out virtually from scratch, which means that it showed the strongest growth. Germany dropped from 9 to 7.5 percent. While some battery manufacturers advertise their products as "Made in Germany", that usually only means that the battery pack is assembled there. The battery cell, the innovative heart of a rechargeable battery, is usually delivered by companies like Samsung, LG Chem, or Panasonic from South Korea, Japan, or China.

Wind energy is the only positive outlier for Germany in energy technologies. In 2019, Germany caught up with the USA in this field and held around 21 percent of the world's top patents. Germany's strength is a major factor in giving the EU about half of the world class patents here. A large share of patents can be attributed to wind turbine manufacturer Enercon. This makes Aurich, where it has its headquarters, one of the most innovative cities in the industry (Windmesse, n. d.). However, industry representatives warn that wind energy could suffer a fate similar to that of solar energy in Germany. Enercon, once a global market leader, is reducing jobs massively. Drastic job cuts in the industry commenced in 2017 already. Opponents of wind energy, nature conservationists, politics, and bureaucracy are preventing the next future industry in Germany, according to industry reports (Handelsblatt 2018).

Number of technologies in which Japan holds the most, second-most, and third-most world class patents.

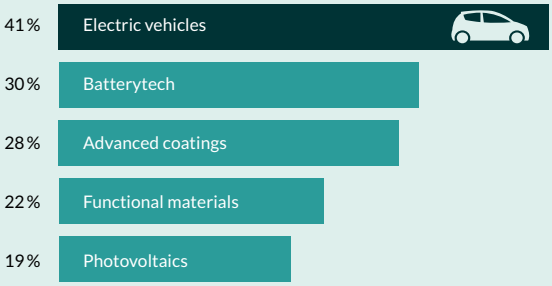
JAPAN

LEADING IN MOBILITY, ENERGY, AND MATERIALS

With electric vehicles, batterytech, and advanced coatings respectively, Japan holds the largest number of world class patents in one technology each from the technology fields of mobility, energy, and materials. The country occupies at least one top 5 position in every other technology outside of these three fields.

FIGURE 7
ELECTRIC VEHICLES

Technologies in which Japan holds the highest proportion of world class patents internationally (2019)



WEAKNESSES IN HEALTH AND DIGITALIZATION

Japan has lost its place in the top 5 in three technologies each in the fields of health and digitalization.

SLOW DESCENT FROM A HIGH LEVEL

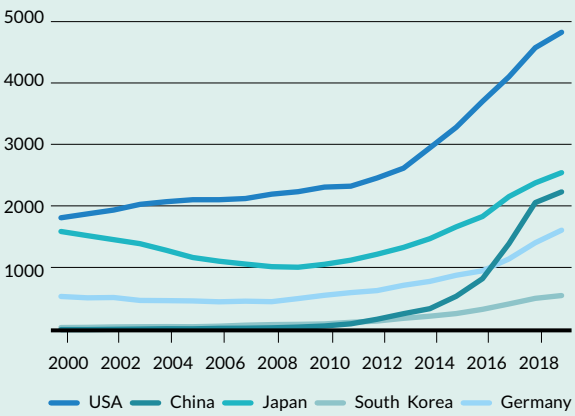
In 2000, Japan still ranked among the three countries with the largest number of world class patents in 49 of 58 cutting-edge technologies. In 2010, this was still true for 46 cutting-edge technologies, and in 2019 only for 38.

UNDER PRESSURE IN THE INDUSTRIAL FIELD

With its traditional strength in this area, Japan remains ahead of China and South Korea in all four technologies. Still, the other two countries are catching up quickly with higher growth rates.

FIGURE 8
PROCESS AUTOMATION

Number of world class patents

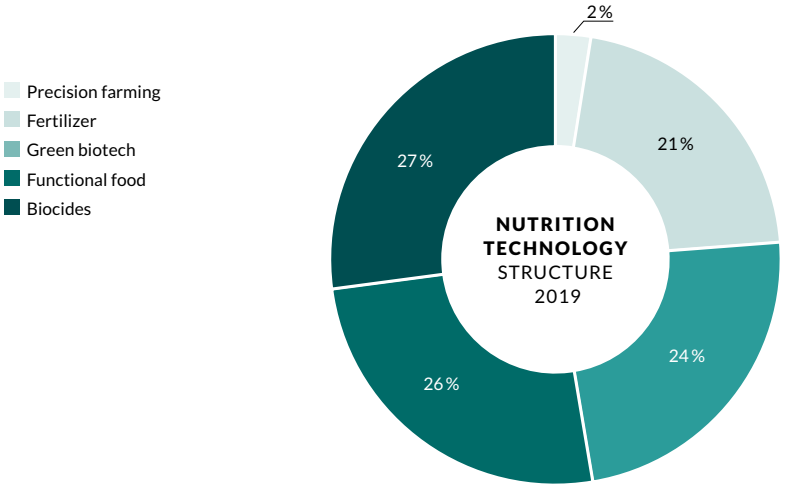


DEFINITION

The target of the technology field of nutrition is creating an efficient agriculture that can supply the world population with food. This includes the use of pesticides and fertilizers as well as genetically modified plants. Technologies for enriching food with additional health-improving ingredients are considered as well.

Important patents of the last two decades in the nutrition technology field:

- US2014323305.A1 – A modern fungicide to combat fungi and spores
- US2003120054.A1 – Pesticide for pest control

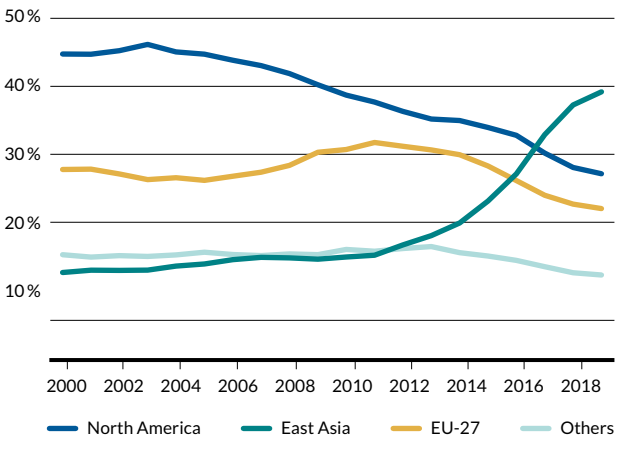


2.3 NUTRITION

The production and preparation of food is subject to constant change. Right now, that change is driven in particular by growth of the world population. According to United Nations forecasts, the world's population will exceed nine billion in 2050 (United Nations 2019). At the same time, the area available for farming is shrinking (Umweltbundesamt 2019). Research and development in nutrition technologies are to help render supply and growth more efficient and sustainable, e. g. by way of process optimization, preservation of resources and further development of fruit and vegetable varieties. Better application of fertilizers and pesticides and the use of enriched or genetically modified plants promise higher yields. Precision farming means that the nature of soils is analyzed from space with satellites to allow farmers to better respond to different needs of their fields and even in segments of one and the same field.

Functional food adds momentum to the food industry. Such foods are enriched by breeding or additives. They are advertised, among other things, as being beneficial to health. Functional food is a broad field. On the one hand, research already has some interfaces with the pharmaceutical industry, e. g. in the therapeutic use of bacteria. Products such as meat substitutes could help solve nutritional issues and alleviate the consequences of factory farming. On the other hand, there is a large field of functional food with the main purpose of allowing manufacturers to create new purchasing incentives in the largely saturated food markets of the industrialized countries. In many cases, the promised health benefits of the added fatty acids, vitamins, minerals, fiber, bacteria, or plant substances such as ginkgo and aloe vera, are not based on any documented evidence at all. Consumer protection organizations warn that functional food often benefits the producer's wallet more than it does the consumer's health (Verbraucherzentrale NRW 2016).

FIGURE 9
NUTRITION
Shares of world class patents



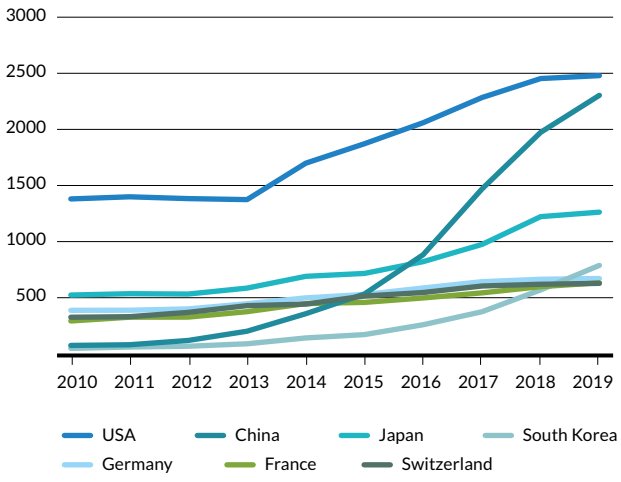
Patents for such supposedly or actually health-improving foods are popular with companies. This is mainly because such changes to plants and products require relatively little effort. Innovations in the functional food industry come with only a fraction of the investment necessary for, e. g. genetically modified plants, while offering great added value. Development of a genetically modified plant costs a company around 100 million euros. Development of a functional food may be in the range of only 1.5 million euros (Matheis 2017).

The major players in the industry use functional food to improve their market positions and establish their own varieties. However, patents on products from breeding are viewed controversially and may meet with resistance among civil-society organizations and consumers (Brücking and Hensge 2015). For example, Syngenta withdrew a European patent for enriched tomatoes in early 2019 in the wake of mass opposition.

As in other industries, research in nutrition technologies has become more dynamic, especially in East Asia. The number of world class patents there is growing by an average of 20 percent per year. The East Asian food industry benefits from a middle class with high purchasing power that increasingly chooses its food products based also on their promised effects on health (Schmitt 2018). East Asia was still clearly behind North America and the EU in terms of patent numbers in the field of nutrition technologies in 2010. China and also South Korea in particular caught up sharply in the following period with steep growth rates. Japan's share in the industry's innovations remained consistently high. These countries together left the other two major world regions far behind: In 2019, East Asia was responsible for 39 percent of the world class patents in nutrition technologies (Fig. 9). However, closer comparison of the technologies reveals that the European market is also on the move.

The non-EU countries of Switzerland and Norway are prominent players in the field of food technology. Switzerland is particularly well represented by the seed and agrochemicals manufacturer Syngenta and the food group Nestlé. These play major roles in functional food, for example. In 2019, Switzerland's share of 5 percent was roughly equal to that of Germany and France. Taken together, the EU countries are still ahead of North America, but the USA leads this field with about 20 percent by country comparison, followed closely by China with around 19 percent (Fig. 10).

FIGURE 10
FUNCTIONAL FOOD
Number of world class patents



BOX 2

From meat substitute to meat imitation

Meat substitutes are a very new, though highly promising technology subgroup within the field of functional food. They are not a new phenomenon: Products such as tofu, tempeh, and seitan have been common in Asia for centuries. In the past, meat substitutes mainly had to offer attractive prices or were meant to compensate for food shortages. Today, the increasingly intense debate on animal welfare and climate protection, ethical, moral, and environmental considerations are vital issues as well.

Demands to the product have also changed considerably. Meat substitutes are expected to be near-indistinguishable meat imitations now. This is called the meat analogue (or alternative meat). Beyond merely replacing meat as a foodstuff, it is to have similar product characteristics and should be suitable for preparation in a similar way. However, the development of meat imitations that come very close to actual meat in texture, taste, appearance, and smell poses high demands to technology.

The taste of meat is determined by a protein (heme) found in blood and muscle tissue that is responsible for oxygen transport. The same substance occurs in plants, albeit at much lower concentrations. Heme to be used in mass production of newer meat imitations is obtained from genetically modified yeasts. Since this has not yet been approved as a genetically modified food, some newer meat imitations are not marketed in the EU yet. Meat substitutes based on beetroot juice are, however, available.

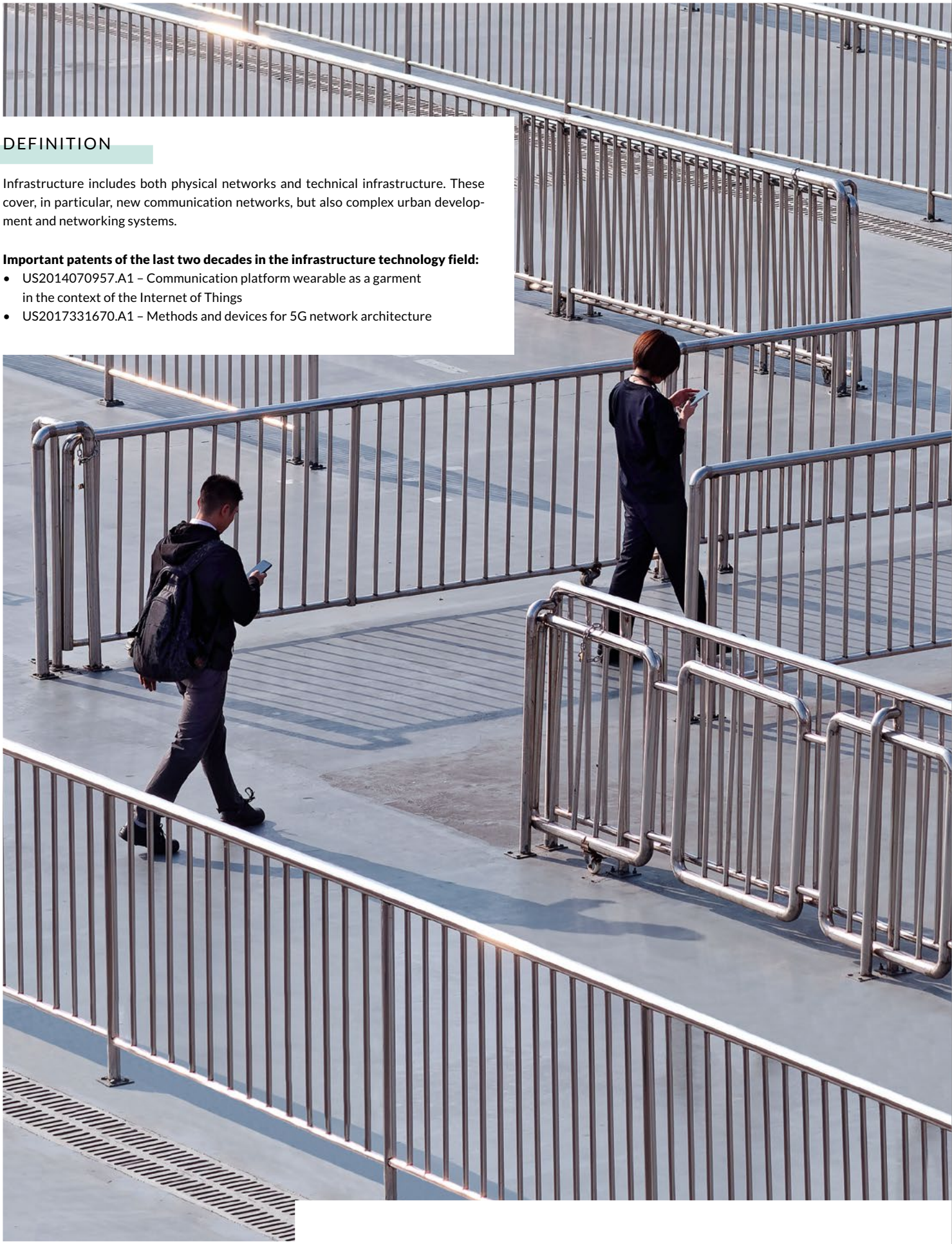
The market has traditionally been held by large food manufacturers such as Nestlé, Unilever, DuPont, and Mars. However, smaller companies have made progress in the last few years, especially by improving the authentic meat taste. They include in particular the two Californian companies Impossible™ Foods and Beyond Meat.

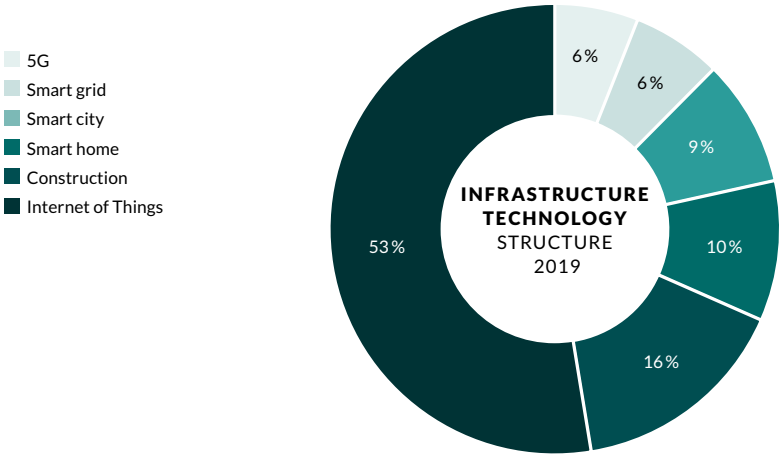
DEFINITION

Infrastructure includes both physical networks and technical infrastructure. These cover, in particular, new communication networks, but also complex urban development and networking systems.

Important patents of the last two decades in the infrastructure technology field:

- US2014070957.A1 – Communication platform wearable as a garment in the context of the Internet of Things
- US2017331670.A1 – Methods and devices for 5G network architecture



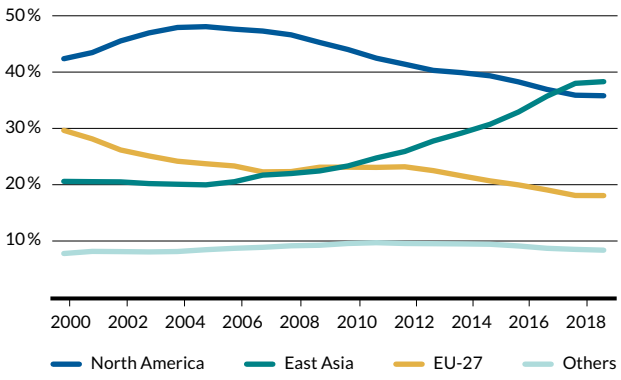


2.4 INFRASTRUCTURE

The extent to which technical progress in China is disturbing the West, economically as well as politically, becomes clear in the dispute over the development of 5G mobile networks. On three international companies are currently the most likely candidates for network expansion: Chinese company Huawei joins the two familiar European players Nokia and Ericsson in this competition after establishing itself as a leading provider of network technology, primarily due to the rapid ascent of China (Stacey 2019). In Germany, as in many other western countries, however, people are now concerned about whether Huawei and its smaller local competitor ZTE may be commissioned with the 5G expansion. The secret services of the United States and its allies warn that Huawei may grant Chinese safety authorities to access the networks of its customers unnoticed (Kühl 2018). As a result, they urge their Western partners to exclude Huawei from 5G development. Though German Chancellor Angela Merkel has stated that all providers should be examined impartially, there are more and more members of the government who would rather leave Huawei out. Telecommunications companies, on the other hand, warn that Chinese components are vital for building 5G, or that it would at least become considerably more expensive without them (Koch 2019).

This example reflects the powerful position China has gained through targeted innovations in this key technology: Projects will be difficult without the Chinese provider. All in all, East Asia has clearly exceeded the shares of North America and the EU in world class patents in digital infrastructure technologies. In 2019, 38.5 percent of all active world class patents came from East Asian countries. 35.4 percent were from North America and 17.8 percent from the EU, both of which have lost significant shares (Fig. 11). The new 5G mobile radio standard is a prime example of how these infrastructure technologies are to connect people, machines, and equipment of all kinds. The Internet of Things is designed to connect increasing numbers of devices to the Internet, at high speed, with fast connection and the lowest possible power consumption. The high level of data exchange is aimed at creating the conditions for autonomous mobility, Industry 4.0 with digitalized production processes, and digitally connected healthcare system. Developments of technology, economy, and ultimately also society will be based widely on this technology.

FIGURE 11
INFRASTRUCTURE
Shares of world class patents



Accepting any weaknesses in this field would destroy cross-sectoral development opportunities and may even create undesirable dependencies.

Innovations in the infrastructure technologies selected here have gained momentum, especially in the time since 2010. This segment includes anything that drives the interconnection of people, products, and machines, which means new communication networks, complex urban development as well as networking systems. Apart from 5G and the Internet of Things, such systems comprise smart city and smart home, as well as smart grids. There also is a number of innovations in the construction industry that are essentially related to CO_2 reduction, air conditioning, and fire and seismic safety.

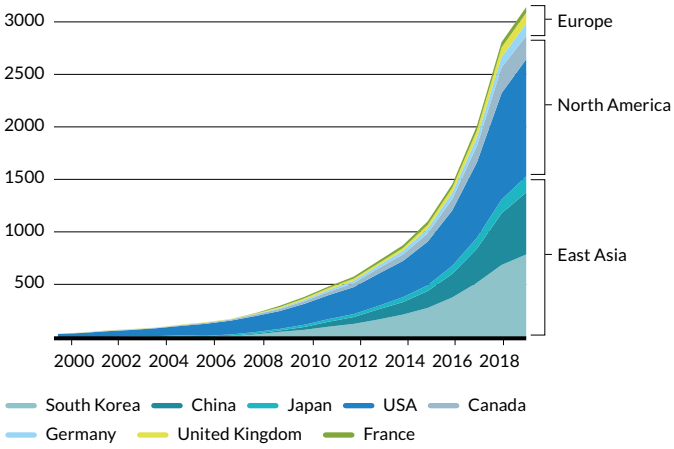
In 2019, the Internet of Things accounted for the largest share of infrastructure technologies by far, making up 35 percent. Developments in this industry show that China, and in part also South Korea, are catching up immensely, while the United States and the European Union have lost shares and are growing just a little more than half as much as East Asia. The faster growth in the East Asian countries suggests that their lead will increase even further.

The USA's loss is particularly striking. At the turn of the millennium, North America dominated innovations in these infrastructure technologies; by 2005, it had increased its share in the world's most important patents to 48 percent. This share has now reduced to just slightly above 35 percent. In 2000, the EU still accounted for around 30% of all new patents in the industry, but its share has since fallen to a bit above 18 percent in 2019. Although the member states' growth rates are similar to that of the USA, they started out at a lower level and thus have largely fallen behind.

South Korea's strong development is also striking. 5G and the technologies associated with it are beneath a Chinese, particularly a South Korean story of success. Apart from that, the main success is found in South Korea, which holds even higher market shares in some areas. South Korea was below the USA in 5G technology in 2019, with a share a little above 19 percent, but still ahead of China with around 14 percent. Chinese companies like Huawei are also focusing more on network interfaces, i.e. the connections between the network and terminal equipment (Fig. 12). In contrast, South Korean companies mainly deal with the implementation of 5G and the required terminal equipment. South Korea has sensational success to show: While other countries still have not decided who they want to charge with the network expansion, South Korea was the first country in the world to report completion of a nationwide 5G network in April 2019. It may have started out bumpy and incomplete, but some early issues have been corrected already (Kölling 2019).

When the 5G network was launched in April 2019, South Korea's President Moon Jae-in announced that his government would spend the equivalent of around 23 billion euros on network development in the course of the next four years (Waring 2019). The battle to launch 5G brought about many new developments in its course and boosted local companies. For example, Samsung used to hold only a small market share in the segment. It has now surged forward as a provider of 5G network technology and strives to exploit Western skepticism against its Chinese competitor Huawei. South Korean providers want to bring 5G-based autonomous shuttles onto the road next year. 1,000 buses controlled by 5G are to follow five years later. An excavator remote-controlled by 5G has already been presented, along with the first holographic navigation system using augmented reality elements. 5G-connected dating and karaoke games are a matter of course in South Korea as well. The Internet of Things is an important growth market there. Market research and consulting company International Data Corporation estimates the country among the top 5 world-wide in terms of investments in this industry (Hirschle 2019).

FIGURE 12
5G
Number of world class patents



#InnovationBSt // World class patents

Number of technologies in which South Korea holds the most, second-most, and third-most world class patents.

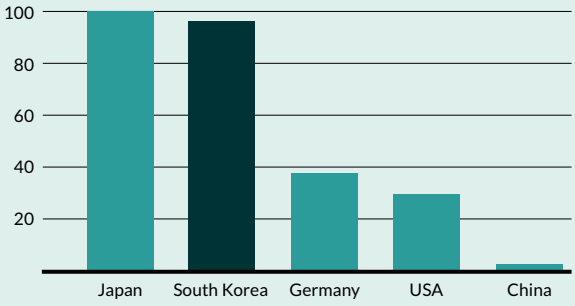
SOUTH KOREA

STRENGTHS IN ENERGY, MATERIALS, AND INFRASTRUCTURE

South Korea is among the top 3 countries in one technology each in these three fields (batterytech, nanomaterials, 5G). It even comes in second in world class patents for 5G technology.

FIGURE 13
BATTERYTECH

World class patents per 1 million residents (2019)



WEAKNESSES IN HEALTH, NUTRITION, AND ENVIRONMENT

In spite of its strong growth, South Korea has not gotten to any of the top 5 places in the field of health, and only made one in the nutrition and environment industries each (functional food, water treatment).

TWO DECADES OF STRONG GROWTH

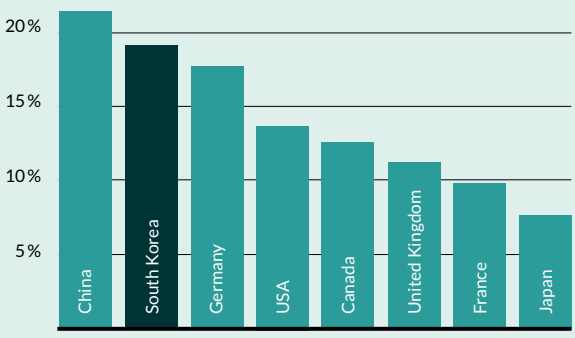
In 2000, South Korea did not occupy any of the top 5 places in any cutting-edge technology yet. In 2010, it had already made it to the top 5 in 14 cases, a number that was increased to 29 by 2019. This means that South Korea holds fifth place or higher in terms of the number of world class patents in half of all technologies considered.

GREAT POTENTIAL IN THE FIELD OF DIGITALIZATION

Although South Korea has not made it to the top 5 in the technologies of artificial intelligence, big data, and cloud computing so far, its growth figures in the last few years have been immense.

FIGURE 14
CLOUD COMPUTING

Average annual growth rate of world class patents (2016–2019)



NORTH AMERICA

3. NORTH AMERICA

The USA is still world's strongest innovation site by far. Seven out of the ten companies that spent the highest research and development (R&D) budget in 2018 were from the USA. Amazon leads the ranking compiled by the management consultants Ernst & Young, with a research expenditure equivalent to 24.4 billion euros in 2018. Google's parent company Alphabet makes second place at 18.2 billion euros, followed by South Korean Samsung, and then Microsoft (EY 2019).

The only German company among the top 10 is Volkswagen, spending a bit above 12 billion euros. Its ranking reflects recent developments well: The German car manufacturer spent years at the top of the list. It was only replaced by the US IT groups in 2016. They, more than anyone else, have massively increased their investment in innovations with every passing year. The increase as compared to 2017 was 27 percent for Amazon, 29 percent by Alphabet, 11 percent by Samsung, and 13 percent by Microsoft. Apple increased its R&D spending by 23 percent and has climbed to the same level as Volkswagen, which increased its research expenditure by a comparatively modest amount of 4 percent.

The consequences of this development are reflected in the world class patents that originate in the USA. The USA dominates especially in the technology segments where digitalization has the greatest effect, even after losing some ground. This is where the large American IT companies put in their weight. In digitalization technologies, for example, more than half of the top patents come from North America. The USA leads in artificial intelligence with a share of 45 percent and in big data with 50 percent. Both figures are far ahead of China with 16 and 19 percent, respectively. Cloud computing is largely in US hands with over 52 percent. In virtual / augmented reality the USA is in the lead and still makes 40 percent.

In terms of digital infrastructure, East Asia has overtaken North America in a comparison of the world regions. Compared country by country, however, the USA makes first place in all individual disciplines such as 5G or the Internet of Things, though the margin is lower. The same applies to IT-based security technologies such as fintech and payment, cyber, product and network security, and authentication and identification technologies, where the US reaches around 40 percent, a good distance from China in second place. On top of this, IT groups such as Google with its mobility division Waymo are clearly shaking up the business of traditional industries in cutting-edge technologies such as autonomous driving, where the USA leads well ahead of Japan with 40 percent. The strongest impulses in this area do not come from traditional car manufacturers that are digitalizing their business, but from digital experts conquering new application areas for their IT.

The USA defends its lead with only slightly lower shares in the health sector, where major pharmaceutical companies are in charge of the majority of promising technologies, and in industries such as digital medtech, where top companies in the IT industry are also involved in research. In addition to leading companies, outstanding universities contribute to the USA's position.

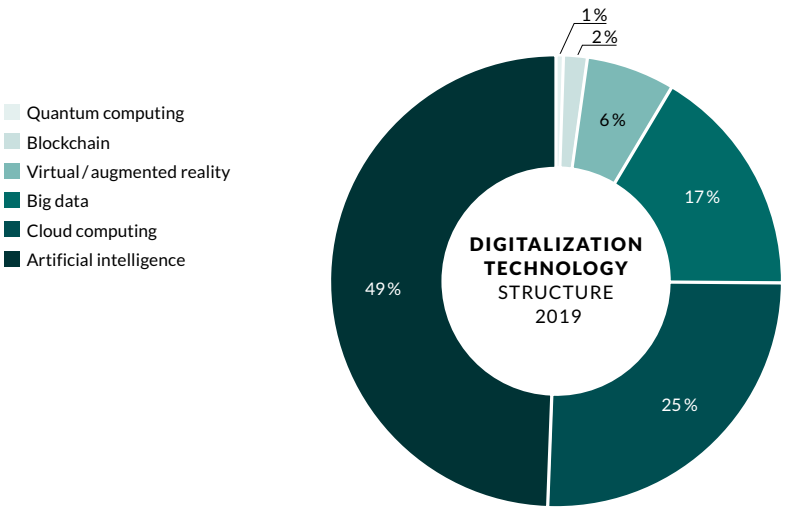
It must be careful, however. China's growth has exceeded the USA's in most technologies. It is certainly more dynamic than European development. In some future industries, the question will not be whether China will overtake the USA, but when.

DEFINITION

Digitalization generally is a field for cross-sectional technologies that are effective in interaction with other technologies. The digitalization technologies considered here are particularly advanced: AI, cloud computing, big data, quantum computing, block-chain and virtual/augmented reality bring about new products and processes at the interfaces between digitalization and other technologies in the scope of the digital transformation. Because of this, the field of digitalization has a significant impact on other technology fields.

Important patents of the last two decades in the digitalization technology field:

- US2008174570.A1 – Multi-touch display
- US2015205126.A1 – Virtual and augmented reality systems and methods



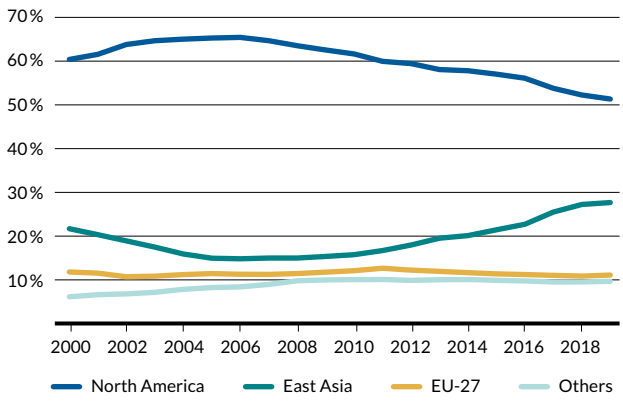
3.1 DIGITALIZATION

Digitalization technologies record the highest growth in world class patents among all technology fields: Their number showed an annual growth of around 18 percent worldwide from 2010 to 2019. It is only logical that the number of top patents in the field is twice as high today as it was five years ago. East Asia has been growing the most dynamically here as well since 2010, at an average of 26.5 percent per year. However, digitalization comes with one significant difference: China and its neighbors are not even close to catching up with the USA so far. North America is the unchallenged leader in this field, owning more than half of all world class patents. One could say that the old world order is still unchallenged in digitalization, although the share of North America has steadily decreased there as well, after peaking at nearly 65 percent 15 years ago: The EU makes third place with a patent share of around 11 percent, behind East Asia with 28 percent (Fig. 15). No other area of technology is growing as rapidly. Europe has also seen an annual high growth rate just above 16 percent here since 2010, exceeding the rates in all other technology fields. However, this is still not enough to make up the shares lost in this technology field.

This is cause for concern for Europe. After all, the technologies summarized in the field of digitalization are no less relevant than the interconnection offered by the new mobile phone standard 5G, or development of the Internet of Things. This is a cross-sectional technology that carries a substantial proportion of further economic and technological developments. Further progress may become difficult if it is not possible to keep up in digitalization. Its true impact is only evident in combination with other technologies: Further development of the economy towards a connected Industry 4.0, modern healthcare, modern energy production, and autonomous mobility depend on it. Analysis under the collective term of digitalization includes particularly relevant technologies that bring about new products and processes to benefit digital transformation.

The most important technology in this area is artificial intelligence, followed by cloud computing and big data. Artificial intelligence describes the automation of various technology processes that require a high degree of autonomy and typically involve machine learning. Strictly speaking, this is an umbrella term, rather than a technology of its own. Although artificial intelligence is attracting great attention and has

FIGURE 15
DIGITALIZATION
Shares of world class patents



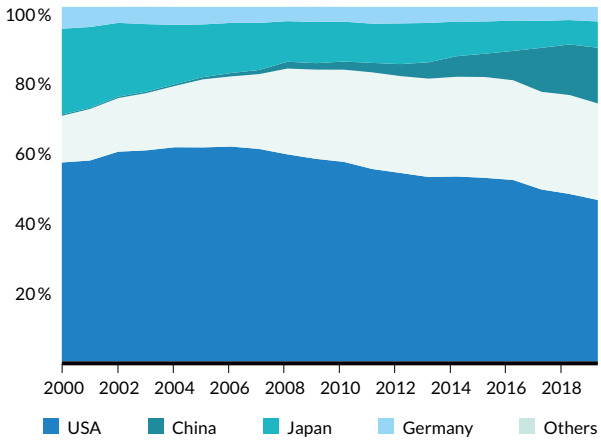
a futuristic air to it, the concepts for some of our current algorithms date back to the 1970s. The reason they are only seeing proper use now is that the current technical possibilities finally allow processing of the required data volumes.

The competence in artificial intelligence, which is reflected not least by the distribution of top patents, is currently found mainly in large IT companies from the USA, such as IBM, Microsoft, Google's parent company Alphabet, and Intel, as well as some Asian companies such as Huawei, Baidu, and Samsung. The market power of the major players has seen constant growth. Only a few corporations such as Siemens and Philips are able to keep up with this in Europe. The USA as a site for world class patents dominates the field accordingly with a share of 45.5 percent. This corresponds to around 14,840 patents in the peak segment. China reaches 15.7 percent in this field. After starting virtually from scratch, however, it has shown by far the most dynamic growth, at 46.6 percent per year, since 2010. Japan has lost ground considerably, now accounting for around 7 percent of the total figures, after achieving 24 percent in 2000. In 2019, Germany reached around 4 percent in this field (Fig. 16).

Holding around 3.5 percent in all sub-fields, the United Kingdom shows remarkable relative strength in the field of digitalization technologies. This factor could turn into a problem for both the British and the remaining 27 EU states when the United Kingdom leaves the EU. One third all European companies in the field of artificial intelligence, for example, are currently British. Many US companies have located their research in the United Kingdom. British universities are vital for the country's research. The university environment also brings about innovative start-ups, some of which are being acquired by large corporations. The United Kingdom has set ambitious political targets for artificial intelligence. They aim to strengthen that industry with financial injections. London's mayor wants the city to become a global AI center. According to industry experts from the McKinsey Global Institute, the United Kingdom is better placed than the EU states to take advantage of the opportunities offered by the AI industry, which is still under development. Research results have not been sufficiently implemented so far, however (McKinsey Global Institute 2019). AI is already more common in businesses in the remaining part of the EU. Brexit happens in the midst of this. If European research cooperation becomes more difficult due to this, the United Kingdom may lose its participation in European programs, and potentially also its function as a European bridgehead for companies from outside of Europe.

Digitalization also includes blockchain, a technology that has drawn particular attention in the last few years. This very young field did not see any significant dynamics before about 2013. Rapid growth and developments in that area currently change this field from month to month rather than over the course of years. By 2014, the USA had been clearly in the lead, with a world class patent share of almost 70 percent. China has used the years since to catch up. All in all, East Asia, at 41.7 percent, is now ahead of North America, at 37.8 percent, in a comparison of world regions. The EU's share has slightly receded in these five years, dropping from 10.5 to 8.5 percent.

FIGURE 16
ARTIFICIAL INTELLIGENCE
Shares of world class patents



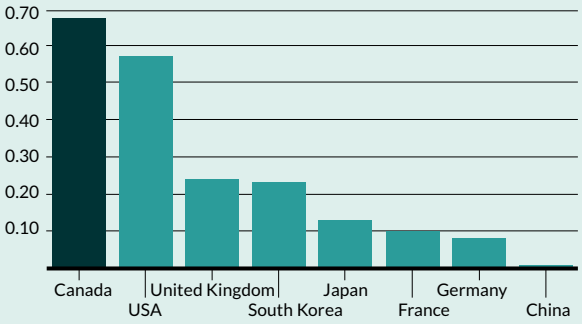
Number of technologies in which Canada holds the most, second-most, and third-most world class patents.

CANADA

STRENGTH IN DIGITALIZATION

Canada and the United Kingdom are the strongest western countries in the field digitalization after the United States. Only the USA holds more world class patents than Canada in quantum computing. It ranks at least fifth in three more of the six technologies from the field of digitalization.

FIGURE 17
QUANTUM COMPUTING
World class patents per 1 million residents (2019)



WEAKNESS IN MATERIALS

Canada has fallen behind in recent years or has never been particularly strong in this area, but also in mobility, nutrition, industry, and environment. The country is not (any longer) among the top 5 in any of these technologies today.

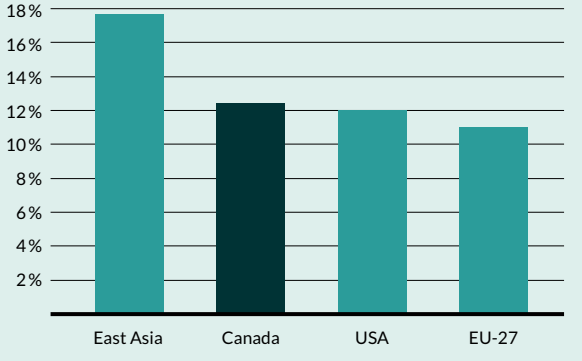
UP AND DOWN AGAIN

In 2000, Canada in ten technologies in the top 5. In 2010, the country had already made the top 5 in 26 technologies (especially after overtaking France and Sweden). In 2019, only nine were left (mainly due to the rise of China and South Korea).

POTENTIALS IN INFRASTRUCTURE

Canada holds a relatively large number of world class patents in the infrastructure field. It should continue to benefit from its strength in digitalization in the next years, as further advances in infrastructure technologies can be expected.

FIGURE 18
SMART CITY
Average annual growth rate of world class patents (2010-2019)

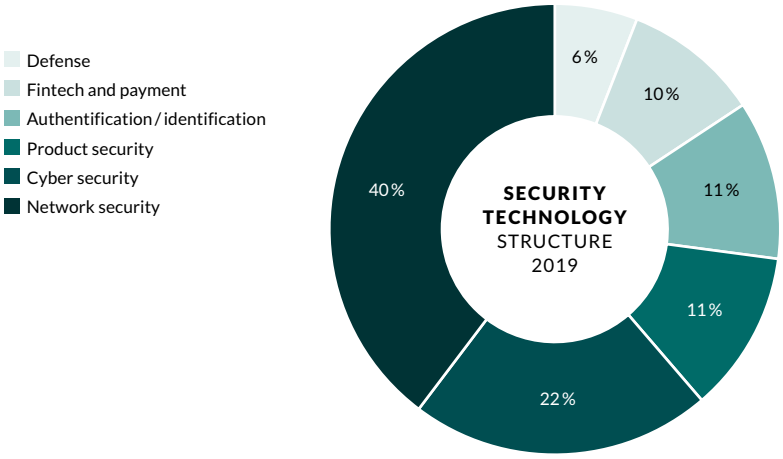


DEFINITION

Security encompasses various technologies to protect information and end products. These include the production of banknotes, passports, and drug packaging, secure access to and use of data on networks using firewalls, anti-virus software, encryption and other measures, and the authentication of persons and objects in the digital world.

Important patents of the last two decades in the security technology field:

- US2017005804.A1 – Blockchain-based fintech payment methods
- US2009083847.A1 – Authentication solution for electronic devices such as smartphones



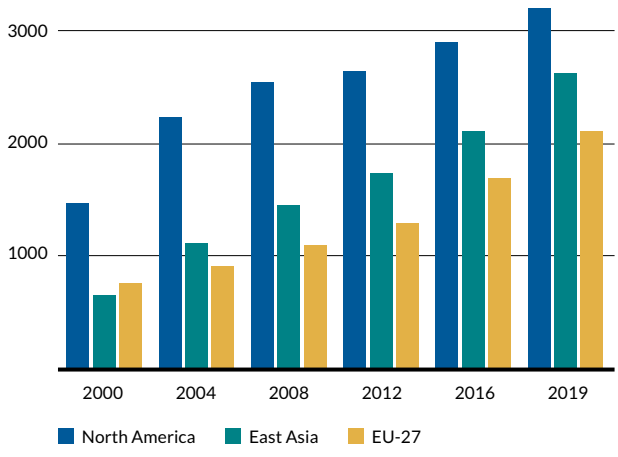
3.2 SECURITY

Economy and society alike are facing challenges in the wake of progressing digitalization of our working and living environments and the growing virtual contacts and interconnected systems it brings: We need to be able to verify that the people, companies, and products we deal with are genuine, that networks are secure, that information is accurate, and that means of payment have the promised value and cannot be counterfeited. In short, we need to create security in a digitalized world. Various technologies are used to protect information and end products.

It is vital for companies to be able to convince their customers of their products' authenticity and security. Product security covers all areas, from branded clothing and drug packaging to the production of banknotes and passports. The main task of network security is ensuring the protection of data. Digital transformation increases the number of connected devices in companies and private households. We use anything from smart heaters and language assistants to smart refrigerators. Each of these devices comes with its own issues regarding digital product security and consumer protection. What data are sent where? How do devices communicate with each other? How well is a digital device protected against attacks? Firewalls, anti-virus software, and encryption technology are used, among other things, make such connections secure. People and objects such as mobile phones, vehicles, and other items also must be authenticated in the digital world. Military security is another essential part of the technologies.

Germany and the EU show robust results in particular in the field of conventional product security. Although the 27 EU states had temporarily lost shares, they had, as in 2000 before, combined a bit more than 23 percent of all world class patents by 2019. Germany achieved a stable value of 11 percent across the entire determination period (Fig. 19). Banknote

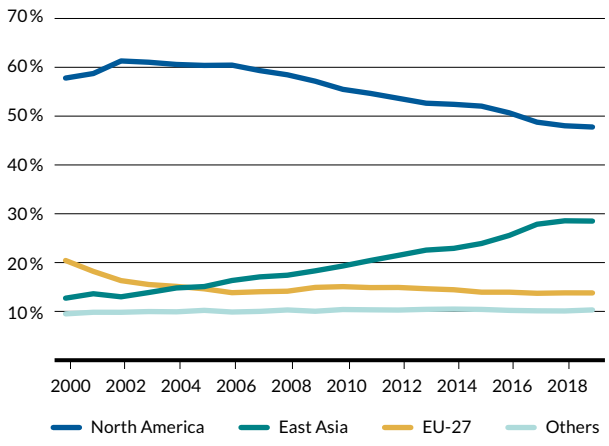
FIGURE 19
PRODUCT SECURITY
Number of world class patents



security is one of the largely undisputed German specialties. For how long, however, will at least a part of these security technologies still be needed? If old technologies such as banknotes disappear, this European bastion of traditional product security will fall. Analog products are already authenticated by digital technology. In the diamond trade, for example, blockchain is now used to ensure that the stones do not come from conflict regions.

The field is opening up to competitors from East Asia as digitalization of security technologies increases. In any case, China and its neighbors are expanding their share in the field at a rate of around 13 percent. While not as rapid as in other technologies, this is still disproportionate, and has enabled them to increase their share to 29 percent. North America, as the leading region, is suffering a clear loss of market share.

FIGURE 20
SECURITY
Shares of world class patents



After still growing for two years after 2000, developing from just under 58 to around 62 percent, its share has shrunk continuously to 47 percent in 2019. East Asia has long since left the 27 EU states behind. The EU still held a little more than a fifth of world class patents in 2000. It could not quite reach 14 percent in 2019 (Figure 20).

Cyber and computer security are impressive examples of how the USA has to give way to others in a former domain that it still ruled unchallenged at the turn of the millennium. It held around 70 percent of the world class patents at the time. In 2019, its share was still at 46 percent, while China's percentage was a relatively moderate 15 percent. However, taking into account that China's level was extremely, at 0.1 percent, in 2000, that it had entered the field with a single top patent and that it has since been surging into the field with a dynamic growth exceeding 40 percent per year, we can expect it to catch up with America sooner or later. The EU has kept its share largely constant across the 19 years. Fluctuations have been minor. Germany also kept its share stable at 2.6 percent, while France lost shares and dropped to 1.8 percent in 2019, after 4.5 percent in 2000.

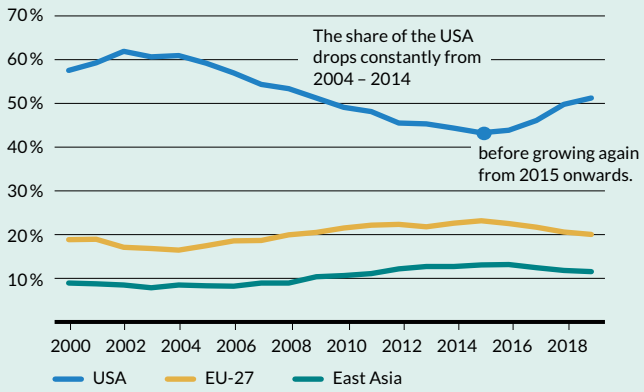
Number of technologies where the USA holds the most, second-most, and third-most world class patents.

USA

IN THE LEAD NEARLY ACROSS THE BOARD

The United States holds the largest number of world class patents, covering 50 of 58 technologies. It is particularly far ahead in the fields of health and security.

FIGURE 21
PRECISION MEDICINE
Shares of world class patents



WEAKNESSES IN NUTRITION AND ENVIRONMENT

If weaknesses can be found at all, they are mostly located in the technology fields of nutrition and environment. In this field, the United States had to give up its lead to China in two or three technologies.

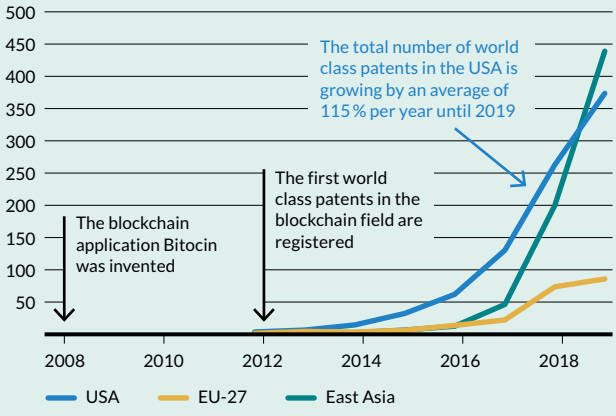
A SLOW DESCENT FROM A HIGH START

In 2000, the United States held the top position in 55 out of 58 technologies. In 2010 it held the lead in 54 cases, and in 2019 it had dropped to 50.

FLUCTUATING DYNAMICS

The number of American world class patents is still showing extremely dynamic growth in essential cross-sectional technologies connected to digitalization. The USA is also the only industrial nation able to keep up with China in where entirely new technologies are concerned. In other areas, such as the environment, the USA shows the weakest growth rates among the major economies.

FIGURE 22
BLOCKCHAIN
Number of world class patents

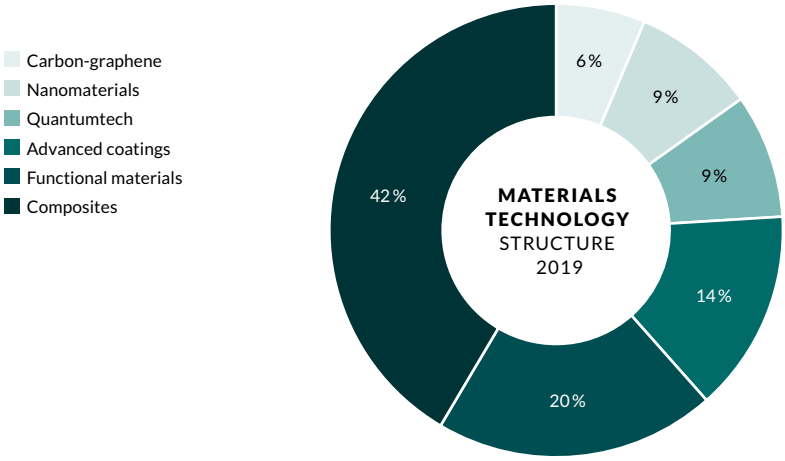


DEFINITION

The development of new substances and new materials is mainly driven by the chemical industry. Functional materials with certain properties such as conductivity (electric current, heat), elasticity, toughness, durability, luminosity, or reflection are particularly relevant. These materials may be crystalline or metallic. Very often, they are polymers. Composites that can combine different properties in one material (e.g. carbon fiber materials) are used more and more commonly now.

Important patents of the last two decades in the materials technology field:

- US6911271.B1 – Electroluminescent materials for organic light emitting diodes (OLED)
- US2008170982.A1 – Multifunctional nanomaterials

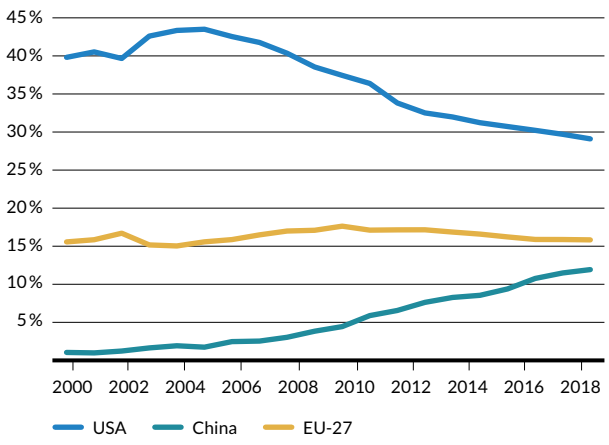


3.3 MATERIALS

Materials may be less obvious as an important basis for economic development than digitalization or faster networks. Different composites, functional materials or coatings are, however, indispensable for innovations in many parts of the economy. Modern materials increase solar cells and power plants efficiency while reducing the fuel consumption, and as a result the emissions, of cars. In fact, they have only made electric vehicles possible. They are setting new medical standards, among other things with long-lived implants. Sustainable materials are gaining in importance. New materials that can conduct electricity or heat, that are particularly elastic or tough, particularly long-lived or luminescent, are found frequently and in more diverse uses than before. Different properties can often be combined in a single material.

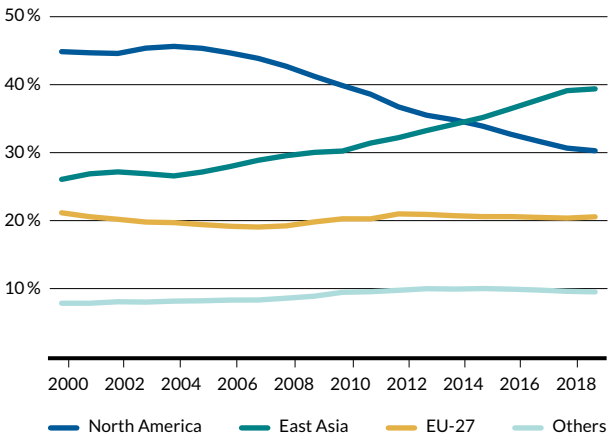
The example of carbon-graphene shows the diversity still abounding in innovations in the field of materials. The EU even managed to increase its share in this area slightly, achieving just above 16 percent of world class patents in 2019. China has caught up strongly, but at 12 percent still does not come even close to the USA, with its almost 29 percent (Fig. 23). Even Japan continues ahead of China. Germany remains fairly stable at 6 percent. The traditional division of labor still exists for materials in some areas, at least from a European point of view. Where carbon fiber composites are concerned, for example, this would look as follows: German chemical producers develop high-quality adhesives that are sent to China, where carbon fiber compounds are produced. These are returned to Europe for processing with high added value. Where innovations in the materials industry are concerned, the EU as a whole remains stable at around 20 percent of world class patents. The local market is dominated by many specialized small companies.

FIGURE 23
CARBON-GRAPHENE
Shares of world class patents



Ever shorter innovation cycles, driven among other things by new technologies such as additive manufacturing, are changing the traditional structure of production and the economy as a whole. Chinese researchers are now changing the odds in the field of nano- and quantum materials. East Asia's relevance increased in material technologies before it did in other areas, where significant dynamics often did not become evident before 2010. Its high growth rate has enabled East Asia to increase its share of patents for materials to almost 40 percent. In 2015, East Asia replaced North America as the leading region in this respect. North America's share dropped from 45 percent in 2005 to the current 30 percent (Fig. 24).

FIGURE 24
MATERIALS
Shares of world class patents



BOX 3

LCD, LED, OLED, … Material complexity in screen technology

The luminescent materials used for modern displays and energy-efficient lighting are a particularly important subgroup of functional materials. The conventional backlit LC display (liquid crystal display) is in the process of being replaced by self-illuminating LED displays (light emitting diode displays) with complex material layers in screen technology. Screens with LED technology have individual pixels, each consisting of three self-illuminating LEDs (red, green, blue). Blue LEDs proved a challenge for materials researchers for a long time. Japanese researchers Isamu Akasaki, Hiroshi Amano, and Shuji Nakamura received the Nobel Prize in Physics in 2014 for their development.

Carbon-based OLEDs (with O meaning "organic"), in contrast, are made of luminescent materials sprayed or printed onto a carrier and applied with a color filter. Very thin screens with high resolutions can be manufactured this way. However, organic carbon compounds are sensitive to water and oxygen, requiring elaborate sealing. Micro-LED technology (MLED), which is based on inorganic semiconductor materials, achieves better color and brightness values. Along with its extended service lives, this makes it a good solution for this weakness. Even so, the high pixel density of smaller displays and the expensive manufacture continue to pose a problem for micro LEDs.

Quantum dot light emitting diodes (often called QD LEDs) are an alternative. Quantum dots are dot-shaped round semiconductor nanocrystals. They can both filter light by color and convert electrical energy into light with special characteristics. While the generation of light and color as such is at the long-term focus of research, quantum dots are currently used primarily for light conversion. This process uses a nanoparticle layer made up of quantum dots to filter and color the light from blue LEDs.

Japan and Germany are leading in this technology. Merck KGaA, for example, has opened a plant in Darmstadt to produce the basic chemical elements required for OLED technology. It has acquired Israeli company Qlight Nanotech, a start-up of the Hebrew University, for its extensive know-how in the field quantum materials.

EUROPE

4. EUROPE

Concerns that Europe is falling behind in the digital transformation increase. This is happening at a time when the fourth industrial revolution is about to fundamentally change the traditional forms of economic activity. The expected gains from efficiency increase to be brought about by digital renewal are huge. However, digitalization is progressing only in tiny steps, especially in the EU. Europe is threatening to develop an innovation gap. Although it, and Germany in particular, has some leading companies in the processing industry and pharmaceutical fields, application of new digital technologies to traditional industries remains slow.

Comparing the development of the EU to the other two relevant world regions confirms this assumption. Health is the only superordinate technology field where the EU countries have not yet fallen behind their East Asian competitors. Important areas like digitalization make the gap particularly visible. The EU holds only about 11 percent of the patent volume there. This is half the score of East Asia and not even a third of the US share. The United Kingdom, the strongest European player in this area, has been lost to the EU by Brexit. The decline is particularly painful in areas where Germany and its neighbors once showed great potential, e. g. in batterytech, solar thermal energy and photovoltaics, and in environmental technologies such as recycling. It would, therefore, seem logical to discard Germany and Europe in the global competition for innovation.

But that would be too easy. Signs of change and hope are evident on the continent. Europe has a long tradition in research and development. After all, around 20 percent of the money that flows into innovations worldwide is spent here. Venture capitalists invest more and more in start-ups in London, Berlin, or Paris. The European industrial top dogs, now afraid that digital change will disrupt their business, are tackling new approaches.

Furthermore, the distribution of world class patents, especially in the technologies described below, also reveals where Europe and Germany show great resilience and continue to have the potential to keep up internationally. In addition to the already-mentioned field of wind energy, where Germany in particular excels as an innovation power, the country ranks second behind the USA in additive manufacturing, also called 3D printing, with a bit more than 15 percent. This brings the EU as a whole to 28 percent, which is 7 percentage points ahead of East Asia. As the home of some leading companies, Germany is a competitive location in the field of robotics. In creation of the smart and networked factory called smart factory, Germany holds a good position as a leading industrial site as well.

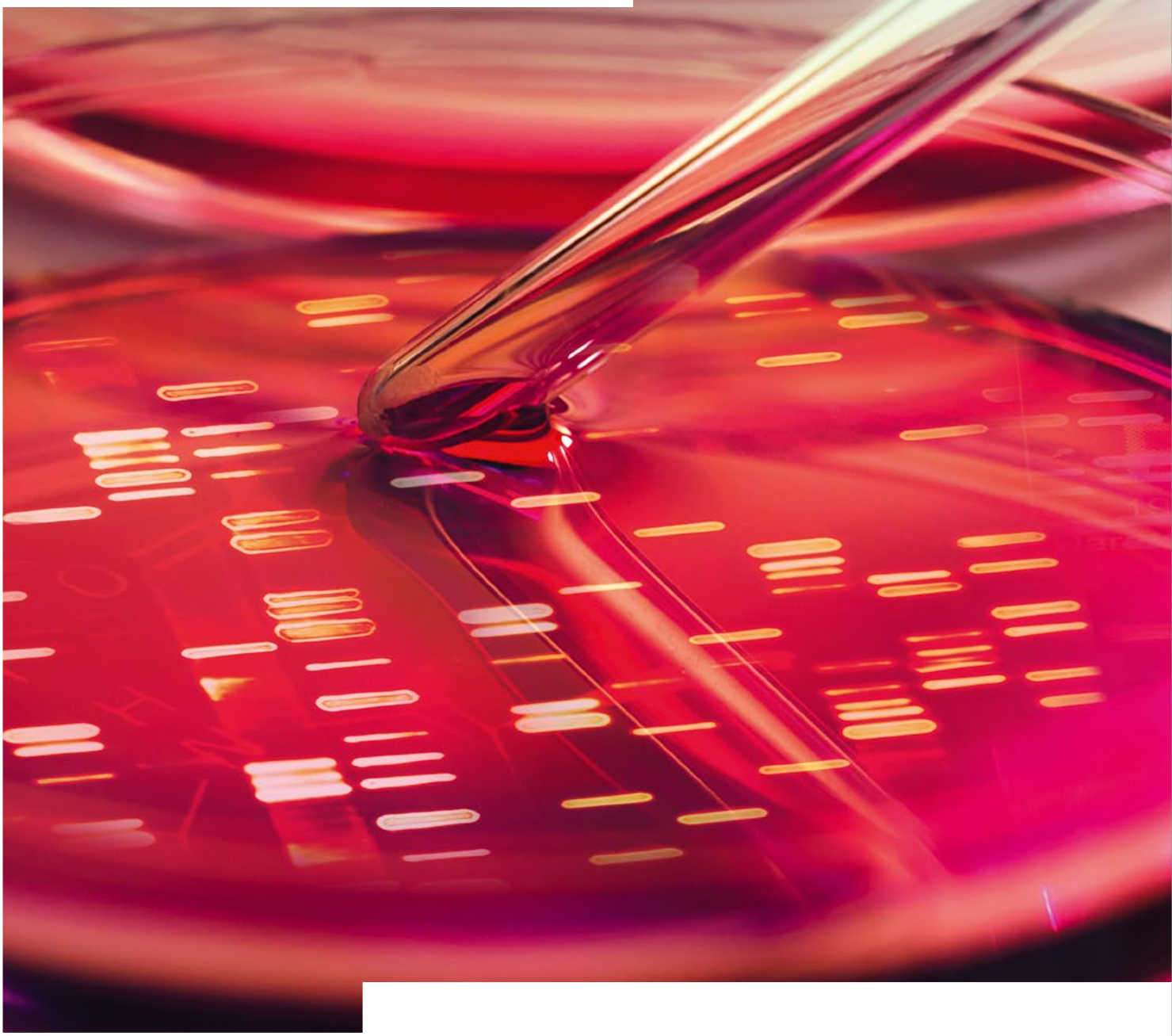
Europe has a strong tradition of industries that were not digital from the beginning, but that can now generate huge gains through clever digitalization. While North America and Asia are racing ahead, it is time for Europe to use its strengths wisely.

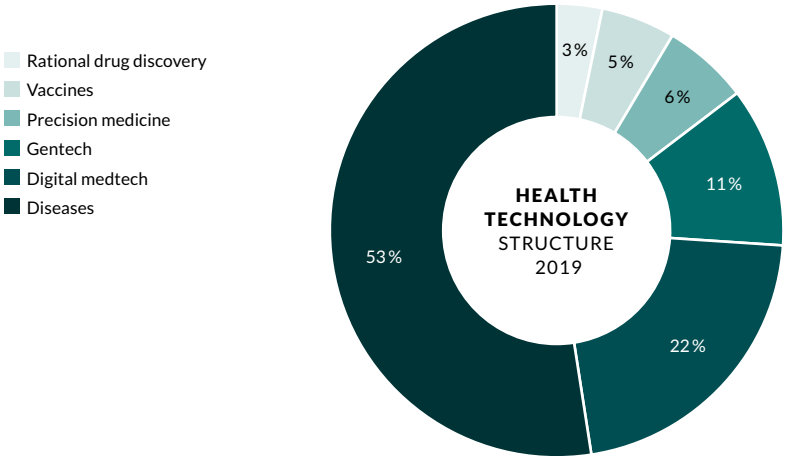
DEFINITION

Within the area of health technologies, the technologies at the interfaces between pharmaceutical and biotech technologies are particularly important. In particular, genome editing with CRISPR/Cas9 and gene therapy are being developed there. Applications of artificial intelligence in X-ray image analysis, medical additive manufacturing and robot-assisted treatments are of interest in the field of medical technology. Bioinformatics, drug design and vaccines are added to these.

Important patents of the last two decades in the health technology field:

- US2014179006.A1 – CRISPR/Cas9 as a method for manipulating DNA sequences in the genome
- US2010203056.A1 - Improvement of the function of T-cells (cancer research)





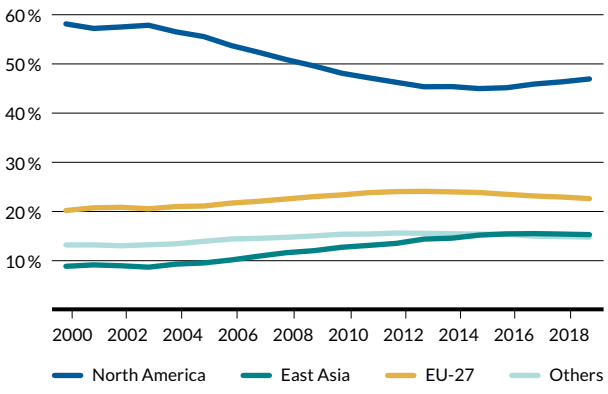
4.1 HEALTH

Health technologies are the only field where Europe remains ahead of East Asia. In the early 2000s, North America dominated the field with almost 60 percent of world class patents. It lost shares thereafter due to the positive developments in East Asia and in the EU (Fig. 25). In absolute figures, North America is still holding as many patents as East Asia and the EU combined. Growth rates suggest that East Asia will take the lead in the long run, but North America, as well as Europe, are still clearly ahead for the moment. One reason for this is that the high-quality innovations have been developed primarily by the large pharmaceutical companies based in the western industrialized countries so far.

Europe and Germany are particularly strong in vaccine technology, which is where attention currently focuses due to the coronavirus crisis. Europe is very dynamic in this field, in contrast to most other technologies. It has reduced the gap to the USA continually in the last few years (Fig. 26). German growth from a bit more than three percent of world class patents in 2000 to over ten percent in 2019 is amongst others associated with the name of the Tübingen-based company CureVac. The steep increase in the number of COVID-19 cases in the United States in March led to rumors that the US government wanted to secure exclusive access to the company's research. Although CureVac denied having received an acquisition bid of this kind (Dunn 2020), the episode impressively demonstrates the diplomatic pitfalls of the struggle for strategically important innovations.

It is also striking that patenting has declined sharply in the traditional healthcare sector, especially by well-known pharmaceutical companies. This is true, above all, of the major industrialized countries. While this does not mean that patent numbers in the health sector are not increasing overall, driven, e. g. by Asian medicine, the reduction in the traditional field indicates that the business model is changing there. Developments go towards individual, personalized medicine. Rather than the function of individual molecules, linking of molecular properties with the help of large databases has become essential for the development of new drugs (Bundesministerium für Bildung und Forschung, n.d.). Digitalization plays a decisive role in this context. The high public and private investments in the course of the coronavirus crisis could give an enormous boost to patenting in the conventional health sector.

FIGURE 25
HEALTH
Shares of world class patents



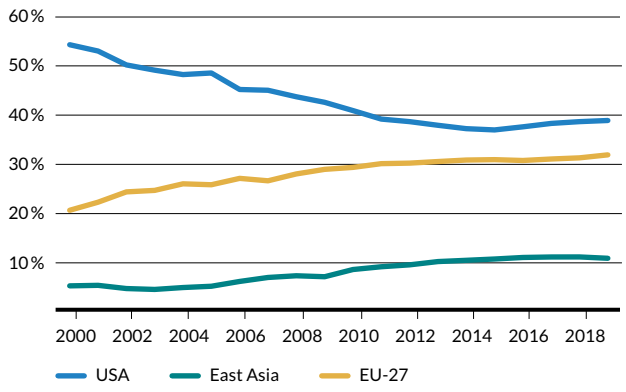
Large quantities of available patient data of increasing quality allow treatment of every patient in accordance with individual conditions, even beyond the functional diagnosis of the disease. Treatments can be continuously adjusted to recovery progress. The companies find themselves at the interface between pharmaceuticals and biotech. Gene therapy and genome editing (technical term: CRISPR/Cas9), a new method that enables specific modification of DNA, develop particularly well in this interaction, and bring about new dynamics in health technologies. Conventional development methods have little left to offer. They are increasingly being displaced by bioinformatics and rational drug discovery, which refers to the targeted development of active ingredients, often using artificial intelligence.

All in all, technology activities dominate in the field of serious diseases such as cancer or AIDS. Once again, the EU was able to slightly increase its share from 21.2 to 24.1 percent. North America's share has declined from 55.7 percent in 2000 to 42.7 percent in 2019. East Asia reached 16.5 percent in 2019, with China's share of 7.1 percent the largest contribution to this. Still, it is far from being as strong as it is in other technology fields. The USA clearly dominates with a share of almost 40 percent in a country-by-country comparison of world class patents. Germany, the United Kingdom, and China present similar figures.

In addition to this, medical technology and, as a result, the digital and industrial technologies are growing in importance. Artificial intelligence is appearing in force in this area, for example in x-ray analysis. This involves "feeding" the corresponding machines with a large volume of x-ray images and making them faster in the discovery of tumors by machine learning, in order to support doctors in their initial analysis. Moreover, the importance of medical additive manufacturing and robot-assisted treatments is increasing.

Looking at the dominant companies on the market, it stands out that although China as a whole is the most dynamic location in the field of health technologies, its growth is not driven by Chinese companies. Chinese innovation strength in this area increased due to the large international pharmaceutical and biotech companies such as Roche, Bristol-Myers Squibb, and Novartis, which align their research activities with the strengths of the respective locations. Their research institutions in China are becoming increasingly important in this. There are no Chinese companies among the leading innovation drivers in the pharmaceutical technology and biotech industries.

FIGURE 26
VACCINES
Shares of world class patents



Number of technologies in which the United Kingdom holds the most, second-most, and third-most world class patents.

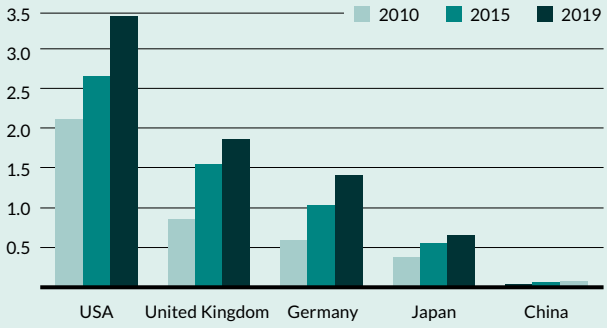
UNITED KINGDOM

STRENGTHS IN THE FIELDS OF HEALTH, DIGITALIZATION AND SECURITY

The United Kingdom is among the top 5 countries with the largest number of world class patents in all seven health technologies. It even holds the second-most patents for rational drug discovery. The United Kingdom holds four top 5 positions in digitalization and five out of six that are available in security technologies.

FIGURE 27
RATIONAL DRUG DISCOVERY

Countries with the largest number of world class patents per 1 million residents



WEAKNESSES IN MOBILITY, MATERIALS, AND INFRASTRUCTURE

The United Kingdom no longer has enough world class patents in any of the three fields to rank among the top 5 countries for even one technology.

A SHARP DECLINE IN THE PAST DECADE

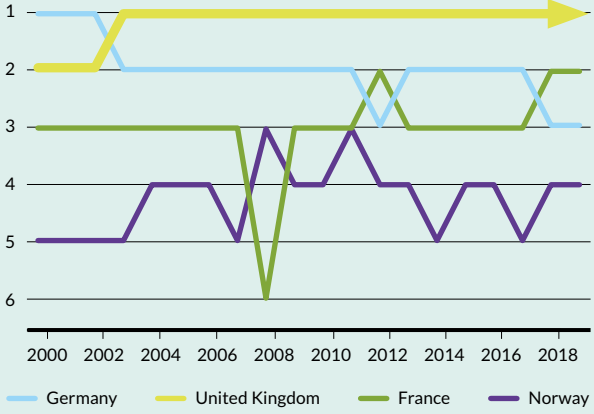
In 2000, the United Kingdom still ranked among the top 5 countries in 41 of 58 technologies. In 2010, it still held 40 places in the top 5, a number that almost halved to 21 by 2019.

THE FIELD OF ENERGY REMAINS STABLE

The United Kingdom's ability to maintain its share of world class patents in the field of energy technologies in recent years is particularly interesting in light of the almost completed, and so far successful, coal phase-out.

FIGURE 28
HYDROPOWER

Ranking of the countries with the largest number of world class patents within Europe

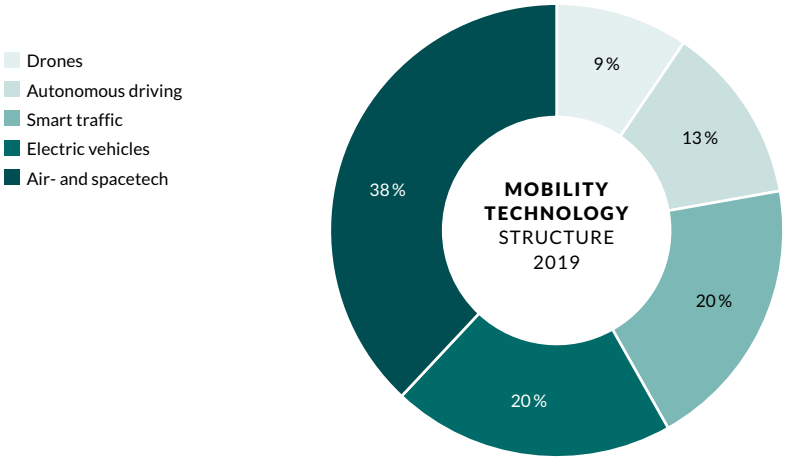


DEFINITION

Mobility includes the essential challenges of vehicle construction and new forms of mobility. In addition to new technologies such as autonomous driving and drones, traditional technologies such as air- and spacetech and electric vehicles can be found here. Autonomous driving goes beyond cars to include autonomous vessels and railways.

Important patents of the last two decades in the mobility technology field:

- US2012083964.A1 – Zone approach for autonomous driving to control driving
- US2010225271.A1 – Inductive charging device for electric vehicles

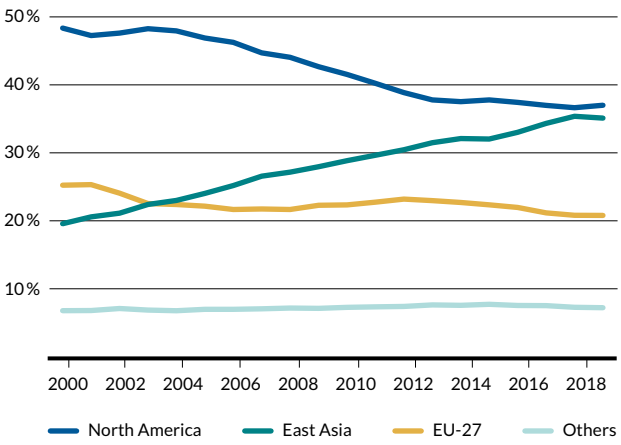


4.2 MOBILITY

There is still great uncertainty in the development of future mobility concepts. It is largely dependent on cultural influences and habits. One of the major moral questions concerning our future mobility can be seen as exemplary for this lack of certainty: What should an autonomous car do when it is faced with an unavoidable accident and has to decide whether it is better to hit a car in which a child is sitting with its parents, or to swerve, which would harm three elderly people instead of the family? There will be algorithms that will make that decision in a split second. It will depend on the preferences set by the programmers. However, the question as to which decision is preferable is answered very differently across the world. In most Western countries, the majority would be more likely to save a child. On the other hand, age is valued so greatly in countries like Japan that majority preferred to save the elderly in a survey (Huang 2018).

This exemplary question of principle is not the only item not yet determined: How will people want to travel in the future: Will they prefer their own cars, or will they use robot taxis? Will autonomously driving cars actually drive autonomously, or will they merely be an item in a centrally controlled traffic concept? Will car manufacturers continue to set the pace, or will they soon only produce the shells for the digital machines inside their vehicles? As these many unanswered questions show, the industry is undergoing rapid change, and the number of world class patents around the world has doubled in the last five years in this field. The target is not yet clear, and the battle for the lead among innovation locations is similarly undecided. At an overall share of 36.8 percent, North America is in the lead in this field. East Asia follows closely behind, with 35.2 percent. Although East Asia shows the greater growth dynamic, it is not large enough to call the race already over. At 20.7 percent, the EU is at least keeping up with developments (Fig. 29). In short, North America and Europe have lost ground in future mobility, but East Asia has not yet left them behind entirely, or at least not hopelessly far.

FIGURE 29
MOBILITY
Shares of world class patents



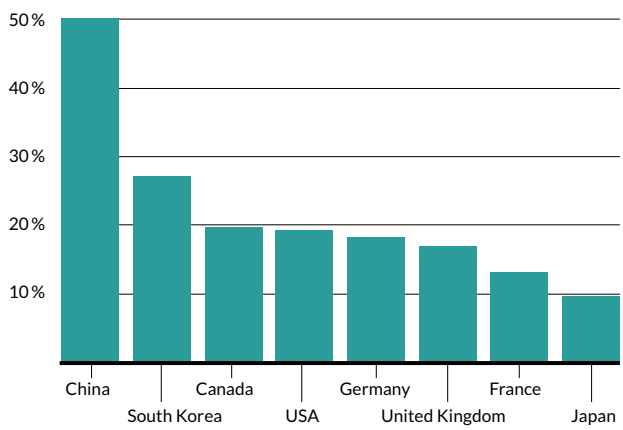
In this context, mobility encompasses all the main challenges of vehicle construction as well as the new forms of mobility. In addition to autonomous driving and the development of drones, this also concerns traditional technologies such as air- and spacetech. The turn towards electric vehicles is also considered. After a development phase that has continued for a while, a new dynamic is finally emerging there. Autonomous driving covers not only to cars, but also to vessels and trains. The field of electric vehicles includes the drives, while the batteries are part of the field of energy technologies. The new mobility concepts also include smart traffic, which refers to the interconnection of vehicles with their environment, traffic flow management, and navigation. Air- and spacetech is the largest field for innovations in mobility, followed by electric vehicles and smart traffic.

Different dynamics must be reconciled especially in the area of car traffic. Major impulses from IT companies are coming from the USA. Like Google with Waymo, its subsidiary for autonomous cars, they come streaming into this industry. They are facing off with the traditional car manufacturers, including those in Germany, who are struggling to digitalize and convert their production and their cars alike. At around 40 percent, the USA is the clear leader in the top patents for autonomous driving. Although they only show the third strongest growth after China and South Korea, they have steadily increased their share (Fig. 30). China comes in at 7.4 percent, while Japan's share has been cut in half as compared to 2000, leaving it at 15.3 percent. Germany makes third place behind Japan with just under 12 percent.

Japan's hybrid drive did not live up to the expectations to its success and sustainability. Still, Japan clearly leads the field with a 41 percent share of world class patents, after holding more than half the patents in 2010. The USA has lost a third of its share and now stands at 19.6 percent. It is well known that German manufacturers had a hard stance in e-mobility from the very beginning. Tesla brought electric cars that are capable of driving long distances into the spotlight more clearly than some traditional manufacturers could have wished. These are now trying to catch up with the leaders. Volkswagen, for example, plans to invest 3.5 billion euros in digitalization by 2025 (Fasse 2018).

Manufacturers must handle the fact that part of the added value, for example in batterytech, is no longer generated by them. Germany's share of patents for electric vehicles in 2019 was at around 11 percent, a bit more than half of the share from the year 2000. The traditional business field of car manufacturers are losing importance. They must become active into the field of comprehensive mobility concepts, which is new to them and where they are no longer able to set the pace alone.

FIGURE 30
AUTONOMOUS DRIVING
Average annual growth rate of world class patents (2010-2019)



Number of technologies where France holds the most, second-most, and third-most world class patents.

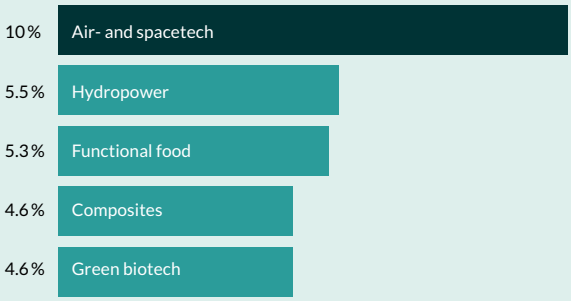
FRANCE

STRENGTHS IN NUTRITION AND HEALTH, OUTLIERS IN AIR- AND SPACETECH

France is among the top 5 nations in world class patents in two nutrition and three health technologies. In the field of nutrition, these are green biotech and fertilizer. In the field of health, they are precision medicine, vaccines, and diseases. France even ranks second air- and spacetech in the field of mobility technologies.

FIGURE 31
AIR- AND SPACETECH

Technologies in which France holds the highest proportion of world class patents internationally (2019)



WEAKNESSES IN DIGITALIZATION, INDUSTRY, AND INFRASTRUCTURE

France has lost its top 5 positions in all technologies from these three fields. In the fields of materials, security, and environment, the country is only able to hold on to one top 5 technology each.

A STEADY DESCENT

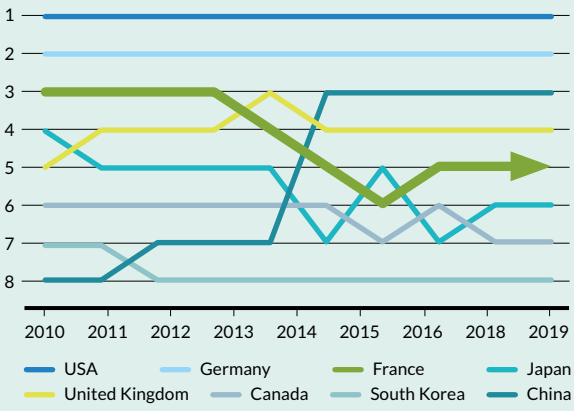
In 2000, France and the United Kingdom were among the top 5 countries in 41 of 58 technologies. In 2010, that number had already dropped to 19 for France, which is less than half the original figure. In 2019, it only had twelve places in the top 5.

PARTICULARLY SEVERE LOSSES IN THE FIELD OF SECURITY

In 2000, France was still the country with the third-most world class patents in five of the six security technologies. In 2010, it had lost all top 3 places except for defense. Today, France occupies only fifth place there anymore.

FIGURE 32
DEFENSE

Ranking of the countries with the largest number of world class patents

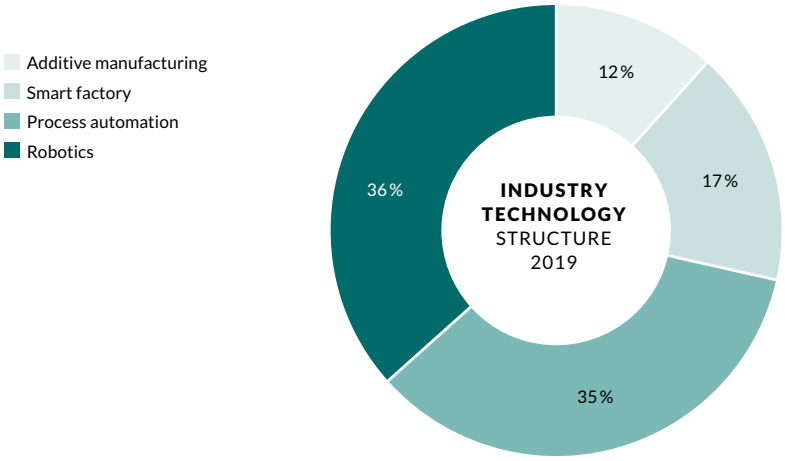


DEFINITION

The technology field industry focuses on modern production technologies in a connected environment. This is not so much about the specific production of objects, and more about the requisite processes, including control systems, robotics, additive manufacturing, and the smart factory.

Important patents of the last two decades in the industry technology field:

- US2017129702.A1 – Use of robotics for the transport of storage bins
- US2015097315.A1 – Additive manufacturing method



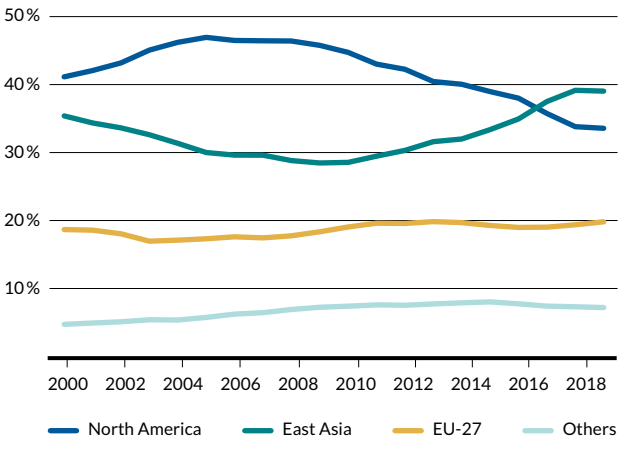
4.3 INDUSTRY

Industry 4.0 will soon come true in Karlsruhe, at least in a research factory to be founded by scientists from the Karlsruhe Institute of Technology (KIT) together with researchers from the Fraunhofer Society and company representatives. They want to find out how the smart factory concept, i.e. the interconnected, customer-oriented, and self-optimizing factory, can be transferred to the country's factories as efficiently as possible. This know-how seems to be vital. After all, studies keep finding that although the persons in charge have realized by now that they cannot avoid this new type of industrial manufacture, developments rarely progress beyond pilot projects, digitalization projects are not connected and are poorly coordinated (Mersch 2019). How are machines supposed to connect if even people do not?

The processing industry is the field in which Germany could make full use of its locational advantage. It is, however, uncertain whether the companies with their predominantly medium-sized structures can match the global dynamics. Digitalization has not played a leading role for a long time for many traditional mechanical engineering companies. In contrast to the large car manufacturers, which have also shown great reluctance to become involved for the longest time, most of the medium-sized enterprises simply cannot simply cough up several billions to make up for past omissions.

Significant movement in industrial technologies is visibly lacking almost worldwide in the first half of the period under observation until 2010. Only in 2011 did the dynamics in the three major regions significantly increase, with the result that the number of patents has doubled in the last five years alone. Once again, the steep growth East Asia has seen since 2011 is particularly evident. This has allowed to region to take away North American leadership in industrial cutting-edge technologies in 2017. East Asia now holds 39 percent and North America holds 33 percent of the patent volume. The EU has slightly increased its percentage over the years. It is currently stabilizing its share at around 20 percent (Fig. 33). This puts the Europe behind the two leading regions, but with a chance to catch up again, and with better growth rates than second-placed North America.

FIGURE 33
INDUSTRY
Shares of world class patents



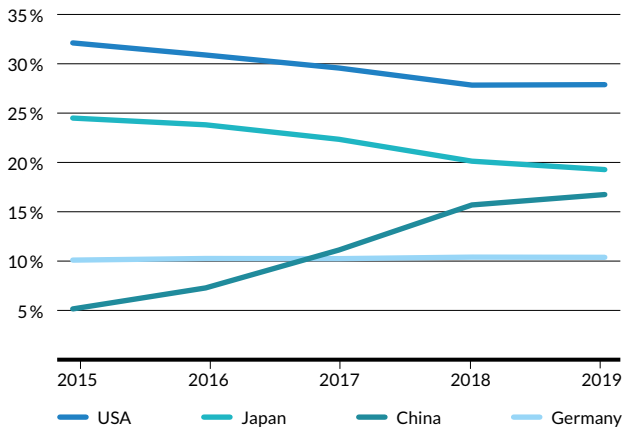
We believe that the most important focus in industry is on modern production technologies in a connected environment. This is not so much about the specific production of objects, and more about the requisite processes that include controls, robotics, the smart factory, and technologies such as additive manufacturing. Robotics holds the greatest share among the industrial technologies, followed by process automation.

Where patenting of these technologies is concerned, the question also arises of where the important impulses for future development are going to come from: Will they originate among traditional robot manufacturers now digitalizing their machines, or with large IT companies in search of applications for their information technology? Global market leaders like Japanese electronics and mechanical engineering company FANUC or robot manufacturer KUKA from Augsburg, which is majority-owned by Chinese Midea Group, develop their own digitalization concepts. The USA leads the robotics patents with 27.7 percent in a comparison on country level. At almost 50 percent, China has the highest average annual growth rate to show. It holds around 17 percent in world class robotics patents. Japan is only slightly ahead of it with 19 percent. Germany remains stable at 10.5 percent.

Some medium-sized companies suffer from the fact that they have neither any qualified personnel nor the capacity to develop the AI-driven intelligent factory in-house. The robotics companies are reacting to this, with KUKA already offering a complete and variable smart factory as a service for such cases. However, experts are pointing out that German industrial companies must expand their expertise in mechanical engineering with in-depth knowledge of artificial intelligence in order to maintain their leading role. The country shares of world class patents in the smart factory are similar to those in robotics. Germany was able to keep its share stable at a bit more than ten percent. In spite of reduced shares, the USA remains in the lead, followed by Japan and China, which held only nine top patents in 2010. With 1,135 patents, they have now reached more than half as many as the USA has to offer. (Fig. 34).

A great opportunity for Germany lies in additive manufacturing, the smallest segment of industrial technologies. A larger proportion of companies than in any other industrialized country are already using the technology there. Chemical companies, software manufacturers, gas companies, the leading additive manufacturing companies, and industry customers are already cooperating well. The question now is whether this industry is strong enough to shape additive manufacturing into a new German core industry on the global market. Germany has already managed to significantly increase its share of world class patents, from just under 10 percent in 2000 to 15.5 percent in 2019. This leaves Germany in second place behind the USA. It is about twice as strong as Japan and China with 8.7 and 7.8 percent, respectively. So far, the new technology fits perfectly into the German mechanical engineering expertise, the manufacturing and value-added chains of the German world market leaders in the processing industry. Chances here are better than anywhere else.

FIGURE 34
ROBOTICS
Shares of world class patents



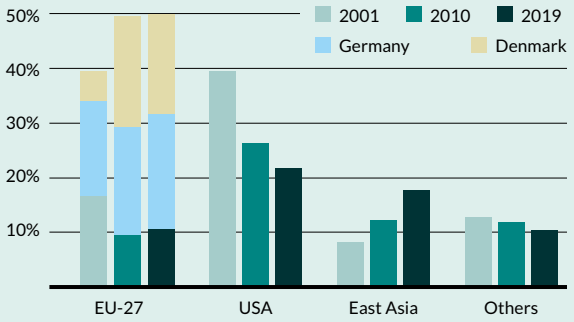
Number of technologies where Germany holds the most, second-most, and third-most world class patents.

GERMANY

STRENGTHS IN THE FIELDS OF HEALTH AND WIND ENERGY

Germany makes second place in out seven of the 58 technologies under examination. It is particularly strong in wind energy, where Germany is extremely close behind the USA, with 958 to 991 world class patents and accordingly high shares. The gap with the United States is larger in its four second places in the health field (precision medicine, gentech, vaccines, diseases).

FIGURE 35
WIND ENERGY
Shares of world class patents



WEAKNESSES IN DIGITALIZATION AND INFRASTRUCTURE

Germany has lost its place among the top 3 countries in all technologies in these two fields. In the field of digitalization, it only makes a top 5 place in two of the six technologies (artificial intelligence, virtual/augmented reality).

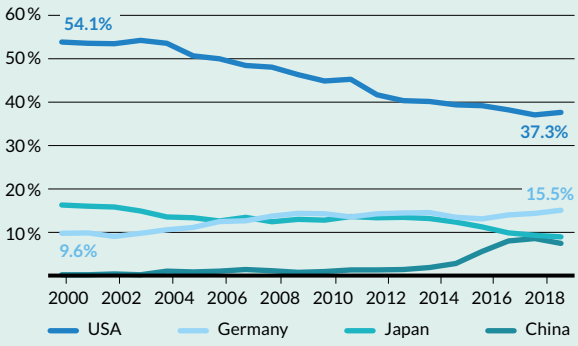
A STRONG DECADE, A WEAK DECADE

With 43 out of 58 technologies, Germany was among the top 3 countries in terms of world class patent numbers in 2000. In 2010, the country once again improved slightly, even reaching 47 top 3 places. By 2019, that figure had dropped to less than half, remaining at only 22 technologies.

HARD-PRESSED IN THE TRADITIONAL STRENGTHS OF MOBILITY, AND INDUSTRY

Germany used to be among the three leading countries in all technologies from these two fields in 2000 and 2010. The country remains strong in individual technologies from these fields, but makes the top 3 places far less often now.

FIGURE 36
ADDITIVE MANUFACTURING
Shares of world class patents



EUROPE

0 COUNTRIES ARE NOT STRONG ENOUGH TO HOLD A 1ST PLACE ON THEIR OWN

Not a single European country occupies the top position among the 58 cutting-edge technologies where world class patents are concerned. Germany comes closest with its strength in wind energy. However, only three countries (USA, China, Japan) with larger populations and greater economic results occupy the top positions.

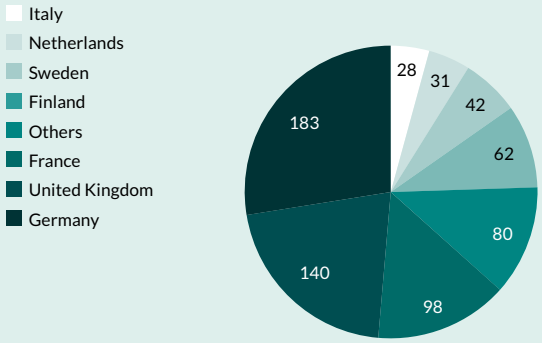
2 THE EU-27 ARE MORE COMPETITIVE AS A COMMUNITY

The EU-27 as a whole at least holds the largest number of world class patents in two technologies, which is more than research-intensive nations such as the USA, China, or Japan. Germany and Denmark contribute the largest share in wind energy technology. Success is carried communally in functional food: In addition to the usual strong countries Germany and France, the Netherlands, Italy, Denmark, Belgium, Spain, and Sweden also hold more than 100 world class patents each here.

FIGURE 37

VIRTUAL/AUGMENTED REALITY

Number of world class patents within the EU-28 (2019)



5 BREXIT MAKES A DIFFERENCE

The EU-28 (including the United Kingdom) were even stronger. Together with the island state, they were able to hold five top positions, in hydropower, biocides, and composites in addition to functional food and wind energy. However, the loss of United Kingdom's strength in the cross-sectional cutting-edge technology of digitalization will surely weigh more heavily than the loss of these top positions.

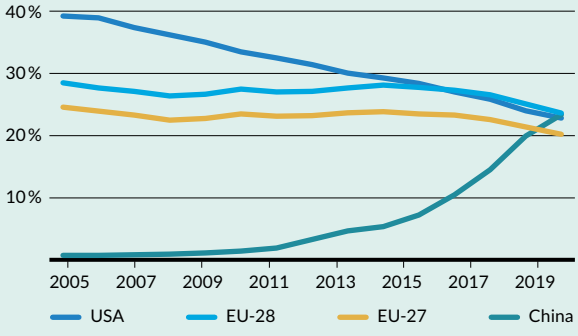
12 EUROPE AS A CONTINENT IS THE LEADER IN ENERGY, NUTRITION, MATERIALS, AND ENVIRONMENT

Adding up the world class patents of all European countries, Europe would still take first place in 12 out of 58 technologies. Four top positions in the energy field would be followed by two each in nutrition, materials, and environment, and one each in health and security.

FIGURE 38

WASTE MANAGEMENT

Shares of world class patents

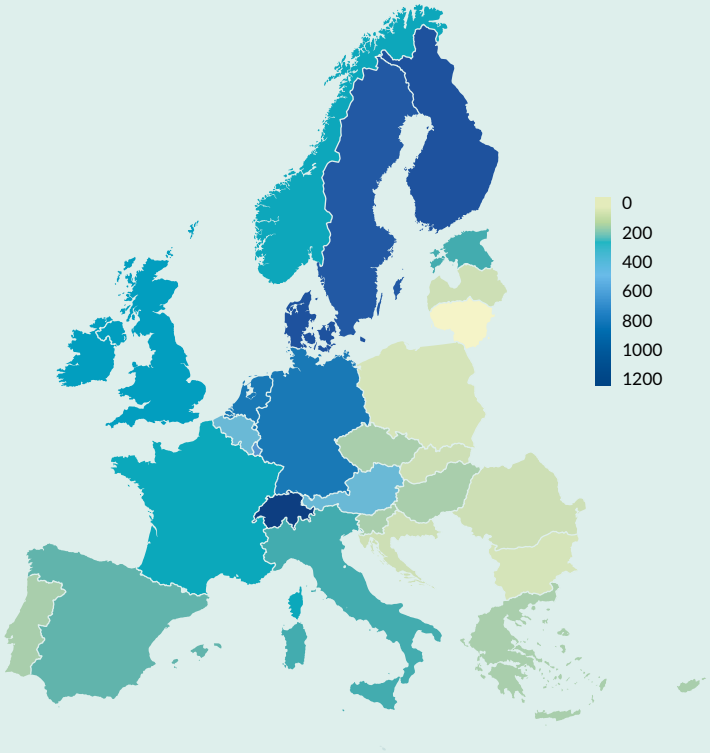


HARDLY ANY RESEARCH IN EASTERN EUROPE

Research and world class patents within Europe are generally concentrated in Northern Europe, while world class patenting activity is very low in Southern and Eastern Europe.

FIGURE 39
RESEARCH ACTIVITY IN EUROPE

Research activity measured in world class patents per 1 million residents (2019)



SMALL COUNTRIES SPECIALIZE

Smaller EU countries often specialize in certain technologies, with a focus on only one or a few lighthouse companies (e.g. Ericsson and ABB in Sweden, Philips in the Netherlands).

SWITZERLAND AS AN EXCEPTION

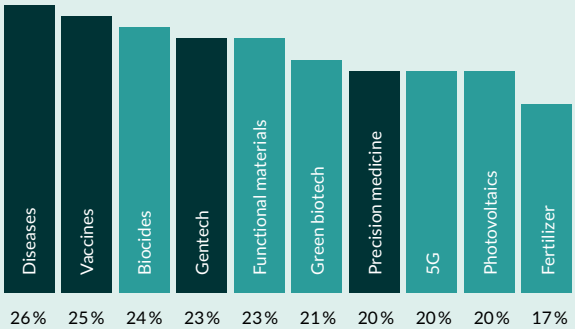
Switzerland stands out as a small country. Calculated based on the number of residents, its count of world class patents is significantly higher than that of other nations with strong research. Switzerland also has a broad basis and covers in particular the fields of industry, materials, digitalization, and health very well, where it achieves high global shares.

STRENGTH THROUGH EU-WIDE COOPERATION

International research cooperation is already an important contributor to European patent success. Especially in the field of health, where Europe performs very well by international comparison, the proportion of world class patents developed by researchers from several EU countries together is high.

FIGURE 40
RESEARCH COOPERATIONS IN THE EU

Shares of world class patents with researchers from at least two EU states (2019)



5. CONCLUSIONS

This study corrects the image of global innovation. While focusing on particularly valuable and relevant patents does not overthrow all that has been assumed so far with regard to the relevance of the world regions and the most important locations for research and development. It does, however, highlight the essential aspects. On the one hand, focusing on world class patents can support a more sober view whenever another alarming report on China's crushing economic dominance appears. After all, a large proportion of the patents filed there are either hollow or simply irrelevant and do not play any role here.

However, that does not mean that challenges are nonexistent. On the contrary, the power and dynamics of China and Southeast Asia as revealed by this study must be taken all the more seriously. Even after selection of the particularly high-quality and internationally relevant patents, South East Asia has already overtaken North America in some cases and comes close to doing so in others. China and its neighbors, with South Korea first among them, are developing more dynamically than their American competitors – and Europe – in nearly every single field. Countries outside of the three world regions mainly considered here and holding the highest patent power can hardly challenge this dominance. This clearly shows: The international division of labor has led to a certain diversification of the global innovation power towards East Asia, but by no means to a broad global distribution.

However, we are not the only ones to analyze this matter. The index of the most innovative countries published by the business news service Bloomberg, for example, recently showed Germany as displacing South Korea from the top position (Jamrisko and Lu 2020). Many observers see this as a welcome opportunity to highlight Germany's strengths as a location for innovation: High generation of added value in industrial production, many domestic companies in the high-tech sector, high spending on research and development, and – last but not least – a large number of patents. Germany makes a very good third place behind the United States and the People's Republic of China in the Bloomberg ranking, which puts the number of patent applications in relation to the size of the national economy. Does that mean that there is nothing wrong with Germany's innovation power?

This question cannot be answered with a clear yes or no. In any case, nothing is lost yet. Germany and Europe can certainly use their strengths in the development of cutting-edge technologies in the international comparison. However, both also reveal weaknesses that give reason for concern. Nothing is gained by overlooking or talking down these deficits because Germany does well in some ranking or another. If Germany and Europe are not to be viewed as mere spectators in the competition between the major innovation locations, they must take a proactive approach to tackle their weaknesses. Otherwise, developments will move beyond a relative reduction in international comparison of cutting-edge technologies and could lead to a loss of economic significance, which could ultimately weaken confidence in the social market economy and representative democracy.

Germany and Europe must remain active to improve their weaknesses in vital cross-sectional technologies such as digitalization. Moreover, intensifying efforts especially in those areas where they are already relevant innovation drivers internationally may pay off. This will allow a significant increase of their share in the development of cutting-edge technologies and enable them to keep up with the competition. Under no circumstances must Europe and Germany endanger their previous strengths in some sectors through incorrect decision making or negligence. In light of this, we consider the following three recommendations to be particularly important as an impetus for discussion.

I. Developing European and international cooperation

The study shows that individual European countries do not stand a chance on their own when going up against the top dog USA and the dynamics from Asia in the international research and technology competition in most promising technologies. But jointly, Europe can play a role in many technologies. European countries often are clearly positioned well within the scope of their possibilities. They should pool and exploit their strengths on a European level.

Key digital technologies are not among the strengths of their research and development. Europe must not surrender to this issue. This would not merely mean dropping the ball on some technical development that can be confidently left to others. Artificial intelligence, virtual reality, and quantum computing are particularly important as cross-sectional technologies. They form the basis for many other promising developments. Without mastering these, Europe will prevent progress. Quick action is needed to avoid falling behind. That action must be in the scope of a more ambitious European digital strategy, rather than on a national level.

Germany and Europe must work consistently on improving their weaknesses in the indispensable cross-sectional technologies such as digitalization.

While Europe combines great knowledge about building international cooperation programs, with examples including “Horizon 2020”, the EU’s funding program for research and innovation, and its successor “Horizon Europe”, the European innovation landscape is too fragmented. Brexit is likely to exacerbate the problem, particularly regarding digital technologies, where the United Kingdom is comparatively

strong. At the same time, other economic regions are increasingly relying on state support for innovations: They support public and private institutions in the technology industry, boost domestic innovations with the state's market power, or give venture capital to young research-intensive companies (Bertelsmann Stiftung 2020a).

To react to this, the member states and institutions of the EU should think and act more strictly on a European level. What Europe needs is more consistent and effective cooperation, always aimed at creating synergy effects. This can be achieved in research cooperation, but also with a coordinated innovation strategy. The joint internal market is large, but the countries of Europe must use and strengthen it in order to compete with other world regions and to enable disruptive innovations with a potential of fundamentally changing technology and society and render them more resilient to crises.

European cooperation does not mean that cooperation should stop at Europe's borders or be at the expense of weaker regions. The coronavirus crisis may even reinforce or trigger separation tendencies out of a misplaced assumption that this will increase control over one's own fate. Separation does not make an economy and society more innovative. On the contrary: International competition and the exchange of ideas are indispensable. This includes keeping an open attitude towards foreign direct investment or the establishment of foreign companies. In the best case, they will bring money and other resources for innovations or import their new developments to Europe (Bertelsmann Stiftung 2020b).

In spite of their weaknesses as pointed out in this study, Germany and Europe still maintain outstanding research sites and a vibrant science scene.

II. Better application and commercialization

Despite the weaknesses pointed out in this study, Germany and Europe continue to maintain some outstanding research sites and a vibrant science scene, especially in the technology fields of health, mobility, and industry. They produce many good ideas, though application and commercialization are often lacking. The United States in particular, but increasingly also China, is often faster at turning new ideas into successful products and companies.

In order to bring more promising approaches to market maturity, one needs to be open and bold about business ideas, including those that may seem absurd at first. This requires a positive attitude towards entrepreneurship. People willing to found a company must be encouraged and supported. Lack of success must not be considered as failure. While closely connected to mentality and a general culture of innovation in the society, this also depends on specific support: Founding start-ups with a scientific background must be made easier by improving the interlock between research and market perspectives. Researchers should be encouraged to improve mar-

keting of their ideas as well. This includes better interconnection of basic research at universities and institutes with applied research and development that can be found within companies. However, adequate university funding is a vital prerequisite for top-level research. Beyond this, the financial and infrastructural support for start-ups, especially in the high-tech field, must be improved.

III. Combining innovation and societal progress

Germany and its neighbors are connected by more than just commercial economic interests. Europe is more than just an economic area. Historical and cultural similarities characterize our interaction based on values that fluctuate only little. As a result, the technology battle is not just about chasing after standards set by others. Innovations also must be aligned with the needs arising in our societies. From this point of view, innovation is more than just a competition to reach a pre-defined target. Innovation also means that our society is working out the path that we want to follow with the help of research and development. The dramatic break left by the coronavirus crisis offers an opportunity to review and shift societal priorities in this context.

This crisis is at the center of public attention at present, as it should be. However, we must not lose sight of the other challenges Germany and Europe, as well as other countries and regions, are facing at the same time. While demanding a great deal of us, these also offer many opportunities: Digitalization is changing everyday life; demographic developments are making it harder for welfare states to operate; globalization

Innovations also must be aligned with the needs arising in our societies.

is bringing new markets and new competitors alike, and climate change is threatening civilization as we know it. The cutting-edge technologies described are a key to mastering many of these developments and issues, and to making our lives easier. Modern, ambitious innovation politics should, therefore, aim not only at challenging targets in the economy, but also in society. This could also help us move away from perceiving digitalization primarily as a risk or threat, and towards viewing it as an opportunity. People will benefit most if the state, economy, society, and science tackle the tasks that lie ahead of them together, be they health for all, nutrition, or climate protection. All the thinkers and developers contribute, knowing that they are helping to shape an economic development that is humane, fair, and democratic. The momentum is available. After all, the call for expertise is louder than it has been for a long time at the moment.

METHODOLOGY

WORLD CLASS PATENTS IN CUTTING-EDGE TECHNOLOGIES

Patent analysis is an unparalleled opportunity to consistently track key technology trends, both globally and at country level. Conventional methods of patent analysis, however, look only at the number of patent applications for specific patent classes or general technology fields. Apart from this, such analyses fail to consider the country-specific differences of patent offices. This leads to less than satisfactory results. For example, incremental progress is patented more frequently in Japan than in other countries. In China, tax breaks are a method to encourage researchers to patent as many inventions as possible with the goal of making China more relevant as a research location (Fischer 2018). Merely measuring patent activity with a focus on new patent applications exaggerates the role of certain countries and distorts the general image. Furthermore, relevance of the individual inventions is not considered if all patents are counted the same. On top of this, technological classification is vague at best and does not lead to any new insights. As a result, such traditional approaches measure activity rather than quality.

EconSight focuses on the quality of research in this study conducted for the Bertelsmann Stiftung. This is the first time that big-data analyses are applied to provide a new view of the technological landscape while avoiding the deficits found in the patent analyses of the past.

Focus on world class patents

The analysis is based on a new scientific approach by the PatentSight GmbH. It evaluates each patent's strength worldwide (Ernst and Omland 2011). This way, the quality of individual patent families can be assessed in a weighted and standardized manner in comparison to all other patent families worldwide. This study uses the terms of patents and patent families interchangeably. Technically speaking, the correct term is "simple patent family" or "simple family". A "simple family" is a group of patent documents covering a single invention with identical technical content. The patents of a "simple family" all have exactly the same priority. The priority period commences with the first application for an invention in any country. The applicant has the right to patent the same invention in other countries within the following twelve months. He may claim the priority date of the first application for such subsequent applications, which means that this priority date will be observed for novelty assessment of the later applications' inventions.

Quality of the individual patents is determined based on market coverage and technological relevance. Market coverage refers to the worldwide legal coverage of patent protection, determined by the number of countries with active property rights (scope and extension of the patent family). This reflects how companies and state research institutions assess the importance of their own invention. The higher the number of countries in which the patent application is filed, the more expensive patent protection becomes. A broader international market coverage thus indicates that the patent applicant considers his patent to be promising (self-assessment). The technological relevance of a patent is determined by how often the examiners at the various patent offices refer to it and cite it. Examiners at the various patent offices use relatively similar methods to check whether a pat-

ent application is new and inventive, and use other, previously published patents. This reflects the relevance of an invention as compared to other patents in the same technology (external assessment). The combination of market coverage and technological relevance ("individual patent power") suggests the impact of a patent family on competition.

The relative assessment of worldwide patents based on individual patent power leads to quantifiable classification into important and less important patents, avoiding the distortions in the patent system as described above. EconSight focuses its analysis on the world class patents: These comprise the best 10 percent of all patents within a defined technology, measured by individual patent power. This group of patents can then be assigned to countries.

Detailed technology definitions

Most patent analyses use either vague technology fields or very specific patent classes. Either concept has its advantages and disadvantages. The established World Intellectual Property Organization (WIPO) technology fields structure the patent landscape into broad categories. They help identify which general research priorities are found in different countries. However, they are not sufficiently up to date to derive any statements about the sustainability of technologies. While individual patent classes make up the core of the patent classification system, they are too technical and often too specific for strategic analyses. By developing specific technology definitions, EconSight therefore chooses a middle ground between both concepts in order to capture the technological activities of companies, research institutions, regions, and countries. Each technology is developed individually and based on queries of a number of patent classes and subject-specific keywords. If necessary, this definition is reviewed for plausibility by other experts before the patents are identified, among other things using AI-based application from cooperation partner Averbis GmbH. The last step is a quality control review of the results. 58 technologies were defined for this study. They are connected to current technology trends that are important according to a debate of economic policy, and that accurately reflect technical progress in terms of the particularly relevant cutting-edge technologies together.

Active patent portfolio instead of new applications

This analysis identifies and counts the patents based on the reporting date concept. This means that all active and published patent families and patent applications are included in the analyses annually as of December 31st. Patent families are counted if they have at least one legally valid patent or pending application. This procedure differs from other patent analyses that may, for example, only count new patent applications per year or use all patents – including inactive ones. Instead of only measuring the de-

Merely measuring patent activity exaggerates the role of certain countries and distorts the general image.

velopment dynamics, our approach focuses on the absolute size and power of a patent portfolio at the respective time. The study shows time series from 2000 to 2019 while the 31st December is the reporting date (2019: September 9th). All patents published and granted up to the respective date, as well as any pending applications, are identified for each point of time. All patents from previous years that continue to be active are also included.

Country allocation based on inventor address

A patent is the result of research work usually involving several researchers. These often do not all come from the same institution, and sometimes not even from the same country. A decision must be made on how to count such patents, and to whom they should be attributed. Geographical allocation is based on the places of residence of the inventors involved in this study. If, for example, a patent names researchers with an address in Germany, the patent will be assigned to Germany. In the case of a research cooperation with additional researchers from other countries, the patent will be assigned to those countries as well, under the assumption that the technology competence is available in each of the countries involved. The registered office of the filing party is irrelevant for this analysis. For example, only researchers resident in the USA may have been involved in a patent held by a company based in Germany because the company has a research location in the USA. In this case, the patent would be assigned to the USA since the research took place there exclusively. At this time, exclusive software patents can only be filed and granted in the USA. However, foreign companies may apply for software patents there, and they use this option accordingly.

A patent can be produced by researchers from different institutions and countries.

International research cooperations generally can either be counted proportionally, with only a fraction of a patent attributed to each participating country, or fully, in which case the patent is fully attributed to each participating country. This study uses the full count method. As an example to illustrate the advantage of a complete count below: A country with internationally well-connected companies or research institutions would be allocated significantly fewer patents in the fractional count than a country whose companies conduct purely domestic research. The full count ensures that in particular international research cooperations, which generally achieve significantly better results, are given due consideration. A disadvantage of the full-count method is that the sum of the countries' patents is about 10 percent higher than the effective global patent number. Since this analysis focuses on the comparison of countries, this effect is negligible.

OVER VIEW

OF ALL 58 TECHNOLOGIES

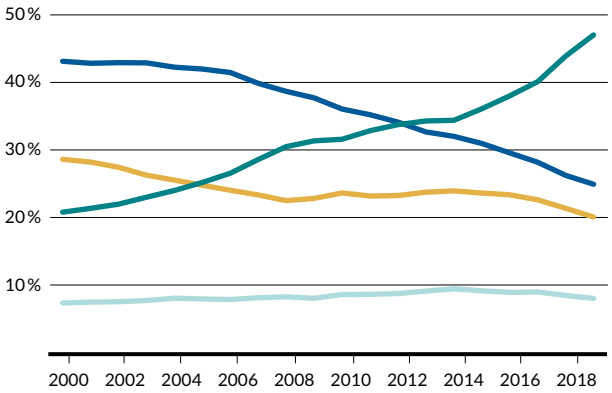
Since we were unable to go into every single one of the 58 technologies in detail and with graphic illustrations in the text, we have listed the definitions and the development of the regional patent portfolios below for each technology.

ENVIRONMENT

WASTE MANAGEMENT

Waste management means the management of solid, gaseous, or liquid waste. The technology covers all types of industries and fields, from food and household waste, to the purification of air, smoke, and exhaust gases with purifiers or catalysts, to disposal processes for solid waste, waste containers, or waste transport vehicles.

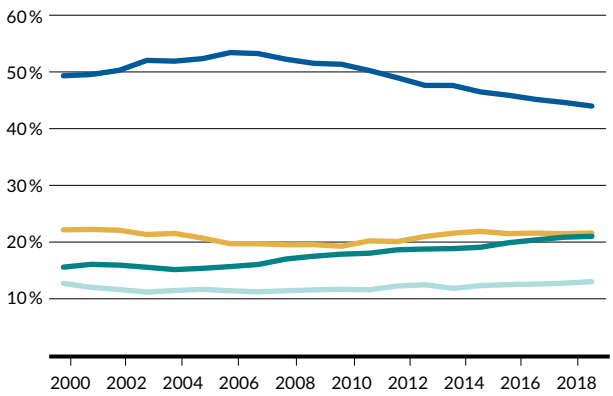
Shares of world class patents – **Waste management**



SUSTAINABLE PACKAGING

Sustainable packaging includes technologies for using biologically produced or biodegradable materials for packaging laminates, bottles, trays, and bags. In addition to polymers such as celluloses, many kinds of specific biomaterials used in barrier and functional layers (e. g. natural fibers) are covered.

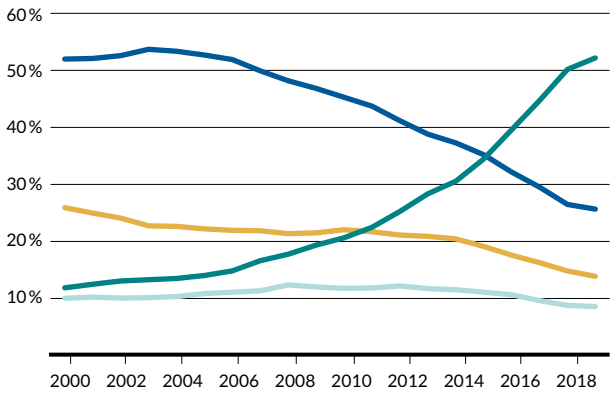
Shares of world class patents – **Sustainable packaging**



WATER TREATMENT

Water treatment includes processes and materials that decontaminate wastewater and purify water to a high quality. On top of drinking water treatment, this area includes industrial wastewater treatment and ultrapure water as well. This also includes technologies for the discharge of municipal wastewater, sewers, and water drainage systems.

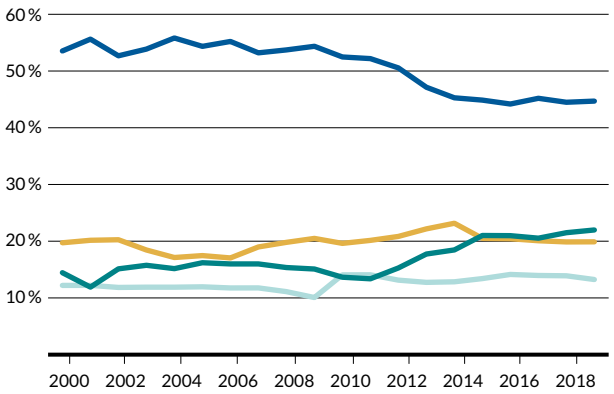
Shares of world class patents – **Water treatment**



CARBON CAPTURE

Carbon capture refers to methods that reduce the amount of CO_2 in emissions or that convert CO_2 into other, mostly useful products. Typical procedures include absorption or adsorption, biological, physical, or chemical separation processes, filters, as well as collection devices.

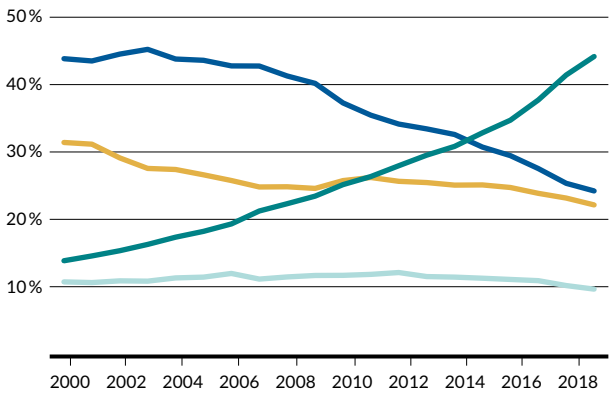
Shares of world class patents – **Carbon capture**



RECYCLING

Recycling is the reuse and processing of polymer waste, metals, and the like. Though there is an overlap with waste management, recycling focuses more strongly on the aspect of reprocessing, i.e. improving the product cycle and complete recycling systems. Rather than being limited to the recycling of municipal waste, reuse of waste materials also involves industrial reuse of process wastes.

Shares of world class patents – **Recycling**

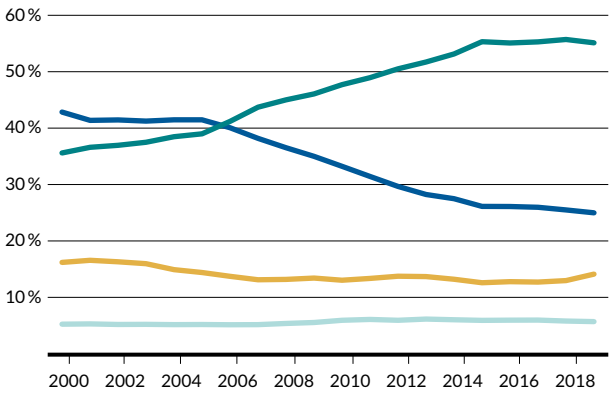


ENERGY

BATTERYTECH

Batterytech covers all fields of storing electrical energy by charge separation from charge carriers. The technology includes all types of batteries, their electrodes, and separators. It also covers technologies connected to the use of battery cells in battery elements.

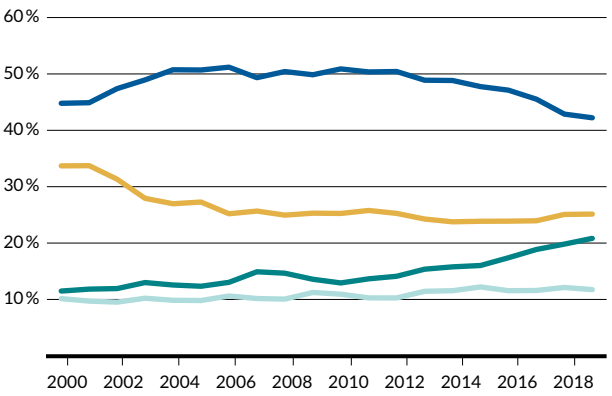
Shares of world class patents – **Batterytech**



BIOFUELS AND BIOMASS

Biofuels/biomass refers to the conversion of biocarbon, in particular from carbonaceous waste, into fuels. Conversion of biomass into energy (bioelectricity) or energy sources (biogas) is another area covered.

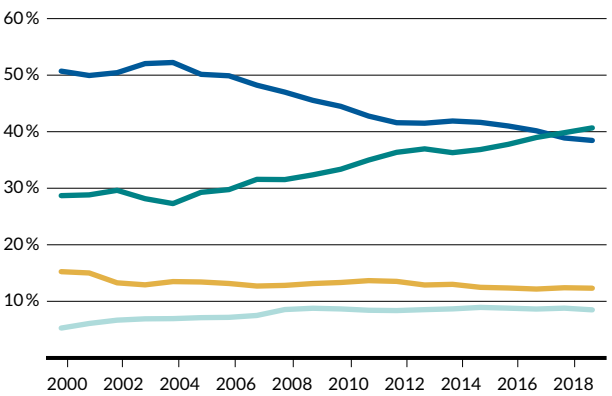
Shares of world class patents – **Biofuels and biomass**



ENERGYSAVINGS

Energysavings relate to energy-saving procedures, usually from the electronics area. They mainly include semiconductors with lower power consumption, stand-by circuits, power-saving, and sleep functions as well as energysaving server installations.

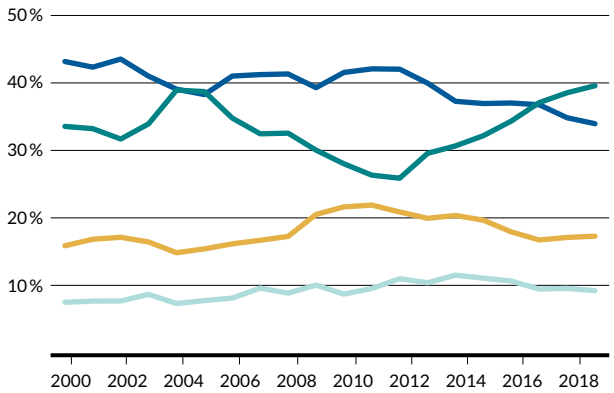
Shares of world class patents – **Energysavings**



ENERGY CONVERSION

Energy conversion is a field encompassing various forms of energy conversion. In addition to the dominant AC/DC converters of different frequency ranges, it also contains DC/DC converters and various dynamoelectric devices up to the conversion of thermal energy into mechanical energy.

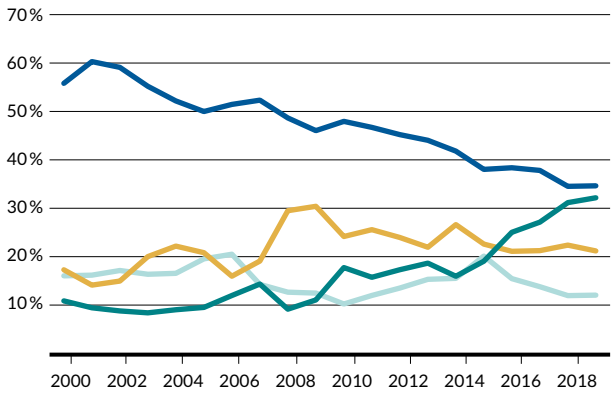
Shares of world class patents – **Energy conversion**



GEOTHERMICS

Geothermics describes the use of geothermal energy as a renewable energy source. It also includes heat pumps that can be used directly for converting geothermal energy into thermal energy.

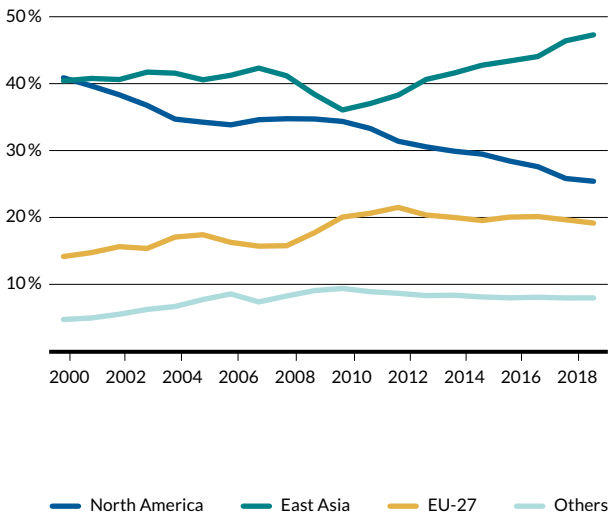
Shares of world class patents – **Geothermics**



PHOTOVOLTAICS

Photovoltaics covers all fields of the conversion of solar energy into electricity. This includes not only the actual solar cells, but also various technologies for the installation, use, and optimization of solar cells.

Shares of world class patents – **Photovoltaics**

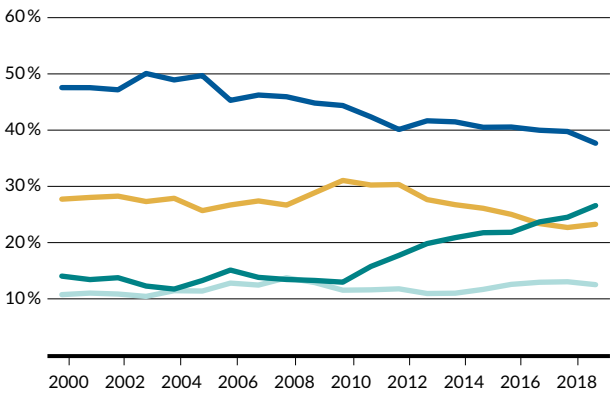


ENERGY

SOLAR THERMAL ENERGY

Solar thermal energy technology comprises solar thermal systems that, unlike photovoltaic systems, generate heat instead of electricity.

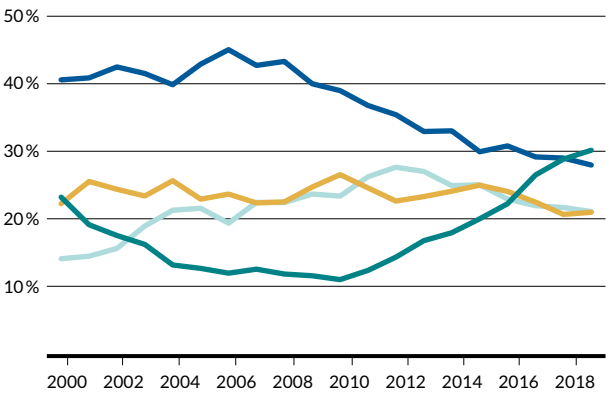
Shares of world class patents – **Solar thermal energy**



HYDROPOWER

Hydropower technology refers to the generation of electricity from various water-related forms of energy, e. g. through tidal power plants, current and wave power plants, as well as conventional hydropower plants.

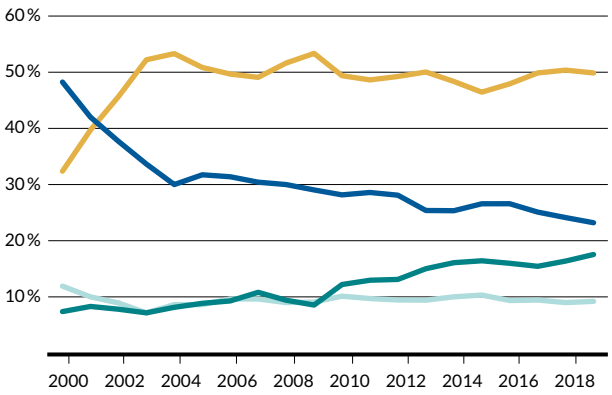
Shares of world class patents – **Hydropower**



WIND ENERGY

Wind energy involves the generation of electricity by various kinds of wind turbines, from rather small applications to wind-powered ships. Individual parts such as engines or rotor blades are also part of the definition.

Shares of world class patents – **Wind energy**



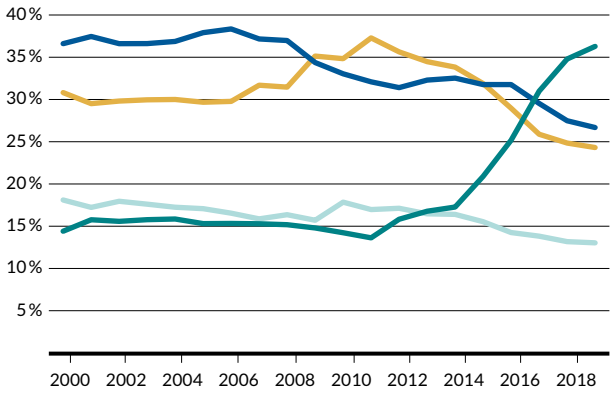
North America
East Asia
EU-27
Others

NUTRITION

BIOCIDES

Rather than only referring to chemical substances for use against pests and micro-organisms, biocides encompasses the larger set of the different plant protection agents, with herbicides, fungicides, and insecticides.

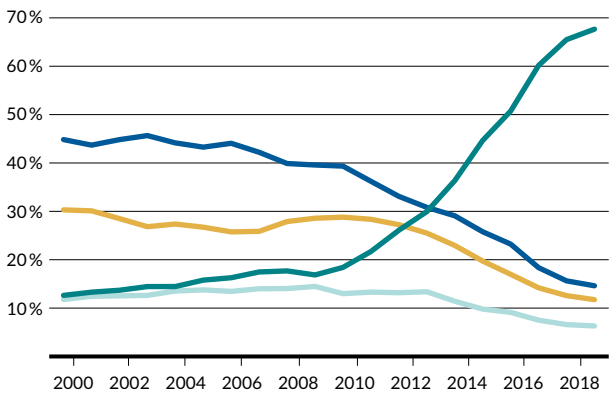
Shares of world class patents – **Biocides**



FERTILIZER

Fertilizers are any growth-supporting materials in field of farming. Such fertilizers may be conventional nitrogen, phosphorus, or other elementary fertilizers, but also include sewage sludge and other materials for soil improvement. Procedures for reducing the use of fertilizer and fertilizer management belong in this group as well.

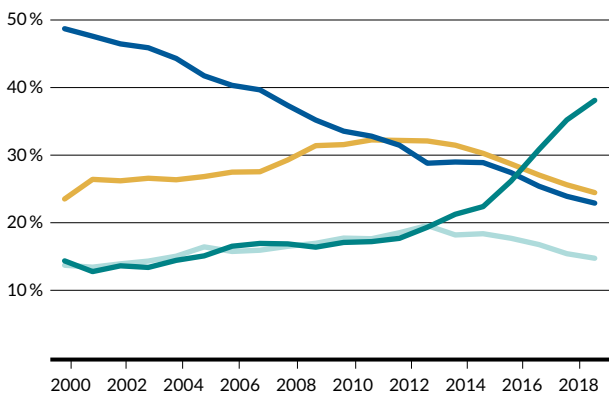
Shares of world class patents –**Fertilizer**



FUNCTIONAL FOOD

Functional food technologies enrich food with additional health-promoting substances. This places them at the interface to health technologies. This encompasses either additives or substitutes, or processes to optimize or amplify health-promoting ingredients. Intestinal bacteria (microbiomes) tailored to the needs of individual patients to support medical therapies are part of this group as well.

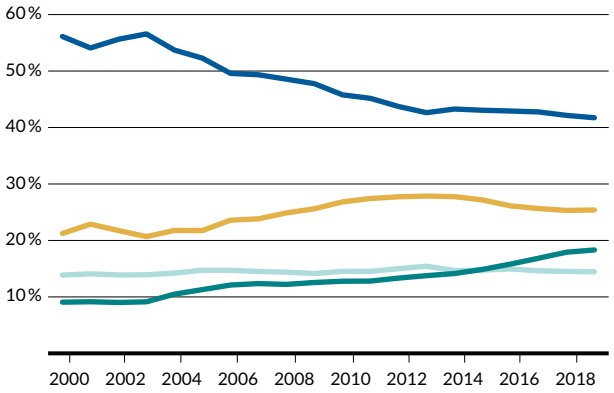
Shares of world class patents – **Functional food**



GREEN BIOTECH

Green biotech is the biotech subsection for plant applications, agriculture, and food. The core area of this technology is the genetic modification of plants and seeds.

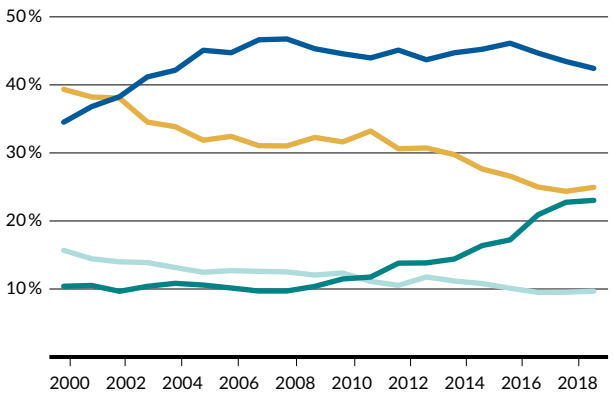
Shares of world class patents – **Green biotech**



PRECISION FARMING

Precision farming aims to increase agricultural efficiency. This includes the use of drones or autonomous vehicles such as farm and harvesting robots, but also the analysis of soils by satellites and the use of machine learning in the agricultural field.

Shares of world class patents – **Precision farming**

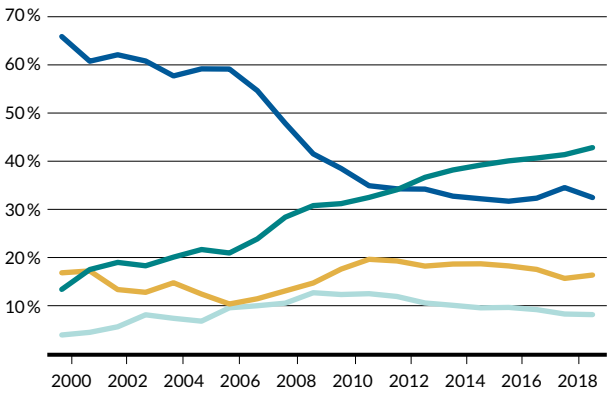


INFRASTRUCTURE

5G

The 5th generation of the mobile network is a technology with a significantly higher data rate than the previous version. With up to ten gigabits per second, 5G promises to address 100 billion mobile devices simultaneously. Use of multiple transmitter and receiver antennas and frequencies in the millimeter range makes it possible to supply mobile receivers specifically with high data rates.

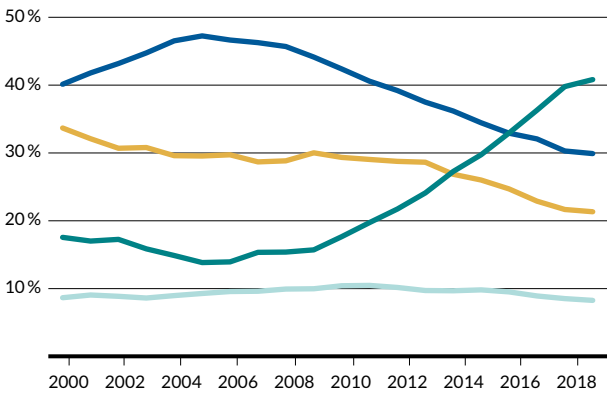
Shares of world class patents – **5G**



CONSTRUCTION

Construction only refers to the security-relevant part of construction in this context, along with heat, sound, radiation protection and thermal insulation. It also includes measures to protect buildings against storms and floods and other, particularly climate-relevant, adaptation technologies.

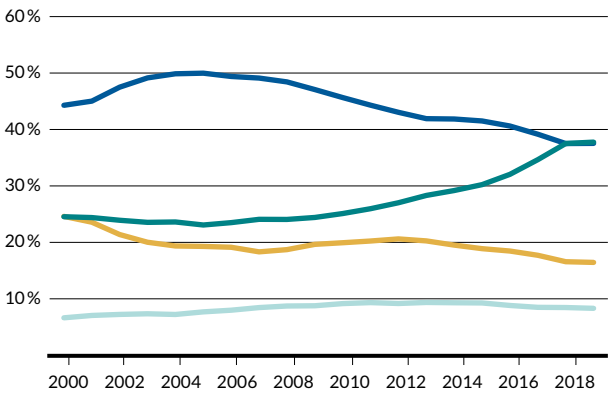
Shares of world class patents – **Construction**



INTERNET OF THINGS

The Internet of Things as a whole is focused on connecting devices in wireless and wired networks alike. Machine-to-machine communication in the industrial context and methods for devices to communicate with each other are included in this definition. This also includes the connecting elements of smart city, smart home, and smart grid, but not the end devices.

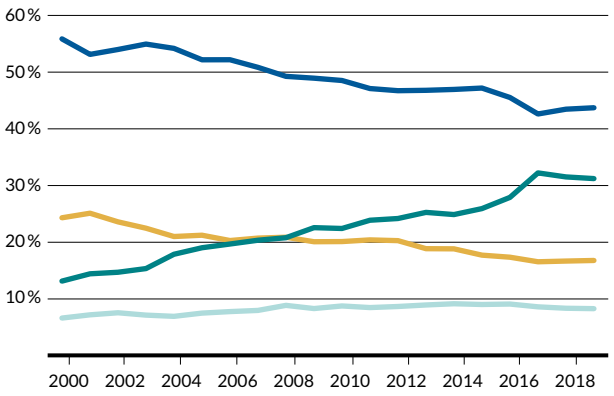
Shares of world class patents – **Internet of Things**



SMART CITY

The term smart city is defined vaguely, including all aspects of modern digital and, as a result, more efficient urban development, from transport, security, health, and environment, to energy and water supply as well as new forms of social participation. Traffic flow systems and energy supply options currently dominate this technology.

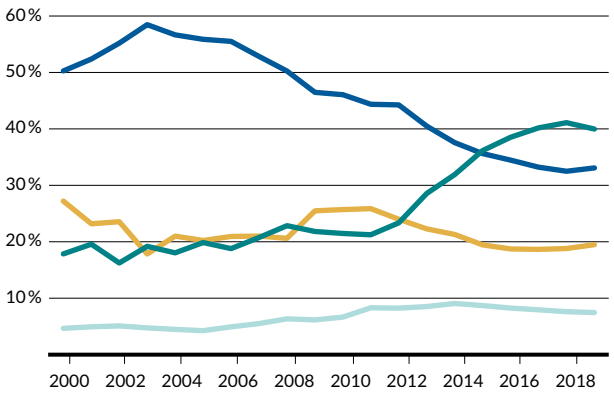
Shares of world class patents – **Smart city**



SMART GRID

Smart grid comprises the management of power grids. It includes a variety of methods for predicting or controlling loads in power grids with central or distributed generators to the end consumer sites.

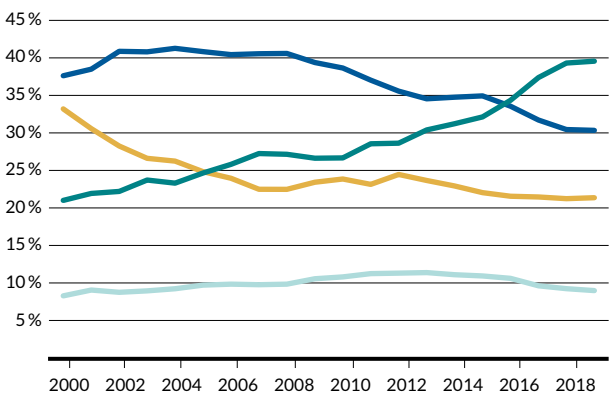
Shares of world class patents – **Smart grid**



SMART HOME

Smart home refers to the sensor/actuator and network concepts for applications in buildings, as well as building automation. End devices are not classified under smart home if the network component or automation elements are not an essential part of them.

Shares of world class patents – **Smart home**

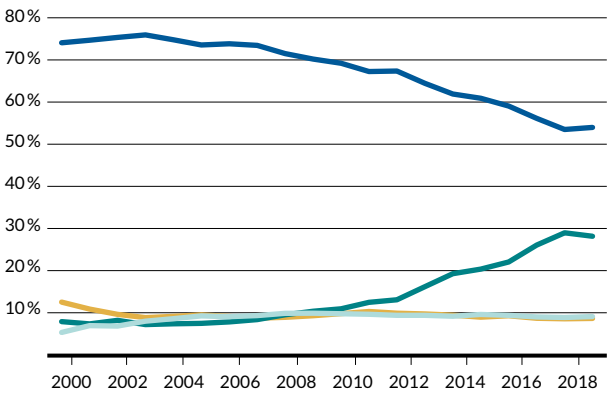


DIGITALIZATION

BIG DATA

Big data is about data sets that are too unstructured, too extensive, or too complex to be managed with traditional data processing software. This technology includes new processes for searching, indexing, managing, and analyzing data, as well as the business methods that can be developed based on it.

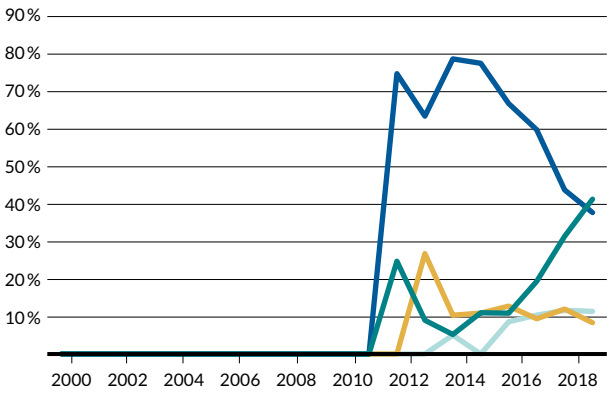
Shares of world class patents – **Big data**



BLOCKCHAIN

Blockchain is a shared database technology that directly links consumers and suppliers of a transaction. All transaction details are recorded and can be viewed and verified by everyone involved. Apart from Bitcoin, the most popular blockchain application, this technology can also be used for contracts (smart contracts) or elections. The continuous verifiability of supply chains is another application field.

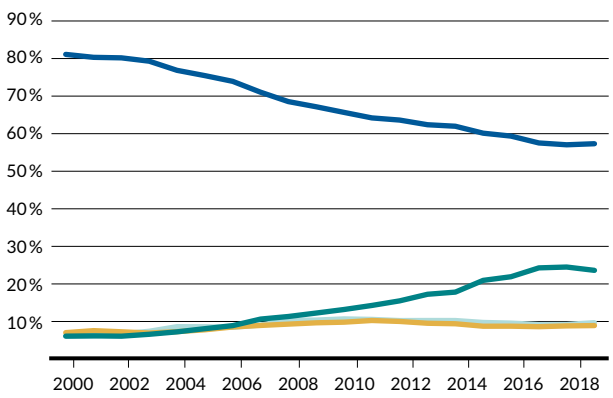
Shares of world class patents – **Blockchain**



CLOUD COMPUTING

Cloud computing serves the development and management of a virtual IT infrastructure to replace local systems. In addition to scalability of the required infrastructure (infrastructure as a service), the technology encompasses access to applications (software as a service), and computing capacity (platform as a service).

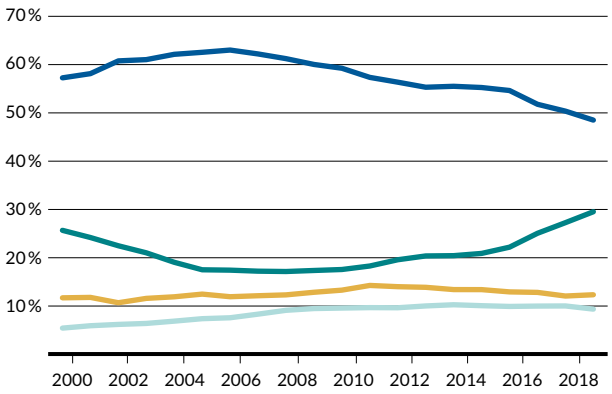
Shares of world class patents – **Cloud computing**



ARTIFICIAL INTELLIGENCE

Artificial intelligence describes applications that mimic human cognitive skills, such as problem solving. The technology includes various approaches such as machine learning, neural networks, and deep learning. These can be used for new developments in the fields of speech recognition, image analysis, character recognition and data analysis.

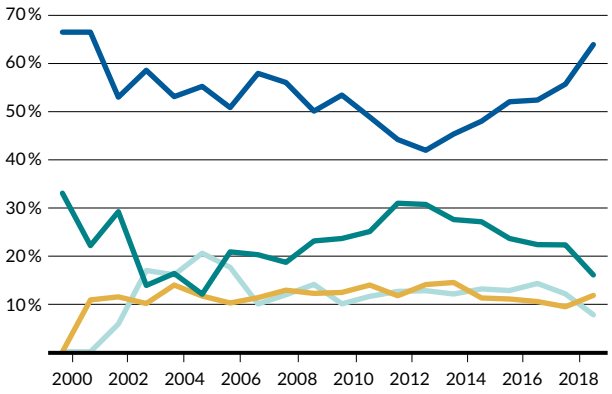
Shares of world class patents – **Artificial intelligence**



QUANTUM COMPUTING

Quantum computing refers to next-generation computers that operate on the basis of quantum mechanical states rather than physical laws.

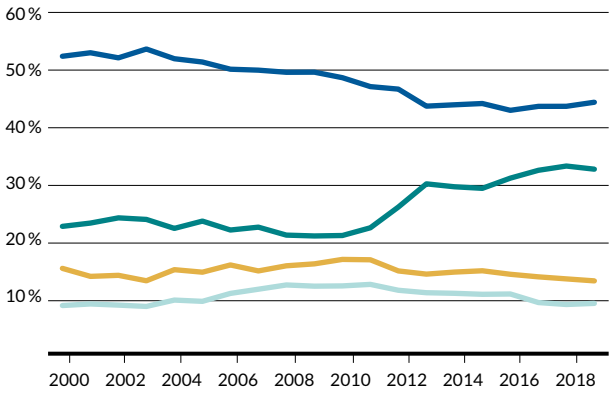
Shares of world class patents – **Quantum computing**



VIRTUAL / AUGMENTED REALITY

Virtual / augmented reality means perception of reality in a computer-generated and interactive environment. Beneath virtual reality, augmented reality is part of the analysis. In this case, users see the real world with some additional information.

Shares of world class patents – **Virtual / augmented reality**

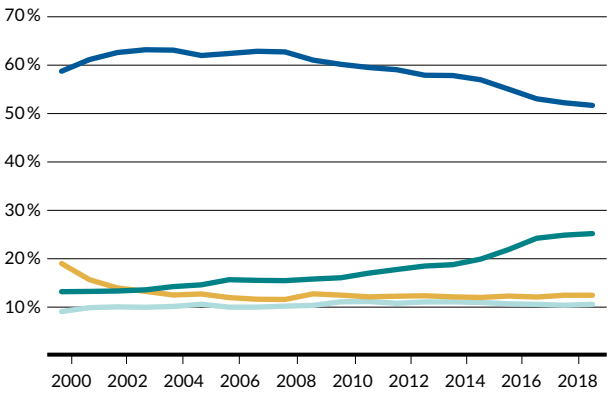


SECURITY

AUTHENTICATION/IDENTIFICATION

Authentication describes the sub-field in which participants in security-relevant digital connections are identified. It includes biometrics and fingerprint sensors as well as ID tokens, special blockchain applications, and digital wallets.

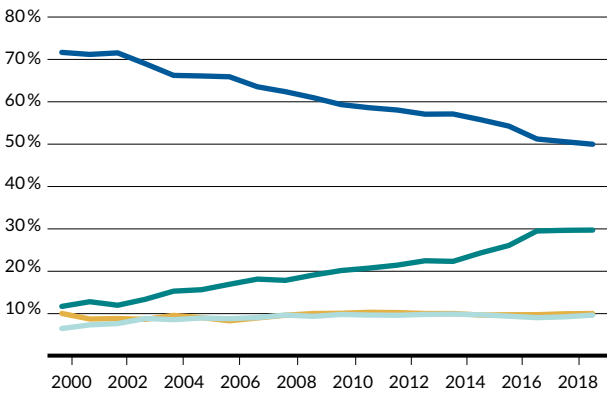
Shares of world class patents – **Authentication / identification**



CYBER SECURITY

Cyber security prevents undesired intrusion into computers and digital devices, among other things by a wide range of anti-malware.

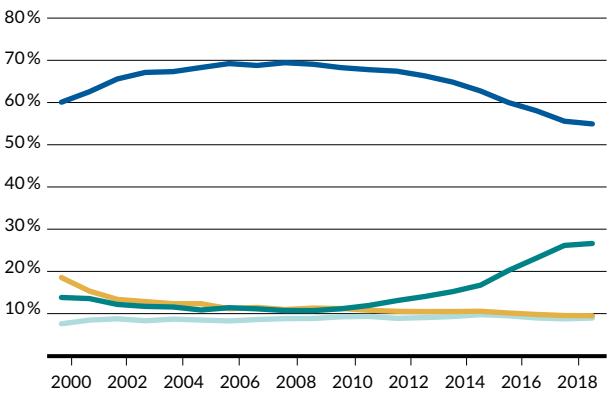
Shares of world class patents – **Cyber security**



FINTECH AND PAYMENT

Fintech and payment describes the field of financial engineering procedures and methods from the banking, insurance, securities, and transaction systems. This encompasses simulation software applications and machine learning for pattern recognition and prediction. Applications for enabling payments, e. g. in online trading, are also classified here.

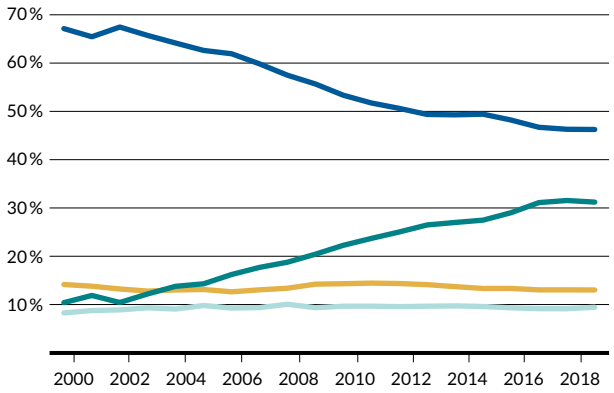
Shares of world class patents – **Fintech and payment**



NETWORK SECURITY

Network security means any measures to secure data and information distributed in networks, including encryption technologies.

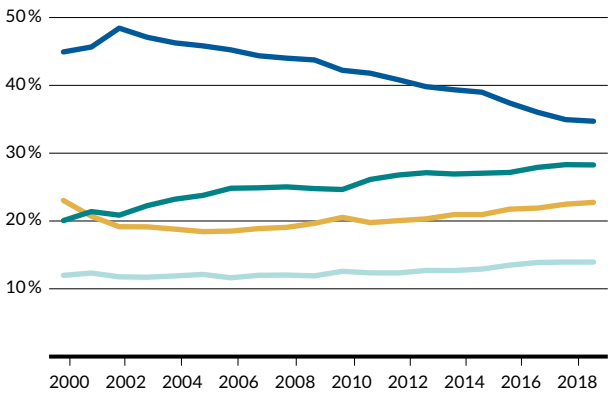
Shares of world class patents – **Network security**



PRODUCT SECURITY

Product security comprises measures to guarantee the genuineness, safety, and authenticity of products, e. g. in the manufacture of banknotes, passports, and pharmaceutical packaging.

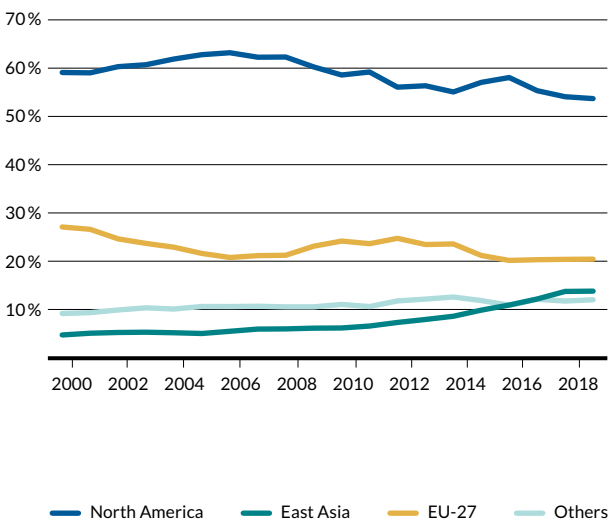
Shares of world class patents – **Product security**



DEFENSE

Defense includes weapons and armaments. Apart from ammunition for firearms, rockets, and cruise missiles, it also comprises armored vehicles, military drones, artillery, and anti-aircraft weapons.

Shares of world class patents – **Defense**

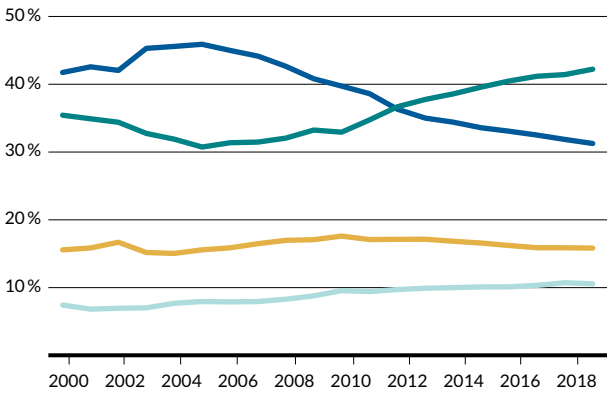


MATERIALS

CARBON-GRAPHENE

Carbon encompasses a large number of carbon compounds such as carbon fibers, fullerenes, or carbon nanotubes as well as other nanostructured carbon materials. This does not include any amorphous carbon products such as activated carbon. Graphenes are a subgroup in which carbon is arranged in two dimensions and that does not include carbon composites.

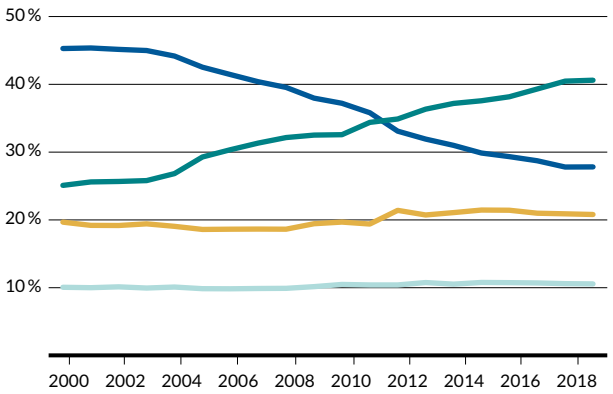
Shares of world class patents – **Carbon-graphene**



FUNCTIONAL MATERIALS

The group of functional materials comprises various substances characterized by special functions. They include self-healing, conductive, or shape-memory polymers, xerogels, hydrogels and aerogels, luminescent or piezoelectric materials.

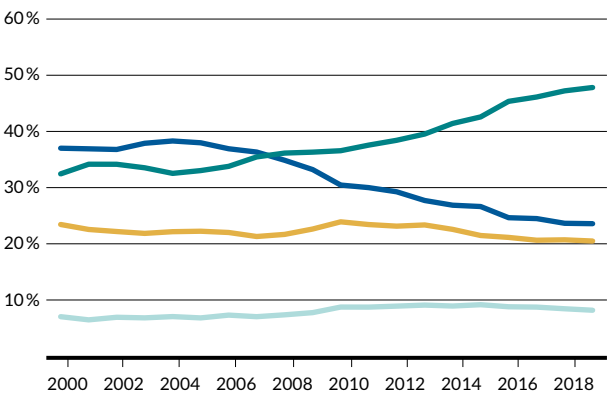
Shares of world class patents – **Functional materials**



ADVANCED COATINGS

The class of advanced coatings summarizes various types of coatings that are, e. g. self-healing, electrophoretic, thermosensitive, electroluminescent, conductive, fireproof, flame-retardant, or anti-corrosive.

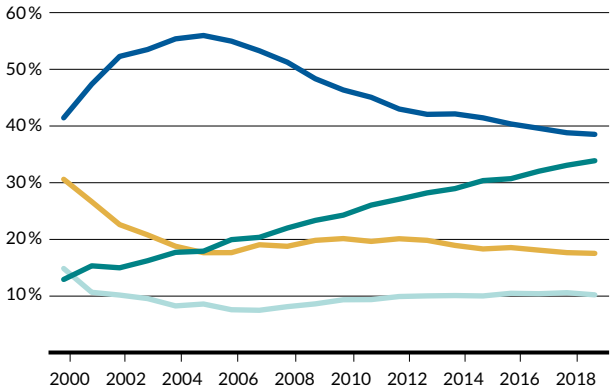
Shares of world class patents – **Advanced coatings**



NANOMATERIALS

Nanomaterials are all materials with primary particle that are less than 100 nanometers in size. One important application of nanomaterials is processing of silver nanoparticles as an antibacterial agent in objects of daily use.

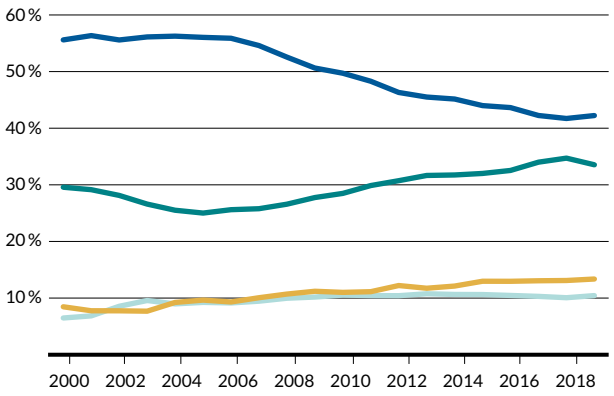
Shares of world class patents – **Nanomaterials**



QUANTUMTECH

Quantumtech comprises various materials and processes at quantum mechanical level. Control of individual quantum systems using the specific properties of quantum mechanics constitutes a new field of research. High expectations are placed mainly on the fields of quantum sensor technology and quantum cryptography. Quantum computing is a category of its own.

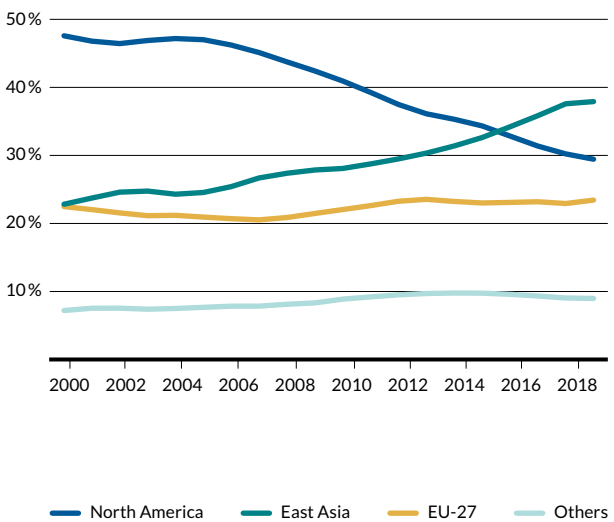
Shares of world class patents – **Quantumtech**



COMPOSITES

Composites are a group of heterogeneous materials comprising of at least two different materials. They are combined into new materials with often greatly amplified properties. The most popular example is carbon materials, a composite of carbon fibers and a polymer.

Shares of world class patents – **Composites**

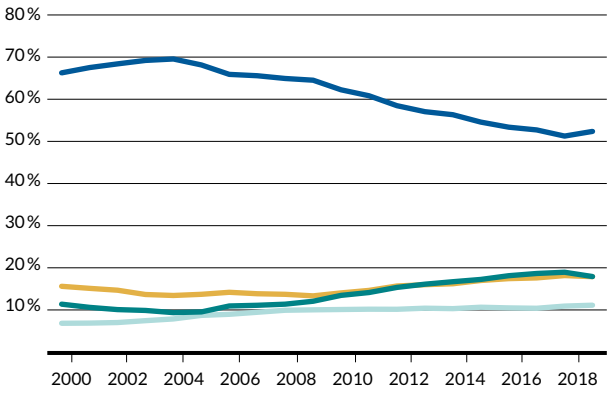


HEALTH

DIGITAL MEDTECH

Digital medtech refers to artificial intelligence applications in diagnostics, e. g. X-ray analysis, medical additive manufacturing, and robot-assisted treatments. The interconnection of information concerning interfaces between medical devices and automated recording of patient data also falls into the field of digital medtech. This technology field also comprises biosensors and portable devices with digital elements for measurement, diagnosis, and treatment in and on the human body.

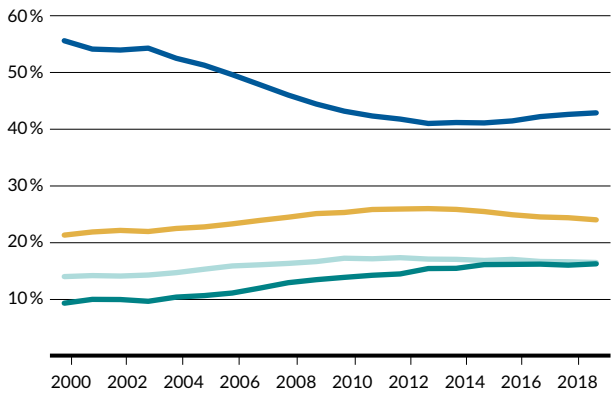
Shares of world class patents – **Digital medtech**



DISEASES

The field of diseases includes all activities relating to the “major” diseases of cancer, HIV, diabetes, and COPD. In addition to therapeutic approaches, patents also describe new test methods in this context. This technology does not include any medical technology applications such as insulin syringes.

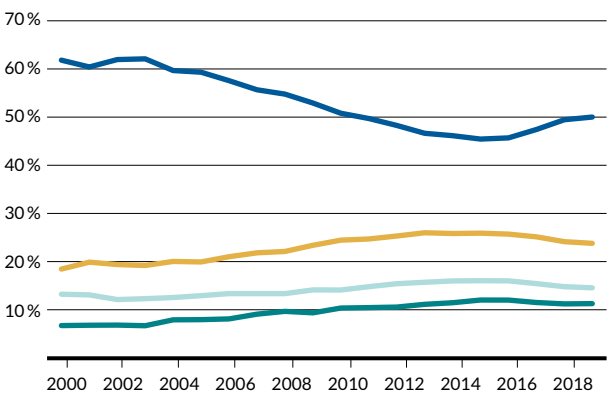
Shares of world class patents – **Diseases**



GENTECH

Gentech comprises various aspects of gene therapy as well as genome editing in the medical field. It serves as an umbrella term for molecular biological methods for targeted modification of DNA. CRISPR/Cas and related techniques also fall into this segment.

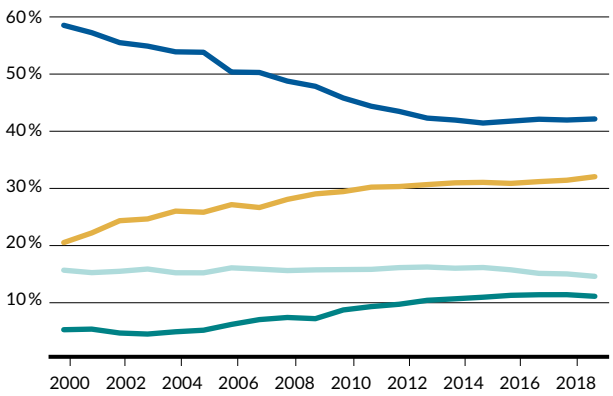
Shares of world class patents – **Gentech**



VACCINES

Vaccines are the technology field in which pharmacologically active substances are developed for active or passive immunization of humans and animals against viral or bacterial infections. This includes all medical vaccine preparations, along with the corresponding antigens and antibodies. Virus tests, immunoassays, and application techniques for the vaccines are not included.

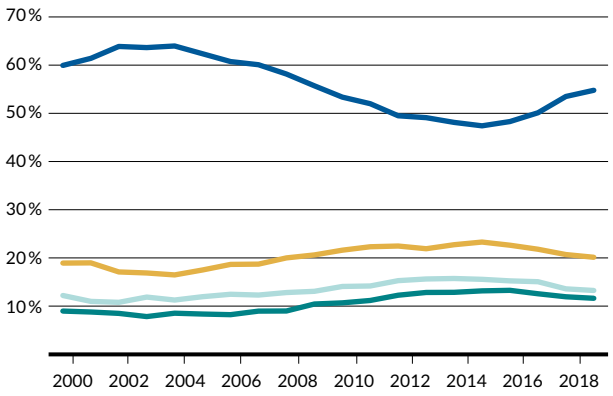
Shares of world class patents – **Vaccines**



PRECISION MEDICINE

Precision medicine is a new technology focused on customized treatment of patients with tailor-made medicines, specific immune therapies, and individual organ printing.

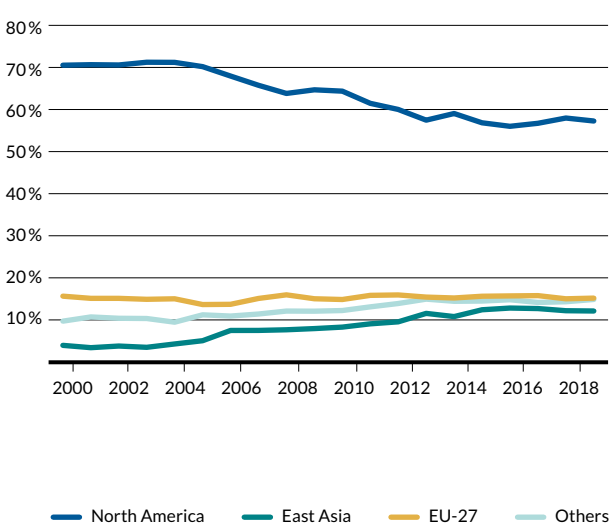
Shares of world class patents – **Precision medicine**



RATIONAL DRUG DISCOVERY

Rational drug discovery means the research of medical active ingredients with digital methods outside the conventional laboratories, e. g. in molecular libraries and by various application and calculation methods from basic chemical research. Digital research in the biotech environment falls into this category as well.

Shares of world class patents – **Drug discovery**

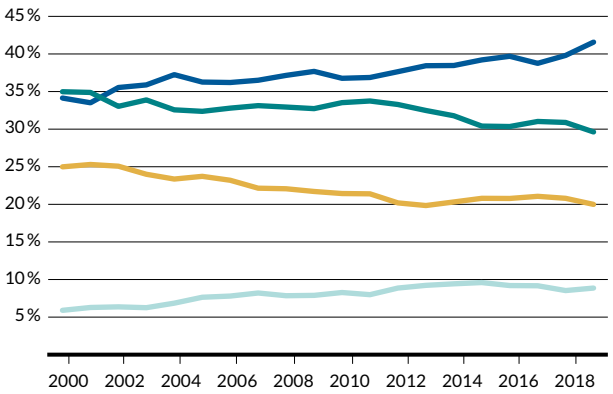


MOBILITY

AUTONOMOUS DRIVING

The technology of autonomous driving refers to the development of autonomous vehicles, including all five stages of automation, from stage 1: Assisted driving – assistance systems that support the driver in certain tasks, to stage 5: Autonomous driving – where the vehicle operates completely autonomously, i.e. all persons in the vehicle become passengers.

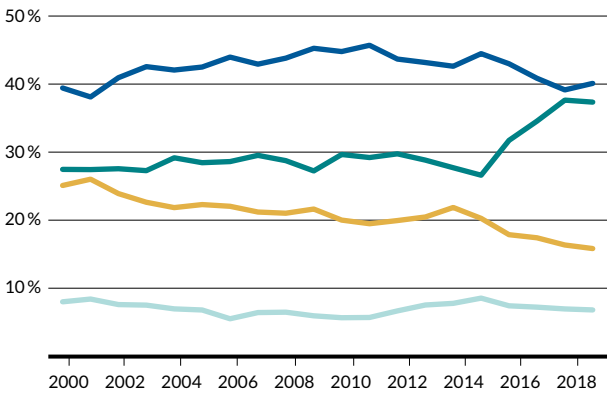
Shares of world class patents – **Autonomous driving**



DRONES

Business applications are at the focus for drones. Drones can perform inspections and collect data faster, cheaper, and more frequently than humans or helicopters. In addition to drones used in the logistics sector (delivery services), military drones and various unmanned and self-steering driving devices such as mining robots or unmanned submarines are also part of the technology. The latter differ from autonomous vehicles because they are not manned. They may, but not do not need to, be self-steering.

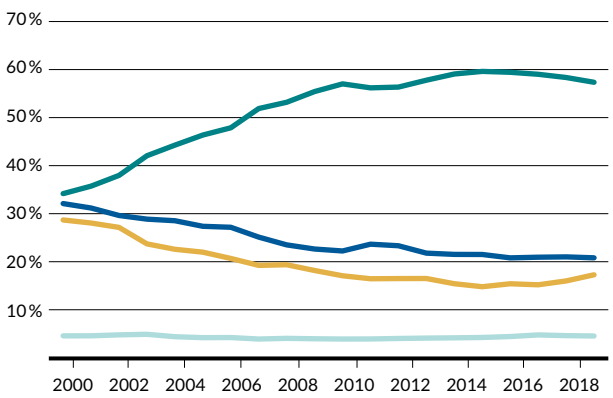
Shares of world class patents – **Drones**



ELECTRIC VEHICLES

This technology encompasses electric road vehicles, with a focus on cars, buses, and trucks, but without excluding any other electric ground vehicles such as bicycles. Aircraft, vessels, and rail vehicles are included as well.

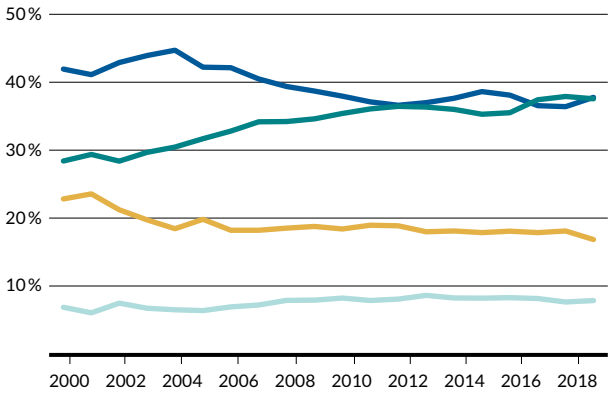
Shares of world class patents – **Electric vehicles**



SMART TRAFFIC

Smart traffic refers to the technologies required for the interconnection between vehicles and their environment. This also includes navigation technologies, traffic flow control methods, and various traffic management systems that typically are a connected flow of information.

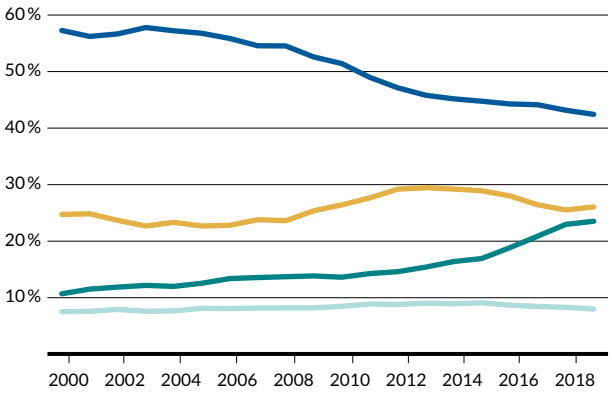
Shares of world class patents – **Smart traffic**



AIR- AND SPACETECH

Air- and spacetech covers all fields of air- and spacecraft and processes connected to them, including aspects of aircraft, spaceships, flying drones, helicopters, and space stations.

Shares of world class patents – **Air- and spacetech**



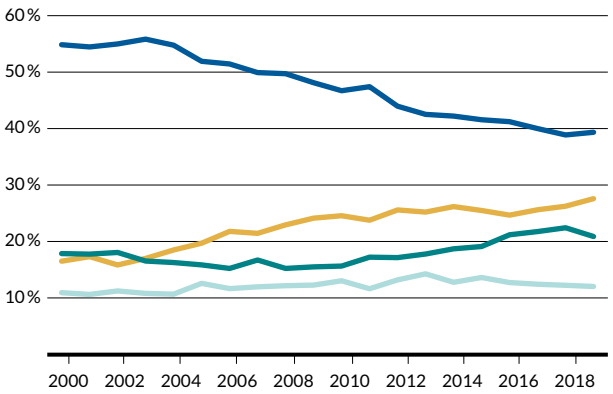
North America East Asia EU-27 Others

INDUSTRY

ADDITIVE MANUFACTURING

Additive manufacturing describes production technologies where products are built from multiple material layers. This makes it possible to improve existing process chains and opens up new production options. Applications cover everything from production equipment to consumer goods and medical technology.

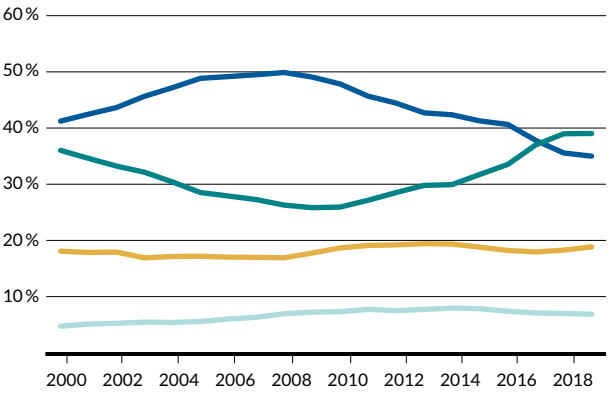
Shares of world class patents – **Additive manufacturing**



PROCESS AUTOMATION

Process automation concerns a large range from the control and regulation of manufacturing units to various software solutions in industrial manufacture.

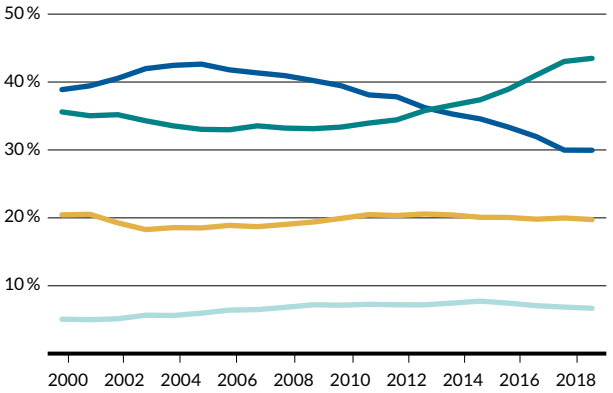
Shares of world class patents – **Process automation**



ROBOTICS

This technology comprises all aspects of robotics, i.e. conventional industrial robots, as well as the newer co-robots that specialize in cooperation with humans, e. g. in surgery and nursing.

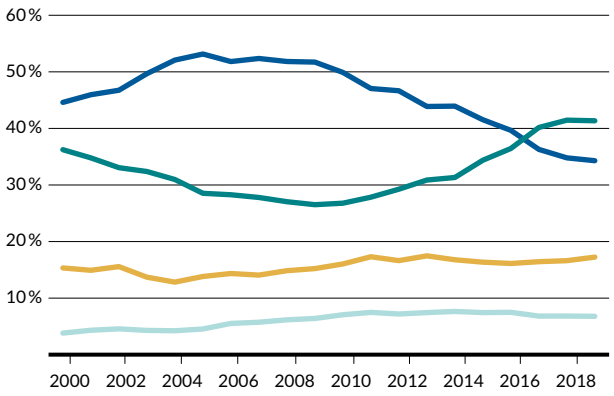
Shares of world class patents – **Robotics**



SMART FACTORY

The smart factory comprises modern methods such as predictive maintenance of, e. g. connected robots and other predictive methods that render production more efficient, including central factory control, interactive troubleshooting, machine vision and industrial image processing.

Shares of world class patents – **Smart factory**



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DOI: 10.11586/2020027

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