Technology Outlook 2021

English Version

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Imprint

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April 2021

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Foreword

In the past decades, the world has become richer and – spoiled by the industry's ever-growing performance – more demanding. It has become absolutely normal to obtain (and to demand) better results from manufacturing companies year after year. All market players rationally understand that perpetual exponential growth is not possible, but they are convinced that a skillful mix of successful products, strong market presence and clever novelties must enable them to achieve outstanding new results. The question is, however, how to identify, understand and use these novelties. In order to provide some guidance, "Technology Outlooks" have been developed worldwide and have become international references on these issues.

The SATW published its first *Technology Outlook* six years ago. Back then, despite it being a rather simple product, it received encouraging approval and feedback from engineers and researchers in Switzerland. The editions that followed gradually gained in depth and substance. You are now holding in your hands the fourth, more "mature" edition, which builds on its predecessors and introduces new prospects.

The dominance of the digital world was already remarkable in the 2019 edition, and it is even stronger in this edition.

The articles on technologies and areas of application focus – as the title suggests – on practical, industrial and commercial applications, covering topics like 5G applications, big data analysis, collaborative robots, quantum computing and many more. The articles on technological trends prepare readers for broader discussions and cover wide-ranging topics such as autonomous systems, cybersecurity, digital agriculture and of course also the omnipresent artificial intelligence and quantum technologies.

This *Technology Outlook* begins with an international comparative analysis (European trends and comparison with Switzerland). Data has been accurately collected over several years, enabling for the first time to display the strengths and weaknesses of different countries over time.

In the name of the Scientific Advisory Board, I wish you a stimulating read and hope the *Technology Outlook 2021* can provide valuable orientation and guidance.

Ulrich W. Suter | President of the SATW Scientific Advisory Board

Introduction

SATW's key mission of early identification comprises the detection, description and assessment of technologies that will be significant for Switzerland's economy and society in coming years[1]. Every two years, these activities are wrapped up in the publication "*Technology Outlook*", which in 2021 has reached its fourth edition.

The *Technology Outlook 2021* builds on the 2019 edition. The technologies described back then have been newly assessed with regard to their technological maturity. Those having a time horizon of less than three years till market maturity, like continuous manufacturing processes, have been excluded. In collaboration with SATW's two early identification bodies, we have identified 12 new relevant technologies that will gain significance in Switzerland and that correspond to the targeted time horizon of at least three years until product maturity. These include artificial photosynthesis, microbiota and microbiome and also mobile robots. Two other articles address general aspects of digitalisation: the self-determined use of personal data and the trust in digital products and services. The *Technology Outlook 2021* presents a total of 45 technologies and areas of application.

Each technology is depicted with an icon. An overview of all icons can be found on the side flap at the end of the publication.

For this edition, SATW has again collected quantitative data on the different technologies and used the four-quadrant diagram "Economic significance of technologies for Switzerland / Available research competence in Switzerland". This allows for the first time to identify certain trends. Have certain technologies acquired greater economic significance? Has the research competence available in Switzerland grown for certain applications? Or have some technologies even lost impetus? The continuous collection of data through social media also makes it possible for the first time to analyse trends at international level.

The technologies here presented interact with each other and enable therefore to establish much broader technological trends. Hence, this edition of the *Technology Outlook* features something new, i.e. 13 technological trends that are highly visible in the media, including wide-ranging topics such as circular economy, artificial intelligence or smart cities. The *Technology Outlook* explains the meaning of terms, sounds the potential for Switzerland's economy and society and makes a direct link to the individual technologies. This shows which technologies act as drivers for the development of a trend or, conversely, which technologies benefit from the steady development of a trend.

The publication starts broadly with an international comparison of technologies and then focuses on the significance of each technology for Switzerland. The final chapter "Technological trends" provides again a broader overview.

Dr. Claudia Schärer, Project Leader of the *Technology Outlook*, thanks the numerous authors, whose dedication, patience and expert knowledge have made it possible to produce a publication of such comprehensiveness and depth. To our readers, we wish you an informative and hopefully also highly insightful read. We appreciate your feedback at any time!

[1] Technology Readiness Level 4–7, product maturity in 3–5 years. Details are found in the chapter "Methodology" starting at page 22.

European trends and comparison with Switzerland

Changes through time

An international comparison of technologies: while the *Technology Outlook 2019* could only present a snapshot for the year 2018, a trend analysis is possible in this edition. Which are Europe's top technologies? Which technologies have climbed the ladder since 2018? Which technologies have lost impetus?

For the past three years, SATW has been following discussions on the official social media accounts of 1300 European institutions of higher education. Twitter is the most frequently used channel. By using a tool created by LinkAlong (https://linkalong.com), we search through and analyse by specific terms the official Twitter channels of the European institutions of higher education. We deliberately focused on the official communication channels of the institutions of higher education to ensure that our data derives mainly from sources with high relevance and credibility.

To analyse the European trends, we took into consideration data from seven countries, namely from countries neighbouring to Switzerland (Germany, France, Italy and Austria) and from three countries that are comparatively relevant to Switzerland (Great Britain, the Netherlands and Sweden). The data pertaining to Switzerland is presented separately and is therefore not included in the data of the European countries. Compared to the *Technology Outlook 2019*, the search terms relating to the technologies have been revised and all data for 2018, 2019 and 2020 have been newly collected and analysed. For this reason, the results found in this publication cannot be directly compared to those of the 2019 edition, but they are consistent in themselves. Due to the corona crisis, the data for 2020 is to be interpreted with some reservation, since in 2020 the number of posts on the technologies described in the *Technology Outlook* had declined.

Figure 1 (page 8) shows how the discussion on the top 10 technologies in Europe developed in the period 2018–2020. It also shows the development of bioplastics, i.e. of the technology with the strongest increase of posts in the period 2018–2020 beyond the top 10 technologies.

The top 10 contains a striking number of technologies from the area of research "digital world". Only two technologies, i.e. additive manufacturing and photovoltaics, come from other areas of research. On the one hand, this indicates that digital technologies are topics that enjoy a high visibility. On the other hand, those here concerned are so-called enabling technologies, which means that many areas of application benefit from their further development.

While big data analytics, augmented reality and blockchain dominated the academic discourse in 2018, the intensity of discussion in the social media channels of European institutions of higher education has decreased slightly. In 2020, additive manufacturing attracted most attention of all. The percentage of posts on additive manufacturing has almost doubled in the past three years. Posts in 2020 mostly concerned face shields, plexiglass protective screens and respirators, all of which can be manufactured with 3D printers. Evidently, even institutions of higher education seize the opportunity to portray themselves to the public as being up to date. →

Use the QR code to visit our website, where you will find more information on the European trends.

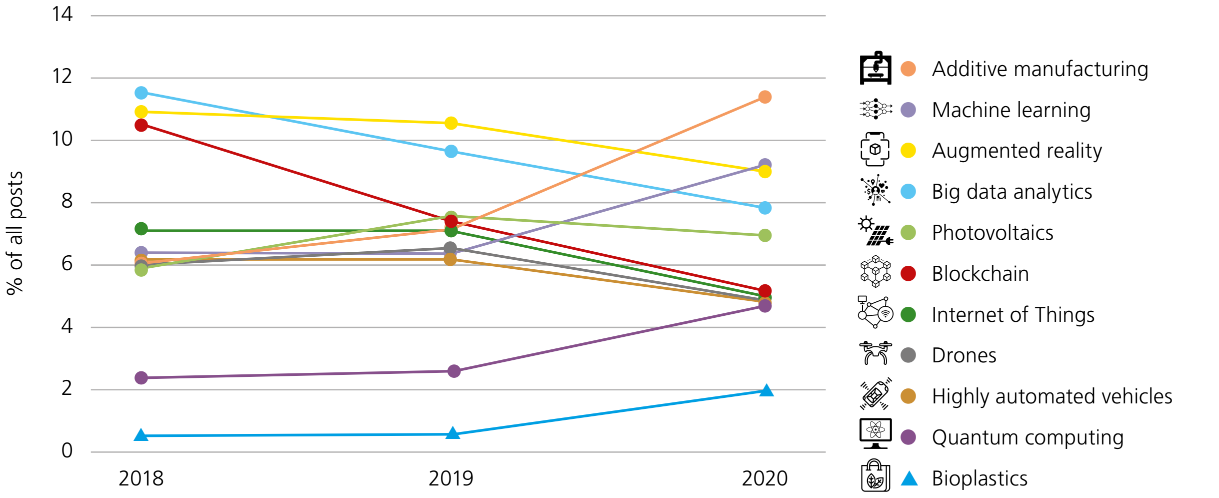

Figure 1: Trend analysis 2018–2020 of the top 10 technologies in Europe
This figure shows how the relative frequencies of the posts on the 10 most discussed technologies have developed in the years 2018, 2019 and 2020. The average values of the seven European comparison countries are shown as a percentage of the total amount of posts on all the technologies discussed in the *Technology Outlook 2021*. Bioplastics (shown as triangles) are shown in addition to the top 10 technologies (shown as dots). This technology shows the strongest increase of posts in the past three years besides the top 10.

Blockchain and highly automated vehicles have lost some attention in the European academic discourse, while tweets on bioplastics have strongly increased. This could reflect the increased efforts performed by the EU to reduce single-use plastic and to promote the use of natural biopolymers.[2]

It is interesting at this point to compare these results to those pertaining to Switzerland. Figure 2 shows the trends in the period 2018–2020 for the top 10 technologies in Switzerland. Like figure 1, this figure includes some additional technologies beyond the top 10 that feature a strong trend, namely synthetic biology (strongest increase of posts) and mobility concepts (strongest decrease of posts).

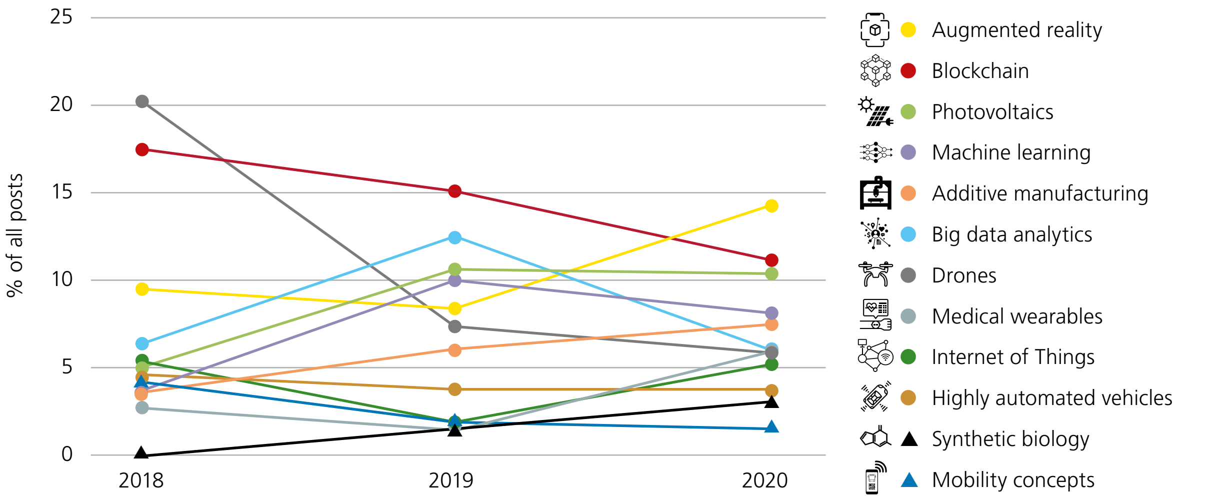

Figure 2: Trend analysis 2018–2020 of the top 10 technologies in Switzerland
The relative frequencies of posts on the different technologies are shown for the years 2018, 2019 and 2020 as a percentage of the total number of posts on all the technologies discussed in the *Technology Outlook 2021*. In addition to the top 10 technologies (shown as dots), this figure includes synthetic biology, with the strongest increase in posts, and mobility concepts, with the strongest decrease in posts beyond the top 10 (both shown as triangles).

There is an apparent shift compared to 2018. Mobility concepts have lost some attention in Switzerland and have disappeared from the top 10. This decline concerns not only the academic discourse, but also the significance of this technology for Switzerland. This is confirmed by the drop in revenue observed by experts in the field, as shown in figure 5 (pages 14–15) in the following chapter. Failed national initiatives have led to this. Medical wearables are the new entry in the top 10. In 2020, almost half the posts on medical wearables concern health apps. Synthetic biology shows a clear, steady increase of posts, which correlates with the estimates provided by experts regarding an enhanced market potential.

In Switzerland, the academic social media discourse in 2020 was dominated by augmented reality, blockchain and photovoltaics. While the growth of photovoltaics was continuous in the past years, augmented reality regained strength after a slight decrease in 2019. Posts mostly address applications in medicine, education and art, while almost no posts whatsoever address industrial applications. Social media posts on photovoltaics cover a broad range of topics and include new developments of materials, additional areas of application and ecological aspects. Owing also to its numerous academic and industrial research groups, Switzerland seems well equipped to establish a significant position in niche markets.

Discourse on additive manufacturing has intensified in Switzerland, too. The increase of the percentage of posts on additive manufacturing, however, is not quite as pronounced in Switzerland as it is in the European comparison countries. In a European comparison, the posts of Swiss institutions of higher education have a more industrial focus and do not discuss almost exclusively applications relating to the corona crisis.

Although blockchain still generates more discussion in Switzerland than in the average of the European comparison countries, the percentage of posts has decreased sharply since 2018. There seems to be a certain disillusionment. What is noteworthy is that an increasing number of posts on blockchain are written by economists and attorneys. Academic discourse on drones has strongly lost significance in Switzerland, slipping down to rank 7 this year. This is due to the increasing outsourcing of technological developments to spin-offs and start-ups[3] founded by graduates of institutions of higher education, to a change of generations at the leading Swiss institutions of higher education, and to their stronger focus on legged robots.

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[2] *Welcome to European Bioplastics.* Retrieved (on 26 February 2021) from https://www.european-bioplastics.org/

[3] This analysis does not include the posts written by spin-offs and start-ups.

Comparison of Switzerland and Europe

The differences between Switzerland and Europe can be displayed graphically. Figure 3 compares the relative frequency of posts of institutions of higher education in Switzerland (horizontal axis) to the relative frequency of posts of institutions of higher education in the seven European comparison countries (vertical axis).

The results are displayed in a four-quadrant diagram. The technologies in the top right quadrant are subject of intense discussion in the social media channels of the institutions of higher education both in Switzerland and in Europe. Only augmented reality and machine learning belong to this category. Photovoltaics and in particular blockchain in the bottom right quadrant are clearly subject of more intense discussion in Swiss academic circles than in Europe, which corresponds well to the classification of both technologies in the Swiss but not in the European top 3. Additive manufacturing is the only technology in the top left quadrant and is discussed more frequently in Europe than in Switzerland. In the bottom left quadrant are the top 10 technologies featuring the lowest discussion intensity both in Switzerland and in Europe. Some differences can nevertheless be identified: medical wearables, for example, attract growing attention in Switzerland, but are much less mentioned in the social media channels of the institutions of higher education in Europe. An opportunity for Switzerland?

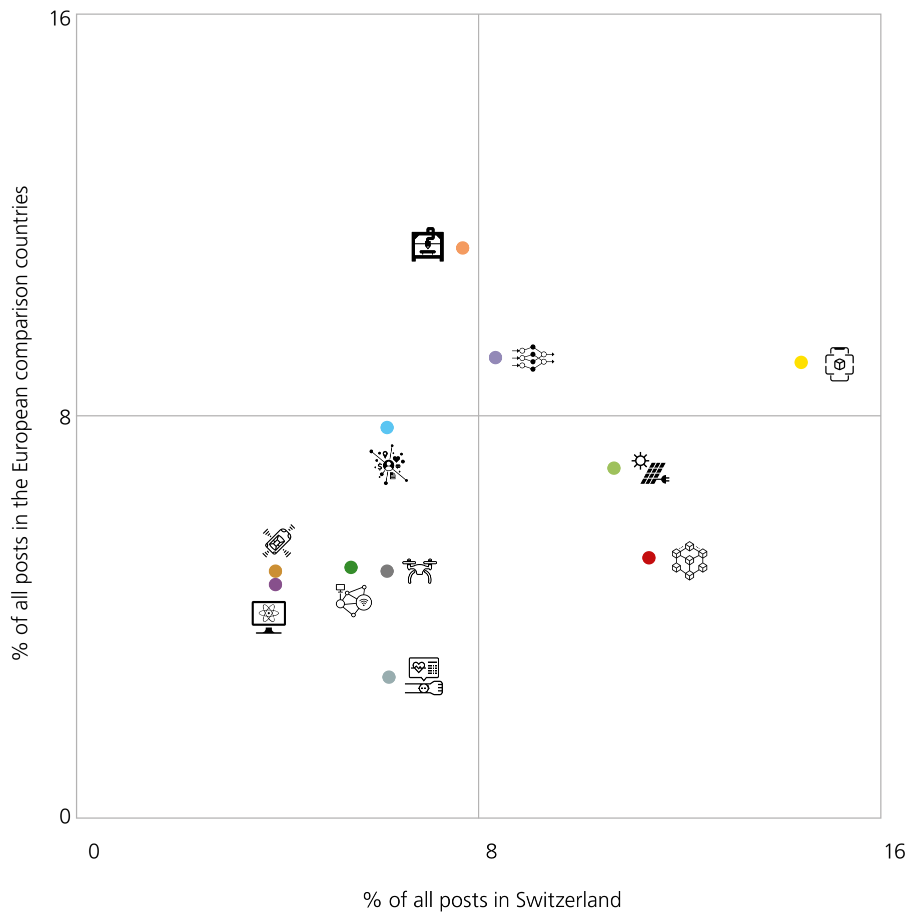


Figure 3: Comparison of the relative frequency of posts on Swiss and European top 10 technologies for Switzerland and Europe in 2020
The horizontal axis charts the relative frequency in Switzerland of the posts on the different technologies in 2020 as a percentage of the total number of posts on all technologies listed in the *Technology Outlook 2021*. The vertical axis charts the average percentages for the seven European comparison countries. A legend to the icons can be found on the side flap at the back.

Cross-country comparison

It is worthwhile breaking down data for the selected European countries and making a comparison at country level. Figure 4 (pages 12–13) shows the social media mentions of the top 5 technologies and the sum of the remaining technologies for Switzerland and for six of the seven selected countries for the year 2020. No data is shown for Sweden, since the number of posts in 2020 was considerably lower compared to the previous years, therefore offering no direct insight.

Overall, the top 5 technologies of the seven selected countries include 13 different technologies. The posts on the top 5 technologies represent around 50% of all posts. In Great Britain, additive manufacturing is dominant with 23% of all posts; ranked second are augmented reality and drones, each reaching just under 8%. In the other countries, the relative frequency decreases rather gradually. The pie charts clearly show the significance of augmented reality and of machine learning. Both technologies are in the group of top 5 technologies in all countries except the Netherlands (augmented reality is missing) and Great Britain (machine learning is missing). Also additive manufacturing is within the top 5 in all countries except Italy and the Netherlands.

It is worthwhile having a closer look at some country-specific characteristics. Photovoltaics occupy first place in the Netherlands and are also mentioned remarkably often in Switzerland. An above-average number of posts in Switzerland originate from the EPFL, where photovoltaics research is carried out at a world class level. Posts by researchers in the Netherlands regard among others the installation of floating solar systems, since the surface available for solar panels is very limited there.

Highly automated vehicles rank among the top 5 only in Germany and in the Netherlands. This result is not a surprise as far as it concerns Germany, considering that its automotive industry represents a major economic sector[4]. The importance attributed to this technology in the social media of Dutch institutions of higher education is surprising only at first. In *KPMG's 2019 Autonomous Vehicles Readiness Index* the Netherlands ranked first, far ahead of Germany[5]. The study reported that the Netherlands and Singapore offer the best conditions worldwide for autonomous driving, among others when it comes to infrastructure and acceptance by the population. This is why posts by Dutch institutions of higher education mostly address the interaction between autonomous vehicles and humans and other road users.

In the Netherlands and in Austria there is a remarkably high number of posts on quantum computing. Dutch institutions of higher education, led by TU Eindhoven, address material developments as well as the possible threat to data security posed by quantum computers. In Austria, the universities of Innsbruck, Linz and Vienna lead the discussions on quantum computers and cover a wide range of aspects, from technical developments to explanations for the public at large.

In Austria, academic discussion is dominated by posts on the topic of blockchain and is led by several universities. Contents are broad, including developments in research and advancements in industrial and economic applications, but also some examples from the cultural sector. →

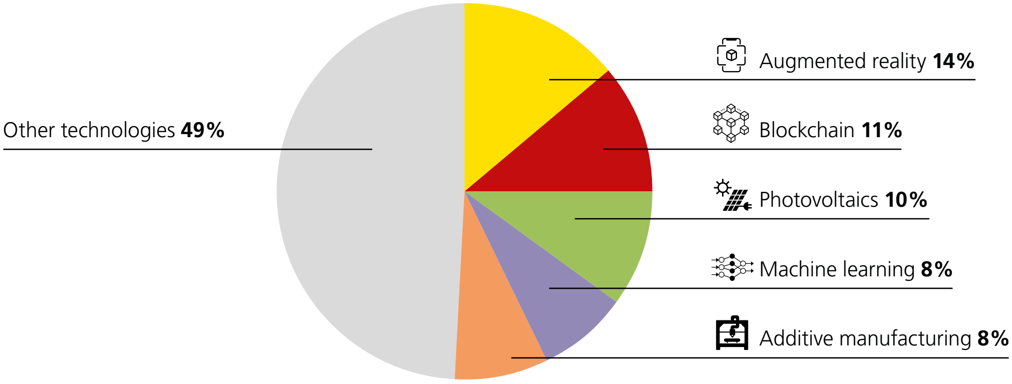
4 *Federal Ministry for Economic Affairs and Energy – automotive industry.* Retrieved (on 26 February 2021) from https://www.bmwi.de/Redaktion/DE/Textsammlungen/Branchenfokus/Industrie/branchenfokus-automobilindustrie.html

5 *KPMG International (2019). 2019 Autonomous Vehicles Readiness Index.* Retrieved (on 26 February 2021) from https://assets.kpmg/content/dam/kpmg/xx/pdf/2019/02/2019-autonomous-vehicles-readiness-index.pdf on 26 February 2021.

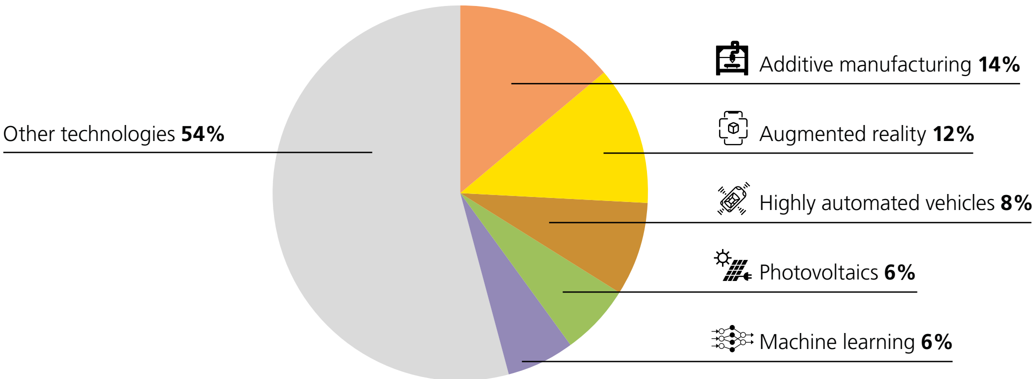
On the social media channels of Great Britain's institutions of higher education there is also a large amount of discussion on drones. Analysing the posts' contents reveals an interesting link. Researchers in Great Britain discuss the possible use of drones to respond to the corona pandemic, for example by monitoring the lockdown or by disinfecting large public spaces from the air.

Data provides a timely impression of which countries discuss which technologies and with which intensity. Although data yields no direct information as to a technology's economic significance, it does provide a reflection of the academic research activities and allows to draw conclusions as to the thematic areas of focus. A solid basis in academic research is essential for successful industrial developments and therefore also for the economic significance of a technology.

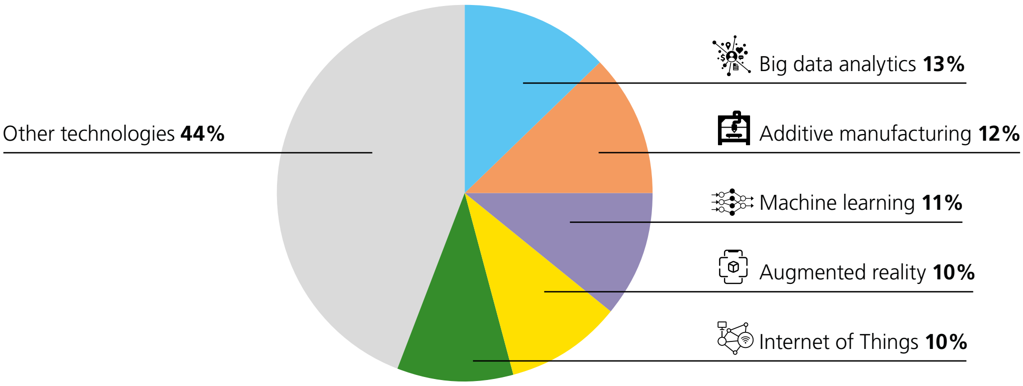
Switzerland



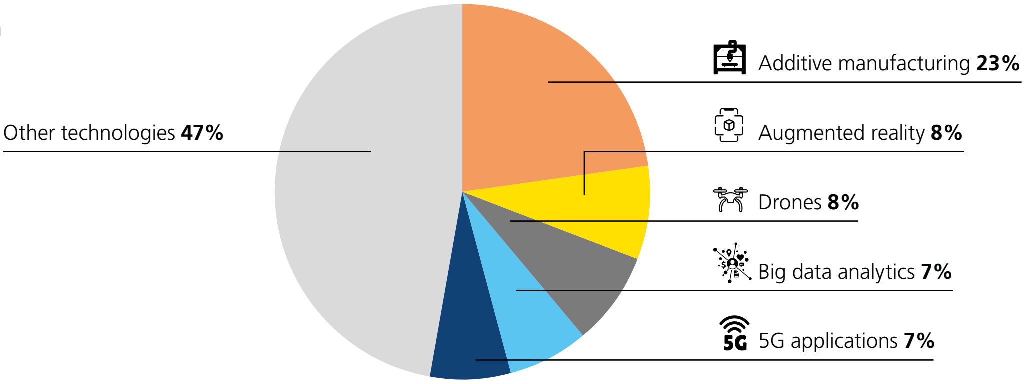
Germany



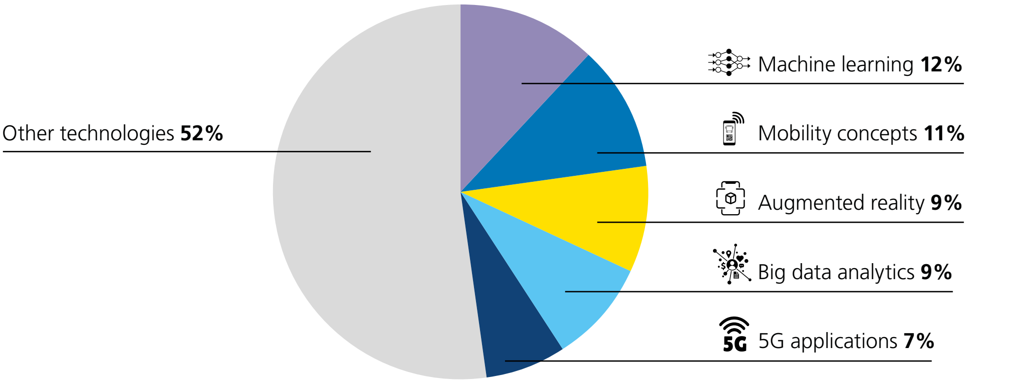
France



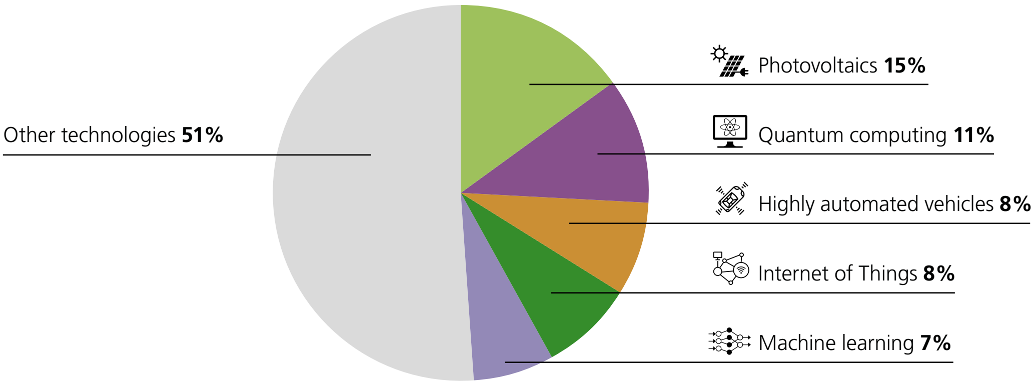
Great Britain



Italy



Netherlands



Austria

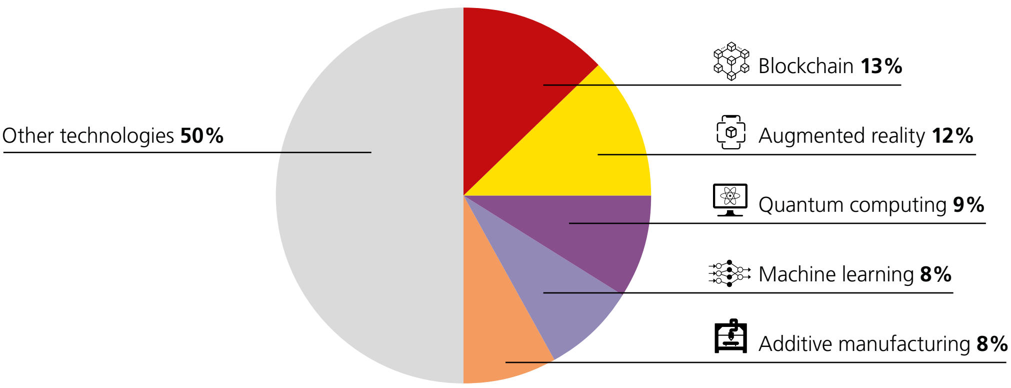
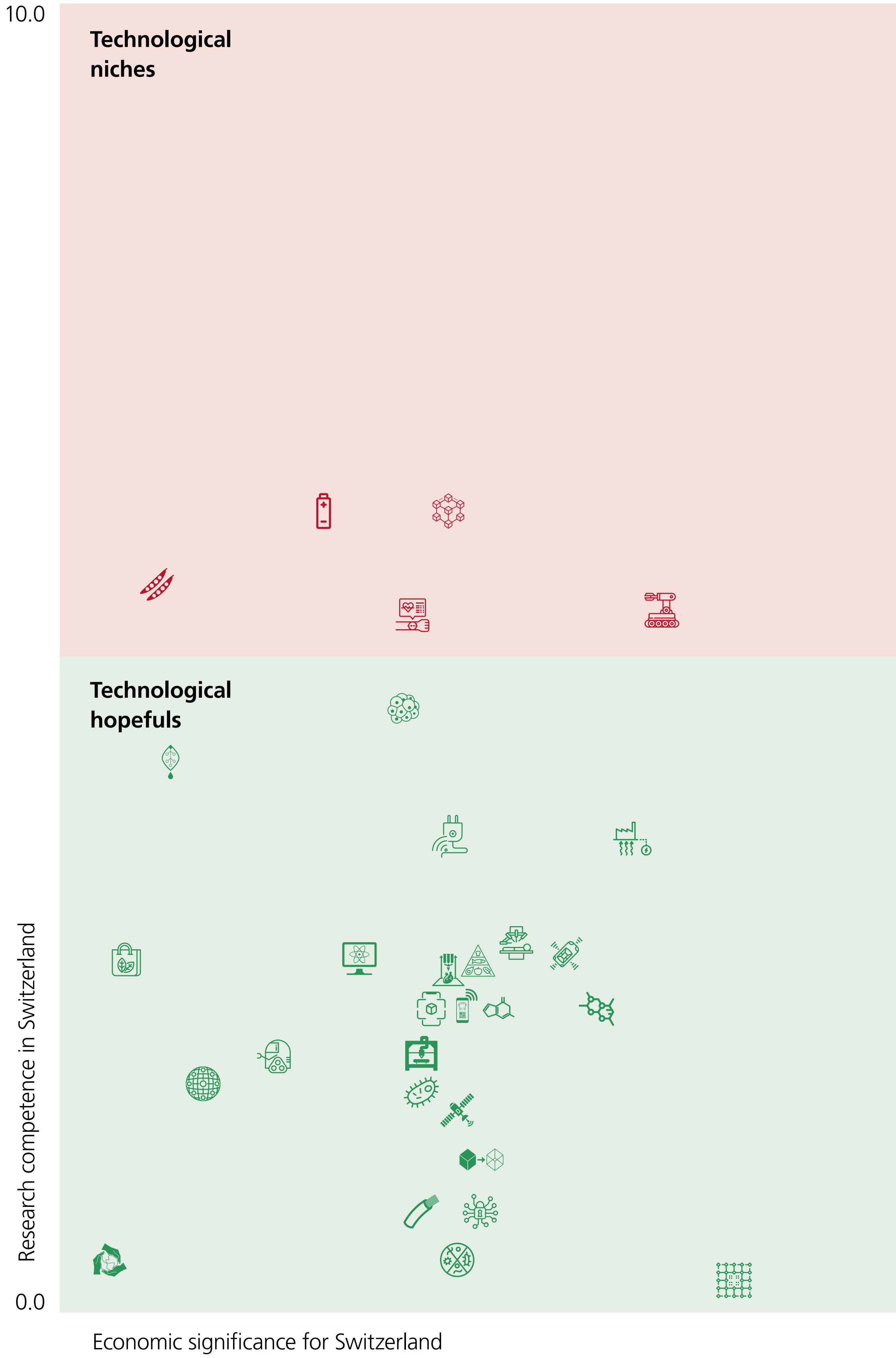


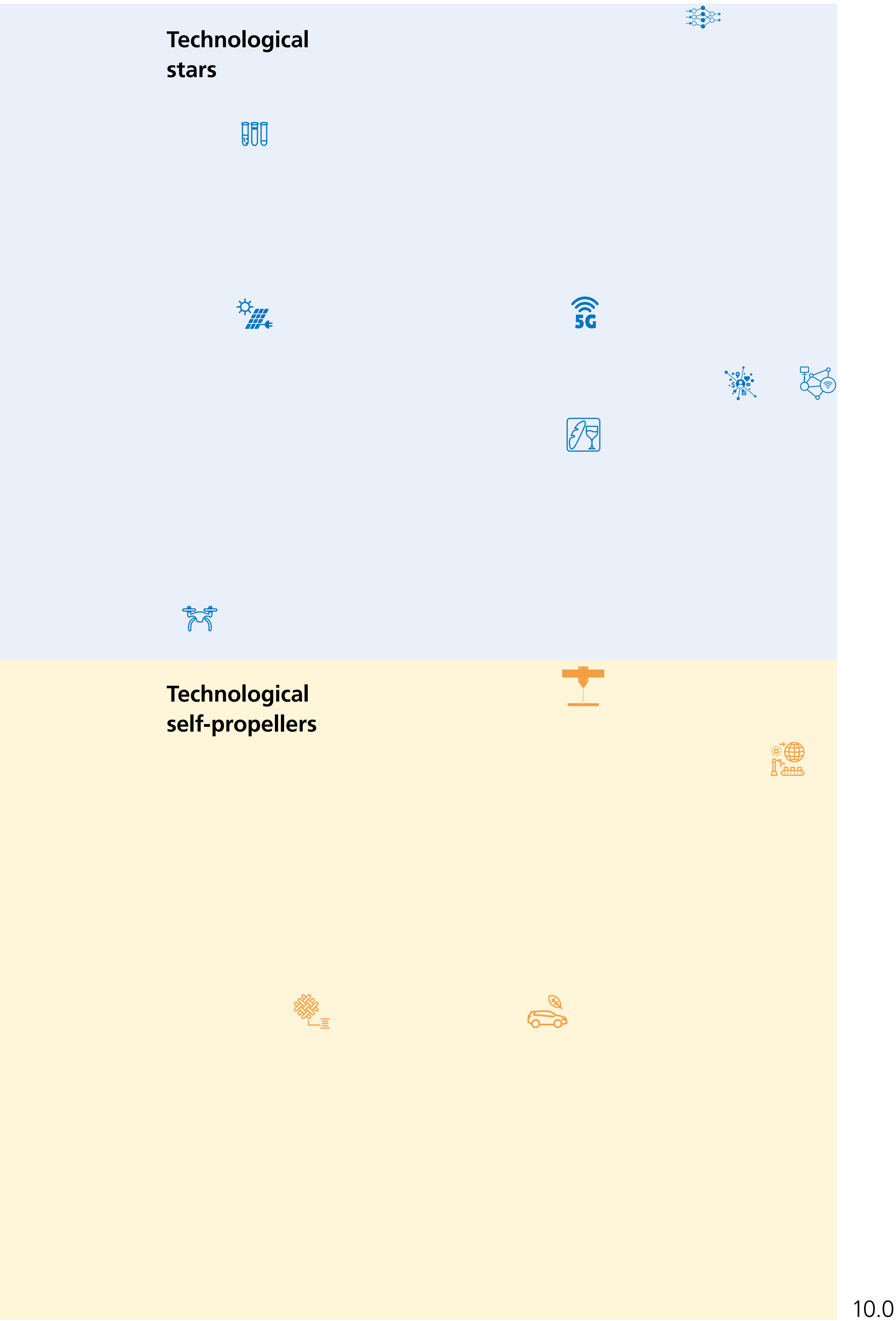
Figure 4 shows the relative frequency of social media mentions of the top 5 technologies for Switzerland and for six of the seven relevant European comparison countries for the year 2020. Each technology is colour coded. The pale grey slice comprises all other technologies beyond the top 5. The slice size reflects the relative frequency of posts on the different technologies in relation to the total number of posts per country with reference to the technologies addressed in the *Technology Outlook 2021*.

Significance of the technologies for Switzerland

Figure 5: Relative significance of the technologies for Switzerland
The horizontal axis charts the economic significance of the technologies for Switzerland, the vertical axis charts the available research competence in Switzerland.[6] Digital trust and data sovereignty are not shown in the four-quadrant diagram, as these two topics concern the application methods of digital technologies rather than specific technologies. A legend to the icons can be found on the side flap at the back.



[6] The diagram is explained in detail in the chapter "Methodology" starting at page 22.



Use the QR code to visit our website, where you will find more information on the significance of the technologies for Switzerland. The filter function will also allow you to make your own selection.

Figure 5 (pages 14–15) maps on a four-quadrant diagram the significance of the technologies for Switzerland based on estimates provided by experts, sector and company reports and own research. The horizontal axis shows the economic significance, which is measured with four indicators: 2019 revenue, market potential in the next five years, legal and regulatory framework and acceptance within Swiss society. The vertical axis shows the academic and industrial research competence available in Switzerland, which is also based on four indicators: number of relevant academic research groups and their competence, number of industrial research groups and their competence. The economic significance is a snapshot with an outlook to the near future and is based on figures relating to the year 2019. The calculation includes an estimate as to how the market potential will develop and therefore information about the coming three to five years.

The diagram is divided into four quadrants with the different significance of the technologies for the Swiss economy: "stars" (top right), "self-propellers" (bottom right), "niches" (upper left) and "hopefuls" (bottom left).

The blue quadrant at the top right contains eight "technological stars", for which research competence and economic significance are high in Switzerland. These technologies provide local companies with strong revenues and many job opportunities, and research activity in these fields is intensive.

The four technologies in the yellow quadrant at the bottom right are referred to as "self-propellers". Even though these technologies are the focus of little research, they form the base of products that generate high revenues. The "self-propellers" are mature, widely-established technologies, whose current development is rather slow. Investing in developing and expanding competences will possibly pay off.

The red quadrant at the top left contains the "technological niches". These five technologies are subject of intense research activity, the available competence in the industry and the institutions of higher education is high, and yet their economic significance is low. Some of these technologies could become "stars" if framework conditions are good and if applications based on these technologies pervade the market. It is essential here that companies develop innovative and sustainable business models that enable a wide spectrum of applications.

The green quadrant at the bottom left contains the technological "hopefuls". The 26 technologies contained in this quadrant represent over half of all technologies described in the *Technology Outlook*, which is not surprising in the light of the Technology Readiness Level[7] taken into account in this publication. For these technologies, the academic and industrial research competence and also the economic significance are still estimated to be low. It is important to continuously closely monitor these technologies as their development is still unclear.

[7] Details on the Technology Readiness Levels can be found in the chapter "Methodology" starting at page 22.

Four areas of research

The different technologies listed in the *Technology Outlook* are assigned to four areas of research: digital world, energy and the environment, manufacturing processes and materials and life sciences. Table 1 clearly shows that a good third of the technologies described in this publication are digital technologies. This emphasises two points: firstly, that digitalisation will continue to shape the years to come, and secondly, that there is still a need for a judicious digital policy.

	"Stars"	"Self-propellers"	"Niches"	"Hopefuls"	Total
Digital world	5	1	2	8	16
Energy and the environment	2	1	1	6	10
Manufacturing processes and materials	0	2	0	5	7
Life sciences	1	0	2	7	10
Total	8	4	5	26	43

Table 1: Number of technologies according to area of research and quadrant

When averaging the values to determine the significance of the different technologies, it seems that the average research competence for technologies belonging to the three areas of research digital world, energy and the environment and life sciences is significantly higher than the research competence for technologies belonging to the area of research manufacturing processes and materials. The technologies belonging to the area of research digital world also have, on average, the highest economic significance. This is probably partly due to the fact that many technologies deriving from this area of research are enabling technologies, like big data analytics and machine learning, which are located in the "stars" quadrant. Such enabling technologies are the base of many products and services in different fields of application.

A third of the technologies described in this *Technology Outlook* derive from the area of research "digital world". These technologies attract lots of attention in public discourse. The *Technology Outlook* points out clearly, however, that the less discussed technologies from the areas of research "energy and the environment", "manufacturing processes and materials" and "life sciences" are crucial to ensure a durable and successful development of the industry.

New technologies in this edition

In addition to the 31 technologies listed in the *Technology Outlook 2019*, this edition comprises 12 new ones. All 43 technologies are mapped in figure 5 (pages 14–15). The *Technology Outlook 2021* also addresses the topics of "digital trust" and of "data sovereignty". No values were collected for these topics since they both describe methods of application rather than specific technologies. The technologies appearing for the first time in the *Technology Outlook* are: 5G applications, alternative engine systems for vehicles, antimicrobial materials, Internet of Things, artificial photosynthesis, medical wearables, microbiota and microbiome, mobile robots, quantum computers, new Internet architecture SCION, recycling of rare earths, and heat-conductive electrical isolators.

Most of the newly added technologies are positioned among the "hopefuls" or narrowly in the quadrant "niches". There are two exceptions: first, the alternative engine systems for vehicles are classified as "self-propellers", but upon closer observation they are a somewhat broader revised version of the article on e-mobility published in the *Technology Outlook 2019*[8]; and second, the Internet of Things as a "technological star" replaces the article "Smart homes"[9] published in the previous edition. Unlike the notion of smart home, Internet of Things applications also play a role for the industry, which explains their high economic significance. The large build-up of 5G infrastructure makes 5G an enabling technology with a potentially very wide range of application. For this reason, and owing to the broad public 5G debate, 5G applications have been included in this edition of the *Technology Outlook*, even though the basic technology is already beyond the level of maturity this publication focuses on.

[8] Cf. *Technology Outlook 2019*, p. 40

[9] Cf. *Technology Outlook 2019*, p. 45

How have the technologies developed since the last edition?

Regarding the 31 technologies described in both the last and this edition, it is worthwhile comparing their positions back in 2019 and today. Particular attention is paid to those changes supported by the estimates provided by experts. A selection of such changes is shown in the following diagram.

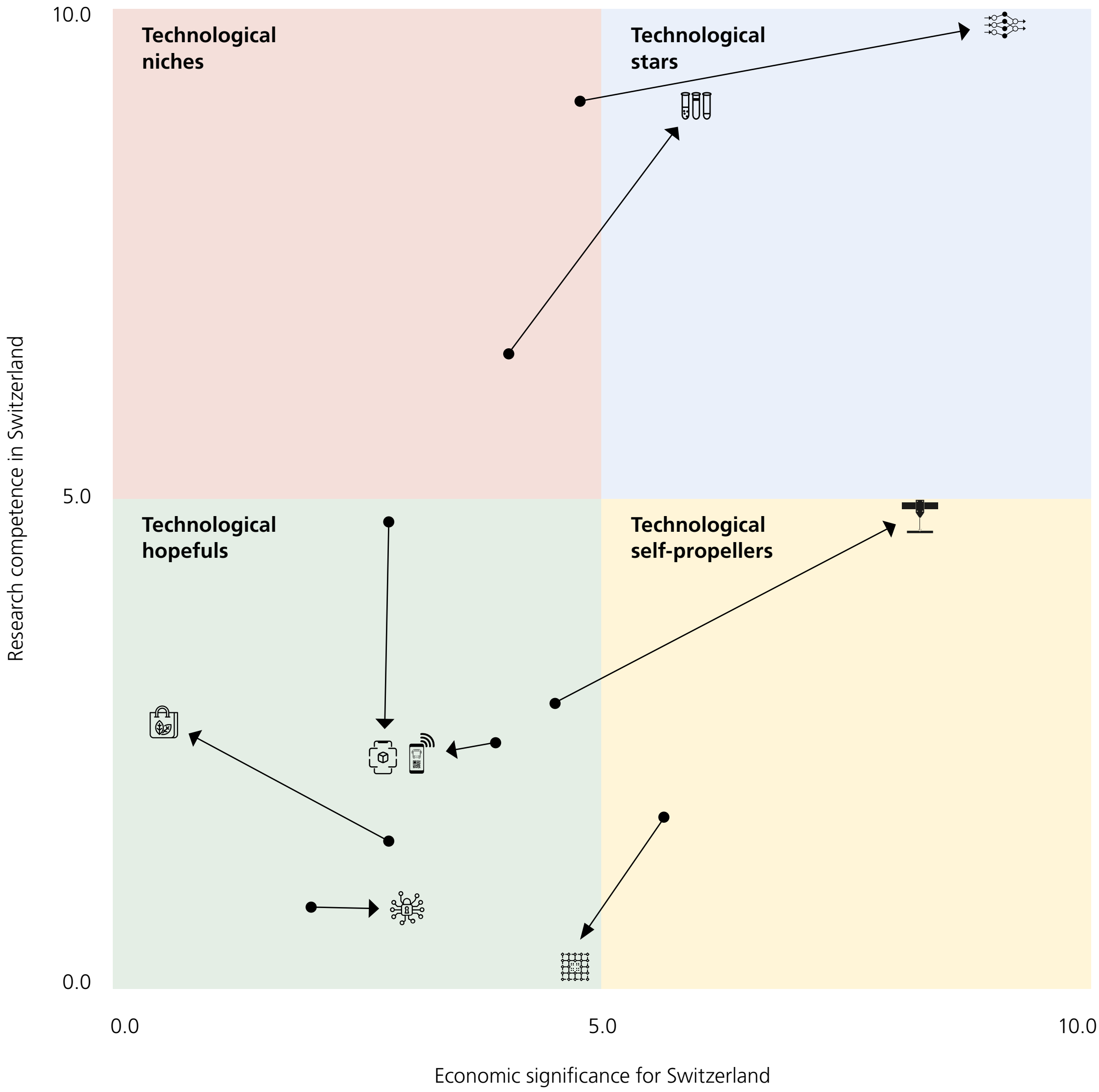


Figure 6: Comparison of the significance of the technologies for Switzerland in 2019 and 2021
Selection of technologies showing a significant change in research competence and/or economic significance compared to the 2019 edition.

Positive developments are seen in machine learning, photonic manufacturing and point-of-care diagnostics. Revenues generated with applications using machine learning have doubled in the two years between the Technology Outlook 2019 and 2021 editions, taking the technology from "niches" to "stars". Interestingly enough, this development is also reflected in the official social media channels of the institutions of higher education: the relative frequency of posts on machine learning increased considerably both in Switzerland and in average in the seven European comparison countries. Also photonic manufacturing applications have doubled revenues in the past two years, so the technology has now been classified as "self-propeller", right below the edge of the "stars". A positive development on the economic axis is seen also for quantum cryptography. In fact, there are meanwhile first encryption products that are hard to crack even for quantum computers and the market potential is therefore higher rated than two years ago. Also point-of-care diagnostics have developed positively, with an increase of research competence and also of economic significance, making this technology a "star". Since data was collected only till 2019, this development is not affected by the corona pandemic.

The developments in mobility concepts, smart grids and augmented reality are somewhat unexpected. The decline in revenues due to numerous failed initiatives and projects in this area is the cause for the estimated lower economic significance of mobility concepts compared to the 2019 edition. This is reflected in the decrease of social media posts by Swiss institutions of higher education. Smart grids are being replaced more and more by programmable power cells, which causes their importance to decline. The development of augmented reality is less distinct. Since the number of research groups is essential in our model to be able to determine research competence, a decrease in this area as seen in the past two years for augmented reality has a negative impact on the research competence values. Nevertheless, the fact that augmented reality is subject of intense discussion in the social media channels of the institutions of higher education suggests that this technology has not lost any of its importance.

Bioplastics show an opposite development with regard to research intensity and market evolution. Despite increased efforts made in promoting research, the use of bioplastics has stagnated in absolute figures, which means that as plastic consumption increases, the share of bioplastics in the total volume of plastic is declining. This is as a clear sign of a declining market potential, which is why the economic significance of bioplastics has been estimated much lower than two years ago despite increased research competence.

Conversely, the positions of some technologies have shifted, even though – according to the experts – there has been no identifiable development in the market or in research competence. In some cases, this is due to a broader or narrower definition of the technology. This has a direct impact on the number of relevant research groups and on estimated revenue: connected machines were given a broader definition, distributed energy systems a narrower one. In other cases, the change of position of certain technologies is due to the reassessment of the parameters provided by new experts. This concerns geothermal energy, digital twins and the mass cultivation of stem cells. Nevertheless, the parameter estimates are consistent throughout the technologies.

Summary

The three technologies with the highest economic significance in Switzerland are: Internet of Things, connected machines and big data analytics. All three technologies are products of the digitalisation and will further promote the digitalisation of the industry. In addition, what they have in common is that in the past years they have become more accessible also to SMEs. To remain competitive, it is essential for Switzerland to provide a framework to SMEs that promotes the use of such technologies with the purpose of increasing quality or efficiency.

The four technologies for which available research competence in Switzerland is highest are: machine learning, point-of-care diagnostics and, both in third place, 5G applications and photovoltaics. Many jobs in different branches could be created if these competences find an even better integration in business models.

Since the 2019 edition, the technologies whose economic significance has increased the most are machine learning, photonic manufacturing and point-of-care diagnostics. All three technologies benefitted from the available research competence in Switzerland. It would be worthwhile analysing more in depth why and how these technologies succeeded in translating research competence into economic significance.

The three technologies featuring the strongest growth in research competence are point-of-care diagnostics, photonic manufacturing and 3D bioprinting. In coming years, the aim will be to make this increase in research competence available also to the industry.

Machine learning is not only the rising star of the year, but also overall the highest rated technology of this edition.

Methodology

This chapter describes the methodology used for the *Technology Outlook 2021*. First, it shows how the technologies were selected. It then describes which procedure was used for social media analysis and explains what data the chapter "Significance of the technologies for Switzerland" (starting at page 14) is based on.

Selection of technologies

The SATW Scientific Advisory Board is responsible for selecting the technologies. A first draft list of technologies was compiled in cooperation with the heads of the topical platforms. Experts assessed the maturity of all suggested technologies and their significance for Switzerland. The final list only contains those technologies that have a Technology Readiness Level (TRL) between 4 and 7 and a high importance for Switzerland. The Technology Readiness Level is a model used to describe the level of technological maturity.

TRL	Definitions
1	Basic principles observed
2	Technology concept formulated
3	Experimental proof of concept
4	Technology validated in lab
5	Technology validated in relevant environment
6	Technology demonstrated in relevant environment
7	System prototype demonstration in operational environment
8	System complete and qualified
9	Actual system proven in operational environment

Table 2: Technology Readiness Levels according to the European research programme *Horizon 2020*

Social media analysis

SATW used the semantic search tool created by Swiss company LinkAlong (https://linkalong.com), which uses as its data set social media channels like Twitter, Facebook and Instagram as well as websites referenced therein. This search tool allowed to collect and analyse all posts of the official social media channels of the institutions of higher education in Switzerland, Germany, France, Great Britain, Italy, the Netherlands, Austria and Sweden regarding the different technologies described in the *Technology Outlook*. A list of search terms was then created describing each technology in detail, including national languages of the countries studied, different names used for one same technology and various possible spellings.

This allows to determine how often a certain technology is mentioned in the official social media channels of the European institutions of higher education. Since the frequency of publication on social media differs greatly between institutions of higher education, the relative frequency was determined for each technology and each country. The total amount of posts for all technologies presented in the *Technology Outlook 2021* was defined as 100%, which allowed to calculate a percentage (i.e. the relative frequency) for each technology. For the time series (figures 1 and 2 on page 8), we analysed the posts not just of the year 2020, but also of the years 2018 and 2019. This allows us to observe how the interest for a certain technology changes over the years.

In order to determine the European average, we averaged the relative frequencies of the seven countries (figure 1). The European average is therefore the average of the percentages. This advantage of this calculation method is that equal weight is given to the percentages of all comparison countries. This is necessary because the institutions of higher education in Germany and in Great Britain are much more active on the social media channels than for example in Austria and in Sweden.

We then transposed the five technologies most frequently mentioned per country into a pie chart in order to generate a country profile (figure 4 on pages 12 and 13). In this way, percentages can be compared across the different countries.

Significance of the technologies for Switzerland

In order to determine the importance of the technologies for Switzerland and to compile figure 5 (pages 14–15), we assessed eight parameters for each technology of the *Technology Outlook*. Four of them are intended to determine the economic significance and four to determine the available research competence in Switzerland. The eight parameters are: 2019 revenue generated worldwide with products and services by companies based in Switzerland, market potential in the next five years, legal and regulatory framework in Switzerland, acceptance within Swiss society, number of relevant academic research groups in Switzerland, competence of these academic research groups in an international comparison expressed by their average h-index[10], number of companies in Switzerland with R&D activities in the given field and competence of these companies by international standards. Value ranges were then transposed into a point system.

2019 revenue (R), based on estimates provided by experts, sector and company reports, statistic databases and Internet research:

Value (in million CHF)	<10	10–99	100–499	500–999	≥ 1’000
Points	1	2	3	4	5

Market potential in the next five years (M), based on estimates provided by experts:

Value	small	medium	large	very large
Points	0.4	0.8	1.2	1.6

Legal and regulatory framework in Switzerland (F_L), based on estimates provided by experts:

Value	unfavourable	neutral	optimal
Points	0.8	1	1.2

Acceptance within Swiss society (F_S), based on estimates provided by experts:

Value	hindering	neutral	encouraging
Points	0.9	1	1.1

[10] The h-index is based on information provided by ResearchGate. Values were compared to those from Google Scholar and then checked for plausibility.

Number of relevant academic research groups in Switzerland (R_A), based on information provided by experts and Internet research:

Value	<10	10–19	20–39	40–49	≥ 50
Points	1	2	3	4	5

Competence of academic research groups (C_A), based on the average h-index of research groups in Switzerland working in a given field:

Value	<20	20–34	≥ 35
Points	0.8	1	1.2

Number of companies in Switzerland with R&D activities in a given field (R_I), based on information provided by experts, sector and company reports and Internet research:

Value	<10	10–29	30–69	70–99	≥ 100
Points	1	2	3	4	5

Competence of these companies by international standards (C_I), based on estimates provided by experts:

Value	low	medium	high
Points	0.8	1	1.2

Transposition of values into the four-quadrant diagram

The values so determined were transposed to a position on the horizontal axis (economic significance) by using the following formula:

$$R * (M + F_L + F_S)$$

Parameters are given different weightings. Revenue, which is based on sound figures, is defined as the main parameter, while the other three parameters act as modulators. The influence of market potential on the development of revenue is assessed as greater than the influence of the legal and regulatory framework, whose influence is in turn considered greater than that of social acceptance. This weighting is reflected in the transposition of parameter value ranges into the point system.

A technology's position on the vertical axis (available research competence) is computed using the following formula:

$$R_A * C_A + R_I * C_I$$

The numbers of academic and industrial research groups are defined as the two main parameters, modulated by their respective competence. This is reflected in the transposition of parameter value ranges into the point system.

These calculations yield values between 2.1 and 19.5 for the horizontal axis and between 1.6 and 12 for the vertical axis. To simplify the visualisation, these values were converted using a linear transformation, yielding a minimum possible value of 0.0 and a maximum possible value of 10.0 for both axes.

Technologies and areas of application

Digital world

5G applications

Gregor Dürrenberger (FSM – Research Foundation for Electricity and Mobile Communication) and **Christian Gasser** (ASUT)

The fifth generation of mobile telephony, so-called 5G, is a combination of hardware and software. Compared to the previous standards, 5G allows to transfer more mobile data faster and safer. Its performance is clearly higher when it comes to bandwidth, response times and number of simultaneous connections. In other words, transferring the same volume of data results in lower radiation and energy consumption than with previous mobile telephony generations. Another new feature of 5G is the general use of adaptive antennas. Unlike omni-directional antennas, adaptive antennas transmit the signal directly to the sending and receiving devices.

The situation today

5G networks are being set up in Switzerland since the beginning of 2019. A main driving force of this development is the growing volume of mobile data traffic, which has been pushing the existing mobile networks to their limits. Strict environmental requirements contribute to setting limits to capacity and performance, which means that more efficient technologies are required to be able to deal with the growing volume of data. 5G is a classic enabling technology that provides the infrastructural basis for a wide array of applications. 5G enables new applications for wireless control and production process monitoring, connecting sensors and exchanging data. For critical infrastructures like power grids or traffic control systems, which can be increasingly controlled via mobile telephony, 5G offers the advantage that such systems can be operated in own applications that are isolated from the rest of the mobile network, thus significantly increasing their safety. Moreover, 5G allows to reserve network capacities, which makes its use especially valuable for blue light organisations and for critical business processes. Latency in 5G is much lower than in previous mobile communication standards, which enables processes and machines to be controlled almost in real time. Technical basic research focuses on new transmission frequencies and corresponding antenna technologies. Applied research focuses on the integration of the new technology in existing or newly created commercial and IT processes.

South Korea and China are international pioneers. In Switzerland, 5G networks have been in operation since April 2019. In June 2020, 14 EU countries and Norway have launched commercial 5G networks. Besides the US and South Korea, Switzerland is one of the first countries worldwide to provide commercial 5G services. In Switzerland there are already several 5G pilot projects, for example in agriculture (smart farming), in machine industry (industry 4.0), in broadband supply and in train operation (*Smart Rail 4.0*) or in tourism. As regards grid extension, Switzerland is among the world's best. However, restrictive radiation protection regulations and permit denials in municipalities and cantons obstruct the establishment of a high-performance network throughout the country, thus making its development very expensive in international comparison.

Future prospects

The EU has set the goal to have all urban areas and transportation routes supplied with 5G reception by the end of 2025. Digitisation and mobile communications are high on the European agenda and are seen as a necessary prerequisite for innovation and competitiveness.

The industry hopes that 5G will increase the automation of its processes, thus shortening production times and reducing failures. Furthermore, production processes can happen more just-in-time and become more customised. A study by *ASUT* shows that 5G technologies will generate an additional production value of over 40 billion CHF by 2030, of which about 88% will return to user sectors. A good political and economic 5G framework would promote the further digitalisation.

Big data analytics

Alessandro Curioni and **Patrick Ruch** (IBM Research – Zurich)

The analysis of big data encompasses the methods and technologies applied to derive actionable insights from large and diverse amounts of data. Advances in communication and computing infrastructure as well as artificial intelligence (AI) make it easier to extract more business and technology insights from big data. Specific sectors, including banking, insurance, pharmaceuticals and manufacturing, benefit from this development.

The situation today

Big data and AI have become even more intertwined and synergistic. Global market growth will be driven by data and AI services delivered via the cloud. The future will be automated by AI-driven analytics to provide continuous, actionable insights. SMEs can access a range of services provided by cloud vendors that promote the adoption, customization and deployment of AI technologies for the analysis of big data. As a result, previous barriers in terms of recruiting or developing in-house expertise and investments in infrastructure will be mitigated. In terms of current challenges, data governance and security remain priorities and are becoming key decision criteria for enterprises seeking to adopt commercial solutions for the analysis of big data. In addition, clients are demanding flexibility regarding cloud environments and striving to avoid lock-in to a particular vendor. Therefore, strategies built on open infrastructure will become more prevalent.

For Switzerland, the findings from SATW's 2019 *Technology Outlook* report remain valid today. The largest industry in terms of the market opportunity for big data is banking, which has helped accelerate the adoption of technologies for big data analytics. It is worth noting that select large enterprises have adopted and evolved a big data strategy in retail, telecommunication and transportation for personalized services and customer profiling. To date, there is little evidence of widespread use of big data among SMEs.

Future prospects

The combination of big data and AI will act as a key enabler for digital transformation initiatives. One important trend is the expected convergence of AI and edge computing, meaning that increasingly more data analysis – 50% in 2023 compared with 5% in 2019 – will be carried out at the point of capture, according to a study by *Gartner*. Correspondingly, the ability to process data by edge computing will become an imperative for real-time decision-making. A continuing trend is the growing investment in public cloud services to increase flexibility. The same study predicts that 75% of all databases will be on cloud platforms by 2023, which will directly impact vendors of database management systems. Generally, cloud environments will be very heterogeneous, with enterprises expected to rely on a mix of on-premises private clouds, multiple public clouds and legacy platforms. This hybrid, multicloud environment will drive the adoption of containerized applications that can run on any platform. The capture of real-time data combined with streaming analytics will continue to become more important to allow the building of applications that sense, think and act in real time. A major obstacle for many enterprises in adopting big data solutions is appropriate governance and security mechanisms. Solutions to monitor and demonstrate digital trustworthiness will become critical assets. Data security will remain a priority. Therefore, enterprises need to incorporate a focus on robust security and privacy practices as well as continuous compliance monitoring throughout their digital transformation journey. →

For Switzerland, SMEs may be confronted with skills gaps and resource limitations in adopting novel technologies. Herein lies a chance in terms of new data management technologies that automate manual and tedious tasks for data management, governance and administration. Hybrid cloud management platforms are being developed to simplify the creation and deployment of big data applications in environments that combine private on-premise computing resources with resources from a public cloud, which brings virtually unlimited computing resources to companies of all sizes. These big data "fabrics" make it possible to identify all valuable sources of data within a company to quickly realize business and technology insights. Investments will be further shifted towards integration platforms.

Augmented reality

Andreas Kunz (ETH Zurich)

The term augmented reality (AR) – or rather mixed reality (MR) – describes the visual overlay of real objects with computer generated (virtual) information. We are also witnessing a boom in virtual reality (VR) applications, i.e. the full immersion into a computer-generated world. Typical applications of these different technologies are found in education and teaching, in product development and production and in the medical field. Many companies in Switzerland already use AR successfully.

The situation today

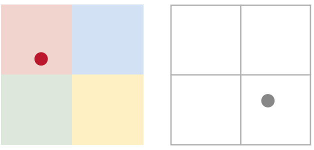
Significant progress has been made in hardware development in the past years. This especially regards the extension of the visual field of MR goggles, like in *Microsoft's HoloLens II*. New devices allow for improved gesture recognition, which optimises the interaction with the superimposed virtual objects. The technology connected to position detection, which is paramount in AR applications, has also been greatly improved and miniaturised. An example is the semiconductor-based, radar-related technology called LiDAR, which is already commercially available in the *Apple iPad Pro 2020*. The higher the display quality, the more new challenges arise in the interaction with virtual objects. Improved gesture recognition or automatic position detection is intended to make this interaction more natural and closer to a real-life experience than it is today.

In the past years, many companies have established themselves in Switzerland in the production of virtual contents and in adapting their appearance and different elements of interaction. An increasing number of industrial users use VR and MR technologies, for instance for entertainment or education and training. Developers are now challenged to provide such solutions for Swiss SMEs in consideration of the company's goal of making its investment profitable within a short time. In recent years, the initial hype has given way to sound disillusionment. Now that it is clear what the benefits are and how these new technologies can be used purposefully, their application has been somewhat consolidated. →

Future prospects

Today's MR devices are still too expensive for a wide audience. In coming years, prices are expected to drop significantly as technical performance increases. More MR will be used with real objects in user trainings (vehicles, machines) and for maintenance and service jobs.

Swiss companies are well positioned at international level and will have a technological edge in future owing to shorter development and production times. Next to services or products, digitality as an additional benefit will become a distinctive feature and a potential competitive advantage. For Swiss companies to maintain their leading position, they will need to describe the problem precisely in order to select and apply the right technology. In order to be timely informed about new technologies and possibilities, companies should have direct exchanges with research institutions, offer bachelor and master programmes in cooperation with institutions of higher education, and seek research collaborations.



Blockchain

Thomas Puschmann (University of Zurich)

Blockchains and distributed ledgers are often called "technologies". Strictly speaking, however, they are lists of data elements that are linked cryptographically. Blockchains and distributed ledgers display the following characteristics: distributed data storage and validation by means of consensus mechanisms (e.g. proof-of-work and proof-of-stake), auditability and persistence. There are two different types: permissionless (anonymous or pseudonymous users) and permissioned (limited circle of known users). Going beyond mere data structures, one finds so-called "smart contracts" with semantically interpretable or software readable contents that are able to execute automated transactions.

The situation today

In recent years, standardisation has become the new success factor for blockchains. Currently, there is competition between different blockchains, like *Ethereum* or *Hyperledger,* and various protocols have been created that are partly not interoperable. The *World Wide Web Consortium* (*W3C*) is therefore working on adequate standards and rules that also apply for cross-border use. Another question is how to protect the user's privacy if pseudonyms can be deanonymized using data linking. Further central issues that are still unsolved are the proof-of-work mechanism and the high energy expenditure. Alternative consensus mechanisms for validating transactions, such as proof-of-stake, are still at research stage.

Switzerland's "Crypto Valley" is home to several start-ups of international renown. Five of these, so-called "unicorns", have a value of over 1 billion USD: *Bitmain, Dfinity, Ethereum, Libra* (*Novi*) and *Polkadot.* The Swiss corporate landscape, however, is mostly characterised by young start-ups, which (still) generate little turnover. There are many areas of application here as well as internationally. Examples in Switzerland are smart contract solutions for insurance contracts (*B3i*), supply chain management for the pharmaceutical industry (*Modum*), trade finance (*UBS*) or consortiums like the *Swiss Digital Trade Platform* founded by *Novartis, Swiss Export Risk Insurance, Swiss Post, University of Zurich* and *Zurich Insurance.* →

The implementation of these new areas of application is closely tied to at least three success factors that have developed positively since 2019: (I) The availability of talents and their training at institutions of higher education: more courses are now offered. (II) A well-functioning ecosystem consisting of institutions of higher education, established players and start-ups with good access to venture capital: the number of start-ups has increased to 842, employing 4400 workers in Switzerland and Liechtenstein. *SEBA* and *Sygnum* are the first two companies to have been granted a banking license. (III) A flexible regulatory and legal framework: on 17 June 2020, the Swiss National Council approved an innovation-friendly law for decentralised applications and business models.

Future prospects

In general, blockchains and distributed ledgers, with their underlying protocols, are emerging as the new infrastructure for the next Internet generation ("Internet of Value"). This greatly influences IT-intensive service providers like the finance sector, but in combination with the Internet of Things also the industry, such as in power generation, trading and consumption. Houses with built-in smart meters and solar cells benefit from intelligent control: digital currencies support peer-to-peer trading and smart contracts simplify digital trading and production. In Switzerland a consortium was founded by the *Swiss Association for Standardization* (*SNV*) called *DLT-for-Power.* Another important area of application is the so-called "Central Bank Digital Currencies" (CBDC), i.e. digital currencies issued by central banks, like the digital Swiss Franc. Worth mentioning in this area of application is the *BIS Innovation Hub* founded by the *Bank for International Settlements.*

The only "killer application" for blockchain so far is *bitcoin*. Many other applications are still at experimental stage and concern, for instance, commerce (*IBM* and *Walmart*), logistics (*Maersk*), transportation (*Novotrans*) or public administration (Netherlands). Further potentials for innovation are found in sustainability, like for example in the traceability of products, of their parts and of their production conditions along the entire supply chain.

Connected machines

Daniel Liebhart (ZHAW) and **Philipp Schmid** (CSEM)

Connected machines ensure a highly-automated, connected and predictive production, i.e. a smart factory. These intelligent and interactive machines enable flexible, efficient and extremely precise manufacturing down to lot size 1, and they create innovative solutions.

The situation today

For many countries with a high wage level, this technology represents a key success factor in international competition. Research and development focus therefore on process optimisation, inline quality control, concepts for "smart maintenance", continuous information flows, high flexibility of manufacturing robots and of their grippers, and also sustainability in production. This results in numerous applications that can be made ready for the market in large companies, in the research centres of institutions of higher education and other research institutions, and also in SMEs and start-ups.

Switzerland's challenge is to use these innovations to create profitable business models as rapidly as possible. A few Swiss high-flyers rank among the leading players worldwide. They are economically significant due to the high qualification of their staff and to their high competitiveness.

Future prospects

The worldwide technological development supports smart factories and process automation, because computing power, network bandwidth and the capacity to solve complex problems with computers are developing rapidly. Companies will learn how to handle the security risks involved. In future, it is necessary to implement innovations gradually, with patience and accuracy.

The Swiss industrial manufacturing sector will assert its position on the global market owing to its readiness for innovation. This means to pursue and to promote the efforts made in applied research. The performance of the smart factory concept increases the more informatics, mechanical and plant engineering and sector expertise are made to interact together. A good network, coordination as well as the cooperation between talents working in research and in practice are needed so that SMEs – the backbone of Swiss economy – can derive maximum benefit.

Digital twins

Andreas Kunz (ETH Zurich) and **Daniel Schmid** (ZHAW)

The main focus of the digital twin technology is the virtual mapping of real products or processes, resulting in a digital replica for production and operation purposes. For this, it is necessary to develop simulation programs, to interlink manufacturing steps and to connect product lifecycle management data to enterprise resource planning data. One of the main areas of application of digital twins is in manufacturing. New uses are possible for manual process steps (e.g. human-robot interaction and cooperation), for designing the virtual workplace or training, and also for remote maintenance. Besides technical feasibility, it is a challenge to maintain the economic balance between costs and revenues. There are many possible options, and a well-thought-out concept will help companies to increase efficiency. The opposite is true if they choose the wrong approach. Attention must also be paid to the changes affecting the workforce. Changes can lead to resistance, which must be dealt with appropriate change management processes.

The situation today

While large industries, like the automobile industry, hold a leading position in other countries, the Swiss industrial landscape, dominated by SMEs, is lagging behind. On the one hand, digital twins are regarded as a chance; on the other hand, the necessary investments constitute a major hurdle – a situation faced by other countries as well. When comparing to Asian countries, digital twins are perceived positively and are strongly supported, especially in China. In Switzerland, SMEs are expected to draw an advantage from the powerful concepts around industry 4.0 and smart factories only if the focus of all benefits is placed on humans.

Future prospects

The possibilities offered by digital twins will boost the industry digitalisation and increase the complexity of product development. In future, products will have a replica in the virtual world and therefore higher functionality and efficiency. This means more customer value. But the increased complexity of processes also represents a challenge. SMEs must find a way to develop their knowledge in order to use digital twins profitably and keep them constantly updated. SMEs need to discover how they can use digital twins to create an advantage for customers and internally and to learn which tools to use. Just like its physical counterpart, the digital twin covers the entire life cycle of development, production and especially operation. In coming years, research and development will address the entire chain more in depth. One difficulty is the long latency between the development of a product and the moment in which the benefits can be reaped. For example, if the goal is to provide data-based services in the context of smart maintenance, this must be taken into consideration already during product development. In future, companies will need to collect data not only for internal purposes, like quality assurance or process optimisation, but also for such services. The pressing questions are: "Where is there a need for data that is not yet being collected?", but also "Where is data being collected that no one needs?". The answers to these questions show the way towards gaining benefits.

Swiss industry should explore the potential of digital twins. Experiences must be collected rapidly considering the latency between product development and benefits. Although there is no immediate need to change the established business model, the fields concerned should develop their knowledge and adopt first measures.

Drones

Roland Siegwart (ETH Zurich)

Professional drones are widespread in cartography as well as in aerial surveying and surveillance. They are also used increasingly in agriculture to monitor fields, in disaster situations or for transport tasks.

The situation today

Spearheaded by *ETH Zurich* and *EPFL*, Switzerland has evolved into a hotspot for drone technology and start-ups in this field. Switzerland plays a leading role in the development of new concepts and of the technology required for autonomous navigation outdoors and in buildings. Drone technology is becoming a flagship sector of the Swiss economy that is of economic relevance and fast growing. It is also promoted by the *Federal Office for Civil Aviation* (*FOCA*). It is not surprising that drone technology figures among the promising technologies in most leading industrialised countries. Commercial drones, in particular those produced by world market leader *DJI*, are becoming more autonomous and their use is growing in many areas. The number of sold drones, however, is an indication that the consumer market is saturated. Instead, the professional use of drones has strongly evolved. As drones are more and more frequently regarded as a future technology of great importance, a small trade war has sparked between the US and China: the US has strongly limited the import of Chinese drones in order to support its domestic drone industry. This situation entails new risks for Swiss drone companies, but also an opportunity. The regulation regarding the integration of drones in public airspace is making good progress, with Switzerland leading in Europe.

The excellent position held by Switzerland in drone research has evolved well, the existing start-ups have grown and new ones have been founded. The *FOCA* plans to launch an online tool in 2021 to integrate drones in public airspace. With this tool it will be possible to enter the planned flight route and time and to receive authorisation almost immediately. Swiss start-ups will gain a significant market advantage and attract foreign drone companies. For the drone industry to thrive, open and clear regulation is essential.

Future prospects

In coming years, there will be a strong development of drones for professional use. Well-evolved fields such as agriculture, aerial surveillance or surveying, will be professionalized, and drone operators will offer new services. The long-standing dream of transport drones will slowly but steadily evolve, with first applications to be found in delivery services or medical transports in remote areas. But mass drone transport services in densely populated areas will struggle to become established.

Latest generation drones can fly in open airspace, but can also be used in buildings and even go into direct contact with the environment. This opens up new areas of application, like bridge inspections or energy plants, where the sensor must make contact with the infrastructure with maximum precision. These new types of drones tap areas in which today scaffoldings, cranes or climbing ropes must be used. Also in this area Switzerland is leading, with the start-up company *Voliro*. Next to the technological development led by start-ups, there are new market opportunities for commercial services with drones, like aerial photographs for real estate companies, farmers and infrastructure operators.

Highly automated vehicles

Bernhard Gerster (BFH) and **Wolfgang Kröger** (ETH Zurich)

Vehicles with conditional automation are equipped with driving assistance systems that enable a self-execution of specific driving tasks (level 3). In critical situations, however, the driver takes over. At the level of high automation (level 4), the vehicle drives autonomously from A to B within a predetermined range and shifts to a low-risk state when needed. At level 5 a vehicle is capable of executing driving tasks autonomously in all situations.

The situation today

The development of automated vehicles is evolving rapidly owing to governmental and industrial support programmes. A leading role is played by the US, by giants like *Alphabet* or *Baidu*, and also by collaborations of larger automobile groups. Europe's "Roadmap 2019" has set ambitious goals: level 3 and even level 4 passenger cars and trucks are soon to be widely available. But experts lower these expectations, even though, in November 2019, *Alphabet-Waymo* tested a self-driving car in Arizona without a safety driver. At levels 4 and 5, advanced assistance systems play a significant role and some of them will be mandatory for new models as of 2022 according to the EU safety directive. A gradual step by step implementation is expected in order to benefit from the experiences made. Developers, however, are pressing to skip level 3 or 4.

The development of automated systems for passenger and freight transportation is gaining more research focus at *ETH Zurich* and *EPFL*, at universities of applied sciences and at developers of sensors, of safety analytics, of software and of special vehicles (e.g. *Kyburz*). Switzerland's role in this field is gaining importance due to the density of its transport services, to its high mobility and to the experiences made with autonomous shuttle buses.

Future prospects

Initially, the attention was placed on vehicles for individual transportation. Today, vehicles for special uses are viewed as forerunners, like slow delivery trucks, shuttle buses and taxi fleets outside the city centres, and also truck platooning. A mixed traffic of human-driven and self-driving vehicles interacting with other road users is inevitable and raises major planning challenges. While self-certification applies in the US, in Europe the customary licensing procedure is based on type approval. It is still unclear which safety level needs to be attained and which proofs need to be provided. Considering that testing in real traffic conditions is highly time-consuming and expensive, alternative solutions are necessary. The focus is on developing critical scenarios and on testing first on test rigs and in specific areas. Other emerging challenges: the gigantic volumes of data (8 terabytes per vehicle per hour) and the protection of these highly complex vehicles from cyberattacks. The public opinion is ambivalent, showing high expectations (e.g. increased safety and comfort) but also fundamental concerns (e.g. loss of control).

It is paramount that Switzerland jumps on the bandwagon despite not having an automobile industry or large system suppliers. Swiss companies can focus on developing special technical solutions, but also act as test lab for innovative mobility concepts and new business models that are under development or in some cases already being tested. In doing so, Switzerland could attain a pioneering role, which would be highly profitable in the light of an emerging market worth billions.

Internet of Things

Felix Wortmann (University St. Gallen)

The Internet of Things (IoT) stands for the vision in which potentially any physical object is connected with the Internet. The result is a merge of the physical and digital worlds and the possibility of creating new products and services. The Internet of Things does not focus on a specific technology, but on the pervasive interconnection of physical things. Examples of concrete areas of application are smart cities, smart homes, smart manufacturing or smart mobility. Whether highly automated vehicles, intelligent houses, medical fitness trackers or connected production systems, the disruptive power of the IoT will change fundamentally the business logic of many sectors.

The situation today

Numerous IoT applications have already existed for years, like RFID tracking in production or connected domestic heating. Nevertheless, manufacturing companies – a significant pillar of the Swiss economy – are finding it difficult to tap the potential of the IoT. The "digitalisation paradox" describes the worldwide phenomenon according to which the high investments made in connectivity do not generate the expected revenues. In practice, the focus is on how to solve customer problems with innovative IoT services. What might seem simple at first glance is in fact a fundamental culture change for many manufacturing companies. The common off-the-record statement is: "We can network, but the IoT works with digital services, and our company simply does not think in terms of services". Applied research in institutions of higher education and in industry therefore concentrates more and more on how the new technical possibilities can be translated into commercial success.

Future prospects

The Internet of Things is evolving continuously. The example of connected and highly automated vehicles illustrates that the IoT must not be considered isolated. It must take into account two other key technologies: on the one hand, artificial intelligence (AI), which transforms connected objects into intelligent objects, and on the other hand, value creation occurs more and more in distributed ecosystems. Distributed platform technologies, like blockchain for example, allow for objects to communicate in a safe and direct manner with other objects, without using a central server. In future, connected objects will become increasingly self-sufficient and independent players.

The manufacturing industry is of paramount importance to Switzerland. The implications of the IoT are far-reaching. Next to improving internal processes (smart factory), connectivity can also create new products and services (smart products). The next few years will show whether Switzerland's industry consistently seizes the opportunities offered by connectivity and defends or even extends its strong position. What is for sure is that digitalisation is reshuffling the cards: highly innovative companies, above all also in Asia, are pushing into the market. The Tesla case is a blunt reminder not to rest on one's current leading edge. Ultimately, it takes above all courage, pragmatism and entrepreneurship, and also the willingness to take the risk of trying out something new.

Collaborative robots

Max Erick Busse-Grawitz (maxon motor ag)

Robots that work together with humans and take over unpleasant or dull tasks, thus making the production process more cost-efficient: collaborative robots, in short cobots, can satisfy this need. But the technology is still lagging behind the need, which is why collaborative robots are still a technological hopeful and not yet a star technology.

The situation today

The term "collaborative robot" is precisely defined in ISO norms 10218 and 15066 and includes the sporadic or constant collaboration between humans and robots. These collaborations require direct and contextual interaction: either the robot slows down when moving into the human working area, or the robot application is so safe that cobot and human work hand in hand. The major challenge lies in making robot applications safe and economically feasible at the same time: large quantities are best performed by dedicated machines, while for small volumes it is significantly cheaper to instruct a worker than to programme a robot. What remains are medium sized lots where both robot automation and manual work by themselves would be too expensive. As of today, there are few of those applications for cobots. Most often they would be too expensive and too slow due to safety requirements and to the lack of technological maturity. The general safety requirements are defined in ISO 13849 or IEC 62061 and in ISO 10218-1 and -2, and are specified for collaborative robots in DIN ISO/TS 15066:2017-04. The latter norm is based on methods that are known in academic research, but that have barely made it to the industry. The technological gaps concern the fast force control with low inertia, impedance control strategies and their implementation in easily programmable industrial products. There has been some progress in three areas, however: intelligent grippers and intelligent robot skins combine sensors and actors. In software, there has been progress in terms of user interfaces and easier programming. And there are now several manufacturers offering integrated solutions with cobots on mobile platforms.

In Switzerland, the situation remains unchanged: there are many SMEs featuring small lot sizes, a high variance and high unit labour costs, making the use of collaborative robots attractive. Still, the integration of collaborative robots into production is slow, both in Switzerland and internationally. In Switzerland, cobot sales figures are decreasing and there is some disillusionment. A cobot is not just an intuitively programmable work colleague surrogate. That is why today we still find cobots in low-frequency tasks, like loading and unloading of machined parts. These and other tasks for cobots commonly fall under the "4D": dull, dirty, dangerous, disallowed.

Future prospects

Using cobots will become attractive once there is a change in thinking and products and production infrastructure are "designed for automation", for example by creating suitable shapes or by using fiducials. As a matter of fact, the key technologies required for a productive use of cobots are advancing steadily, but very slowly. Progress is expected in the following realms: grippers with integrated compliance and rapid force measurement, cheaper and more robust object recognition, and intuitive programmability. For these areas, it would be wise for large and small enterprises to consult with possible research partners prior to purchase, in particular with universities of applied science working in collaborative robotics. Such institutions can suggest effective approaches to reduce costs while increasing the robustness of the production process, or the possibility of providing an unbiased assessment of robots. Long-term research focuses on intuitive, task-based programming and on human-robot collaboration with intent detection and dynamic path adjustments.

Machine learning

Alessandro Curioni and **Patrick Ruch** (IBM Research – Zurich)

Machine learning is a form of artificial intelligence (AI). It is the process of training a software algorithm using example data rather than explicit programming. Machine learning algorithms based on neural networks have resulted in spectacular breakthroughs in speech recognition and translation as well as image recognition. The combination of machine learning and big data offers disruptive potential for various sectors.

The situation today

In the last two years, several cutting-edge advances in machine learning have been achieved, such as generative adversarial networks (GANs) producing artificial videos or speech and leading to progress in understanding the outcomes of AI models. There are several entry barriers, however, such as adequate skills of staff, understanding of the business use case, and readiness of data. In addition, tools to promote the adoption of machine learning made substantial progress as well, with cloud services simplifying, accelerating and governing its deployments. An important challenge continues to be the aspect of trust in machine learning. Solutions must ensure that AI systems are free of bias, provide explainable results, can be audited through their life cycles and are safe, secure and privacy-aware.

Switzerland holds a pioneering role in AI research and should thus take a leading role in certifying AI systems, promoting unbiased AI and informing the public on AI. Therefore, policy makers need to engage in addressing the main concerns around the bias, ethics, explainability, privacy and security of AI. In 2019, the Federal Council published an analysis of challenges and recommendations for AI in Switzerland. The analysis underlined the need for policy makers to address the challenges listed above. Initiatives are needed to strengthen interactions among academic, commercial and political stakeholders. With the definition of specific action fields and responsibilities within the Swiss Confederation, a critical step has been made towards a widespread adoption of machine learning. The hype around AI technologies can lead to unrealistic expectations, ultimately increasing the chances of failure in AI projects. This risk needs to be counteracted by establishing an informed AI strategy at the enterprise level.

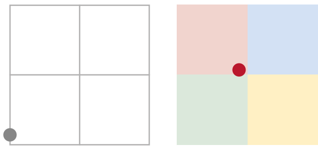
Future prospects

It is expected that the continued evolution of cloud machine learning will drive the adoption of AI by enterprises, allowing them to quickly integrate and scale machine learning while benefitting from the flexible use of computing and development. Distributing AI to the edge of computing systems where data is captured has disruptive potential (page 32). It will increase the training efficiency of deep neural networks by requiring less data transfer and less human interaction. Once embedded at the edge, AI will unlock new application fields, including intelligent robots, drones and machines. The degree of automation enabled by machine learning has the potential to disrupt business models and cost structures. It is expected that by 2024, AI-powered enterprises will respond to customers, competitors, regulators, and partners 50% faster than their peers.

Swiss enterprises preparing for AI adoption should prioritize use cases, ensure access to the right skills, and establish an informed AI strategy to make the appropriate platform and technology choices for governance and scalability.

Mobile robots

Agathe Koller (OST)



The field of mobile robotics is concerned with mobile autonomous systems in unstructured and dynamic environments. Mobile robots are able to adapt in changing circumstances, to move independently in their environment and to operate autonomously and according to the situation. Mobile robotics covers a wide range of indoor and outdoor applications using ground, aerial and underwater robots and also legged robots.

The situation today

Currently, most robots are stationary and designed for specific industrial applications. Technical progresses made in sensor technology, control systems and connectivity, coupled with a price drop, allow for the flexible automation of more and more processes by means of mobile robot systems. The use of mobile robots is increasing in particular in logistics, where they support the transport of goods in production and distribution centres. Using multisensors, navigation and control algorithms, mobile robots move autonomously in production halls and take decisions independently. These cognitive skills play an important role also for other highly promising areas of application, such as the exploration, inspection or maintenance of installations.

Switzerland operates at the forefront in the development of mobile robot solutions. Research focuses most importantly on the perception ability and on the adaptivity of mobile systems. In these areas, the Swiss institutions of higher education and universities, in particular *ETH Zurich* and *EPFL*, are among the leading players internationally. Mobile robotics has spawned many start-ups in Switzerland.

Future prospects

In future, mobile robot systems will be more and more capable of performing unspecific tasks. They will be equipped with the ability to configure themselves, enabling one same robot to perform several tasks and meet changing needs. In production, mobile robots will work collaboratively in hybrid human-robot teams. As a result, rather static production lines will turn into dynamic and self-configuring units. Innovations in artificial intelligence and in navigation technology will increase the importance of mobile robotics considerably. Future areas of application include in particular safety and agriculture. One day, mobile robots will be used to search and rescue people in disaster zones or to protect plants and eliminate weed. Research will also explore other areas of application, for example assistance robots that support people with a physical disability in their daily routines.

The increasing use of mobile robots has the potential to radically change many business sectors, such as commerce, industrial production, agriculture, logistics, medical technology and transportation. Robots will also support people in their everyday private lives. For a wider deployment of mobile robots to occur, it is necessary to define uniform safety standards and also ethical, legal and social framework conditions. The use of mobile robots will also strongly depend on user acceptance.

New Internet architecture SCION

Adrian Perrig, Ilona Wettstein and **Shancong Yu** (ETH Zurich)

The increasing digitalisation of all areas of life and of the economy requires a secure Internet. The Internet is based on the Border Gateway Protocol (BGP), which has remained almost unchanged for 30 years and which transmits data packets over the Internet. At each network node, the protocol determines the route to the next node. Data can easily be attacked, diverted or copied at these nodes. There are ways of solving the problems related to this protocol, such as installing private lines, which, however, is expensive and lacks flexibility. SCION is a new kind of Internet architecture that builds on the Internet's network infrastructure. The path that data packets must take is already specified upon sending. This prevents the data from being misdirected or redirected. Also, specific individual nodes can be omitted. In this way, SCION greatly improves transmission reliability, which also leads to higher transmission speeds. As a result, BGP could become redundant. This new Internet architecture can be deployed at any scale and can be extended beyond national and institutional boundaries.

The situation today

Companies depend on being able to send data securely over widely distributed networks. However, these widely distributed networks make the delivery vulnerable to disruptions and attacks. A trusted infrastructure is also important for small players, who, for example, wish to get into online selling but do not dispose of the financial means for a dedicated line.

The SCION project began at *ETH Zurich;* its development has benefited over time from the cooperation with research groups coming from other universities. As part of a consortium, Internet service providers from Switzerland and abroad act together as integrators and providers of corresponding services. Switzerland plays a pioneering role both in the development and in the utilisation of SCION. Several Swiss banks use SCION for secure and highly available data exchange. And the Swiss federal government uses SCION to ensure secure communication with embassies. Efforts are currently being made to develop individual sector networks using SCION, which will ensure a secure exchange of information also beyond one Internet service provider.

Future prospects

The next five years will be dedicated to further developing SCION also for IoT applications. In order for SCION to establish itself and replace the BGP, Internet service providers worldwide must add SCION to their product range. First international Internet service providers support SCION and are now offering corresponding products. Preparations are underway with other Internet service providers. Also, a foundation will be established in order to coordinate the further development of SCION and to create a certification standard.

As is the case with many open-source software projects, it is essential that an active, international community be formed to ensure the further development and consolidation of SCION. In order to master this challenge, individual economic sectors or countries could create their own secure data space based on SCION. Switzerland could play a pioneering role in developing such sector networks.

Optical space communication

Reinhard Czichy (Synopta)

Optical space communication is the transmission of data between satellites in space or to Earth using free-space optical connections. The lasers used operate in the near-infrared range. The carrier frequency of these data transmission systems – and hence the available transmission bandwidth – is several orders of magnitude higher than for radio frequency systems: the laser wavelength of 1.55 µm corresponds for instance to a frequency of 270 THz; commercial radio frequency systems in satellites operate today in ranges up to 40 GHz. This technology unlocks therefore new bandwidth resources.

The situation today

Testing of optical space communication with data rates of > 1 gigabit/s between satellites in low Earth orbits (LEO) began in 2007. In 2016, the *European Space Agency* (*ESA*) launched the first satellite carrying an optical terminal for operational use in geostationary orbit (GEO). Today, two GEO satellites as relay stations and four Earth observation satellites in LEO with optical data transmission systems are operating. Next to the continuous development of these systems in the US and in Europe, in the past years new technologies for the transmission of highest data rates (terabit/s) between ground stations and satellites were created that enable an entirely new system architecture to distribute data. Challenges are posed by the high complexity of remote system controls or by issues regarding laser technology and optics.

Optical space communication combines a number of complex technologies that are available in Switzerland, like laser, material technology, mechanics, microelectronics, optics and software. From the very beginning, Swiss research and industry have successfully invested their relevant skills, establishing a good starting position. The challenges that Swiss industry now faces are mostly the result of the strong incentives given by national technology programmes to foreign competitors.

Future prospects

Next to applications for space agencies and government services, the successful use of this technology in space has spiked international plans to further develop commercial satellite constellations with optical links that are designed for mobile services with very high data rates and global coverage. These constellations use optical data links between satellites and with ground stations. Given the steadily growing need for transmission capacity and the trend toward improved mobile services, optical space communication is evolving at rapid speed. This concerns the setup and operation of satellite networks, the development of equipment and components (optical terminals for satellites and ground stations), but also the services area and the development of innovative applications.

Swiss industry is able to supply high-quality components and equipment for satellites or ground stations as well as to develop successful business models for managing and using information in real time. However, the continued strong and targeted commitment of the Swiss government is necessary in order to strengthen international competitiveness and develop marketable products.

Quantum computing

Andreas Fuhrer and **Thilo Stöferle**
(IBM Research – Zurich, Swiss Physical Society)

Unlike today's prevailing digital technology, quantum computers systematically use the basic principles of quantum mechanics (so-called quantum superposition and quantum entanglement).

The situation today

Certain problems will remain unsolvable even with the largest classical computers available because the computing resources required for the solution (memory, computing time) grow exponentially with the size of the problem. In contrast, the computing resources required by quantum computers for such problems increase only very moderately. Complex optimisation tasks are one example: the number of possible configurations to be tested grows so quickly with the size of the problem that conventional computers cannot possibly master the task. For certain problems, however, a quantum computer can check all such configurations simultaneously and has therefore an enormous potential compared to conventional systems. Initially, quantum computers will be used in data centres in addition to classic mainframe computers.

Today there are different hardware platforms: ion traps, superconducting circuits, semiconductor quantum dots and photonic systems. In recent years, research has made huge progress in controlling these quantum systems. There are some first commercial quantum computers by *Alpine Quantum Technologies, Google, Honeywell, IBM, IonQ* and *Rigetti* with up to about one hundred quantum bits. Although their performance is still limited due to the instability inherent to quantum systems, they are already being used to solve some problems that are difficult to solve with conventional computers. At international level, a very active ecosystem has developed. The first applications are being tested for a wide range of areas, and specific component supply chains are being set up for matching hardware platforms. Switzerland holds an excellent position in the field of quantum research. Apart from several large companies, only few SMEs are active in this field, mainly as suppliers of individual high-tech components for complex quantum computer systems.

Future prospects

In the coming years, hardware development will focus on increasing the number of quantum bits and in particular on further suppressing and ideally completely correcting errors that can occur in calculations. In terms of applications, intensive efforts are being made to develop algorithms for solving optimisation problems in the chemical, financial, pharmaceutical, logistics, transport and other industries. The challenges are so complex that the next steps in the development of quantum computers will most likely be led by large research collaborations and industrial research centres.

Switzerland cannot afford to miss the boat. Compared internationally, there is still a potential for Swiss SMEs and start-ups in the field of quantum software and in subfields of quantum hardware. Over the next five years, the cloud-based use of quantum computers is expected to move on from research and education to first applications in industry. It is important to take action now, and this applies not only to larger companies in the financial and pharmaceutical industries. Smaller companies too should assess whether quantum computers could offer alternative solutions for their computing-intensive tasks. Especially in the sectors linked to high-frequency, materials, microtechnology and optics, it is worthwhile that manufacturers investigate the use of their high-tech components in quantum computer supply chains and, if necessary, that they optimise such components for this purpose.

Quantum cryptography

Bernhard Tellenbach (ZHAW)

Secure cryptographic methods are essential to protect sensitive information and communication links. Quantum cryptography plays a significant role in averting the threat posed by quantum computers. On the one hand, this technology spawns cryptographic methods based on physical laws governing the state of photons (quanta) that – unlike today's methods – are not concerned with the capabilities of (quantum) computers. Quantum Key Distribution (QKD) is a leading technology that enables the secure exchange of a key over an unsafe channel. On the other side, quantum cryptography can also be used to develop methods that allow quantum computers to attack some of today's widespread cryptographic standards more efficiently than traditional computers. In response, new cryptographic methods have been developed, whose security rests on mathematical problems that quantum computers are not able to solve significantly faster than conventional computers. The collective term post-quantum cryptography (PQC) is used to refer to these methods.

The situation today

Great progress has been made lately. An important limiting factor for QKD is the maximum distance for successful operation. Over the past few years, the use of QKD has been extended to long distances (over 500 km) and areas (2000 sq. km) and to high rates (10 Mbits/s). New suggested protocols are intended to secure QKD over even longer distances. Further improvements concern the security of QKD against attacks at detector level. Although advances have been made and some milestones have been reached, like the opening of a new segment in Great Britain's quantum network, QKD still barely occurs in practical applications. Building quantum repeaters is essential if a large-scale use of QKD is to occur without it being necessary to rely on the QKD network operator.

The *US National Institute of Standards and Technology* (*NIST*) is still working on the PQC standardisation process for quantum-resistant signatures, public key data encryption and algorithms for key exchange. Despite the participation in the race for new PQC standards and the market leadership of *ID Quantique* in QKD, there is still little interest for quantum cryptography in Switzerland.

Future prospects

Various solutions and products use PQC or have at least integrated an upgrade trajectory, but it is still unclear which solution approaches will prevail. The methods published until now are purely informative. An important milestone is therefore *NIST's* conclusion of the standardisation process of quantum-resistant signature and key-establishment procedure expected in 2022–2024. By then at the latest, these could be adopted in common security solutions and play a significant role by 2030. The US government plans to complete the transition to PQC not prior to then, which could mean that quantum computers are still long in coming.

There are several solutions and products in the QKD field, too. Due to a number of limitations, however, like their use over longer distances, they are not used on a broad scale. This is unlikely to change in the short term despite the advances made. Further to the position paper published in March 2020 by *UK's National Cyber Security Centre* (*NCSC*), some critical opinions also entirely advise against the current use of QKD.

PQC is of minor significance for Swiss researchers even though Switzerland is participating in the race for new PQC standards. The changeover to PQC methods offers new opportunities for the economy to launch innovative products and services. The opposite applies for QKD: despite *ID Quantique's* market leadership, the economic importance of QKD for Switzerland is currently low and will remain so in coming years. On the other hand, research activity is increasing, especially when research is also considered a necessary basic element for QKD. Maintaining technological leadership in QKD is important at this point in time.

Energy and the environment

Alternative engine systems for vehicles

Christian Bach (Empa)

Today there are about 1.3 billion vehicles registered worldwide, of which roughly 90% are powered by conventional gasoline and diesel engines. The rest are vehicles with alternative engines, which according to EU Directive 2014/94/EU comprise hybrid and fully electric engines and all vehicles not powered by gasoline or diesel. Currently, 40% of all alternative engines run on ethanol/methanol, another 40% on gas/liquid gas and the remaining 20% are hybrid/electric vehicles.

The situation today

It is expected that the percentage of alternative engines will increase considerably. We will see two main developments: the electrification of engines and the electrification of fuels. The electrification of engines began with the progress made in battery technology, which enables ranges and charging rates previously unimaginable. The electrification of engines ranges from simple hybrid concepts and full hybrids to entirely electric concepts using batteries or fuel cells. Research focuses on the optimisation of energy management (e.g. recuperation or waste heat utilisation for cabin heating, charging management) and on the development of non-critical materials having higher storage capacities for batteries.

The electrification of fuels includes the production of hydrogen and synthetic hydrocarbons. This involves, in a first step, using renewable electricity to break down water into oxygen and hydrogen. The latter is then used either directly in hydrogen vehicles or indirectly by converting it with CO_2 into hydrocarbon for powering hybrid or conventional vehicles. Given the high sensitivity of energy costs, research here is primarily focused on increasing efficiency.

Future prospects

With regard to CO_2 emissions, all concepts based on renewable energy achieve comparably low values. Total costs are therefore the most decisive factor for market development. In all engine concepts, most costs are generated beyond the vehicle itself, for example by the infrastructure or the storage and production of energy. Taking into consideration all aspects, we expect a high percentage of electric engines (battery and fuel cells) in passenger cars or commercial vehicles mostly used locally/regionally, while for interregional, long-distance and freight travel, we expect to see vehicles powered by synthetic fuels.

Owing to its research institutions and industries, Switzerland holds a good position in terms of technology in both areas of development. The openness to technology and keeping a competitive framework are essential in order to promote innovation in the best possible way in both areas.

Distributed energy systems

Kristina Orehounig (Empa)

Distributed energy systems are local groupings of several buildings that together use an array of energy carriers (e.g. biomass, gas, geothermal energy, oil and solar energy) and of energy conversion and storage technologies (e.g. batteries, photovoltaics or combined heat and power). This kind of energy system enables to optimally manage the production and demand of energy in terms of space and of time, and to reduce load peaks.

The situation today

Research and development today focus on identifying, quantifying and exploiting the potentials of flexibility in the electricity grid. The question is how to make the demand and the production of energy more flexible in order to avoid having to expand the grid and to facilitate a wider integration of solar and wind power, which are fluctuating energy sources. To be able to understand the full potential of distributed energy systems, one must consider all aspects of the gas, mobility, electricity and heating sectors. The local provision of services such as balancing energy, but also a wide range of energy conversion options that can be used in a variety of ways for buildings, mobility or industry (e.g. Power-to-X, which is the conversion of electricity to gas or liquid energy carriers), show the possibilities residing in sector coupling. Currently, investment costs for distributed systems are still very high. In future, however, energy production costs are likely to drop significantly due to scaling effects and to the exploitation of renewable energy sources.

The Swiss government intends to liberalise the electricity market in order to promote innovation in energy supply, to strengthen domestic renewable energies and to reach its climate goals – this is in consideration of the fact that Switzerland, in comparison with its European neighbours, is lagging behind in the development of solar and wind energy. The regulatory requirements this entails have not yet been solved and are preventing a faster liberalisation of the electricity market. On the other hand, the first business models for distributed energy systems have been created since 2018 by allowing self-consumption communities, who generate and manage their own solar energy locally.

Future prospects

If the further liberalisation of the energy markets and sector coupling occur in coming years, distributed energy systems will gain more importance. As a result, Swiss companies will have many new possibilities to jump on the bandwagon. Examples are the development, planning and integration of renewable energy systems and of storage, conversion and grid technologies, smart home solutions, new distribution models, contracting solutions and other energy services that promote the transformation of the energy system. At the same time, also cities and municipalities will play an increasing role at implementation level, as the developments made in the energy sector give them a lot more leeway.

Geothermal energy

Katharina Link (Geothermie Schweiz)

Geothermal energy is thermal energy stored in the Earth. Over 99% of the globe's mass is hotter than 1000 °C. Geothermal energy thus provides carbon-free energy – at any time. Hydrothermal geothermal energy harnesses the warm water that is naturally present in certain earth layers. In contrast, petrothermal systems pump water deep underground to create or extend artificial water flow paths. Both technologies extract the warm water from deep underground through a borehole, pump it into a surface circuit, take the heat to produce electricity or heating, and return the cooled water into the ground through a second borehole. The deeper the reservoir, the higher the water temperature. Systems up to approximately 500 metres and 30 °C are referred to as shallow geothermal energy and are used for heating and/or cooling buildings. Geothermal probes are the best-known use. Medium-depth geothermal energy (up to 3000 metres and around 100 °C) is used to heat office buildings, industrial sites and entire neighbourhoods or to feed district heating networks. Deep geothermal energy (more than 3000 metres and over 120 °C) can be used to generate electricity.

The situation today

Switzerland has the highest per capita percentage of geothermal probes. The number of new installations continues to grow. Around 4% of the thermal energy required for space heating and warm water is currently obtained using geothermal probes. No statistics are available yet on the use of geothermal energy for cooling purposes. Shallow geothermal installations are an essential component of intelligent thermal networks: so-called "anergy grids" can supply both heating and cooling to a suitable service area. In this field, Switzerland holds a technological leadership worldwide. Medium-depth geothermal installations are only sparse, although the technology is common in our neighbouring countries and also in many countries internationally. Petrothermal installations have only been realised in other countries.

Future prospects

Hydrothermal installations are established worldwide, but they depend on the natural presence of warm water underground. Petrothermal technology allows for autonomy, which is why it is the focus of research and development worldwide and of pilot projects and demos. Switzerland is one of the most active countries in this field.

The following hydrothermal and petrothermal projects are planned to be implemented in Switzerland in coming years: *AGEPP, EnergeÔ Vinzel, Geo2Riehen* and *Haute Sorne*. In Geneva, the first medium-depth hydrothermal boreholes are being drilled for a district heating network. Based on the new Swiss Energy Act, Switzerland is investing heavily in research. Around 80 researchers are currently working at the *Bedretto Underground Laboratory for Geoenergies*. The various international projects they are conducting help to improve the technological processes and to reduce costs considerably. There is an enormous potential for all applications of geothermal energy in Switzerland, and research will strongly influence the establishment also of medium-depth and deep geothermal energy. Geothermal energy plays a significant role in reaching the climate goals and contributes considerably to creating value locally.

Artificial photosynthesis

Greta Patzke (University of Zurich)

The term artificial photosynthesis refers to processes that convert solar light into sustainable fuels. These processes imitate natural photosynthesis, the process by which plants produce biomass from water and carbon dioxide. In artificial photosynthesis, water is split into hydrogen and oxygen, or CO_2 is reduced to generate basic commodities. Unlike other light-based technologies, such as photovoltaics or solar thermochemical fuel production, artificial photosynthesis processes do not require the addition of biomass or any external electrical energy source.

The situation today

The complex chemical processes that take place in "artificial leaves" require monitoring. The sunlight used to split the different charge carriers must be converted efficiently. These charge carriers activate the fuel-producing processes by splitting water molecules or CO_2 molecules. Current research in artificial photosynthesis focuses on photoelectrocatalytic setups and on the development of hybrid systems. Hybrid systems use results from synthetic biology to design new molecular components. In artificial photosynthesis and related areas, there are well over a hundred research groups worldwide working on the understanding of basic relationships and on prototypes. The EU competition launched in 2017 with the title "Fuel from the Sun: Artificial Photosynthesis" aims at improving the current state of development. Research also focuses on costs, efficiency and durability of the materials involved.

Future prospects

The goal in the near future is to increase performance to 10% solar-to-hydrogen efficiency. Efforts are aimed at increasing the efficiency to 30% by 2050. Furthermore, artificial photosynthesis could benefit from progress in the field of CO_2 capture and from the development of photovoltaic components. The direct storage of solar energy in fuels and in other chemicals is potentially more efficient than biomass-based processes. In addition, the direct conversion of solar energy poses circumvents the food versus fuel debate.

The Swiss research and corporate landscape is well positioned to play a decisive role in shaping the development of disruptive, direct solar-to-hydrogen technologies, even though it is clear that this is only an intermediate step towards the sustainable production of ammonia and other key raw materials. Switzerland's national research programmes in energy research, in combination with a steady increase in international research collaborations, provide an excellent basis for further conceptual breakthroughs. In the related field of solar thermochemical engineering, Switzerland is among the world leaders. Over the past few years, sophisticated bioreactors and other power-to-gas projects emerged from Swiss activities. Being a small country, Switzerland can greatly benefit from technologies like artificial photosynthesis to further differentiate its energy portfolio and to strengthen its independence. Switzerland could export many innovations in the field of artificial photosynthesis, and follow-up developments could be further used for wastewater treatment. In order to meet the upcoming challenges, strong and sustainable collaborations between universities and large enterprises will be indispensable.

Mobility concepts

Thomas Küchler (Schweizerische Südostbahn AG)

The goal of mobility concepts is to merge different means of transportation into one service that is easy and as complete as possible from the users' point of view. The use of automated and shared vehicles plays a key role.

The situation today

After initial successes in Helsinki, Singapore and Vienna, innovative mobility concepts have experienced only limited growth or had to be terminated for lack of commercial success. Overall, there has been no significant progress. Automated vehicles could be a game changer for modern mobility concepts. But vehicle manufacturers have revised their ambitions regarding the timing, since the transition to automation is not as unproblematic as originally expected. The so-called mixed traffic and the gradual increase of the level of automation pose major challenges to the introduction of automated vehicles. The climate debate pushes the automobile industry to focus therefore more on the development of new propulsion technologies. Renowned vehicle manufacturers have abandoned their mobility projects despite the persisting notion that mobility concepts can significantly contribute to reducing CO_2 emissions. The fragmented transport landscape is the main challenge new mobility concepts must face in order to be implemented successfully. Only large internet providers – and not transport companies, nor the public sector – currently have the necessary conditions and data to promote connected mobility. Most offers launched today are driven primarily by commercial interests. Also, the public sector risks not having sufficient influence on such offers.

None of the mobility projects initiated in Switzerland, such as the mobility apps operated by *PostBus* or *abilio*, have managed so far to fully connect various means of transportation. Some of these projects have been abandoned. Only some regional projects are still being developed. Next to the fragmented transport landscape, finding a viable business model for all parties involved constitutes a major challenge on the path to the successful implementation of mobility solutions. Individual trials have shown in this respect a need for a neutral data infrastructure. The successful foundation of special-purpose entities has proven that most existing obstacles can be surmounted.

Future prospects

Mobility concepts regulated at national level can make a significant contribution in mastering the imminent challenges in terms of spatial development, environmental protection and traffic management. For their implementation, it is necessary to first solve the organisational rather than the technical and commercial challenges.

If Switzerland fails to rapidly put into practice a mobility concept that is regulated at national level, it will be hard to avoid an irrevocable relocation towards international Internet companies. To ensure the establishment of nationally regulated mobility concepts, Switzerland needs to bundle all forces and projects with national relevance into one initiative with democratic governance.

Sustainable food production

Erich Windhab (ETH Zurich)

A sustainable food production is based on a system-oriented approach and covers the entire value chain in consideration of ecological, economic and social aspects. The goal is to reach a dynamic balance, first locally, then globally. This requires a multidimensional analysis that displays the criteria in a balanced way along the entire value chain.

The situation today

The food value chain ranges from primary agricultural production to food processing, packaging, storage, transport, distribution and sale, and finally to the preparation and consumption of meals. In order to take into account socio-economic aspects of food consumption and to achieve significant relevance for a comprehensive sustainability analysis, the elements "digestion" and "health" should be added to the value chain. Because a wrong diet can impact sustainability: even if the food eaten has been produced according to best sustainability practices, a wrong diet can lead to illnesses, with implications and treatments that negatively impact the sustainability balance. The analysis focuses on technological aspects and does not take into consideration the health aspect, the latter being covered in the chapter "Personalised nutrition" (page 76). Due to the Covid-19 pandemic, the *UN's 2030 Agenda*, with its 17 Sustainable Development Goals (SDG), has lost its step in 2020, making some SDGs seem unreachable. An adjustment of the SDGs is being discussed.

The Swiss nutrition system and the food industry have largely integrated the SDGs in their objectives. Visible progress has been made in Switzerland since the publication of the SDGs in 2015. It remains to be seen whether the Covid-19 pandemic will cause some adjustments or a shift of priorities. The combination of SDG 3 (good health and wellbeing) and SDG 12 (responsible consumption and production) leads to new focal points and relevant business models that attach more importance to preventing disease through nutrition. The necessary competences are available in Swiss industry and should be more strongly activated.

Future prospects

From a technological perspective, the food value chains can be made more ecologically and economically sustainable through better integration, interaction and flexible interpretation of its components. This calls for interdisciplinary technologies, which take into account the significant diversity of these value chains and of specific conditions. These are for instance robotics, additive manufacturing processes, biotechnology, digitalisation and artificial intelligence, process automation and real-time sensor technology. These technologies might need to be adapted to the food industry's hygiene and safety requirements. The use of blockchain and cryptocurrencies enables transparency and traceability while ensuring data sovereignty and privacy. In future, the safe management of large data volumes will play an important role along entire value chains. The global political leadership should consider adjusting the *Codex Alimentarius* with the purpose of assigning standards to nutritional and ecological food quality standards.

Regarding the interdisciplinary technologies mentioned above, Swiss companies are highly competent and even have market leadership in some areas. Nearly all of the around 2200 companies of the Swiss food industry address issues of sustainability in their objectives. With around 62,000 jobs and annual sales of roughly 25 billion CHF, they represent 5.3% of Swiss GDP. Concerted action is needed to be able to reach Switzerland's sustainability goals and to derive market potentials.

Photovoltaics

Christophe Ballif (EPFL)

Photovoltaics (PV) is the direct conversion of light into electricity using solar cells and solar modules. PV also includes other aspects that enable to use this electricity, such as installation (assembly systems and building integration), areas of application, planning, monitoring, maintenance, forecast and system integration.

The situation today

The PV market has continued to grow steadily worldwide, with almost 130 GW new installations per year and totalling nearly 760 GW in 2020. Mono c-Si modules (monocrystalline silicon) have rapidly replaced poly c-Si modules (polycrystalline silicon). Meanwhile, due to the price drop of monocrystalline silicon and to their higher efficiency, they cover over 70% of the market. More than 90% of solar cell manufacturers have adopted the PERC technology (Passivated Emitter and Rear Cell), which enables an absolute increase in efficiency of 1.5–2.5% at cell level. In 2020, common PERC modules reached 19-20% efficiency. At the same time, the module price dropped below 0.2–0.25 USD/Watt. Improvements to the construction and operation of solar farms have allowed for very low production costs of less than 2 euro cents per kWh solar power in sunny countries.

In Switzerland, PV installation has increased in 2020, with 430–460 MW added. The latest scenarios show that 35–50 GW PV (instead of 12 GW as originally planned in Switzerland's energy strategy), combined with the electrification of transportation and the deployment of heat pumps, would make it possible to achieve a large part of the country's decarbonisation. Swiss roofs and facades have a photovoltaic production potential of 67 TWh solar energy (~65 GW of power). Additional measures are needed in order to increase the number of PV installations to over 1 GW/year in Switzerland.

Future prospects

Several new studies show how solar energy, wind energy and energy storage can become the main pillars of the energy transition. Although PV is competitive in some markets today, regulatory and financial support is needed to increase the worldwide volume of new installations to 1000 GW per year by 2030, minimum level required to fully support global decarbonisation efforts. In the next five years, therefore, we will need a continuous increase in module efficiency and in the demand for advanced silicon module technologies, but also intensified research on low-cost technologies with over 30% efficiency (e.g. tandem and perovskite solar cells). At the same time, it will also be necessary to find new ways to feed large amounts of solar power into the energy system and to store it short and long-term.

Both Switzerland's research institutes and high-tech PV sector for equipment and components continue to hold strong positions worldwide, with significant innovations and products in a highly competitive environment. One opportunity for the industry is to conquer niche markets in Switzerland and Europe for products displaying higher added value. These include special products with ultra-high efficiency, stand-alone systems, building-integrated, coloured, flexible or light PV products, measurement solutions, software for solar power management or for system simulation, and solar mobility solutions for vehicles and ships.

Recycling of rare earths

Xaver Edelmann (World Resources Forum) and
Alessandra Hool (Entwicklungsfonds Seltene Metalle, ESM Foundation)

Resources are considered critical when they have a major economic importance and a high probability of supply shortages. There are many lists of so-called critical raw materials. Almost all include high technology metals like rare earth elements, platinum group metals, cobalt, niobium, tantalum, antimony, gallium, germanium and indium. The criticality of raw materials is mostly attributable to a high demand and also to monopoly positions and poor production reliability. Added to this are ecological and social risks in the supply chain. A low recycling rate and the non-substitutability with other raw materials also have a decisive influence on criticality. Recycling includes the collection, separation and disassembly of single products or parts and separation of the different materials. The causes of criticality and the possibilities of recycling materials differ strongly depending on the raw material.

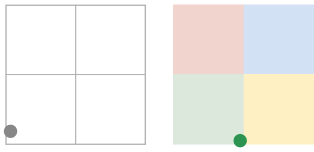
The situation today

A major cause of low recycling rates is when recycling the little amount of raw material used would not be profitable. When it comes to high-value metals, like gold used in electronics or platinum metals used in catalytic converters, the recycling process works well. Due to the large quantities used and the low degree of mixing, recycling of cobalt from electric car batteries is promising and is already a reality in many countries in view of the mobility transition. In this context, the recycling of lithium is also making progress. Regarding rare earth metals, today it is already possible to profitably recycle certain magnets, like in wind turbines and hard disks. Here product return reliability is an important factor. Innovations are therefore needed not only in the recycling process, but also in the logistics and commercial systems.

Future prospects

It is likely that customers will pay more and more attention to the social and ecological problems in supply chains. It is also possible that the security of supply becomes again a topic of social discussion. More efforts must be made to recycle critical metals along the lines of the circular economy. In future, recycling batteries of electric vehicles and recycling aeolian and photovoltaic elements will be of high priority. These are also areas that are particularly suitable for implementing sustainable business models.

In Switzerland, in many cases the amount of recyclable critical raw materials is too small to be profitable. Also, considering these small quantities, using new materials often does not have a relevant effect on costs. Only specialised companies have the necessary recycling know-how, which is why still today the number of recycled products is often small. It is important to identify which technical competences for recycling specialised metals can be developed internally and where it makes sense to join forces with other companies and systems, also abroad. At the same time, it is important to observe the geopolitical developments and, in the light of growing public focus on sustainability, to strive for transparent supply chains. New business models must be developed not only to improve recycling, but also to increase resource efficiency.



Smart grids

Roland Küpfer (BKW)

The purpose of smart grids is to balance the electricity fed in from traditional and distributed sources and also to balance their distributed consumption. In the *Technology Outlook 2019*, smart grids were classified in the yellow quadrant as technological self-propellers. They are mature, well-established technologies, whose current development, however, is rather slow and for which Switzerland is lacking sufficient competencies. But this situation could and should evolve quickly.

The situation today

Distributed electricity generation is expanding rapidly, thus increasing the demand for solutions that optimise load curves. At the same time, demand-side flexibility plays an ever more important role. The result is a fundamental change in the energy sector that goes beyond grid stabilisation and reduction of peak loads. Added to this are the modern mobility concepts and charging infrastructures for electric vehicles, which pose an additional challenge to the target of flexible load distribution. Electricity grids must be designed to withstand maximum loads. From an economic point of view, it is necessary to exploit flexibility in order to minimise the grid extensions that could be required. It is therefore a matter of optimising the existing infrastructure at low operating costs and of reducing the need for grid extensions, thereby saving billions. The development of renewable energy sources increases the complexity of grid management due to the unpredictable fluctuations in the energy injection rate. Smart grids, coupled with smart data analysis, balance the generation and consumption of electricity and contribute to controlling load compensation in order to prevent overloading the infrastructure and extending the grid.

The challenges faced by the Swiss energy sector are known: the discrepancy between the planning horizon and the 24/7 security of supply requirement make immediate action difficult. Also, since the electricity agreement with the European Union has not yet been sealed, Switzerland's security of supply is not guaranteed. The corona crisis clearly showed that countries are primarily concerned with supplying their own population, which underlines the importance of self-sufficiency in terms of energy supply. The evident need to amend legislation is failing to assert itself.

Future prospects

More importance is given today to a comprehensive view of energy generation and consumption owing to the increase in distributed renewable energy sources. All players in the energy market, network operators included, must join forces and work together in order to balance energy production and energy consumption.

In the medium term, Switzerland must find a way to master the increasing unpredictability in energy production and consumption caused by the energy transition. There is a risk otherwise that immense costs incur to extend the grid. A paradigm shift is needed when it comes to planning grid size and to interpreting data to define the true need for grid extensions. The challenges posed by the energy transition, especially with regard to planning and controlling energy grids, move smart grids down from technological self-propellers to technological hopefuls.

Future energy storage

Jörg Roth and **Thomas Justus Schmidt** (PSI)

Future energy storage technologies strive for large-scale energy storage systems that are able to balance the seasonal discrepancies between electricity production and electricity consumption. In future, long-term energy storage systems will be needed to reduce the dependency on energy imports and to lower electricity costs in winter.

The situation today

In past years, increased activity on behalf of energy providers has been observed both nationally and internationally. The gas sector is openly reflecting on ways to better integrate biogas or hydrogen in the energy supply system. In Germany, compensatory payments have been discontinued for some first wind farms, who now have to market their entire production themselves. The situation in northern Germany clearly shows that the overcapacities occurring at certain times can only be exploited reasonably by using storage options. This creates a first-time market for storage systems. Alongside this, the market environment for fossil technologies is losing momentum. As a result, industrial giants like *MAN* are rolling out storage solutions, and the petrochemical industry is investing efforts in renewable base materials, combustibles and fuels to replace fossil energy resources. In the freight transport sector, fuel cells and hydrogen are gaining more attention. In the medium term, the supplier industry must optimise technical components and manufacturing methods for batteries and fuel cells. The chemical industry must focus on synthetic raw materials and be able to supply products like battery electrodes and membranes. The development of business models for storage systems has improved slightly over the last two years.

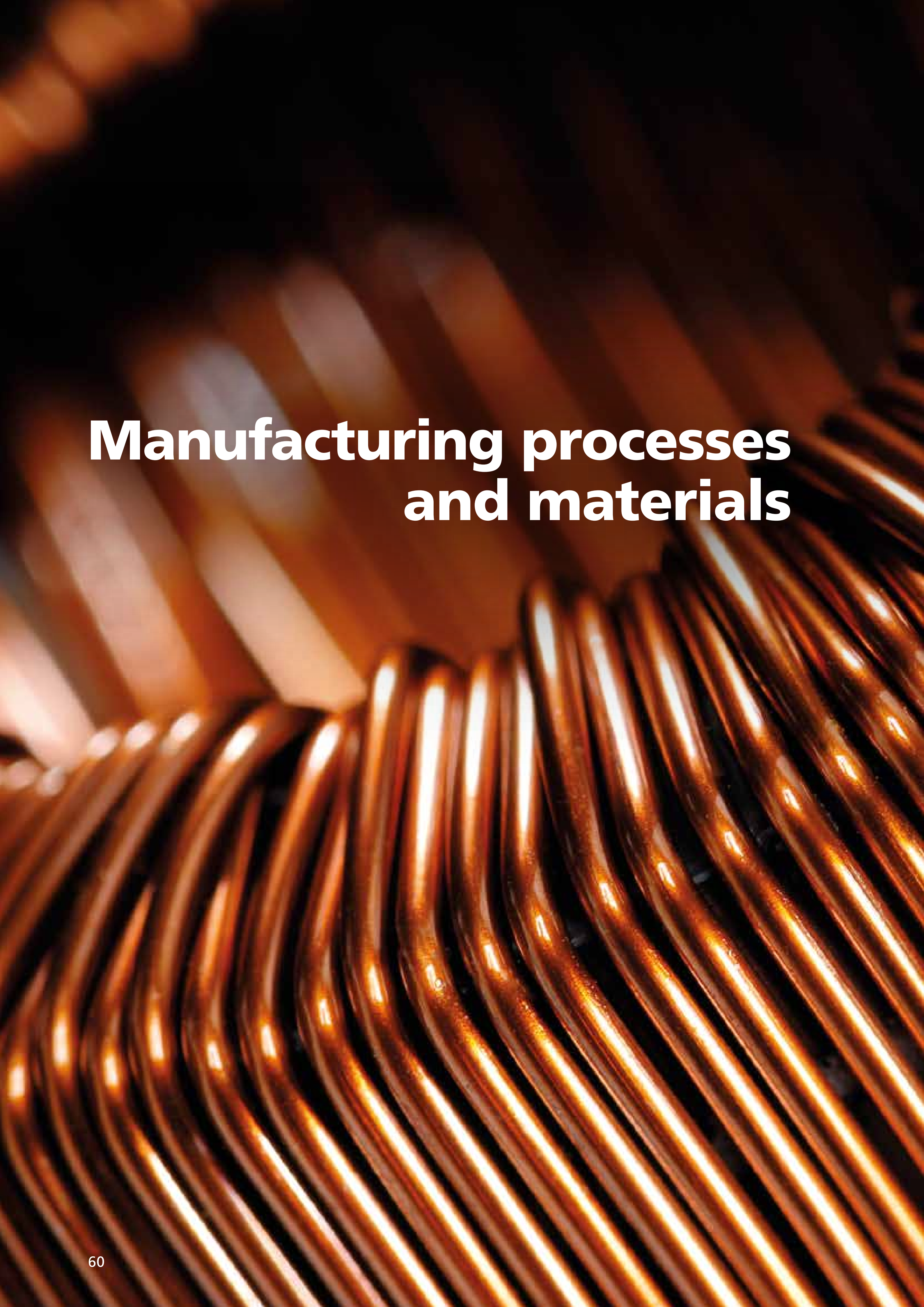
Currently, Switzerland's sustainable energy supply is based on four technologies: hydropower, solar, wind and geothermal power. Based on the production profiles of solar and wind power throughout the year and on the expected energy demand, it is possible to estimate how much energy needs either to be transferred from summer to autumn and winter by using storage options, or to be imported where storage technologies are not available. It is an optimisation task consisting of the interaction between import, energy grids and storage options. The first two areas, "import" and "energy grids", have been widely researched for a long time, while the area "storage options" in a seasonal context is new. In the past seven years, Switzerland has researched, evaluated and developed at laboratory scale the known options for long-term energy storage. This has established a good starting position for implementation: the technologies for a sustainable, comfortable energy future are available at laboratory scale and need now to be developed in order to reach full market maturity. Hence, economic success depends on converting scientific competence into business models.

Future prospects

The next few years will show how the hydrogen sector develops and whether it succeeds in affordably producing methane, methanol or similar compounds from hydrogen, biomass or CO_2 extracted from the air. With regards to thermal energy storage, sorption or ice storage are ready-to-go technologies.

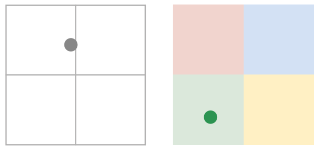
This is an opportunity for Switzerland to convert its energy system in a way that the main costs in future are no longer generated by the use of fuels (oil, gas, uranium), but that future expenditures flow into renewable energy installations (geothermal, photovoltaic, power-to-X, hydropower and wind energy) that retain their value. In this way, spending on energy strengthens the economy at home. This will enable the Swiss energy system to become sturdier and less dependent on raw material markets. Given that the production of components for the energy future is still a new field and that the market is just in the making, the development has a significant economic potential, especially for Switzerland, which is strong in installations. The aim should be to identify this potential in the context of today's business models and to work out opportunities together with customers, suppliers and development partners.

Manufacturing processes and materials



Material development for additive manufacturing

Fritz Bircher (HES-SO Fribourg), **Lars Sommerhäuser** (Empa),
Adriaan Spierings (inspire) and **Anna Valente** (SUPSI)



Materials like metals, plastics, ceramics and composites must be designed for the highly specific processing conditions of additive manufacturing – an understanding that began years ago, especially in the plastics sector. This is the only way to make new high-performance products possible, to meet the high-quality industrial requirements and to implement innovative solutions for most diverse markets like structural and civil engineering, medical technology and aerospace.

The situation today

The development of new metal and ceramic compositions is a relatively new, growing trend. In the past few years, efforts have been made at international level to promote the development of materials for additive manufacturing on different levels and along the entire process chain. The advancements made also led to an increase of the production capacity, since the industry realised that process-specific materials have unique selling propositions. The need for augmented production capacity will increase further with the development of advanced modelling tools, also in combination with artificial intelligence approaches.

Switzerland's participation in this trend is limited, due to the small, but growing number of companies that develop additive production facilities or materials. In addition, the use of advanced modelling tools is still very limited; they are based on multiphysics and must cover several orders of magnitude in terms of length and timescale in order to model large and complex shaped components. This explains why they are mostly used only for research activities.

Future prospects

In coming years, more attention will be given to the developments in multiple materials and graded materials and in biodegradable materials for the circular economy.

Switzerland has substantial expertise in the development of new material formulations and in their associated processes. Combined with a wider application of process and material modelling, Swiss companies would gain a competitive advantage in fields such as metamaterials, 4D printing and the circular economy. This requires, however, that Switzerland continues to focus on its traditional strengths, that digitalisation finds implementation also in material and process development and that companies can benefit from the country's research expertise. The development of materials for additive manufacturing must be accompanied by a targeted support that takes into consideration the entire value chain, including the production capacity for innovative materials. This is a traditional strength of the plastics sector. But the production of advanced materials could also include metal powders, photopolymers or other smart materials, thus enabling Switzerland to secure an excellent position in the field of smart materials and of digital production. This would result in new business models and possibilities along the entire production chain.

Methods in additive manufacturing

Fritz Bircher (HES-SO Fribourg), **Lars Sommerhäuser** (Empa),
Adriaan Spierings (inspire) and **Anna Valente** (SUPSI)

The term additive manufacturing (AM) refers to a group of technologies that allows to manufacture objects by building up material(s) instead of by rotating or cutting. AM technologies encompass the full scope of processing methods for metals, plastics and ceramic. Current developments regard the entire value chain, including pre-processing tools, AM processes and AM machines and also post-processing technologies.

The situation today

Important development trends are technologies for producing large metal parts (also in series) and series parts and also productivity improvements in general. Efforts focus on multilaser approaches, on advanced wire-feed technologies or on the automation of process chains; the widespread use of simulation tools allows to apply these approaches to several sizes. Other important developments that are rapidly on the rise are some aspects of industry 4.0, like the integration of artificial intelligence and data processing methods in machine control. These developments enable new players on the AM market to offer solutions for advanced machine concepts at lower cost. New challenges arise regarding data processing, machine handling and sensor technology: it is crucial to solve them in order to improve process control and obtain a rapid certification of AM components.

Switzerland is partially participating in these trends. A growing number of companies are acquiring know-how in the application of AM or are investing in their own AM activities. In addition, Switzerland's role in AM research is gaining importance. The success of Swiss AM activities depends on the indispensable support to research given by public and industrial cooperation platforms like *IBAM,* SATW and *Swissmem.*

Future prospects

New AM technologies are close to implementation at the industrial level. In this context, binder jetting and direct material jetting technologies become more attractive because they promise considerable productivity benefits. At the same time, there is increasing interest in advanced, extrusion-based processes and in technologies to produce structures with sizes in the micrometre range.

The further industrialisation of AM requires specialised knowledge, which is traditionally available in Switzerland, among others in the following areas: simulation and mechanical engineering, utilisation and integration of AM, artificial intelligence, processing of large data sets, and automation of the production of industrial components for customers in highly regulated markets. Switzerland should support these developments and focus on advanced systems and on process monitoring and process control for the production of high-quality parts. It is necessary to support initiatives that promote the development of next generation high performance technologies and that take into consideration the entire value chain, process combinations and multi-material processing for 4D printing. This will allow Swiss companies to fully exploit the possibilities of additive manufacturing along the entire value chain, to advance the automation of production and to manufacture even more customised products featuring high added value and improved performance. Hence, the industry will be able to react more actively to changing needs, to remain competitive and to keep jobs in Switzerland. An active ecosystem of research organisations, industrial players and platforms must promote the training of engineers, the exchange of specialist knowledge and the support of innovations.

Antimicrobial materials

René Gälli (Livinguard AG) and **Christoph Kolano** (AVA Biochem Ltd)

Infectious diseases caused by bacteria, fungi and viruses are among the most frequent causes of death. The multiresistant germs that occur in hospitals and the resulting infections are particularly problematic because caused by bacteria that are resistant to a large number of antibiotics. In order to reduce the transmission of microorganisms, sometimes antimicrobial agents (biocides) are used to disinfect surfaces. The use of antimicrobial polymers to produce or coat self-disinfecting plastics is also increasing. Most of these materials are based on adding a biocide to the processed polymer. Polymers in the form of fibres are usually impregnated with biocides after having been processed into textile. The biocides reach the surface, where they kill the microorganisms. Commonly used as biocides are metals like copper, silver and zinc or organic antimicrobial agents. One disadvantage of this procedure is that biocides wash out from the treated polymers, thereby decreasing their effect. Also, the biocides come into direct contact with humans and the environment, which contributes to developing resistance.

The situation today

The use of biocides is strictly regulated all over the world, but in Europe regulations are the strictest. Continued tightening of legislation and related constraints constitute a major obstacle for innovative companies and start-ups. As a result, only few companies in Switzerland work in the production and utilisation of biocides in polymers. In recent years, research has turned the attention to polymers with antimicrobial activity but without addition of biocides. The majority of these polymers have a slight positive charge. Since microorganisms have a negative charge on their cell surface, they bind to the positive polymer surface and are therefore physically destroyed. These polymers remain stable and are less toxic for humans and the environment. The risk of developing resistances is considerably lower compared to polymers containing biocides. In Switzerland, different research institutions are working on these antimicrobial surfaces. Another approach pursued by a number of small start-ups in Switzerland and southern Germany uses systems (photocatalysts, enzymes, etc.) that generate biocides in situ. Both approaches are accepted by current legislation. However, given their biocidal effect, the safety for humans and the environment must be certified through tests, which entails high costs.

Future prospects

In 2026, antimicrobial plastics could have a market potential of 65 billion USD. The market volume in Switzerland will range between 800 million and one billion USD. Major market drivers are the increasing hygiene requirements in different areas, for example in the production of antimicrobial surfaces for medical devices and instruments or for work and protective clothing in the health and care sector. Possible fields of application go beyond the medical use: antimicrobial polymers could also be used for packing and storing food, in sanitary products, in water treatment or to produce surfaces in public transportation or in aeroplanes. These developments present significant opportunities for innovative Swiss companies operating in the chemical industry, in plastics processing, in machine industry, in medical technology, in food industry, in textile processing, in packaging industry and in water treatment.

The complexity of the legislation on chemicals is a barrier to innovations and their applications. Many smaller companies are not able to find their way about it nor to face the costs and efforts involved. A Swiss competence centre focused on the regulatory environment and the development of applications as well as disposing of adequate financial means to perform the necessary environmental and toxicological tests would encourage the implementation of innovative technologies and raise the chances on the market for Swiss companies operating in this promising field of activity.

Bioplastics

Roger Marti (HES-SO Fribourg), **Hans-Peter Meyer** (Expertinova AG)
and **Manfred Zinn** (HES-SO Valais-Wallis)

Bioplastics are either plastics produced with renewable biomass but not biodegradable ("agroplastics"), or plastics that are biodegradable and produced either with a non-renewable raw material like petroleum or with renewable biomass. This means that, contrary to popular belief, some bioplastics are not biodegradable. Currently, the worldwide production of plastics totals over 400 billion tons, which potentially burden the environment as micro- and nanoplastics. But there are also bioplastics with exceptional properties that can be used effectively.

The situation today

The plastics consumption per capita in Switzerland continues to increase and is considerably higher than in other European countries. In 2019, 187 countries signed a *UN* agreement to regulate and reduce the transboundary movement of plastic waste. The same year, the EU Parliament approved a law banning certain single-use plastic items. The EU also decided to ban oxo-degradable plastics by 2021, which degrade through fragmentation but are not biodegraded by microorganisms. Costa Rica has announced even a ban on all single-use plastic items starting 2021.

Many countries produce bioplastics for mass-market products, but not Switzerland. The percentage of sustainable and innovative materials used in the packaging industry remains low due to the lack of regulatory control mechanisms and research activities. Nevertheless, changes are slowly happening. *Nestlé* has founded the *Nestlé Institute of Packaging Sciences* in Lausanne, which has taken up the cause of developing functional, safe and eco-friendly packaging solutions. Around 140 companies worldwide develop and produce bioplastics, which are mostly used with mass-market products. The situation in Switzerland is different: given the low availability of raw materials, high quality bioplastics are used predominantly for special applications like in the automobile industry, in agriculture or in medical technology. Several innovative Swiss companies, in cooperation with institutes of higher education, have already proven successful in this limited area with high added value.

Future prospects

Plastics and in particular bioplastics will remain topical at international scale. The Swiss players in this field have different orientations, are not connected and do not share a platform. Next to connecting and to joining forces, a coherent bioplastics vision and strategy for the Swiss market should be developed. Also, consumers should be provided with more education and information on bioplastics. The recently launched research and development activities concerning new high-tech bioplastics (e.g. based on protein) are recommended to be supported. Switzerland is not yet ready to introduce regulatory control mechanisms promoting bioplastics.

Functional fibres

Manfred Heuberger (Empa) and **Urs Mäder** (SATW)

In addition to the inherent benefits of their fibrous form, functional fibres can fulfil new requirements specific to certain applications. These include antimicrobial properties, high water absorption, substance release or protective effect against various impacts. In coming years, functional fibres will be relevant in Switzerland in the areas of life sciences, health and technology.

The situation today

Research in functional fibres is focused on additional functions with high added value in the fields of conductivity of electricity and light and of absorption or release of substances. The areas of application range from communication to medical technology. Multicomponent fibres in particular, in combination with different synthetic materials, are able to meet new technical requirements and enable new variations that respect the balance between stability and degradability. A positive example of application is the *Mobility Assisting teXtile eXoskeleton (MAXX)* by the company *MyoSwiss*: bicomponent fibres featuring a melt-spun sheath are used to allow flexible or rigid structures to merge into each other.

The development of new flame retardants mentioned in the *Technology Outlook 2019* has picked up further speed. The result is commercially available, flame-retardant PET and polyolefin fibres and also textiles for outdoor applications and for public spaces. Switzerland will present such products at the Expo 2020, which will take place in Dubai in 2021. A remarkable discovery was made in this field: these phosphorous-based flame retardants can achieve a chemical stabilisation of polyester melt even at low concentrations. This can be advantageous in recycling processes.

The coronavirus crisis has reminded us of the importance of the adsorption of aerosol droplets and of the interaction of biological particles with fibre surfaces like masks. Investing further efforts in developing such surface structures will challenge researchers in Switzerland and abroad.

Future prospects

The requirements placed on fibres are moving both internationally and nationally towards the sustainability of materials and processes. However, the high stability of synthetic fibres made from fossil resources and their low process costs are an impediment to the targeted production of fibres made from biobased resources, which rapidly deteriorate when used. The development of these fibres will more and more be a question of using the appropriate process. New logistics and business models are needed in order to integrate aspects of the circular economy.

This trend is a significant chance for Swiss companies because it takes into consideration the product's entire life cycle. The Swiss population is aware of the topic. A disadvantage could be that basic research efforts invested in synthetic materials chemistry are no longer a focus nationally and internationally, despite a market with high turnover figures. Swiss companies wishing to benefit from the new developments should connect with the many Swiss research institutes and take advantage of the incentives for feasibility studies. This will allow them to gain specialised know-how in order to develop own products and access interesting markets.

Photonic manufacturing

Andreas Conzelmann (TRUMPF Schweiz AG)

The term surface treatment covers a multitude of processes that alter the properties of a material or texture the surface. Surface treatment is typically carried out by using laser beam sources with medium output power that operate in continuous wave mode, in pulsed mode (micro- resp. nanosecond pulses) or in ultra-short pulse mode (pico- resp. femtosecond pulses). Surface treatment plays a role in almost all sectors, e.g. car manufacturing, battery technology, electronics, communication, aerospace technology, medical technology, food industry, security systems, watchmaking and jewellery, entertainment electronics and defence technology.

The situation today

Megatrends such as digitalisation, globalisation, individualisation and security lead to rising requirements regarding the traceability of components, products and parts along the entire process and logistics chain. New trends such as connectivity, mobility and neo-ecology will increase the importance of surface texturing of metals, semiconductors and polymers, of layer ablation and of production processes in the display or e-mobility sectors. In these latter areas in particular, more new applications are emerging that require laser beam sources with new performance parameters.

Compared to other countries, the Swiss research environment has retained its leading position in photonic manufacturing. This is due, on the one hand, to the excellent basic research work made at *EPFL* and *ETH Zurich*. On the other hand, the institutes of higher education are better establishing themselves in industry-related areas of applied research and development, like for example laser material machining, image processing or optoelectronics. *Swissmem*'s expert group *Photonics* and *Swissphotonics* also act as hubs and as link between education, research and industry. In the past three years, new research groups were formed in Switzerland around the institutes of higher education and some industrial companies, and topics like bio-nano-photonics or microwave photonics are now being addressed. Also Switzerland's education landscape has evolved in recent years: in photonics, several new Bachelor's programmes have been created and a new Master's programme was launched in autumn 2020.

Future prospects

Photonics, and laser surface treatments in particular, is increasingly establishing itself as enabling technology for areas as diverse as autonomous systems, energy supply, digitalisation, artificial intelligence, medical technology, quantum technology, robotics or smart cities.

The Swiss industry could exploit its competencies and experience especially in medical technology and robotics. In Switzerland, the overall photonics market was worth approximately 4.4 billion CHF in 2019, of which over half was generated by the photonic manufacturing segment. Annual growth rates are projected at 6% in coming years. In order to benefit from this growth, Swiss companies should continue to invest in research and development and ramp up their sales activities.

Heat-conductive electrical isolators

Urs Burckhardt and **Steffen Kelch** (Sika Technology Ltd)

It is technically challenging to produce electrical isolators that have excellent heat-conductive properties, because in the case of many materials, e.g. metals or graphite, good thermal conductors are also electrical conductors. Thermal interface materials (TIMs) are important components in the development of new batteries for e-mobility and also for computer and medical technology. TIMs are used as adhesive glues or as gap-filling cast resin.

The situation today

In order to optimise the heat-conductive capacity of electrical isolators, substrates with very low thermal conductivity are combined with suitable solid particles. When applying inorganic fillers on customised surfaces, their interaction between the polymers and the heat-conductive filler is significantly improved. Further developments concern liquid heat-exchange media or materials, which make it possible to use thermally-induced phase changes to evacuate energy. The aim is to create electrically insulating functional materials that are 15 to 30 times more heat conductive than conventional synthetic materials.

Switzerland is an attractive and high-performing location for the automotive supply industry. In this field, the materials used to produce battery modules and (electric) vehicles represent a fast-growing market segment. Considering the advancements in miniaturisation and the resulting increase of energy density in electronic components, heat-conductive materials are faced with new requirements: they must fill the smallest possible gaps. The technological challenges consist in particular in finding systems that are easy to integrate and that ensure good heat conduction and long-term reliability as glue, gap filler, adhesive tape or pad. The e-mobility sector demands TIMs that are easy to dismantle and recycle after use.

Future prospects

Innovations in thermal interface materials have the potential to generate strong added value in large-volume application areas. Till 2025, the global market could reach several billion Swiss francs. But it is rather improbable that the Swiss industry will manage to rapidly catch up with the leading countries in this promising field, unless priority and support are given to research and development in TIMs. In order to stand ground in this demanding global market, it is indispensable to find marketable solutions that can be implemented over a period of five years. Another challenge specific to the Swiss industry: because of its size and importance, Switzerland does not figure among the leading countries in the electronics and automotive industries. It also does not have the resources to play a determining role in this field.

Although key technologies for the production and storage of energy are less appealing to the general public than informatics and health, they are pivotal. The Swiss industry must keep pace with these technologies that are key determinants for the future. The success of Switzerland's industrial and research policy depends on the involvement of the scientific community and the industry in a spirit of international cooperation.

Life sciences

3D bioprinting

Michael Raghunath (ZHAW)

In the field of tissue engineering, 3D bioprinting – or bioadditive manufacturing, i.e. the additive manufacturing of tissues and organs – has established itself as a promising technology. 3D bioprinting differs from standard biomaterials printing in that live cells are part of the manufacturing process. Cells are sprayed on printed structures in a targeted manner or embedded into a biomaterial ("bioink") and deposited in a precise spatial arrangement. 3D bioprinting allows to assemble and build up live tissues layer-by-layer and theoretically endlessly, enabling greater tissue complexity than with standard tissue engineering methods. This should make it possible to achieve an increasingly complete physiological activity of human tissue in cell culture. This is important for the pharmaceutical industry, as the development of medicinal products and cosmetics is very inefficient and costly. Tissues produced in a standardised manner can improve the testing process and also reduce animal testing. In regenerative medicine, 3D bioprinting enables to print vascular structures into the implant, which is impossible with conventional tissue engineering.

The situation today

The extrusion of material and cells from a needle is the core technology and also challenge of 3D bioprinters. Research is therefore focusing mostly on the design of printheads and on printable hydrogels. The patented Kenzan technology of the Regenova printer produced by *Cyfuse Biomedical K.K.* presents an alternative: cell spheres are spiked on vertical needles and placed so close to each other that they fuse together and form structures even without a supporting framework. The production of integrated blood vessels remains a challenge. In 2016, the *NASA* launched a competition to produce in vitro 1 cm^3 of tissue supplied for 30 days by blood vessel-like structures. No successful solution has been found till now.

Switzerland is strongly positioned in all fields that stand to benefit from 3D bioprinting technologies. This applies to the cosmetics and pharmaceutical industries as well as to regenerative medicine. The country numbers many potential suppliers that produce hardware (printer nozzles, electronics, robotic arms, valves) and control software for automated processes. It also plays a leading role for other components required in cell culture. Switzerland will manage to stay in the international arena by integrating this technology in existing industrial and medical processes and by networking with relevant industrial partners.

Future prospects

While the areas of application of 3D bioprinting will remain the same, new printing and cell assembly processes will add on to the current techniques, including the controlled production of spheroids, their optical control, their targeted placement and the repositioning in the spheroids. Some countries have established strong national strategies: South Korea promotes bioprinting to strengthen regenerative medicine and the local pharmaceutical industry. China has its first bioprinting companies. In the US, the *BioFabUSA* initiative was launched in 2016, with a total funding volume of 300 million USD financed in equal parts by the Department of Defense and the industry. Its declared goal is to promote bioadditive manufacturing projects including 3D bioprinting.

Although home to the company *REGENHU*, one of the global leaders in 3D bioprinting, Switzerland seems not to have any comparable national strategy aimed at gaining technological leadership in this area. 3D bioprinting plays no part in the Swiss *National Thematic Network Additive Manufacturing*. Too little attention is currently paid to this technology both at research and at industrial level. In order to remain globally competitive, national research programmes and initiatives must be established for application-oriented basic research. Considering that the manipulation of spheroids represents an alternative to injection moulding and to spraying, it is important that a number of Swiss companies like *InSphero AG, Kugelmeiers AG* and *SUN bioscience AG* provide cell culture plate systems for the production of cell spheres.

Alternative protein sources

Erich Windhab (ETH Zurich)

In recent years, the predicted longer-term shortage of protein supply of the growing world population and also the increasing debate over the sustainability of food of animal origin in industrial countries have spurred significant research and development activities relating to new protein sources and their technological processing.

The situation today

Two main lines of action have crystallised over the past few years. One of them addresses algae and insect protein, which have played a subordinate role as food until now. The other (re)discovers certain plants as protein sources to replace animal protein from eggs, meat and dairy products. Until now, the production of insect proteins lacked an assessment of environmental effects. Meanwhile, companies like *Protix* from the Netherlands have reached industrial production scale, thus making it possible to produce significant ecobalances. Some first analyses have come to the conclusion that insect proteins are already competitive for the production of animal fodder. An additional increase in efficiency is likely in future if unused biomass waste is used as feed source for insects. The life cycle assessments that were carried out also indicate a higher environmental compatibility when organic waste is converted to insect biomass instead of being left to compost or decompose anaerobically.

Algae are a promising protein source featuring a protein content in dry mass of up to 70% and containing essential amino acids and significant amounts of micronutrients. Arthrospira, the blue algae also known as spirulina, and the green chlorella vulgaris algae are considered the ultimate "algae superfoods", as they contain more favourable amino acid profiles than classic plant proteins. However, additional technological developments are still needed regarding the treatment and in particular the profitable extraction of these highly nutritious algal proteins. At the same time, promising applications from Swiss companies are available. Algal biomass from chlorella has already been successfully integrated in high-protein and high-fibre meat analogues.

Future prospects

According to current forecasts, the European market for plant proteins will grow yearly by over 7% and reach a total volume of 2.8 billion CHF by 2024. The flexitarian movement (i.e. people whose diet is mostly vegetarian or vegan) and also the benefits in terms of costs, sustainability and environment are the drivers of this growth. Soy proteins have dominated the market so far. Today, among the "newly discovered" plant proteins derived from cereals, pulses, seeds, nuts and oilseeds, it is especially those derived from broad beans and peas that are gaining significance due to their high protein content and their favourable amino acid profiles. To exploit them, technological proficiency is required to eliminate components with poor nutritional value and to extract the proteins efficiently. Efficiency must be increased even though appropriate, optimised protein isolates and concentrates are already available for further processing into meat analogues, cheese or plant-based milk drinks.

The production of meat analogues based on plant proteins promises synergy benefits from an ecological, economic and social point of view. The excitement perceived in Switzerland since 2018 among research groups, start-ups and companies of all sizes must be encouraged and consolidated by means of other additional technological developments. Also, Swiss business cases must be developed. The opportunities are auspicious.

Biocatalysis and biosynthesis

Rebecca Buller (ZHAW)

The terms biocatalysis and biosynthesis refer to the use of enzymes (natural catalysts) or microorganisms to sustainably manufacture products in addition to classic chemical synthesis: biodegradable biocatalysts can be tailored by means of directed enzyme evolution for many areas of application that are still a challenge for traditional chemistry. Biocatalysis or biosynthesis are already being used in many industries, for example in the production of fine chemicals, in the flavour and fragrance industry or in the production of active agents. Much hope is placed on biocatalysis and biosynthesis for the utilisation of renewable resources as they foster a greater independence from fossil energy sources.

The situation today

Significant advances have been made in recent years. In 2018, the Nobel Prize in chemistry was awarded to Frances Arnold for inventing directed enzyme evolution. Further enzyme families have been made industrially usable and applied in the production of pharmaceuticals, and trend-setting industrial processes have been developed in which several enzymes are arranged in consecutive series to produce complex products. However, regulatory provisions, e.g. regarding using enzymes as adjuvants in food technology processes, and also possible restrictions concerning the open access to bioinformatic data, could prevent the industrial use of biocatalysis and biosynthesis. Many opportunities for sustainable developments based on such data could remain untapped.

Large Swiss companies like *Nestlé* and *Novartis* are expanding their capacities in biocatalysis, biosynthesis and enzyme design and are harnessing the technology to manufacture products with high added value. SMEs are not fully seizing the opportunities offered by biocatalysis and biosynthesis. In Switzerland, new courses of studies and continuing education programmes are being developed in order to overcome the limited availability of trained personnel.

Future prospects

Improved processes for directed enzyme evolution and the increased use of artificial intelligence enable to industrially exploit additional classes of enzymes and to reduce the time-to-market of components produced by biocatalysis. Miniaturisation and automation are further drivers in this process. New biocatalytic processes pave the way for innovations in the area of new active agents. Biocatalysis and biosynthesis can become a game changer in the sustainable production of chemicals derived from non-petroleum based raw materials and also in the degradation of plastic waste.

The corona crisis has clearly shown that Switzerland is not self-sufficient with regard to the production of essential drugs. The active ingredients and the corresponding primary products have to be sourced in particular from Asia. Switzerland should be able to produce at least small amounts of essential medicines needed for emergency care. In this context, biocatalysis and biosynthesis could also play a role. The dialogue between industrial and academic partners is essential to increase the success of biocatalysis and biosynthesis. Switzerland could financially support networking projects that promote the exchange between key partners. Companies interested in incorporating biocatalysis and biosynthesis in their processes should focus on developing knowledge by means of collaborations, of continuous staff training and of specific requirement profiles for new staff members.

Mass cultivation of stem cells

Regine Eibl (ZHAW)

Human stem cells are human body cells that reproduce themselves and that can be differentiated into different cell types or tissues. Their enormous potential for research and therapy of severe illnesses is incontestable. In case for example of neurological, orthopaedic, eye, blood and heart diseases or cancer, stem cells are used to replace or repair damaged cells or tissue. Therapies are performed with the patient's own cells and also foreign cells. Next to pluripotent stem cells, most used are blood stem cells and mesenchymal stem cells (MSCs) derived from bone marrow and adipose tissue. Pluripotent stem cells have the capacity to develop in all cell types of the organism and include the naturally pluripotent embryonic stem cells as well as any body cells that are reprogrammed into pluripotent stem cells in the laboratory. In contrast, blood stem cells and MSCs are multipotent, i.e. they can be differentiated only into a limited amount of cell types.

The situation today

Regardless of cell type, there is an increasing need for human stem cells worldwide. To meet this need, stem cells must be produced in the required amount and quality while retaining their specific properties. Mass cultivation is usually performed in sterile synthetic boxes, so-called cell factories, in which stem cells grow at 37 °C in up to 40 superimposed layers on a total surface of maximum one square metre. But handling stem cells is difficult, and they can only be monitored partially. Larger amounts of cells can be produced by means of a complex and expensive process in which culture boxes are multiplied. In Switzerland, stem cell multiplication for therapeutic purposes is performed in hospitals by using cell factories; there are very few large production facilities.

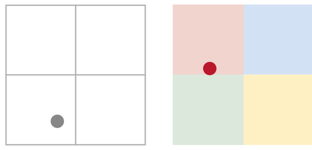
Future prospects

An alternative way of producing stem cells is with automatised single-use bioreactors, in which cells are cultivated in suspension with or without substrates (microcarriers), i.e. in a liquid with finely distributed solid particles. Swiss workgroups have already successfully cultivated stem cells in single-use bioreactors up to production scale. In Switzerland, further important contributions have been made by academic and industrial researchers, who have developed chemically-defined cultivation substrates and microcarriers that are adapted to the different stem cell types. There is still room for optimisation with regard to single-use bioreactors with smaller volumes and to the associated sensor technology. In this context, it is worthwhile exploring the use of 3D printing to produce single-use containers that are adapted to different cells.

According to the market research institute *Analytical Research Cognizance*, in 2025 the global stem cell therapy market will be worth 828.7 million USD. Swiss experts are best positioned to contribute their expertise on mass cultivation of stem cells in national and international research projects and to support producers of cell therapy products, like *Lonza* or hospitals.

Medical wearables

Walter Karlen (ETH Zurich) and **Jens Krauss** (CSEM)



Medical wearables are devices worn on the body with the purpose of collecting health data. This data is forwarded to connected devices (such as computers or smartphones) or to service providers via Internet, therefore providing continuous monitoring of one's health condition and access to personalised medical services. For this purpose, medical wearables combine integrated sensors, actuators, processors and interfaces to collect, process and share data.

The situation today

Medical wearables have been on the market since the 1990s. Early wearables include assistance alarms for the elderly and devices for measuring blood oxygen levels, so-called pulse oximeters. In recent years, wearables have conquered the fitness market. A growing number of these consumer products include medical features, and conversely, medical devices are gradually turning into wearables. Medical wearables are used in preventive healthcare and health promotion, but also in telemedicine, rehabilitation and home care. In 2019, over 30 million units were sold worldwide, which corresponds to a market volume of around 10 billion CHF. What largely influences an increased spreading of medical wearables is their capacity to provide patients with remote medical monitoring. These devices help medical professionals follow the course of a patient's illness and they promote self-empowerment by enabling patients to independently monitor their own parameters and take due action.

Experts from different disciplines must cooperate in the development of medical wearables. The main challenges lie in improved data integrity, data protection, user acceptance, therapy adherence, medical compliance as well as in the seamless integration into clinical workflows. Switzerland has a strong position in order to play a leading role in the development of portable medical devices. In the last decade, hundreds of new start-ups working in this field have emerged across the country.

Future prospects

The use of medical wearables is likely to increase considerably. Future areas of application are in disease monitoring and intervention, especially for chronic diseases, thus making it easier to evaluate and customise treatments to the patient's individual needs. The wider use of medical wearables will pave the way for digital, personalised preventive healthcare. The Covid-19 pandemic clearly shows the need for medical wearables in order to prevent disease, to trace high-risk patients or to observe their health parameters and to support behavioural changes. The main challenges are related to the regulatory environment, with questions such as "Who owns the gathered data?", "How can wearables be integrated into the existing healthcare system?" and "May the respective data be used for health insurances?".

Swiss innovations will influence the medical wearables market. Local manufacturers of medical wearables can further strengthen their good starting position by collaborating internationally with health insurance companies, IT and pharmaceutical companies and smartphone manufacturers. Furthermore, it is essential that investment activities continue in research and development in biomedical sensor technology, (medical) informatics, microtechnology and data analysis. The regulatory framework must be adapted if medical wearables are to achieve resounding success. This entails ensuring that data exchanges are transparent and safe.

Robots in medicine

Bradley Nelson (ETH Zurich)

Medical robotics tightly integrates human clinicians and computer-based technology in order to improve surgery and interventional medicine. This change in healthcare includes the incorporation of artificial intelligence e.g. into diagnosis or detailed monitoring, and the use of more intelligent medical devices to deliver therapeutic benefits. The contribution in the *Technology Outlook 2019* highlighted the most noteworthy commercial successes in the field at that time and the consequences for Swiss healthcare, quantified Swiss research activities in this area as well as the potential economic impact for the Swiss medical device industry, and identified potential regulatory issues.

The situation today

Since 2019, a number of significant international developments have occurred that reinforce the conclusions drawn in the *Technology Outlook 2019*. At the beginning of 2019, *Mazor Robotics*, an Israeli company focused on robot-assisted spinal surgery, was acquired by *Medtronic* for 1.7 billion USD. *Mazor's* core technology is in the area of robotic guidance systems for precisely planning and executing implant placement. In February 2019, *Auris Health*, a US developer of robotic diagnostics and surgical devices primarily focused on lung cancer, was acquired by *Johnson&Johnson* for 3.4 billion USD. *Auris's* core product is the Monarch Platform for remote endoscopy using small cameras and tools that enter the body through natural openings. Later in 2019, the US company *Corindus Vascular Robotics*, maker of a minimally invasive robotic platform for coronary, peripheral, and neurovascular procedures, was acquired by Siemens for 1.1 billion USD. Their core product is the *CorPath GRX* for remote guidance of vascular catheters. In the past two years, *Stereotaxis*, a US maker of magnetically guided robotic technology for heart surgery, obtained an additional 40 million USD in financing and recently announced their new *Genesis* system for remote guidance of magnetically tipped catheters with integrated fluoroscopy. Another robotically guided coronary catheter company, the French *Corindus* competitor *Robocath*, announced that it secured a 40 million EUR financing round in August 2020.

Asia, in particular China, has continued to invest heavily in medical robotics, and further large investments and acquisitions will certainly continue in the coming years. Smaller groups within Switzerland have progressed in technology development. *CAScination*, for instance, continues to improve tumour ablation technology with improved needle placement and reductions in procedure time and radiation exposure. Research in magnetically guided surgical interventions at *ETH Zurich* has resulted in the first portable magnetic navigation systems that can be easily integrated into operating theatres. Despite these advancements, Switzerland has not seen the same level of investment as other countries around the world. Uncertainties tied to the EU's new Medical Device Regulation have most probably dimmed some investor enthusiasm. The long-time horizon that investors must be willing to accept in this area, typically five to ten years before significant revenue is generated, is another reason we see reduced interest in medical robotics from the Swiss investment community.
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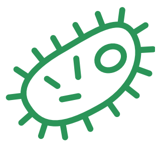
Future prospects

It is clear that medical robotics will continue to impact healthcare worldwide for decades to come. A major promise of the technology is the enhancement of surgical skills while reducing required training and providing surgeons with a safer and more ergonomic operating environment. The renewed interest in telemedicine that the Covid-19 crisis has generated, and the readiness with which robot-assisted surgery lends itself to this, make the case for medical robotics even stronger than it was in 2019.

In order to profit from global developments in medical robotics, it is critical that the Swiss investment community takes an aggressive role in funding relevant startups. Switzerland is in a position to control both the medical robotics platforms and the surgical tools that these platforms use for performing a variety of interventional procedures. It is also important that funding agencies, such as *SNSF* and *Innosuisse*, understand the importance of this area and recognize the long-time horizon that the field requires. It will also be important that regulatory authorities, such as *Swissmedic*, help facilitate progression to clinical trials by providing clear, realistic guidelines.



Microbiota and microbiome

Tomas de Wouters (PharmaBiome)

The human microbiome is the aggregate of all living microorganisms in a human being. In recent years, it became clear that the latter are an essential health factor and can be linked to a number of chronic diseases such as chronic inflammation, metabolic and immunological illnesses, but also neurological diseases. The composition and the function of the microbiome are attracting increasing attention, resulting in promising new approaches for possible therapies.

The situation today

Research on the microbiome and on the resulting therapies is still in its infancy. Many research activities concentrate on the composition and on the activities of microbiomes in ill subjects compared to those in healthy subjects. However, there has been a shift in the focus of research towards identifying causal links between different characteristics of the microbiome and specific physiological states. In the past few years, many new biotech companies have attempted to launch various applications on the market. Most of these start-ups are closely linked to universities. Their work focuses on analyses and on using the results for therapeutic purposes. Apart from developing new drugs, this emerging industry is also concentating on how the microbiome can be used as therapeutic agent. There are some first experimental applications in the US, under the governance of the *Food and Drug Administration* (FDA), that use the microbiome as a whole in the treatment of recurring Clostridium difficile infections. The first global research efforts were pooled in Europe under the *MetaHIT* project and coordinated in the US by the *Human Microbiome Project*.

The key challenge is to understand large populations that present a high degree of complexity. It is believed that the microbiome is highly contextual, similarly to the human immune system. Continuous research in this area is therefore essential for the long-term development of the state of knowledge. Another challenge is the transferability to humans of the causal connections currently explored in animal testing. →

Much research activity on the microbiome is seen in Switzerland, with competencies in microbiology and gnotobiology (the study of animals with specific microbiomes). Two sectors traditionally play a key role in microbiome research, namely the food industry and the pharmaceutical industry.

Future prospects

The first microbiome products will be launched in 2022. As a result, an increase of clinical programmes and of new candidates in the development pipelines is likely to occur. In addition, a series of health-promoting lifestyle products will come out in the next five years. Once the composition of microorganisms is better understood, it will be easier to plan therapies and nutritional measures, which are likely to support the development of the prebiotic and dietary supplements market.

It is expected that microbiome therapies become a significant part of medical treatments. Substantial investments have been made in the early phases of development of therapies, which are now subject to rigorous examinations by the industry. Academic efforts will also impact the speed of further developments in coming years. To ensure the success of microbiome therapies, it is essential to promote the exchange between different fields of scientific expertise that have knowledge in clinical development and know-how in industrial production processes.

Personalised nutrition

Erich Windhab (ETH Zurich)

Personalised nutrition aims at meeting consumers' individual needs and requirements in terms of acceptability, health aspects and preferences. Preferences are mainly related to culinary and sensory impressions, and acceptability is greatly determined by socio-political aspects. Consumers grow aware of diet-related health aspects as a consequence of allergies, difficulties in maintaining ideal weight, illnesses or intolerances, or they receive a diagnosis from specialists in nutrition and health.

The situation today

From the perspective of nutritional counselling and of medicine, all consumers are unique with regard to their genetic makeup and its manifestation, their bacterial microflora (microbiome) and their gut-brain connection. According to recent evidence, nutrition influences all three factors, thus making the ambition to produce personalised food for every individual almost impossible to fulfil and economically very unattractive. But it also means that a targeted diet is able to "tune" the genetic manifestation, the microbiome and the gut-brain connection in a way that improves the individual's well-being. In recent years, research first presented "personalised foods" for different large target groups that differ greatly in terms of age, activity pattern, eating habits, gender, health condition, lifestyle, sustainability awareness and intolerances. Despite there not being any convincing concepts available, the idea of "personalised nutrition" has not been given up, but it has taken a back seat. →

A study published by *ETH Zurich* in 2019 has provided valuable knowledge on key sustainability parameters in Switzerland and their interactions in group-specific dietary habits. A healthy diet pursuant to the recommendations of the *Swiss Society for Nutrition* (*SSN*) was identified as the most viable option, because compared to the current average Swiss diet it can lead to a significant reduction of the ecological footprint (-36%), of consumer expenditure (-33%) and of health damaging effects (-2,7%). A meat-centric diet causes a significant increase of said indicators by 23, 20 and over 4%. Reducing meat consumption with plant-based meat analogues resulted in health benefits with positive effects on health care system costs. The growing interest for "flexitarianism" in Switzerland has initiated a dietary trend that has found resonance among established food companies and has sparked a wave of new start-ups. Since 2018 meat sales in Switzerland have decreased by about 3%. Next to plant-based meat alternatives, also plant-based products in other food categories of animal origin (e.g. milk, cheese) having high valence and improved sustainability have moved into the spotlight of R&D. Switzerland continues to hold an excellent position in this field owing to its industrial, technological and scientific framework.

Future prospects

Today, personalised nutrition has shifted its focus from the individual to clearly defined target groups like older people, infants, malnourished and overnourished persons, babies and pregnant women, but also persons who suffer from allergies, illnesses and intolerances. Considering how healthcare costs are rapidly increasing, it seems appropriate to optimise nutrition for these target groups. Customised functional nutrition to prevent disease is still given too little attention both internationally and in Switzerland.

Besides the above-mentioned target groups, the impact of "nutritional groups" on the rise like flexitarians must be taken into account. With their specific preferences and acceptability, they contribute more and more to the discussion by setting health and sustainability aspects and also animal welfare issues as target criteria. They are also important reference persons when it comes to developments aimed at preventing nutrition-related illnesses and at improving the ecological scorecard of the Swiss nutritional system. The number of flexitarians in Switzerland is likely to increase further in the years to come. Products based on plant proteins will spark new developments that satisfy culinary, sensory and nutritional requirements and that are customisable for specific target groups. The Swiss agriculture and food sector and also the supplying machine industry should exploit this trend and its opportunities.

Point-of-care diagnostics

Daniel Gygax (FHNW)

Point-of-care diagnostics (POC diagnostics) is a subfield of in vitro diagnostics that aims at bringing testing procedures closer to patients. Testing is performed by the patients themselves or by trained personnel working in pharmacies, in doctor offices or for *Spitex* (the Swiss Home Care Association). The best-known POCD application is the monitoring of blood sugar levels in patients suffering from diabetes.

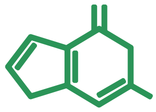
The situation today
In the past few years, POC diagnostics have established themselves in hospitals, and POC tests have been widely integrated in digital mobile health platforms. This procedure shortens the time between testing, diagnosis and therapy. POC tests help monitor illnesses and their course. In order to integrate them in mobile health services like mHealth or telemedicine, the collaboration between several players is needed, which is why they are developing only slowly. The different process parts, from diagnosing the illness to monitoring its course, are not yet coordinated, and some technical and legal questions still need to be clarified.

POC diagnostics have gained lots of attention further to the pandemic emergence of Sars-CoV-2. The usefulness of rapid tests for the detection of the virus by means of an antigen test is controversial because of the lower sensitivity compared to the PCR test and the safe manageability by non-specialists. Analytical methods are able to detect antibodies against proteins found on the surface of the virus in the blood of persons who have survived Covid-19. This POC diagnostics test offers considerable advantages: testing is conducted in decentralised locations and is connected to web-enabled measuring devices. In the phase of easing lockdown rules, great importance is attached to the antibody test because people need to be classified as healthy, infected or immune. This is where the mobile and connectable POC diagnostics test can serve this purpose efficiently. The collected data must be sufficiently accurate and easy to use and must be transmitted to a centralised body via smartphone. The practice of conducting a test becomes the new cultural technique, which needs to be learned and taught.

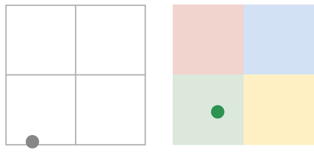
During the corona crisis, Switzerland just as other countries has been left to fend for itself and is now trying to rearrange certain processes. The digital health platform approach can be used in future also for other health problems. It is clear that Switzerland needs to reduce its dependence on global supply and value chains in order to be able to guarantee that its population is supplied with diagnostic and medicinal products.

Future prospects
Already today smartphones are more than simple telephones. In future, in combination with POC tests they will play an important role also for health issues. In coming years, it is both a task and a challenge to establish decentralised and web-enabled POC testing systems for most diverse applications, like monitoring blood levels of drugs like antibiotics, anti-epileptic drugs, anti-inflammatory drugs or immunosuppressants.

For the Swiss industry, POC diagnostics have long been a field of work subject to strong regulations and high cost pressure. Digital health platforms take into consideration individual, regional and national needs and are therefore not easily transferrable nor freely scalable. To ensure the success of POC diagnostics, new business models need to be developed and companies must extend their core skills by means of collaborations, internal growth or acquisition of companies.



Synthetic biology



Sven Panke (ETH Zurich)

The term synthetic biology comprises all activities by which biological systems are applied to the challenges of our times using methods of classic engineering like electrical engineering or mechanical engineering. Similar expectations apply with regard to reliability, speed of development and complexity of the intended concepts. Synthetic biology extends well into all branches of chemical industry and of life sciences and shares many common points with the fields of diagnostics, energy and materials.

The situation today

In the past two years, synthetic biology has continued to make rapid progress especially in the fields of chemical synthesis, genetic circuit engineering and new materials. The use of methods of synthetic biology to create micro-organisms for the synthesis of chemical products at small-scale and large-scale industrial level is growing in product lines and is giving access to new substances. The calculation and the application of genetic circuits in cell lines and animal models have become possible for new diseases. Such circuits are also receptive to external controls like light and electricity. Also continuing at unchanged speed is the radical modification of cells to synthesise proteins with new components or with entirely novel, programmable polymers.

The situation in Switzerland continues to be good. There are outstanding infrastructures and an excellent academic network that, together with the United Kingdom, probably holds a leading position in Europe. The commercial chemical synthesis of large DNA molecules is one of the core technologies of synthetic biology. Despite Switzerland's good positioning, this key technology continues to grow the strongest in other countries. Given the excellent environment in organic synthesis and microtechnology, this represents an untapped opportunity and a strategic Achilles heel for Switzerland.

Future prospects

The history of biotechnology has repeatedly seen the pharmaceutical industry among the first users of innovations. The same applies to synthetic biology. The Swiss players in synthetic biology are providing the sector with lots of knowledge and engineering potential. Overlaps with technologies like *CRISPR/Cas9* provide additional dynamics. It is therefore to be expected in future that pharmaceutical applications and diagnostics will continue to permeate the industry with synthetic biology. Switzerland's large multinational pharmaceutical companies are best positioned, and also a number of other companies are doing very well. More knowledge transfer between academic research and industry is desirable in particular in the areas of chemical synthesis and materials. Intensive collaborations between industrial and academic players represent a significant opportunity for the above-mentioned industrial sectors and could potentially be supported by *Innosuisse*.

Technology and society

Data sovereignty

André Golliez (Zetamind Ltd, Swiss Data Alliance)

Data sovereignty refers to the right and the ability of individuals or organisations (companies, administrations, political bodies, etc.) to control and to use autonomously the data they produced or collected or that concern them.

The situation today

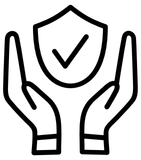
Up to now, the principle of data sovereignty was primarily subject to legislation to protect data from misuse. Examples include in particular the data protection legislation in relation to personal data or the competition and intellectual property law in relation to the use of technical data of private companies. The principle of data sovereignty will play a key role in future given the proactive prospective of enabling a better use of available data while conforming with the rights of the individuals and the organisations entitled to such data. Three main lines of action have crystallised over the past 15 years: the open and free use by anyone of as much non-personal technical data as possible (open data), the use of personal data by the persons concerned (my data) and the sharing of sensitive data between companies and administrations under restrictive conditions (shared data).

Little has evolved in Switzerland with regard to these three pillars of a self-determined and successful data-based economy. Binding legislation is missing for open data, especially for open government data. Legislation regarding personal data still revolves mostly around data protection; the new, revised legislation, however, also includes the right to data portability. A legal framework and relevant organisational and technical infrastructures are necessary in order for companies and administrations to be able to share sensitive technical data in a trusted way.

Future prospects

In coming years, the question will be to determine who owns and who uses the data collected in Switzerland or produced by Swiss citizens. In consideration of the growing exclusive concentration of data on few global platforms, Switzerland's data sovereignty is under serious threat. Legal, organisational, technical and educational measures are necessary at all levels in Switzerland to ensure that all its citizens, political bodies, companies, administrations and other institutions and organisations will be able to use their data in an optimised and self-determined way in future.

In coming years, Switzerland will need a comprehensive data policy to ensure its data sovereignty. Such policy requires the participation of the society, the economy and the scientific community to be able to create together a trustworthy Swiss data space.



Digital trust

Christian Laux (Laux Lawyers AG)

Digital trust means the ability to rely on digital products and services. From the user's perspective, trust can be understood as the expectation that providers will continue to fulfil their obligations also in future. Digital trust can also be described as the users' tendency to use a digital product or service because they assume that the benefit is higher than whatever damage it may cause. In this sense, trust – and therefore also digital trust – is something that is attributed to the provider and not something the provider possesses.

The situation today
Practice shows that digital trust today is influenced by several factors. User experience, convenience, transparency and integrity play a key role. Transparency means that users are able to recognise how data is used and in which contexts. A provider is considered to be of integrity if it protects proactively the user's values and data. The assessment of the provider's trustworthiness also depends on its reputation and reliability. Providers of digital products and services obtain digital trust from their users for a short moment of time. With time this trust may eventually stabilise if the provider's digital offer meets the above criteria.

Digital trust can be measured through surveys or by analysing data. A person who chooses to use a product confirms their digital trust in a company. Important indicators are for example the bounce rate, the brand experience or the affirmative answer to the question "Do you trust this company?". In the development of digital trust technologies, Switzerland is situated in the middle field, i.e. neither at the top of the range, nor clearly lagging behind. The specific application of digital trust principles is only in its infancy.

Future prospects
Contrary to some beliefs, currently nothing indicates that implementing digital trust principles could obstruct the development of successful business models. On the contrary: forward-looking information architectures and business models can integrate digital trust principles in the architecture of digital offers right from the start. This should be taken more into account in the future when planning IT solutions and IT infrastructures. This means that digital trust does not cause any redundant costs and is not a significant cost driver. It is difficult to implement digital trust principles at a later date, especially with large software or cloud solutions, which may pose major challenges to digital service providers.

In the near future, digital trust principles will need to become a matter of course. At political level, the challenge lies in creating coordinated data spaces, like the Swiss Data Space. These data spaces create the possibility of sharing data according to clear rules, which will benefit the economy and society and allow for new data-based projects. Such data spaces must be consistently built in such a way that they have trust-building attributes. Otherwise they will not find acceptance.

Technological trends

Introduction

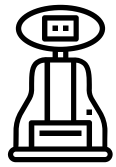
The previous chapter briefly presents the different technologies, grouped by research fields. Since practical applications and commercial products involve several technologies, for the first time a chapter is dedicated to the interaction of the technologies in the context of 13 technological trends that are subject of public debate and are visible in the media. These are wide-ranging topics such as circular economy, artificial intelligence or smart cities, which can be addressed from different angles and therefore with different extents and depths. The *Technology Outlook* explains these terms and explores their potential for Switzerland's economy and society. We have explicitly decided not to include any social and demographic trends.

The following articles explain which of the technologies presented in the previous chapter interact with each other in relation to the different technological trends. Each article shows the icons of the technologies that correlate with the technological trend: a technology can either be the driver of the trend's development or benefit from the ongoing development of the trend. A helpful overview of all icons can be found on the side flap at the back. So 5G applications, blockchain, the Internet of Things, mobility concepts and 18 other technologies act as drivers or benefit from the further development of autonomous systems. Big data analytics, digital twins, biocatalysis and biosynthesis, synthetic biology and 15 other technologies closely interact with the technological trend "biotechnology".

Which conclusions can be drawn from the interaction between different technologies within the technological trends? Seen from the perspective of the technological trends, their complexity is most apparent. In order to be successful, a company working for example in biotechnology must not only master certain technologies pertaining to life sciences, like biocatalysis and biosynthesis or synthetic biology. Also applications dealing with process optimisation, like connected machines and digital twins, could help the company remain competitive by providing it with a decisive advantage. The company should also consider investing in data analysis and data mining and exploring the use of machine learning systems. Technologies from the area of research manufacturing processes might also need to be incorporated in the company's portfolio of activities. On the other hand, a company dealing mainly with artificial intelligence should also keep an eye on applications from the area of research "life sciences", like for example medical wearables, microbiota and microbiome and personalised nutrition. The technologies from the areas of research "energy and the environment" and "manufacturing processes and materials" are as important: worth mentioning here are, for example, mobility concepts and additive manufacturing, which benefit from developments made in artificial intelligence, but which also act as drivers of this technological trend.

Use the QR code to visit our website, where you will find more information on the different technological trends that for lack of space are not included in the paper version.

Autonomous systems



Intelligent machines at the service of humanity

Roland Siegwart (ETH Zurich)

Autonomous systems are machines and processes that are capable of making situation-specific decisions independently or partly independently. Such decisions are based on continuous measurements with sensors and on artificial intelligence algorithms. Automatic systems are systems such as the robots used in production lines or machine tools that make decisions independently within a clearly defined space. In contrast, autonomous systems, for instance self-driving vehicles, drones or delivery robots, operate in an area where decisions are still open and where surprising, unpredictable situations may arise and must be handled reliably. Learning systems represent a promising, yet often overestimated path. While we humans find it sometimes easy to react correctly to unexpected situations, it still represents a challenge for autonomous systems.

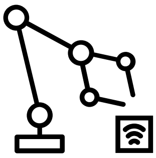
The situation today

Although research in autonomous systems has made great progress in the past years, the majority of such machines are still several years or decades away from their industrial implementation. Autonomous cleaning machines and transport robots, however, are already in use and their demand is increasing. Being very complex, autonomous systems need enhanced R&D investments in order to develop further. Artificial intelligence is highly promising, yet it is important to focus on feasible concepts, like agricultural or transport robots, instead of holding on to grand visions of humanoid robots. Autonomous systems combine actuators, precision mechanics and intelligent control and sensor technologies in order to perform sophisticated processes independently.

Future prospects

The use of simple autonomous systems like inspection, cleaning or transport robots will increase significantly in the next years. More complex systems like self-driving vehicles, indoor drones or agricultural robots will be increasingly deployed in more structured environments. Due to their complexity, it will take time for autonomous systems to take root in our daily lives. An evolution rather than a revolution is what we are likely to see in the medium term. In the long term, however, autonomous systems such as self-driving vehicles or agricultural robots will drastically change different areas.

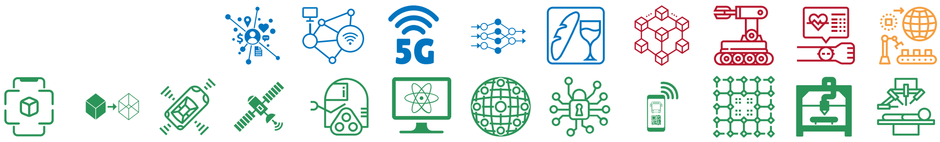
Switzerland's high level of competency in all areas pertaining to autonomous systems enables it more than any other country to develop such sophisticated machines and to successfully bring them to international markets. It is necessary to further consolidate the leadership position held in universities and to implement these technologies profitably in companies capable of rapidly scaling up their businesses.



Cyber-physical systems

The real world and the virtual world in dynamic interaction

Bernhard Braunecker (Swiss Physical Society) and **Guido Piai** (OST)



Initially introduced as a continuation of the Industry 4.0 concept, cyber-physical systems are IT processes in which physical elements (procedures, machines, people, objects, etc.) are digitally imaged and then designed to interact in real-time with that image. Cyber-physical systems are used in almost all areas of society, such as in the finance sector, in healthcare, in industry and manufacturing or in agriculture. Clear examples are the *SBB*'s online train timetable, the *Post*'s package tracking system, the *SwissCovid* app, the social networks (*Facebook*, *LinkedIn*, etc.) and modern production processes. We expect an ongoing development of new solutions and new business models and services. In order to succeed in implementing and using cyber-physical systems, it will be essential to have broadband and resilient Internet infrastructures across the country, central and peripheral computing power and storage capacities, as well as mobile devices and sensors.

The situation today

The US has been leading historically in this field, yet China has caught up considerably in the past decade, followed by Europe and other countries like India. Switzerland will need to find its own way in accordance with the country's skills and industrial strengths. Although many applications have already become reality, it is essential to timely identify and rapidly use the further possibilities connected to the increase of bandwidth, of computing power and of storage capacity. Special measures are needed to continue the digitalisation process in education, industry and society.

Being an innovative country, Switzerland is an active player in digitalisation and counts numerous successful start-ups. However, small and medium-sized SMEs often fail to fully seize the opportunities, often because of the costs involved. New business models must be created to encourage the interplay between technology and business administration.

Switzerland has the necessary academic expertise: in fact, informatics, algorithmic methods and Business Administration are part of the syllabus in Swiss universities. However, when it comes to applications, there is insufficient interaction between engineers, industrial physicists, industrial mathematicians and business management experts. The support of universities, universities of applied sciences but also of academies like the SATW is needed.

Future prospects

Cyber-physical systems merge and bundle different technologies, especially networking and communication technologies. The performance of cyber-physical systems is constantly increasing owing to the technological possibilities that keep growing. The result is new business models and highly efficient production processes for SMEs that can be continuously optimised and adapted to the changing market conditions.

If Switzerland succeeds in bringing together its available core skills, it will manage to gain a leading position amidst the international competition by providing technical solutions for innovative cyber-physical systems. There are great opportunities in particular for the Swiss industry, which is active worldwide in the development of precision machines and precision systems.

Cybersecurity

Technical, organisational and social measures to secure data

Hans-Peter Käser (BWL), **Bernhard Tellenbach** (ZHAW) and **Nicole Wettstein** (SATW)

The term cybersecurity refers to hardware and software components that protect computer devices from unauthorised access, but also to non-technical measures like legislation and user training. Cyberattacks may be designed to access sensitive data of organisations or users, to blackmail data owners or to delete data. Hardware and software manufacturers, infrastructure operators, digital services providers and their users, all have the task of ensuring data confidentiality through adequate cybersecurity measures. Cybersecurity is the basis of a comprehensive and secure digitalisation and is essential for many technological developments.

The situation today

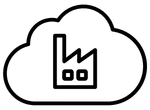
There is political awareness for the importance of cybersecurity. Many countries, just like Switzerland too, follow a national cybersecurity strategy. Given the overall threats context and the similarity of challenges, all these strategies show many points in common. Although new technologies have increased the efforts needed to ensure successful cyberattacks, there are still many security incidents, some of which severe. They often result from the violation of fundamental security principles, which explains why, besides promoting new security solutions, it is increasingly important to provide for the regulation and certification of ICT services, products and processes. For many products connected to the Internet and used privately, cybersecurity is not taken into consideration, there being no legal requirements or due to costs or to the target of a fast product launch.

Owing to its neutrality, legal certainty and political stability, Switzerland is best equipped for a successful cybersecurity ecosystem. Switzerland has obtained results already in many areas and is well positioned in international comparison. The *National Cyber Security Centre* (*NCSC*), the *National strategy for Switzerland's protection against cyber risks* (*NCS*) and the *Cyber Defence Campus* (*CYD*) are the structures that support Switzerland in actively addressing the cyber problem. In addition to this, universities and companies are performing research and providing training on current subjects. During military training, it is now possible to obtain a federally recognised certification as a cybersecurity specialist. With the aim of meeting the growing demand for innovative technological solutions, various innovation support programmes are directed to cybersecurity start-ups.

Future prospects

More automation is needed at technical level. For example, artificial intelligence should help to identify weaknesses in systems and to close gateways. In future, it will also be important to share information on existing threats. International efforts are being undertaken to create improved platforms to exchange information using blockchain technology. At political level, in the near future it will be essential to address issues of regulation and standardisation. In the EU, the *Cybersecurity Act* introduces binding and verifiable standards and rules for essential services that define measures for companies and the public sector in order to secure their logistics networks and processes. →

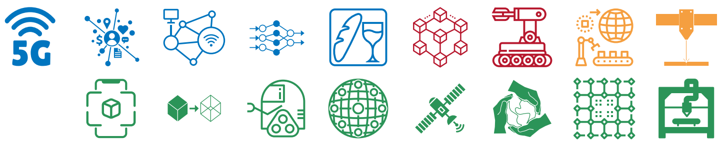
In Switzerland, the obligation to report cyber incidents is subject of discussion, while in the EU this is already compulsory for specific incidents. With digitalisation increasing, the topic of cybersovereignty and the question of giving priority to national solutions for critical systems gain more importance. Switzerland must further develop its own capacities and competencies: the future success of Switzerland as an economic centre depends on the country having its own cybersecurity ecosystem. Also, Swiss SMEs and the population need easy-to-use solutions. Since cybersecurity is also highly dependent on human activity, it is essential that workers but also politicians and private persons understand the mechanisms. Next to technological innovations, there is a need also for education and for unbiased knowledge sharing.



Industry 4.0

Connectivity and digitalisation as key factors to develop and implement innovations

Patricia Deflorin (FH Graubünden) and **Philipp Schmid** (CSEM)



At the core of industry 4.0 are intelligent and digitally connected systems for industrial production that encompass all functions from procurement to logistics. Industry 4.0 rests on numerous innovative technologies and developments like augmented reality, data analysis, storage and transmission, digital twins, collaborative robots and sensors.

The situation today

Two main areas of application can be identified: smart factories and data-based services. In smart factories, industry 4.0 encompasses three levels of process automation: the state monitoring of a machine or process, the data-based process optimisation by means of condition-based preventive maintenance, and the self-organisation of a system based on self-diagnosis and autonomous machine decisions. Data-based services, such as for example preventive maintenance, are the result of increased connectivity between machines and of the continuous collection and analysis of their data. This allows not only to show the state of the machines, but also to derive condition-based preventive maintenance measures. Currently, the main challenges do not concern the technology, but the access to sufficient qualitative data, and this is crucial when it comes to using artificial intelligence.

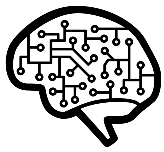
Worth of special mention is the success of implementation in the automotive industry, which other sectors benefit from as well. In Switzerland, real-time quality controls and complete traceability down to unit level are significant drivers for implementing industry 4.0 concepts. Swiss industries are well qualified to take part in the developments of industry 4.0 as efficient implementer. →

Future prospects
Industry 4.0 will pervade the production industry and have a significant economic impact. The convenient availability of computing power, the progress made in artificial intelligence and a higher data usage will enable a number of other applications with regard to smart factories and new services.

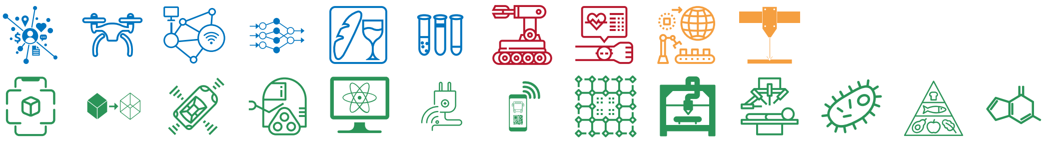
As Switzerland does not have a global supplier of software solutions for factory automation, local connectivity and collaborations are essential. Swiss SMEs in particular rely on solutions by development partners who work in applied research. In order to remain internationally competitive, countries with a high wage level like Switzerland must seize the opportunities offered by industry 4.0.

Artificial intelligence

Machines that think



Alessandro Curioni and **Patrick Ruch** (IBM Research – Zurich)



Artificial Intelligence (AI) enables computers and machines to mimic the capabilities of the human mind in the areas of perception, learning, problem-solving and decision-making. A distinction is often made between narrow or weak AI, which is trained and focused to perform specific tasks, and broad or strong AI, which is applicable across many classes of problems with human-like reasoning and intelligence.

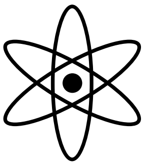
The situation today
AI has experienced several dramatic breakthroughs in the past ten years such as recognizing images, playing complex board games and answering natural language questions in quiz shows. Most of these breakthroughs are based on a particular type of machine learning called deep learning. There are many applications with high maturity, ranging from face, gesture and speech recognition and personalized recommendation engines to drug discovery and medical image analysis.

Switzerland holds a pioneering role in AI research and practical applications. It needs to put policies in place to inform stakeholders transparently about the benefits and risks of AI, as well as establish a regulatory framework to ensure secure, trustworthy, and ethical AI. These measures serve to inform enterprises, political bodies, and society. Further, enabling Switzerland's workforce to acquire the necessary skills involved in developing and deploying AI technologies will be key to the successful adoption of AI by Swiss enterprises. →

Future prospects

It is expected that AI will be increasingly pervasive in our everyday lives and is likely to be considered the normal when consuming news, receiving personalized services, and interacting with intelligent systems at home or work and in social networks. It is hard to imagine an industry that will not be affected by AI in one way or another. Enterprises successfully adopting AI technologies may expect to benefit on two levels: first, by improving the efficiency of internal processes through AI-assisted automation, and second, by embedding AI in products and services to better serve an enterprise's customers and business partners. Accordingly, the skill profile of the workforce will need to change, and industry will have to adapt. For society, the need for more transparency around AI technology will grow as increasingly more consumer-oriented services are being powered by AI, and the use of personal data becomes a focus of attention.

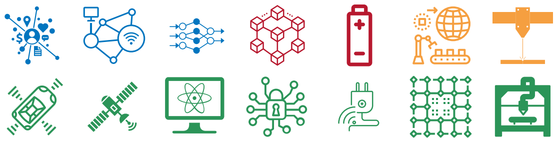
Swiss politics and enterprises cannot afford to ignore AI. AI is disruptive with respect to the automation of business processes, human–machine interaction, and the extraction of important insights from big data. It will therefore be imperative for enterprises to leverage AI in order to remain competitive. On the other hand, AI poses specific challenges that must be addressed. Political stakeholders need to take a proactive approach and demonstrate leadership, as the field of AI is moving fast, and societal concerns around ethics, privacy and transparency need to be addressed.



Quantum technologies

The dance of the quanta is ready for the big stage

Bernhard Braunecker (Swiss Physical Society), **Andreas Fuhrer** and **Thilo Stöferle** (IBM Research – Zurich, Swiss Physical Society)



The term "quantum technology" includes generally all technologies that are fundamentally based on quantum effects such as quantised atomic energy levels, tunnel effect, quantum superposition or quantum entanglement. However, the second quantum revolution often refers only to the subfield which aims at creating completely new types of components or methods by monitoring individual quantum systems. This includes, for example, quantum computing, quantum communication, quantum cryptography, quantum sensors and quantum simulation, although their state of development varies considerably.

The situation today

Some quantum cryptography products are already on the market. *ID Quantique*, a Swiss company, plays a pioneering role worldwide in this field. Quantum sensors are integrated in commercial magnetic field sensors, and the automobile industry and medical engineering experts are also working on future products. The next generation of atomic clocks, so-called optical clocks, feature significantly improved accuracy. Information processing with quantum computers is attracting particular attention: its potential to significantly change our digitalised society is high, especially when it comes to solving computing-intensive problems. Although quantum computers are currently still unstable, they are already being used commercially to test the benefits of new quantum algorithms. In general, the inherent susceptibility to any kind of external interferences, whether electrical, magnetic or mechanical, poses a key challenge and partially explains the complexity of this technology. Switzerland is internationally very well positioned in terms of research in the fields of quantum technologies. Nevertheless, it is important to further develop this expertise by means of long-term research programmes and to build bridges to the industry. It is only by doing so that Swiss companies will manage to tap the market potential in these areas.

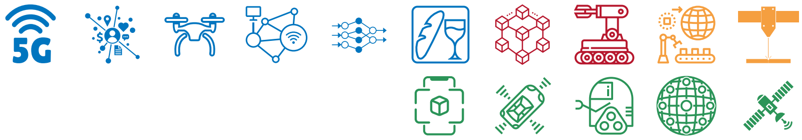
Future prospects

The field of quantum technology has experienced a major boom in recent years, involving significant public and private investment. Consequently, rapid progress has been made, and this trend is expected to intensify over the next five years. More and more solutions will reach market maturity, with quantum communication, quantum sensor technology and quantum computing leading the way. At the same time, when such systems are monitored, extremely high requirements apply in terms of the precision and stability of the mechanical, electrical and optical control systems. This creates numerous opportunities for Swiss SMEs to deliver high-tech components for the manufacturing sector or for operating quantum technologies. The framework plays a crucial role in maintaining a long-term competitive advantage internationally, and involves activities such as training quantum engineers, supporting start-ups and SMEs as well as launching large, strategic initiatives in this rapidly changing field.

Digital agriculture

Digital technologies for an efficient and sustainable agriculture

Thomas Anken (Agroscope)



Agricultural production processes are characterised by complex interactions between the soil, the climate, plants, farm animals and humans. They can be controlled by fertilizing only as needed, by regulating weed with mechanical means and herbicides, or by feeding animals purposefully. This implies preserving natural resources, ensuring animal health, avoiding useless agricultural inputs and achieving optimum yields. The term "digital agriculture" refers to all digital technologies that support the agricultural production process.

The situation today

The rapid progress made in sensor technology has made it possible to collect data about the environment, plants, animals and machines. Such data helps to better understand and quantify the processes involved and, ultimately, to optimise production and avoid unnecessary costs and negative effects on the environment, on animals and on humans. New types of sensors, used for instance to measure soil humidity for the purpose of irrigation, as well as new production methods are being developed.

Some technologies are already widely used in Switzerland, like milking robots (over 800 in use throughout the country), concentrated feed dispensers for dairy cows, or automatic, satellite guidance systems for tractors. Farmers also use various applications on smartphones. All of this must not hide the fact, however, that there is still a large potential for digital technologies in agriculture in Switzerland. This is certainly partly due to the small size of farms, which makes them easy to manage without any digital technologies. But at the same time, there are still many technical challenges to face in order to adequately assess the conditions of plants, soils and animals and then to use the collected data profitably in farming.

Future prospects

Unmanned vehicles will soon be seen on the fields. They detect weeds automatically and treat each plant specifically. Drones and satellite images help detect the nutritional condition of plants and to fertilise them individually as needed, and also to steer tractors precisely to the centimetre. What all these applications have in common is that they work with sensors that collect and process data that is then used to make decisions in the production process, thus complementing the farmers' extensive knowledge and experience. Many applications are still in development and are not yet in use.

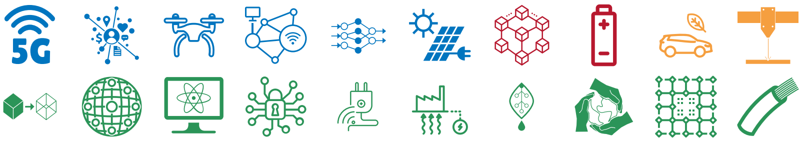
Given the limitation of resources and the growing world population, it is essential to continue to develop knowledge and to improve technologies. Only by doing so will it be possible to produce the necessary amount of food in a sustainable and efficient way.

Much like in the car industry, Switzerland does not play a significant role in the agricultural technology market. However, Swiss companies manufacture many components for digital agriculture, mostly sensors for machines, 3D cameras for milking robots, temperature sensors and sensors for weather stations etc. In addition, various start-ups are launching innovative ideas to automate irrigation systems, to automatically locate sheep on the alps or to build one of the first weeding robots. Clearly, there are many small and large potentials open to Swiss companies.

Energy supply

Sustainable, reliable, safe, affordable

Christian Schaffner (ETH Zurich)



Securing energy supply means covering energy demand at all times in a safe, reliable, affordable and sustainable manner with electricity, combustibles, fuels and heat.

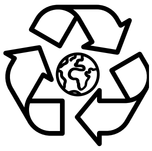
The situation today

The pressure to reduce climate-relevant emissions is causing energy supply to move away from fossil primary energies (such as natural gas and oil) and towards renewable sources (especially photovoltaics and wind). In certain areas of application, like electricity supply, private transport and heat supply in buildings, it is easy to implement the required technological changes. In others, the shift is more difficult, for example in air and freight transport. Technologies for storing electrical energy, especially battery storage, are becoming more and more widespread. In the mobility sector, research is focusing on the use of synthetic fuels and hydrogen. In the building sector, heat pumps are rapidly replacing heating systems running on fossil fuels. At local level, an increasing number of intelligent controls for grids and systems are being tested and in part also successfully implemented.

Switzerland is highly active in the field of energy research. Efforts focus on storage technologies, synthetic fuels and smart grid systems. A number of outstanding scientists of international renown work in basic research, too. In the past decades, building energy technologies have progressed most successfully. As a result, CO_2 emissions have dropped and are likely to continue to decrease. Developments in mobility, in contrast, are slow. Emissions of climate gases are not decreasing in absolute or relative terms in relation to the distance travelled. Switzerland's non-liberalised electricity supply market has an inhibiting effect: unlike abroad, it is rare that innovative solutions are used in the decentralised sector (in distribution grids). Decarbonisation is Switzerland's biggest challenge when it comes to energy supply: the aim is to reduce CO_2 while ensuring a high level of security of supply at affordable prices. This is a major challenge especially for mobility solutions. The increasing electrification of the heating and mobility sectors will lead to an increase in electricity demand, which will need to be met accordingly. Increased flexibility is required in terms of electrical power supply, thus making new technologies and intelligent systems necessary.

Future prospects

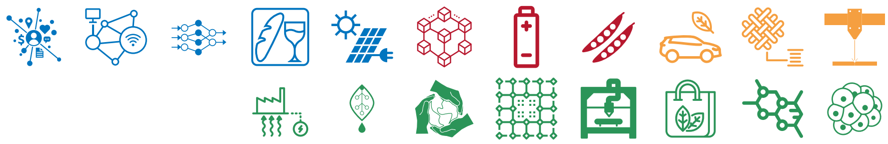
In the mobility and buildings sectors, a timely transition away from fossil fuels can only succeed if stricter regulations are imposed. In the energy sector, innovations that serve a climate goal will be more likely to succeed than others. According to current scenarios, energy prices will rise only mildly. Switzerland's goal of becoming climate-neutral by 2050 is ambitious, but absolutely necessary. In the electricity sector, much depends on whether the Swiss market will open completely. Such a liberalisation would allow market access to many new players and promote important innovations. Furthermore, relations with the EU play an important role: in order to guarantee security of energy supply to a high degree and at relatively favourable prices, exchanges with our neighbouring countries must continue to be flexible and efficient.



Circular economy

Closed material and product loops

Xaver Edelmann (World Resources Forum)



The principle of a circular economy aims at reducing the consumption of natural resources by using raw materials efficiently and as long as possible in their original quality. This involves closing material and product loops and keeping products and materials longer in circulation. Therefore, compared to the current linear economic system, the consumption of primary raw materials decreases. Products become more durable and there is less waste, thus reducing the environmental burden and increasing the creation of value.

The situation today

The European Commission regularly takes steps to strengthen the approaches to circular economy and to create a more sustainable economy. In 2015 it adopted a package to this purpose. The Ecodesign Directive plays a key role in establishing a circular economy. It provides the legal framework necessary to set minimum requirements for household appliances: it defines maximum energy consumption and demands that appliances be repairable.

In 2016, over four million people worked in the EU in sectors related to the circular economy. The global market for circular economy and for material and resource efficiency has grown by over 10% in the past five years, thus making it faster growing than the world market as a whole. At public level, impulse programmes promoting sustainable types of economy also go by the name of "Green New Deals".

Being poor in natural resources, Switzerland has pursued approaches to circular economy already since the mid-1980s and has managed to at least partially close certain loops. In 2018, of the 17.5 million tonnes of deconstruction material accumulated, like concrete, gravel, sand, asphalt and brick, nearly 12 million tonnes got recycled. Over 5 million tonnes, especially mixed demolition waste, did not enter the recycling loop. In households, just over half of the domestic waste is collected separately and recycled. In Switzerland, despite the high recycling rate, the waste volume is immense: almost no other country generates as much domestic waste per capita.

Future prospects

The circular economy calls for a new approach to resources. Economic growth must be uncoupled from resource consumption, and a drastic reduction of the latter is imperative. At the same time, resource productivity must be massively increased, which means higher production by using less resources. Alternative economic approaches are needed to reach this target. In order to move towards a true circular economy, consumers must change their habits.

The social and economic aspects of circular economy have not yet been sufficiently explored; therefore, more research is needed.

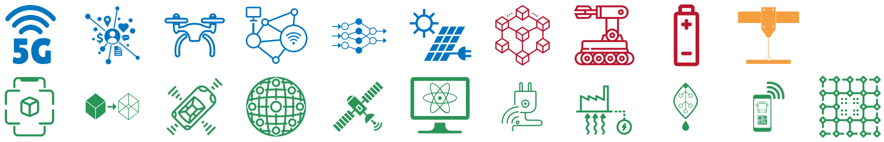
It is indispensable to reduce the consumption of raw materials if the planetary limits are not to be exceeded and if the commitments of the Paris Agreement on climate change are to be met.

Switzerland must commit to truly closing raw material loops and drop simple "greenwashing" measures. This is the only way to decrease the environmental impact of our throw-away society.

Smart cities

Increased quality of life and optimised resource efficiency

Vicente Carabias (ZHAW) and **Andrew Paice** (HSLU)



The concept of "smart city" focuses on using social and technological innovations to increase life quality and resource efficiency in cities and urban living environments. The definition and goals of a smart city have changed significantly in the past twenty years. Today's efforts mostly aim at conceiving improvements based on the digital transformation of the urban environment that benefit the citizens, the environment, the corporate world and the public administration.

The situation today

Smart cities also use various technologies that are based on communication networks and on the real-time availability of data from public space, coupled with the processing of large data volumes. For this to happen, it is necessary to link public and private data sources, which currently are separate. The hope is to be able to make smart infrastructures more efficient and transparent, enabling them to support sustainability and the optimised use of resources and therefore to improve life quality. Examples of such applications include improved traffic routing, the coordination between departments of the public administration etc. The challenges in the development of smart city applications lie in the complexity of such systems and in ensuring data protection and data ownership. For smart city projects to succeed, an informed cooperation between the public, the government and the economy is needed.

Worldwide there are many smart city initiatives, from pilot projects and lighthouse projects to urban transformation processes. Considering the variety of possible targets, no city however has yet reached the full potential of these initiatives. In the rankings that include Swiss cities, the latter belong to the leading group.

More and more Swiss cities have a smart city strategy, which often inspires neighbouring areas to define their own smart city strategy or at least a digitalisation strategy. Of the 84 cities that participated in the *Swiss Smart City Survey 2020*, about 43% are actively working on a smart city strategy. All participating large cities (over 100.000 inhabitants) are evolving into a smart city, while only just under a third of the smaller cities and municipalities (under 20.000 inhabitants) actively address the topic. Interest in the subject is also increasing among smaller and medium-sized cities, despite the challenge primarily due to their limited human and financial resources.

Frequent projects concern e-government applications or efficiency and sustainability goals. The development of a smart city revolves around the axes Environment (46.4%), Living (43.7%) and People (42.3%). All efforts generally aim at making the city a more attractive place for citizens and businesses to live and work in.

Future prospects

The main challenge is to define the meaning of "smart city" for the population, for local businesses and for the municipal administration. Based on this definition, one can then determine how the benefits can be attained while ensuring the acceptance of all parties involved.

In Switzerland, given that both the state and the economy are interested in smart city applications, much activity is seen in this area. But the path ahead is still very long. In the medium term we can expect to encounter various pilot projects and trials, because many cities and regions are seeking suitable solutions. Smart cities are likelier to result from partnerships than from a top-down implementation.

Future materials

Materials shape the future

Pierangelo Gröning (Empa)

The term "future materials" refers to an undefined quantity of materials featuring new or significantly improved physical properties. When developing new materials, multifunctional usability, resource-efficient production and processing as well as closed-loop recycling processes are important goals.

The situation today

The key drivers for the development of new materials are the current ecological, economic and social challenges, such as climate change, recycling management and digitalisation. New materials play a pivotal role in the decarbonisation of industry and society. For example, the storage of electrical energy or the production of synthetic fuels and of CO_2 absorbers are partly based on new materials. In order to make recycling management work, economic sectors such as the construction industry or the packaging industry must increasingly rely on recyclable materials. Quantum materials such as graphene or topological materials, which have different properties on the surface rather than in terms of volume, enable the development of new electronic components based on quantum mechanical effects for the purpose of information processing. This drastically reduces the amount of energy required for information processing. Possible applications include highly sensitive sensors, neuromorphic chips for artificial intelligence or ultra-fast quantum computers. This is particularly important because today's computer architecture will soon reach its physical limits due to the materials used, and ongoing digitalisation will continue to require high-performance computers.

Materials research at Swiss universities and research institutes is very broadly based and competes internationally at top level. Cooperation between public research and industry has been well established for decades and is strongly oriented towards practical application.

Future prospects

Carbon is a promising basic element of future materials and will gain strategic importance: as a composite material, it has outstanding mechanical properties; as a nanostructure, it brings hope for post-silicon electronics; and as an organic material, it is also biodegradable. Carbon thus combines many of the requirements for a future material. Product manufacturing and material synthesis are increasingly integrated, to the point where both processes literally merge, such as in 3D metal printing. This massively increases the complexity of manufacturing processes, since in addition to respecting manufacturing tolerances, it is also necessary to ensure the quality of the material during manufacturing. This is why materials competence and the understanding of processes are becoming increasingly important in modern manufacturing. As a result, the development of new materials is usually also associated with new processing and manufacturing technologies. →

Due to the high level of complexity, only few companies will be able to develop the necessary skills. The Swiss universities and research institutes have the necessary competencies. Innovation and economic success will occur in particular where industry and public research work together as partners. Some public-private partnerships, such as the network of *Advanced Manufacturing Technology Transfer Centers* throughout Switzerland, operate pilot production facilities that are open access. This gives companies the opportunity to familiarise themselves with new materials and their processing technologies thanks to the support of university partners. The experience gained this way benefits both companies and research. Technology transfer from the research laboratories to the industrial realm will therefore become smoother and more efficient. Such initiatives can also minimise the financial risks assumed by companies.

Biotechnology

Natural processes and living organisms at the service of humankind

Hans-Peter Meyer (ExpertInova AG)

Chemistry and physics were the sciences of the 19th and 20th centuries, biology is the science of the 21st century. Biotechnology is the practical application of biology that industrially exploits natural processes and living organisms. Biotechnology benefits immensely from the progress made in genetic engineering, which enables targeted changes and new combinations in the genome. Genetic engineering, which was used industrially for the first time over forty years ago, enables the production of molecules that a microorganism could never produce, like insulin. Genetic engineering has turned biotechnology into a business worth billions worldwide and has become indispensable in the manufacturing process and in environmental protection.

The situation today

In the industrial, biotechnological production of biotherapeutic medicines, i.e. of large molecules like monoclonal antibodies, Switzerland ranks among the leading players worldwide. In 2017, the international heavyweights *Biogen, CSL Behring* and *Lonza* announced almost simultaneously large investments in the production of such molecules in Switzerland. Unfortunately, biotechnology has long been regarded as a competitor to the chemistry sector in Switzerland, which is why still much needs to be done with regard to applying biotechnology in the production of fine chemicals, of natural substances and of complex chemical structures. Another feature specific to the situation in Switzerland is the genetic engineering moratorium that bans the use of genetically modified plants. It has been in force since 2005; in 2017 it was extended for another four years.

Future prospects

Two trends and their combined application will have a significant impact on the future development of biotechnology, namely synthetic biology and digitalisation. As area of application of genetic engineering, synthetic biology will allow to build new, synthetic biological systems that are optimised for industrial production. This will revolutionise the production of organic molecules and address the question of sustainability. Bioprocessing has already long relied on computer applications, be it to process complex and typically noisy data or to automate the management of processes with living organisms. Digitalisation will raise bioprocessing to a new level in terms of flexibility, quality and speed. In Switzerland, a matter-of-fact and dispassionate reassessment of the genetic engineering moratorium will be inevitable, as it is blocking a number of potentially attractive and above all sustainable biotechnology value chains.

Precision medicine

Customised medicine, in the right place at the right time

Mark Rubin and **Timo Staub** (University of Bern)

Precision medicine represents a new paradigm in medical treatment. It is based on the notion that every person is unique. Contrary to conventional medicine, it takes the patient's individual characteristics into consideration for his/her treatment. Therefore, therapies do not only depend on the clinical picture, but also on genetic predisposition, environmental factors and lifestyle. This involves the use of state-of-the-art tools such as the analysis of the patient's genome.

The situation today

Precision medicine has already established itself to some extent in the treatment of cancer and in pharmacology. In precision medicine treatments, genetic disposition influences the choice and dosage of medication. Already today, large pharmaceutical companies strongly focus on precision medicine: they produce precision medicine therapies and also supply the corresponding diagnostic solutions. Smaller companies and start-ups are active, too. Precision medicine is based on the analysis of genomic data. This poses major challenges in terms of protecting personal data, which in turn leads to complex regulatory controls. Health costs must remain within reasonable limits, and yet all population groups should be entitled to benefit from precision medicine. The establishment of stratified medical solutions, in which different standard solutions are used according to the individual situation, might be one way of reducing the costs.

Precision medicine develops at the interface between medicine, computer science (data sciences) and molecular biology. Important technological drivers are machine learning and artificial intelligence, genomic pipelines and developments as well as applications in molecular biology. Precision medicine is a growth market in which large companies and start-ups are equally involved. The Swiss Confederation promotes precision medicine with programmes such as the *Swiss Personalized Health Network* (*SPHN*). Research and therapies could benefit from a regulatory framework that is aligned at national level. Currently, legislation (in particular the Swiss Federal Human Research Act, HRA) provides for cantonal authorisation mechanisms in addition to the regulations of the hospitals involved. As a result, processes are highly complex and bureaucratic, which often makes the exchange of health data exceedingly difficult.

Future prospects

Precision medicine opens a door to therapies that were unimaginable just a few years ago. Precision medicine approaches are already used today in standard therapeutic repertoires. In the next few years, precision medicine will continue to gain importance.

The therapeutic successes achieved with precision medicine lead to increased life expectancy. There is a need for social debate on the topic of people growing older and staying healthy longer.

Individual genomics, proteomics or metabolomics have a major influence on human health. In the future, therefore, apart from being used in medical treatment, they will also play an increasingly important role in disease prevention and in health maintenance, for example in the form of specialised medicine or as rules of conduct in case of increased risk of cancer or of Alzheimer's disease. In order to fully exploit the advantages of precision medicine, a digital copy of the patient comprising all health-related information is required. At the societal level this raises questions about data protection and data security.

Open the flap to see the legend to the icons and further explanations. →

Digital world

Energy and the environment

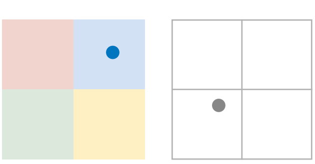
Manufacturing processes and materials

Life sciences

Technology and society

New technologies included in the *Technology Outlook 2021* are highlighted in grey.

Figures in the chapter "Technologies and areas of application"



The figure on the left shows the importance of the technology for Switzerland and corresponds with figure 5 on pages 14 and 15.

The figure on the right shows the relative frequency of social media posts analogous to figure 3 on page 10 (horizontal axis: Switzerland; vertical axis: European comparison countries).

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