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# Technology Outlook 2019

English Version

## **Imprint**

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May 2019

# Foreword

Comparative studies of the performance of Swiss industry and the performance of our global competition often yield results that are as positive as they are undifferentiated. As a consequence, it can be tempting to rest on one's laurels and to simply milk businesses that are currently operating successfully without much need for investment in research and development as "cash cows". Lulled by bottom line results, one neglects to work on renewal and innovation, squandering the benefits of a profitable line of business, whose employees are oftentimes knowledgeable, experienced, motivated, and thus ideally suited for research and development efforts. On closer inspection, however, it quickly becomes apparent that change and adaptation are called for.

Observers of the global industrial landscape will have noticed that novelty has become more important. The pressure to innovate is steadily increasing on established companies. Available time between invention and market entry is decreasing. In order to survive, firms must decide faster than ever which path to take in renewing their product portfolio and how to successfully stand their ground in the race for innovation.

In order to actively tackle the race for innovation at an earlier stage, one needs to be informed at an earlier stage. To this end, in 2015 the SATW published its first Technology Outlook by way of experiment. It was well received, yet it had its weaknesses and blind spots. The Technology Outlook 2017 provided better coverage of "neglected" important areas. The experience of these past four years has shown that publishing the Technology Outlook at two-year intervals provides the right and necessary distance with regard to the twists and turns of a shifting industrial landscape and the accompanying media hype. For the Technology Outlook 2019, the SATW Executive Committee took an important step and handed project ownership to the Scientific Advisory Board. This has certainly benefited both the publication's content and scope. Compared to previous editions, authors have deepened their research, improved the report's structure and taken a more quantitative approach. The SATW's multi-step quality control mechanisms for the material's critical appraisal performed well. In its final form, the manuscript owes much to the SATW Secretariat's editing work. I thank all contributors to this process!

In the name of the Scientific Advisory Board, I wish you a stimulating read and hope the Technology Outlook 2019 can provide valuable orientation and guidance.



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

# Table of contents

<b>Foreword</b>	<b>3</b>
<b>Introduction</b>	<b>6</b>
<b>Significance of the technologies for Switzerland</b>	<b>8</b>
<b>International comparison</b>	<b>13</b>
<b>Description of the technologies</b>	<b>20</b>
<b>The digital world</b>	<b>20</b>
<b>Blockchain</b>	<b>21</b>
Blockchain as a basis for web services	21
<b>Cybersecurity</b>	<b>22</b>
Cryptography and quantum computing	22
<b>Industry 4.0</b>	<b>23</b>
Augmented reality – industrial applications	23
Digital twins	24
Connected machines	25
<b>Artificial intelligence</b>	<b>26</b>
Big data analytics	26
Machine learning and neural networks	27
<b>Robotics</b>	<b>28</b>
Drones	28
Collaborative robots	29
<b>Energy and the environment</b>	<b>30</b>
<b>Energy management</b>	<b>31</b>
Distributed energy systems	31
Smart grids	32
Future energy storage	33
<b>Renewable energy sources</b>	<b>34</b>
Geothermal energy	34
Photovoltaics	35
<b>Agriculture</b>	<b>36</b>
Alternative protein sources	36
Drones in precision farming	37
Sustainable food production	39

<b>Mobility</b>	<b>40</b>
E-mobility: electric vehicles and infrastructure	40
Mobility concepts	41
Automated vehicles	42
<b>Smart living environments</b>	<b>43</b>
Smart cities	43
Smart homes	45
<b>Manufacturing processes and materials</b>	<b>46</b>
<b>Additive manufacturing</b>	<b>47</b>
Material development for additive manufacturing	47
Additive manufacturing processes	48
<b>Materials of the future</b>	<b>49</b>
Bioplastics	49
Functional fibres	50
<b>Photonics and light technology</b>	<b>52</b>
Laser surface treatments	52
Optical space communication	54
Photonics as an enabling technology	55
<b>Life sciences</b>	<b>56</b>
<b>Sustainable chemical production</b>	<b>57</b>
Biocatalysis and biosynthesis	57
Continuous manufacturing processes	59
Synthetic biology	61
<b>Precision medicine</b>	<b>62</b>
Surgical robots	62
Personalised nutrition	63
Point-of-care diagnostics	64
<b>Regenerative medicine</b>	<b>65</b>
3D bioprinting: printable organs	65
Mass cultivation of stem cells	66

A large array of solar panels is shown from a low angle, receding into the distance. The sun is low on the horizon, creating a bright, golden glow and casting long, soft shadows across the panels. The sky is filled with scattered, white and yellowish clouds. The overall scene is bright and optimistic, representing clean energy.

# Introduction

One of the SATW's key missions is the early identification of new, possibly disruptive technologies that will become relevant for Switzerland's economy and society in the next three to five years. Every two years, the SATW therefore publishes a public early identification report that presents these technologies and assesses their significance. The Technology Outlook's third edition introduces several new features.

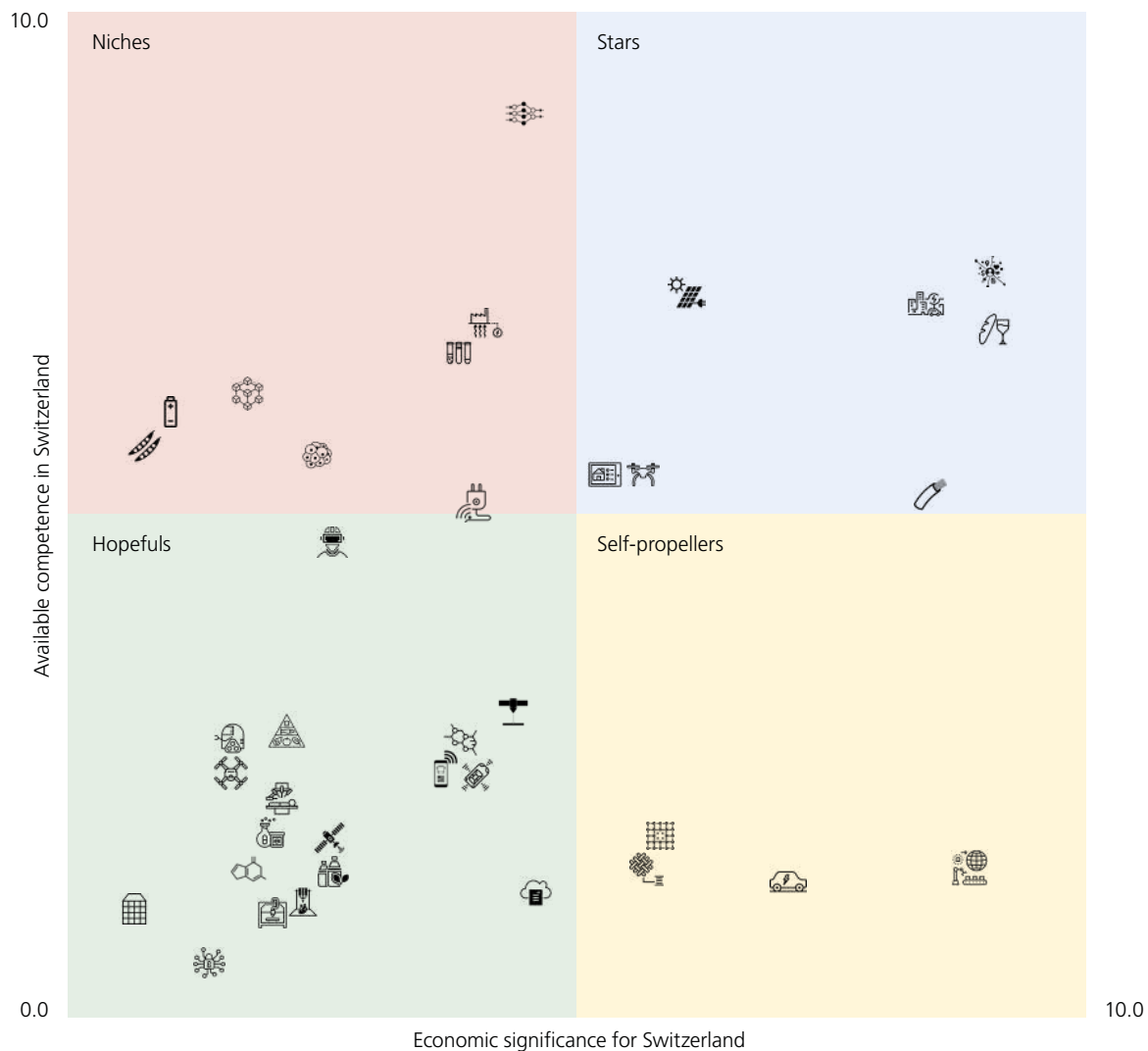
The net was cast significantly wider and more precisely: the current report presents 37 technologies drawn from the fields most relevant to the Swiss economy. This list of technologies was compiled in close cooperation with the Swiss State Secretariat for Education, Research and Innovation (SERI) as well as more than 70 experts. The selection takes into account the technologies' relevance for Switzerland and their technological maturity. Some technologies such as cryptocurrencies, smart sensors and wind power have therefore not found their way into the report, as they either do not fit the targeted time horizon of three to five years or are only of little relevance for the Swiss economy. We are aware that some of the technologies described in the report are closer in scope to thematic areas than to individual technologies. This is due to the political and public perception of these technological developments and can also be observed in other comparable European publications.

For the first time, the Technology Outlook has been substantiated with semi-quantitative data. This information draws on the knowledge of our experts as well as extensive research, and makes it possible to assess the relative significance of individual technologies for Switzerland. "Stars", "self-propellers", "niches" or "hopefuls" – each technology is assigned to one of four categories defined by economic significance and available competence in Switzerland. It will be interesting to observe how each technology's position evolves in the two years leading up to the Technology Outlook's fourth edition.

Another new feature of this Technology Outlook is the cross-country comparison, which both the SATW and the SERI view as valuable and useful. The analysis of posts and tweets relating to the report's 37 technologies published on the official social media channels of European universities allows for comparison between Switzerland and selected European countries. While technologies such as "big data analytics" or "blockchain" dominate academic discussions in most countries, there are also clear national differences. These national specificities match public perception of the respective countries' industrial orientation.

Thank you to our many authors, whose knowledge and dedication have made it possible to produce a publication of such scope and comprehensiveness. And thank you to our readers for their interest. We wish you an informative and insightful read.

# Significance of the technolo



**Figure 1: Relative significance of the technologies for Switzerland**






































The horizontal axis charts the economic significance of technologies for Switzerland, the vertical axis charts available competence in Switzerland.<sup>1</sup>

For each technology presented in the Technology Outlook, a four-quadrant diagram (figure 1) shows its economic significance (horizontal axis) and available competence in Switzerland (vertical axis). The latter is based on academic and industrial research intensity. The diagram is to be read as a snapshot with an outlook to the near future, as economic significance takes into account both current revenue and potential future revenue. The term “revenue” covers sales of products and services generated worldwide by companies established in Switzerland. It

also takes into account revenue generated in Switzerland by the assembly or servicing of imported products. The vertical axis – available competence in Switzerland – charts the number of academic and industrial research groups working in Switzerland. Figure 2 shows the five technologies displaying the greatest economic significance (left) and the greatest available competence (right).



# gies for Switzerland

Niches	Hopefuls	Stars	Self-propellers
 Alternative protein sources	 3D bioprinting	 Big data analytics	 E-mobility
 Blockchain	 Augmented reality	 Drones	 Functional fibres
 Distributed energy systems	 Automated vehicles	 Sustainable food production	 Smart grids
 Geothermal energy	 Biocatalysis and biosynthesis	 Photonics	 Connected machines
 Machine learning	 Bioplastics	 Photovoltaics	
 Mass cultivation of stem cells	 Digital twins	 Smart cities	
 Point-of-care diagnostics	 Drones in precision farming	 Smart homes	
 Future energy storage	 Collaborative robots		
	 Continuous manufacturing processes		
	 Cryptography and quantum computing		
	 Material development for additive manufacturing		
	 Mobility concepts		
	 Laser surface treatments		
	 Surgical robots		
	 Optical space communication		
	 Personalised nutrition		
	 Synthetic biology		
	 Additive manufacturing processes		

## “Stars”, “self-propellers”, “niches” and “hopefuls”

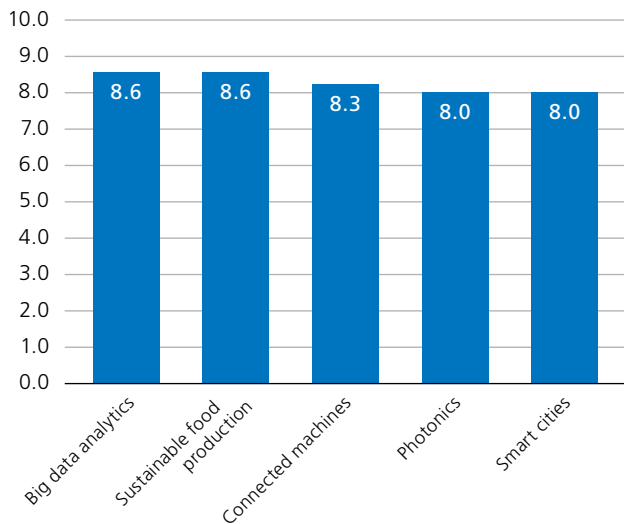
Technologies in the blue quadrant at the top right are the “stars”. Available competence in Switzerland is high due to intense academic and industrial research in these fields, as is their economic significance. These technologies provide Switzerland with strong revenues and create jobs. They are therefore very well positioned for positive future development. These technologies should be reinforced and opportunities for new lines of business should be seized. This requires sustained effort; companies and research bodies involved with technologies located in this

quadrant should not rest on their laurels, but rather use their acquired knowledge more widely.

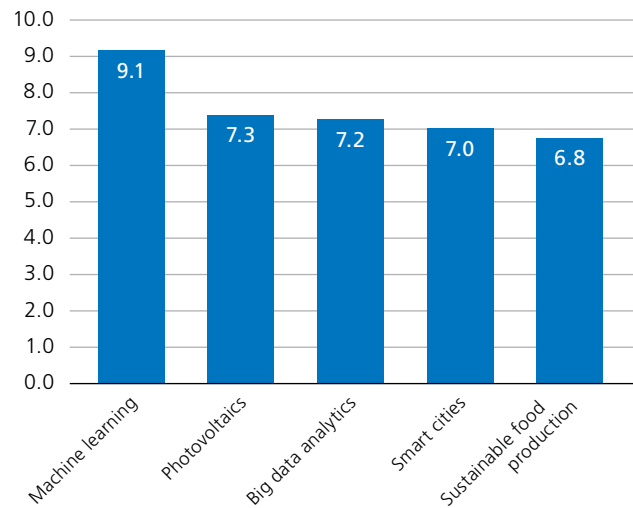
The technologies in the yellow quadrant at the bottom right are a “lucky break” for Switzerland. Even though available competence in Switzerland is rather low, in the sense that only few research institutes are dealing with these topics, they generate high revenues. These technologies are “self-propellers”. They are mature, well-established technologies, which are currently developing only slowly. Yet this situation may change. It is therefore im-

<sup>1</sup> This list of technologies was compiled in close cooperation with the Swiss State Secretariat for Education, Research and Innovation (SERI) as well as more than 70 experts. The selection takes into account the technologies’ relevance for Switzerland and their technological maturity.

**Economic significance for Switzerland**



**Available competence in Switzerland**



**Figure 2: Top 5 technologies for Switzerland**

The left-hand chart shows the five economically most significant technologies for Switzerland, the right-hand chart shows the five technologies for which available competence in Switzerland is highest.<sup>2</sup>

portant to keep closely monitoring these technologies. Investment in training and continuing education as well as in basic and applied research could pay off in future.

The red quadrant at the top left contains technologies that may be viewed as “niches”. Investments in these technologies must be analysed critically: while available competence in Switzerland as measured by research intensity is high, economic significance is rather low. This raises questions as to return on investment and future potential. Some technologies such as “machine learning” are about to break through from “niches” to “stars”, while others such as “future energy storage” are still a long way off. Opportunities provided by improved commercialisation and new lines of business must be unlocked. Firms should also aim to digitalise in-house manufacturing processes in order to lower production costs and increase revenue and profit.

The green quadrant at the bottom left contains the large group of technological “hopefuls”. Their economic significance is still low, as is available competence in Switzerland due to low research intensity. The market Swiss companies are working to develop is not (yet) ready, even though the technological maturity of some technologies is already relatively high. This quadrant also contains many emerging technologies with uncertain future potential. It is therefore important to closely monitor and analyse the development of these technologies and to determine their global market potential. In order to foster these technologies, it seems advisable to facilitate networking between academic and industrial partners and to set up platforms for exchange.

<sup>2</sup> The five technologies ranking highest on the horizontal axis are the five economically most significant technologies for Switzerland; the five technologies ranking highest on the vertical axis are the five technologies for which available competence in Switzerland is highest.

## Methodology

In order to establish the position of individual technologies within the four-quadrant diagram, eight parameters have been assessed for each technology: 2017 revenue, 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 expressed by their average h-index<sup>3</sup>, number of companies in Switzerland with R&D activities in a given field, competence of these companies by international standards. In a second step, value ranges for each parameter have been transposed into a point system:

2017 revenue (R), based on estimates provided by experts, sector and company reports, statistic databases and Internet research:

<b>Value</b> (in million CHF)	< 10	10–99	100–499	500–999	≥ 1000
<b>Points</b>	1	2	3	4	5

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

<b>Value</b>	small	medium	large	very large
<b>Points</b>	0.4	0.8	1.2	1.6

Legal and regulatory framework in Switzerland ( $F_L$ ), assessment provided by experts:

<b>Value</b>	unfavourable	neutral	optimal
<b>Points</b>	0.8	1	1.2

Acceptance within Swiss society ( $F_S$ ), assessment provided by experts:

<b>Value</b>	hindering	neutral	encouraging
<b>Points</b>	0.9	1	1.1

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

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

<sup>3</sup> The h-index is a metric that attempts to measure a scientist's worldwide reputation among specialists in his or her field. It is based on the citation impact of a scientist's publications. A high h-index means that a large number of a scientist's publications are cited often in other publications.

Competence of academic research groups ( $C_A$ ), based on the average h-index of research groups in Switzerland working in a given field<sup>4</sup>:

<b>Value</b>	< 20	20–34	≥ 35
<b>Points</b>	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:

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

Competence of these companies by international standards ( $C_I$ ), assessment provided by experts:

<b>Value</b>	low	medium	high
<b>Points</b>	0.8	1	1.2

### Transposition of parameter values into positions on the horizontal and vertical axes of the four-quadrant diagram:

A technology's position on the horizontal axis (economic significance) is computed 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 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. In order to provide better 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.

<sup>4</sup> Source: ResearchGate <https://www.researchgate.net/>

# International comparison

The four-quadrant diagram shows the relative significance of individual technologies for Switzerland. However, it provides no indication as to their significance for other European countries. This would require collecting and researching relevant data for all countries of interest, at least for the main technologies. The vastness of this task makes it unworkable.

In order to nonetheless look beyond Switzerland and allow for international comparison, we therefore used a tool created by LinkAlong (<https://linkalong.com>), an EPFL startup specialised in smart and user-specific big data analytics. LinkAlong uses as its data set social media channels such as Twitter, Instagram and Facebook as well as websites referenced therein: for the Technology Outlook 2019, we analysed the tweets and posts on official social media accounts of 1300 European institutions of higher education. In order to limit our analysis to high-credibility sources, the data set was deliberately restricted to official communication channels, excluding individual accounts of faculty members and associates. The data conveys a sense of current concerns in academic circles: which technologies are being discussed with what intensity in which countries? However, this analysis yields no direct insight as to the technologies' economic significance.

## Methodology

For figure 3, all posts published during the period from 1 January to 31 December 2018 that mention one of the 37 technologies presented in the Technology Outlook 2019 were counted separately for Switzerland, Germany, France, the United Kingdom, Italy, the Netherlands, Austria and Sweden. The number of technologies featured in each chart varies, as not all 37 technologies are mentioned in all countries. The total amount of posts for all technologies mentioned in a given country is defined as 100%. The number of posts on each technology is expressed as a percentage and represented in a pie chart. Each slice represents one technology and its size reflects the relative frequency with which this technology is mentioned in a given country.

For figure 4, all posts published during the period from 1 January to 31 December 2018 that mention the technologies presented in the Technology Outlook 2019 were counted separately for Switzerland, Germany, France, the United Kingdom, Italy, the Netherlands, Austria and Sweden. For each country, the number of posts on the five most-mentioned technologies was expressed as a percentage of the total amount of posts on all technologies presented in the Technology Outlook and represented in a radar chart. The figures specified along the axis express the percentage of a given technology in relation to all technologies listed in the Technology Outlook 2019. The radar chart only shows technologies that belong to the five most-mentioned technologies in one of the eight countries under review.

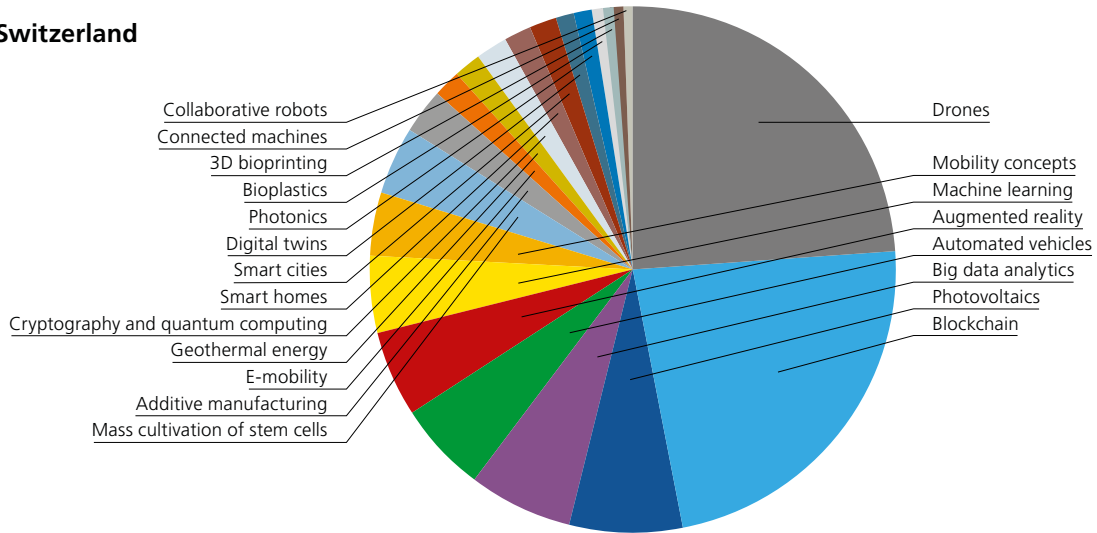
**Figure 3** shows the social media mentions of individual technologies for Switzerland and seven other countries for the period from 1 January to 31 December 2018. It becomes apparent that in Switzerland, France, Italy and Austria, one or two technologies dominate social media posts: “drones” and “blockchain” in Switzerland, “big data analytics” and “blockchain” in France, “big data analytics” in Italy, and “blockchain” and “big data analytics” in Austria. In Germany, the United Kingdom, the Netherlands and Sweden, a group of four or five technologies generates the majority of posts. The composition of these groups is country-specific.

In almost all the countries under review, “big data analytics”, “blockchain” and “augmented reality” are a subject of intense discussion on the social media accounts of institutions of higher education. They seem to constitute a major research focus at many universities. However, the large number of posts can clearly also be traced back to the broadness of the terms used: the terms “big data analytics” and “augmented reality” in particular can be said to cover entire subject areas rather than individual technologies. Some technologies are mentioned only in few countries, such as “alternative protein sources” in Germany, France and Italy, “biocatalysis and biosynthesis” in Germany and Italy, “distributed energy systems” in Germany and the Netherlands, “future energy storage” in Germany, France and Italy, and “surgical robots” in Germany, the United Kingdom and Italy.

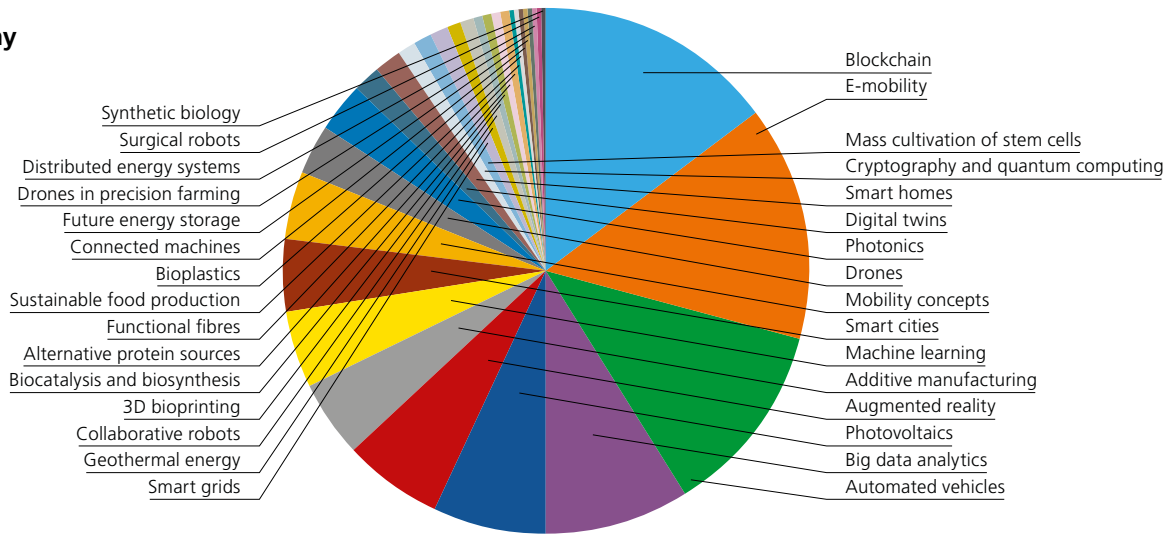
The analysis of social media also reveals which countries are engaged in a broad discussion of technologies that in Switzerland appear in the green quadrant (bottom left) of “hopeful” (figure 1). “Additive manufacturing” is a topic in the Netherlands, “mobility concepts” in Italy and the Netherlands, and “e-mobility” in Germany. These technologies seem to generate more interest in other countries than in Switzerland.

It appears that in all eight countries, the topic “e-mobility” is discussed with a similar frequency as “automated vehicles” or “mobility concepts”. In some countries, the topic “smart cities” is discussed with a similar frequency as “e-mobility”, “mobility concepts” or “automated vehicles”. Thematically related topics thus appear to be discussed with similar intensity.

**Switzerland**



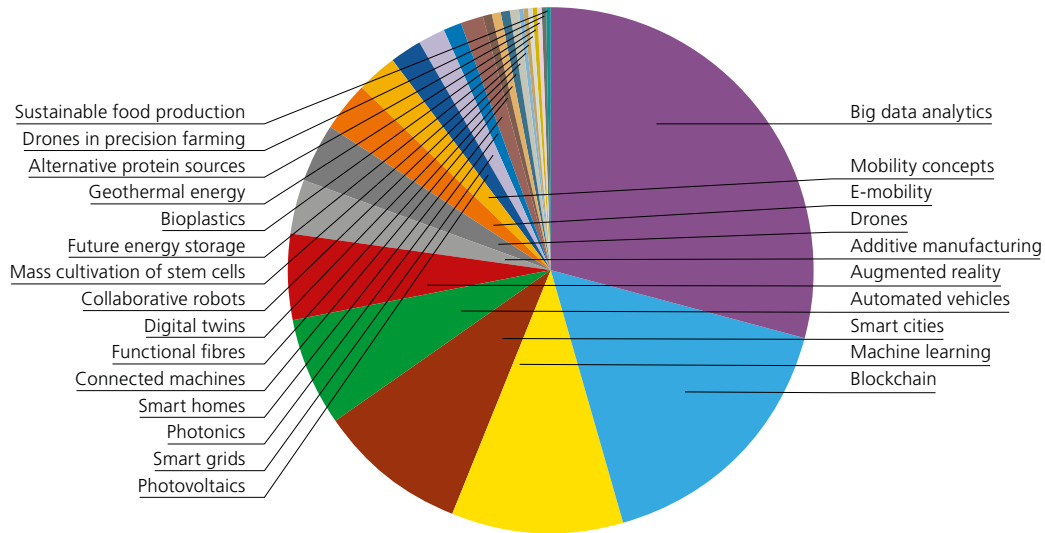
**Germany**



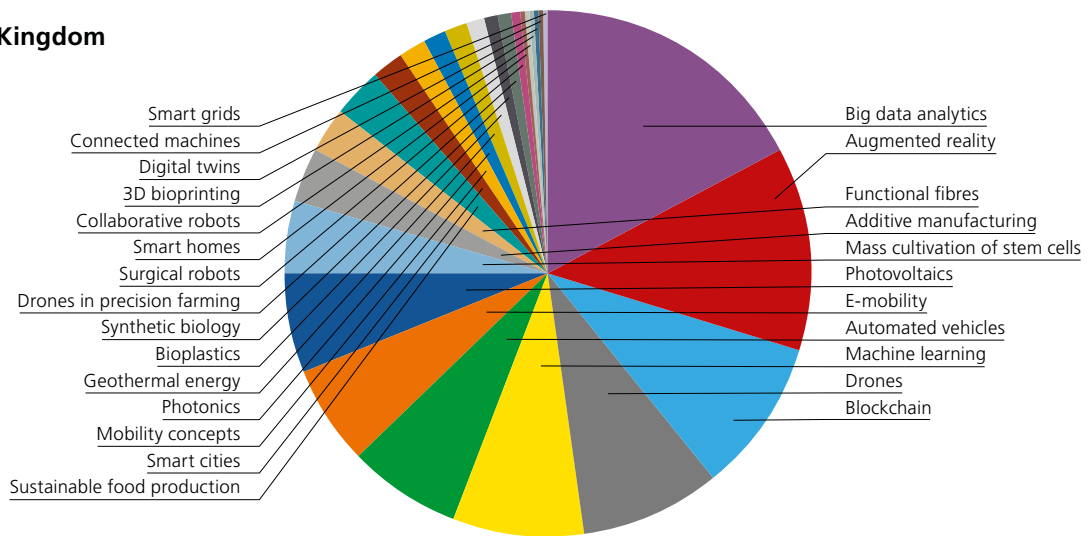
**Figure 3** shows the social media mentions of individual technologies for Switzerland, four neighbouring countries and three other European countries for the period from 1 January to 31 December 2018. Slice sizes reflect relative frequency.



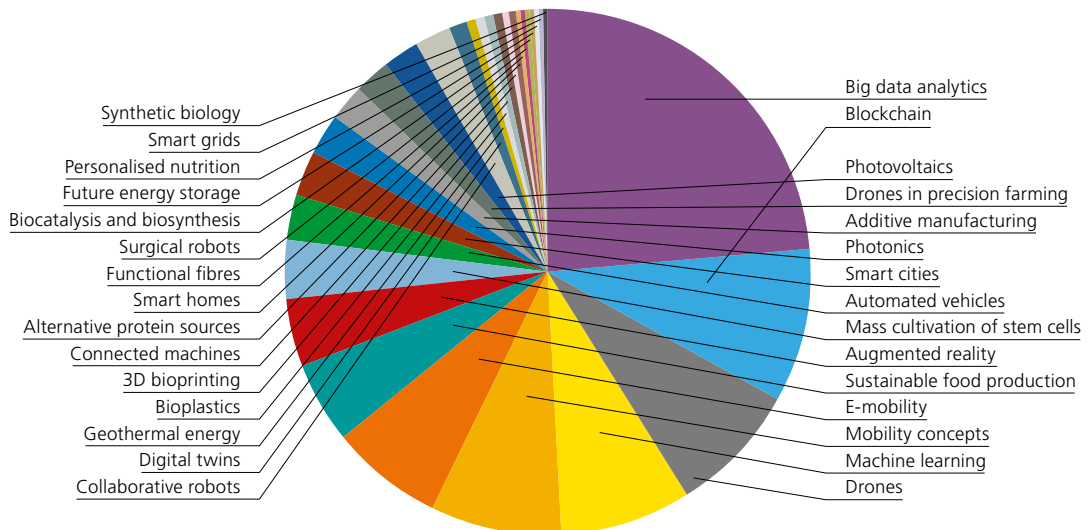
**France**



**United Kingdom**

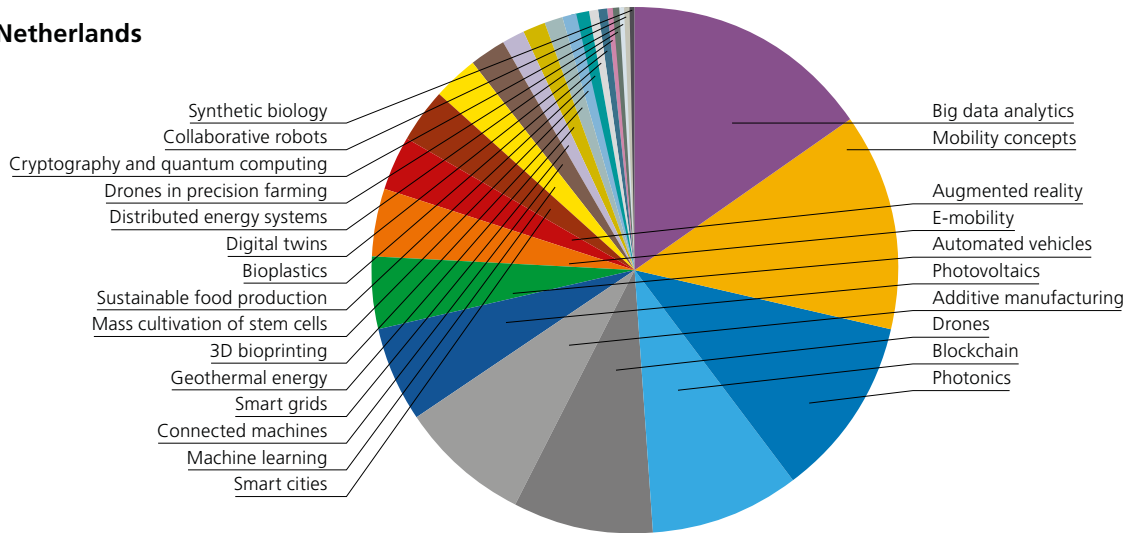


**Italy**

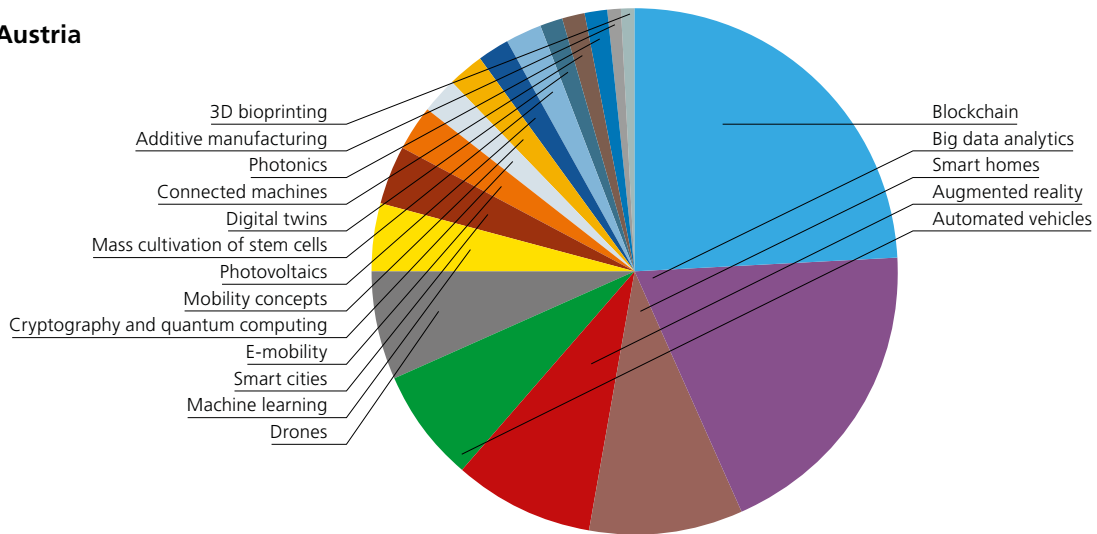




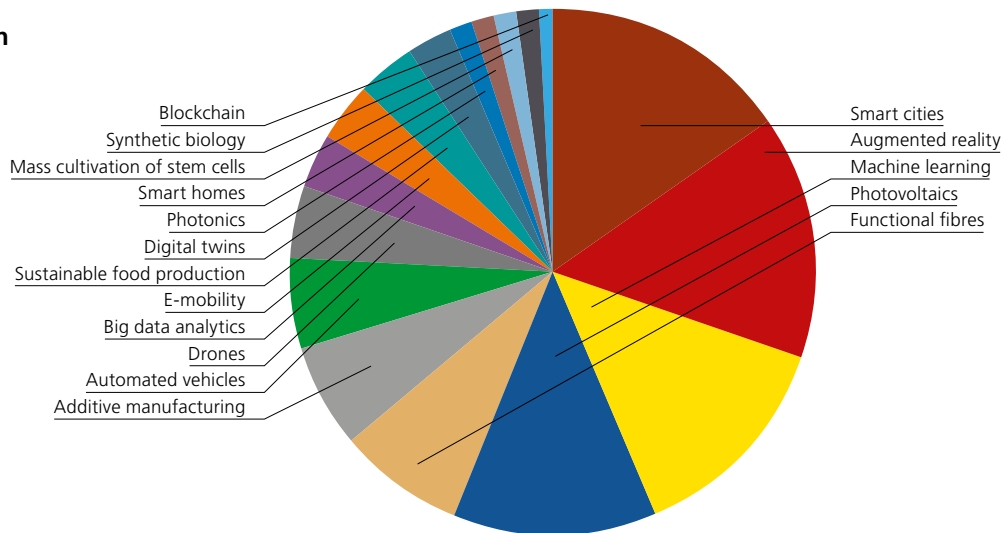
**Netherlands**



**Austria**



**Sweden**



**Figure 4** shows the top 5 technologies for Switzerland and seven other European countries for the period from 1 January to 31 December 2018. Comparing Switzerland with its neighbouring countries brings to light clear differences. In Switzerland, the dominant topics are “drones” and “blockchain”. Switzerland is considered the “Silicon Valley of drones”, a reputation that appears substantiated by the large number of social media mentions of the topic. Even so, in the four-quadrant diagram (figure 1) “drones” narrowly fail to make the top 10 in terms of available competence in Switzerland. This is likely due to the fact that research is limited mainly to only few institutions of higher education. However, these institutions appear very well positioned by international standards, failing which Switzerland’s good reputation in the field of drones would be difficult to account for. Swiss institutions of higher education operate various research centres on the topic of “blockchain”; the EPFL and the ETH Zurich as well as the Universities of Basel, Lucerne and Zurich are very active in this field. The Swiss Confederation’s press release “Federal Council wants to further improve framework conditions for blockchain/DLT”<sup>5</sup>, published on 14 December 2018, also triggered many social media posts. The top two topics “drones” and “blockchain” are followed far behind by “photovoltaics”, “big data analytics” and “automated vehicles”. The technologies most discussed on social media are thus mainly those for which Technology Outlook authors identify high research competence in Switzerland: the four most-discussed technologies are located in the top two quadrants (figure 1). Only “automated vehicles” is located among the “hopefuls”.

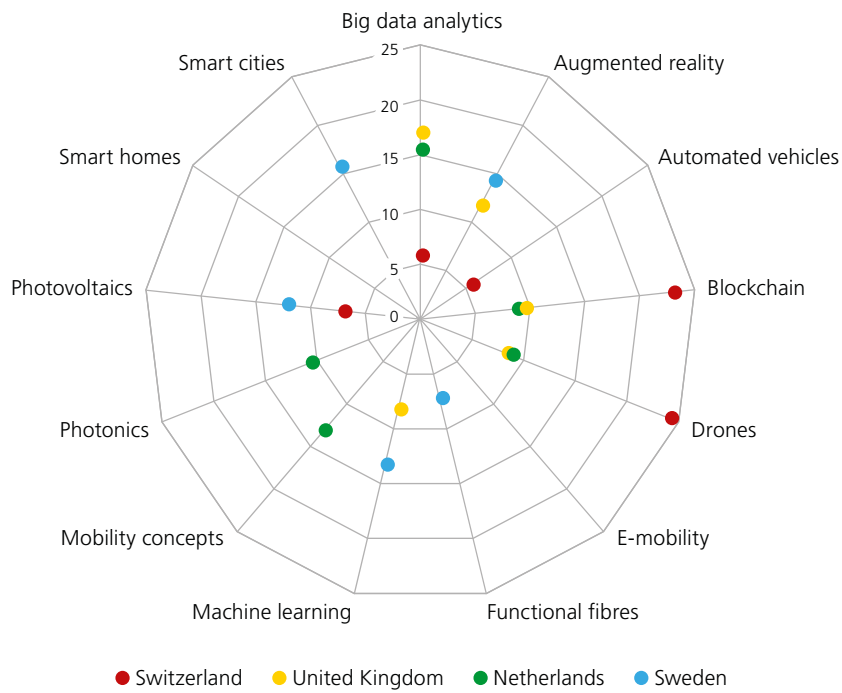
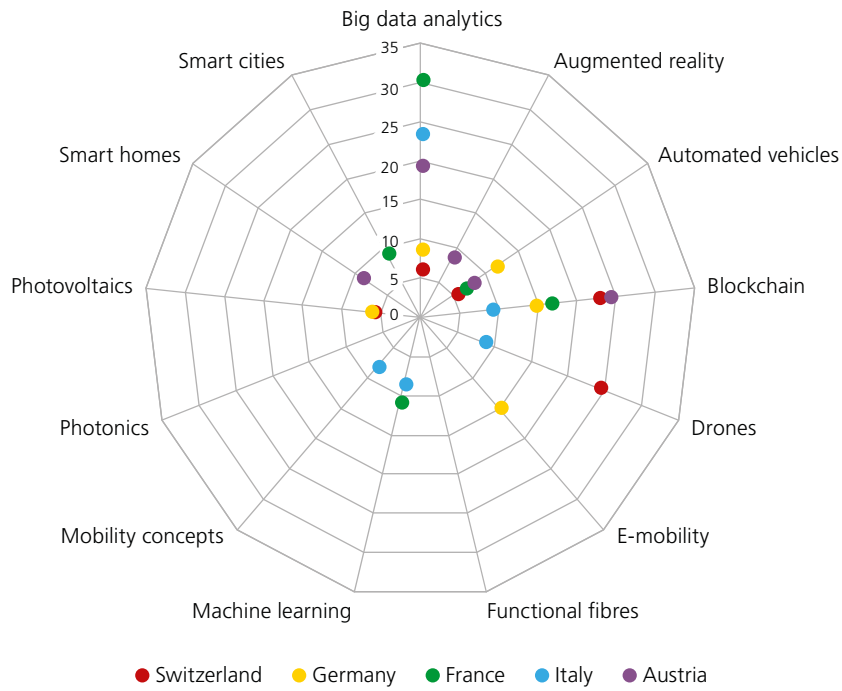
In Germany, the dominant topics are “blockchain”, “e-mobility” and “automated vehicles”. This tallies with public perception of the country’s industrial orientation and with the great importance of its automotive industry. Another large number of social media posts in Germany

refers to “big data analytics” and “photovoltaics”. In France, the dominant topics are “big data analytics”, “blockchain”, “machine learning”, “smart cities” and “automated vehicles”. In Italy and in Austria, the topics “big data analytics” and “blockchain” also dominate academic discussions, followed at a great distance by “drones”, “machine learning” and “mobility concepts” in Italy and “smart homes”, “augmented reality” and “automated vehicles” in Austria. In the United Kingdom, “big data analytics” garnered the most tweets and posts, followed by “augmented reality”, “blockchain”, “drones” and “machine learning”. The picture is different in the Netherlands and in Sweden. In the Netherlands, “big data analytics” takes the top spot, as it does in France, in the United Kingdom and in Italy. However, with the exception of “blockchain”, slots two to five are occupied by technologies that for the most part attract little attention in other countries: “mobility concepts”, “photonics” and “drones”. In Sweden, the most discussed technologies differ noticeably from those in other European countries under review. Not surprisingly, “smart cities” ranks first: in 2017, Gothenburg was for the second time named “most sustainable city in the world” by the Global Destination Sustainability Index. This is followed by “augmented reality”, “machine learning”, “photovoltaics” and “functional fibres”, a technology that does not make the top five in any other country.

While the analysis of official social media posts published by institutions of higher education yields no direct information as to a technology’s economic significance, it does provide a direct and current reflection of academic research activities and allows for conclusions as to thematic areas of focus. A sound basis in academic research is likely to increase the odds of economic success. This approach is exciting and highly promising, even though more time is needed for further validation.

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<sup>5</sup> <https://www.admin.ch/gov/en/start/documentation/media-releases.msg-id-73398.html>



**Figure 4** shows the five most discussed technologies for Switzerland, four of its neighbouring countries (Germany, France, Italy and Austria) and three other European countries (the United Kingdom, the Netherlands and Sweden) for the period from 1 January to 31 December 2018. For each country, the chart shows the number of social media posts for individual technologies as a percentage of the total amount of social media posts for all technologies listed in the Technology Outlook.

# The digital world

## Blockchain

# Blockchain as a basis for web services

Thomas Puschmann (University of Zurich)

Quadrant: niche technologies

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### Present situation worldwide and in Switzerland

“Blockchains” and “distributed ledgers” are often called “technologies”. Strictly speaking, however, they are lists of cryptographically linked data elements. 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). An as yet unsolved issue of the proof-of-work mechanism for permissionless blockchains and distributed ledgers is its high energy expenditure. Alternative consensus mechanisms for validating transactions, such as proof-of-stake, are still at research stage. 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.

Various studies estimate the future potential of blockchains and distributed ledgers as high to very high. In a 2018 study, the *World Economic Forum (WEF)* calculated worldwide efficiency gains of around 1'000 billion USD for trade finance alone. Other areas of application include logistics (*Maersk* plans to optimise its container logistics), retail (*IBM* and *Walmart* are developing a solution for food safety),

insurance (*B3i* is developing a smart contract solution for insurance contracts), energy (*Axpo* is developing a solution for peer-to-peer energy markets), transportation (*Novotrans* stores inventory level data for railway repairs) or public administration (the Netherlands are developing a border control system for passenger data).

### Implications for Switzerland

Such applications can also be transposed to Switzerland. Further examples in this country include *Modum* (pharmaceutical supply chain), *Swiss Prime Site* (property management and rentals) and *UBS* (Utility Settlement Coin, trade finance, etc.). Next to improving efficiency, blockchains and distributed ledgers also open up numerous new fields of business, including new services (e.g. digital identity), software development (e.g. new web services or so-called “distributed apps” or “dApps”) and specialist services (e.g. legal). Their successful implementation hinges on at least three critical factors: the availability of talents and their training at institutions of higher education, a well functioning ecosystem of institutions of higher education, established players and startups (with good access to venture capital), as well as a flexible regulatory and legal framework. While Switzerland has a well functioning ecosystem, it needs to catch up as regards the education of talents and access to venture capital.

## Cryptography and quantum computing

**Bernhard Tellenbach** (ZHAW)

**Quadrant:** technological hopefuls

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### Present situation worldwide and in Switzerland

Secure cryptographic methods are essential to protect sensitive information and communication links. Common methods today are based on prime decomposition and the calculation of discrete logarithms. They include in particular the widespread Rivest-Shamir-Adleman (RSA) protocol, used for example to create digital signatures, or the Diffie-Hellman protocol, used to generate a shared key to protect a communication link. Significant progress in quantum computing presents a challenge for these methods, as quantum computers are highly efficient at mastering prime decomposition and calculating discrete logarithms.

There are fundamentally two approaches to averting the threat posed by quantum computers: post-quantum cryptography (PQC) and quantum key distribution (QKD). PQC is a collective term for cryptographic methods whose security rests on mathematical problems that quantum computers are not able to solve significantly faster than conventional computers. QKD enables the secure exchange of a key. Its security relies on physical laws governing the state of photons. In this context, the processing power and capabilities of (quantum) computers are irrelevant.

Both approaches have already yielded various solutions and products, which remain relatively untested. International and national information security organisations such as the German Federal Office for Information Security (*BSI*), the European Union Agency for Network and Information Security (*ENISA*), the European Telecommunications Standards Institute (*ETSI*) and the US National Institute of Standards and Technology (*NIST*) recognise the need for substantial further research, standardisation and technical innovation. It is also unclear by when powerful enough quantum computers and methods will become available to break vulnerable cryptographic systems. *Gartner* assesses the risk as currently rather low, yet highly relevant within five to ten years. When developing or purchasing new systems, it is therefore important to at least make provisions for an upgrade trajectory for the use of post-quantum algorithms. As these are not compatible with existing cryptographic systems, they are likely to spread only slowly, especially for systems with long lifespans. The many Internet systems that still support the RC4 encryption algorithm, which has been considered unsafe for many years, show just how long such a replacement process can take.

### Implications for Switzerland

Despite the technological leadership of *ID Quantique* in the QKD market and the research leadership of various notable research groups and companies (a.o. the *ETH Zurich* and *IBM Research – Zurich*), the significance for Swiss research and for the Swiss economy is currently still rather low. However, it is likely to increase considerably over the next five years. It is therefore important to maintain and consolidate technological leadership.

## **Augmented reality – industrial applications**

**Andreas Kunz** (ETH Zurich)

**Quadrant:** technological hopefuls

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### **Present situation worldwide and in Switzerland**

Augmented reality – or rather “mixed reality” – combines the visual perception of real and virtual objects. It enables an enhancement of perceived reality by means of technical devices. The aim is to represent additional information. This technology is gaining increasing ground owing in particular to its inclusion of the real world. Mixed reality ties virtual information to ongoing production processes, e.g. in maintenance, order processing or process monitoring. Virtual and real objects are increasingly “merged”, giving rise to the new term “XR” (cross reality). Typical applications can be found in education and teaching, in product development and production (industry 4.0), and in the medical field.

### **Implications for Switzerland**

Making information available in users’ visual field creates many possibilities, be it in distribution (visualisation of product variants) or in service (data provision for technical staff). Switzerland is well positioned, as large and medium-sized companies are already successfully using XR in their development and production activities. The growing availability of technical systems is making XR increasingly interesting also for small companies, a trend that is likely to accelerate over the next five years. Swiss companies conducting research and development activities in the field of XR are globally well positioned and supply highly specific solutions in their respective areas of expertise.

## Digital twins

**Pavel Hora** and **Niko Manopulo** (ETH Zurich)

**Quadrant:** technological hopefuls

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### Present situation worldwide and in Switzerland

Virtual, i.e. computer-simulated, process mapping is now a common tool for planning, dimensioning and optimisation in almost all technical applications. Up to now, the approaches used were for the most part purely deterministic, i.e. involving pre-determined outcomes. By contrast, the mapping of complex, interlinked manufacturing processes poses a major challenge in terms of model precision, computing time and data management. Today, next to widely applicable programmes (general purpose), calculations also rely more and more on simulation tools aimed at specific applications (special purpose), making it possible to streamline the structure of virtual models. A new trend is the direct inclusion of virtual models in “smart” inline process control systems. Based both on digitally generated data and the analysis of direct measurement data, so-called “digital twins” are set up to map and replicate real processes. They operate as the actual “brain” of smart, self-correcting processes. These developments are an important building block for new industry 4.0 concepts.

### Implications for Switzerland

High levels of simulation competence are to be found mainly in large companies with highly automated, robot-assisted production systems. A prime example is the German automotive industry, which has already largely integrated industry 4.0 processes. The integration of such technologies is much less pronounced in most Swiss SMEs, which possess neither the necessary simulation competence nor sufficient experience in developing new, independent software tools. It is likely that these companies will join forces within new networks in order to master the challenges of digitalisation, as this requires a vast array of competences. Successfully meeting this challenge requires sufficient and appropriately trained personnel: the demand for technically-oriented industrial computer scientists is therefore set to increase. In coming years, enough of these sought-after professionals must be trained and educated.



## Connected machines

**Pavel Hora** and **Niko Manopulo** (ETH Zurich)

**Quadrant:** self-propelling technologies

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### Present situation worldwide and in Switzerland

The term “connected machines” covers scientific and industrial endeavours aiming for the continuous and comprehensive digitalisation of industrial firms by unifying data flows across various positions/operations. This form of seamless inter-machine communication creates wholly new possibilities for optimisation in industrial planning, with substantial improvements in overall process transparency. It is therefore likely that this trend will steadily gain ground in coming years. Next to their positive aspects, smart connected machines also give rise to some major challenges: increased process flexibility often goes hand in hand with heightened complexity. Integrating sensors and actuators raises investment costs and maintenance requirements. Adequately trained personnel must be available to service installations. Installations of this kind must therefore bring considerable added value. Consequently, not all processes will prove suitable. This may be one reason the use of connected machines has up to now spread rather haltingly, with the exception of automation and robotisation in manufacturing.

### Implications for Switzerland

The example of automobiles, fitted with ever more assistance systems, illustrates the development of digitalisation: today already, a car with no integrated navigation system has become almost unthinkable. Soon, a car’s standard equipment will include autonomous systems. However, the example of the automotive industry also shows just how complex and costly the development of such systems can be. General machine construction will follow the same path, with added value for users as the main driver. New studies published in Germany on implemented industry 4.0 projects show in part only limited increases in productivity. This suggests that what is technically feasible is not always also technically sensible. Assessing the advisable degree of digitalisation must therefore occur on a case-by-case basis. In order to master the new challenges of connected machines, firms with different areas of competence are likely to enter into strategic partnerships. Many of the initial schemes are now being supported in the context of EU projects. Swiss SMEs would therefore do well to take an active part in these emerging networks. In order to achieve the necessary critical mass, industry-wide cooperation is needed to carry out pilot projects involving all components.

## Big data analytics

Alessandro Curioni and Lukas Czornomaz (IBM Research – Zurich)

Quadrant: star technologies

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### Present situation worldwide and in Switzerland

The growing availability of data is triggering a surge in big data analytics tools, which is in turn favoured by steadily rising network speeds, the number of connected devices and increased computing power. We are currently witnessing strong consolidation within the sector. Exponentially growing data volumes can thus be used more effectively and more efficiently, yielding valuable insights. Contemporary systems are able to record, administer and organise enormous quantities of structured data. Going further, the latest advances in artificial intelligence (AI) are paving the way for processing unstructured data. AI technologies enable a wide array of applications through the use of large data structures. They yield deep insights by learning from the data and from interacting with users.

### Implications for Switzerland

In Switzerland, big data analytics is currently transforming many sectors. It is revolutionising customer care in banking, changing decision-making in investment banking, and improving fraud detection. Insurance companies are using large data platforms to automate claims processing and their business model will evolve with personalised risk assessment. In the pharmaceutical industry, the discovery of new drugs is being revolutionised as big data analytics tools are making it possible to draw upon vast quantities of scientific insights in organic chemistry. With the rise of smart factories (industry 4.0), the manufacturing industry

is currently undergoing a fourth industrial revolution: large data volumes and AI technologies are being used to automate decisions and to steadily optimise productivity, quality and reliability.

Big data analytics solutions have already become economically significant for Switzerland. Their positive impact on the Swiss economy could be strongly enhanced if SMEs were to also make extensive use of such tools, in particular in the fields of electrical engineering, retail, services, machines and watchmaking. Big data analytics enables SMEs to better compete with larger market players, to generate new knowledge and to achieve and maintain technological leadership. The analysis and forecast of market and client behaviour allows them to better meet customer requirements. In order for SMEs to fully exploit the potential of large data applications, data provision, data acquisition, data labelling and data reconfiguration must be simplified. The value and commercial potential of large volumes of data depend on their quality and their credibility. The importance of data protection and privacy provides Switzerland with an opportunity to position itself as a safe haven for data. Establishing a favourable regulatory framework and an open market for data would promote big data analytics by breaking up data silos across companies and industries and stimulating the appraisal and the exchange of data, while ensuring data protection, safety and trust.

# Machine learning and neural networks

**Alessandro Curioni** and **Lukas Czornomaz** (IBM Research – Zurich)

**Quadrant:** niche technologies

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## Present situation worldwide and in Switzerland

Artificial intelligence (AI) technologies such as machine learning algorithms and artificial neural networks can be trained to perform specific tasks with an efficiency and precision that complement or even surpass human ability. The most popular AI technologies such as deep-learning networks are loosely inspired by the way the human brain learns. They typically consist of layers of nodes (neurons) linked by adjustable weight connections (synapses). Each neuron can transmit information to another group of neurons, based on the state of the weighted input. Weights adjust as learning proceeds. The dramatic increase in computing power available in the cloud and in supercomputers, advances in AI research and the recent consolidation around large data platforms have brought AI technologies great success and public visibility. Machine learning methods are increasingly shaping our everyday life: speech recognition, translation, natural speech interaction with machines and image/facial recognition have changed the way in which individuals interact with other individuals and with businesses. However, the disruptive potential of these AI technologies rests on their integration within large data platforms. Machine learning methods are at the core of automating data acquisition, labelling and classification in large data platforms. This will increase their acceptance and greatly accelerate their uptake across all sectors and by businesses of all sizes. Disruptive changes will ensue for banks, services, retail, manufacturing, pharmaceutical and insurance companies.

## Implications for Switzerland

Switzerland has played a leading role in the development of AI technologies. Owing to its outstanding ecosystem for academic and industrial research in the field of machine learning, it remains very well positioned provided research investment and a favourable environment for business and innovation are maintained. In future, research should focus on the development of robust, precise and resilient machine learning methods based on high-dimensional real data (e.g. medical or industrial data). Switzerland has the opportunity to take on a pioneering role in the definition of standards and the certification of AI systems. With the increasingly frequent use of AI, it becomes ever more important to ensure that such models are ethical and safe: they should be devoid of prejudice regarding age, gender, nationality or religion, execute their task within defined boundaries, and be safe from foreseeable attacks. In addition, the need to improve public perception of AI technologies should not be underestimated.

## Drones

**Roland Siegwart** (ETH Zurich)

**Quadrant:** star technologies

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### Present situation worldwide and in Switzerland

Civilian drone technology, i.e. the development of civilian unmanned aerial vehicles, has evolved at a fast pace in the past 15 years. Many of the new technologies, from novel flying object concepts to the necessary control and navigation algorithms, originated at Swiss institutions of higher education, especially the *ETH Zurich* and the *EPFL*. Switzerland has thus established international leadership in the field of civilian drones, attracting established firms and fostering the creation of various startups. Drones have long been a familiar feature of military activities. With the availability of inexpensive technologies such as IMUs (inertial measurement units) to stabilise drones in space, GPS or navigational cameras, and associated technologies for robust control and autonomous navigation, civilian use in particular has evolved rapidly. In the field of consumer drones, currently dominated by Chinese providers (most notably *DJI*), more than one million units are sold yearly. The field of professional drones is growing even more rapidly, with already widespread use in cartography as well as aerial surveying and surveillance. Semi-autonomous drones are being used increasingly in agriculture (field monitoring), in disaster situations (fires, natural disasters, rescue operations) or for transportation. While current drones operate mainly in open airspace, new flight concepts and advanced navigation systems will allow future drones to move in contact with their surroundings. This will enable wholly new applications in the inspection of infrastructures, the cleaning and painting of buildings, the construction industry and many others.

### Implications for Switzerland

Swiss institutions of higher education are leading the way worldwide as regards technological advances and possible applications, and our startups are also about to attain international leadership. In coming years, the aim will be to strengthen and consolidate this research and market position, in order to once and for all become the “Silicon Valley of drones”. Conditions are ideal. Strong cooperation between institutions of higher education, startups, regulatory authorities (*Federal Office of Civil Aviation FOCA*), established partner firms and end customers will allow Switzerland to develop this exciting, economically relevant and fast growing market for the country’s social and economic benefit.

## Collaborative robots

**Max Erick Busse-Grawitz** and **Ulrich Claessen** (maxon motor)

**Quadrant:** technological hopefuls

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### Present situation worldwide and in Switzerland

Manufacturing at many Swiss SMEs features small lot sizes and high product variance, leading to a dilemma: should production tasks be entrusted to humans, whose skill and dexterity often make them more productive than robots and automats despite their high hourly wage – or should products be redeveloped at considerable expense in order to make them suitable for automation and robotisation? Collaborative robotics at least partially remedies this quandary. Collaborative robots (“cobots”) are defined as robots that share the same workspace as humans and are able to interact with them (as defined in ISO 10218 and 15066). Safety standards set limits on the robots’ speed (1.5 m/s) and kinetic energy (40 joule). Instead of leaving all operations to robots, humans are to retain those activities in which they display superior skill. Simple routine tasks, however, are to be carried out by robots. Dividing tasks into “complicated” and “simple” makes cooperation between robots and humans indispensable, as both types of work are closely interwoven in production.

Collaborative robotics is still in its infancy, but will certainly play an important role in future. Ever shorter innovation cycles and smaller lot sizes call for a flexibility that rigid forms of automation struggle to provide. Robotics enables replicable, fatigue-free processes and hence consistent quality – a key aspect for Swiss industry, which relies on high added value. In order to tap their full economic potential, robots must be affordable and easy to programme and configure, which is more and more the case.

There is much untapped potential when it comes to the deployment of collaborative robots. This is due to numerous technical limitations, but also to the fear of change and job losses. However, as the majority of products are supplied in price-elastic markets, a pricing structure streamlined through the use of robots creates more jobs than it destroys. Investment costs, often perceived as dissuasive in conventional robotics, are less high for collaborative robots, which can do without many of the safety features required by rigid robots. Auxiliary camera systems are also becoming increasingly affordable and easy to use. The growing use of artificial intelligence in automation supports this trend. Typical current applications must take into account collaborative robots’ as yet limited agility and speed. For the moment, collaborative robots are therefore mainly used to handle lightweight components and to perform simple assembly tasks. In the next five years, collaborative robots’ direct learning from humans will remain confined to rather simple processes.

### Implications for Switzerland

With its sizeable industrial manufacturing sector and high labour costs, Switzerland is an ideal candidate for the use of collaborative robots. While the country is considered the “Silicon Valley of flying robots”, it lags behind in the development of collaborative robots. The European leaders in this field are currently Denmark, Germany and Sweden. Many startups operate within the orbit of large firms. Both in regulatory and educational terms, Switzerland is very well positioned to take up the trend, which is likely to accelerate as improved robots and simpler programming broaden the scope of applications in production.



# Energy and the environment

## Distributed energy systems

David Grosspietsch (Technology Fund and ETH Zurich)

Quadrant: niche technologies

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### Present situation worldwide and in Switzerland

Distributed energy systems are systems or groupings of several buildings equipped with renewable energy production facilities, which combine various energy carriers such as electricity, heat or hydrogen as well as featuring energy storage facilities (e.g. batteries, thermal storage) and energy conversion technologies (e.g. heat pumps, electrolyser). The aim is to cover the bulk of energy consumption with local production by harnessing the flexibility of on-site storage and the conversion of energy carriers (power-to-heat/gas).

Despite high initial investments, distributed energy systems offer many advantages such as reduced energy costs through increased self-consumption or the possibility to smooth power peaks through energy storage and conversion. This increases flexibility in the low-voltage grid, making it possible to avoid grid extensions. Other possible benefits include the integration of power-, gas- or hydrogen-based mobility and the provision of further services such as balancing energy. Switzerland already numbers several successful examples of distributed energy systems, from single-family homes to industrial sites. One instructive example is the energy self-sufficient multi-family home conceived by *Walter Schmid AG* in Brütten, which has been operating since mid-2016. In general, applications span the range from energy-integrated urban neighbourhoods to self-sufficient systems in remote areas. The smooth interplay of various technologies, players and institutions is key to a successful extensive rollout of distributed energy systems.

### Implications for Switzerland

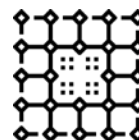
The trend toward distributed energy systems will intensify in future with the global evolution of technology costs and sector coupling across electricity, industry, transportation and heating/cooling. Compared to other countries, the relative innovativeness of the Swiss construction and energy sectors creates many economic opportunities for Switzerland, especially in terms of developing, financing, implementing and operating such systems. However, integrative system solutions involving numerous technological configurations and a plurality of stakeholders will remain challenging in the short and medium term.

## Smart grids

Roland Küpfer (BKW)

**Quadrant:** self-propelling technologies

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### Present situation worldwide and in Switzerland

The term “smart grids” is currently the energy sector’s most frequently used. According to Switzerland’s Energy Strategy 2050, smart grids are key to balancing on the one hand electricity fed in from both traditional and distributed renewable energy sources and on the other hand distributed power consumption. Strongly fluctuating, weather-dependent electricity generation is a novel factor that in the medium term will put grid stability to the test in terms of voltage and frequency. This is due to the fact that, with electricity generated from many distributed renewable energy sources, feed-in locations and peaks only become known at short notice. Yet power grids are always designed to handle peak loads: taking into account peak loads for all new energy sources would call for an extension of distribution networks in the double-digit billion range. This is why efforts are focussed on smart network management.

A control system building on the use of data and communication technology will help meet these challenges. Smart measuring and metering systems are necessary to process data and ensure future grid stability. “Smart meters” are an important building block of the Energy Strategy 2050 and will gradually replace traditional energy meters; by 2028, the coverage rate should reach 80%. Data acquisition via smart meters should help balance grid fluctuations. In practice, this will work as follows: when a power surplus is detected, the smart grid activates additional consumers such as boilers to take on the overflow. In case of power shortage, electricity generation from tra-

ditional sources is stepped up. In future, cost-effective and reliable grid planning will play an important role. Fundamental rules and regulations are currently being established for the use and safety of data, especially load profile data that make it possible to draw inferences about consumer behaviour. It is equally important to conduct research on inexpensive and effective power storage in the context of smart grids that will influence future product design. Appliances, building technologies and charging stations for electric cars will become intelligent power consumers that communicate with smart grids and provide important information for network control. A major challenge facing distribution network operators will be the gap between the traditional physics of power transmission and the possibilities created by digitalisation.

### Implications for Switzerland

Swiss energy supply is currently excellent. The Swiss Energy Strategy 2050 aims to curb rising electricity consumption, promote personal responsibility through increased awareness of individual use, and optimise consumption. With its technological know-how, Switzerland is very well equipped to successfully implement smart grids, even though research intensity in this field remains low. However, digitalisation leads to a disproportionate increase in complexity. Challenges include the massive proliferation, safe transportation and necessary encryption of data, as well as the management and control of networks using acquired data, all this in the context of a surge in private power feed-ins.



## Future energy storage

**Thomas Justus Schmidt** (PSI)

**Quadrant:** niche technologies

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### Present situation worldwide and in Switzerland

Future energy storage technologies strive for large-scale energy storage systems able to seasonally balance the discrepancies between power production and power consumption that can be caused by the transition from fossil and nuclear baseload energy provision toward fluctuating renewable power supply. Given the level of acceptance displayed by the Swiss population for the Swiss Energy Strategy 2050 (adoption of the Swiss Energy Act by voters in May 2017), it is likely that the transition described above will indeed take place. Should no new storage technologies become available by 2030, this would greatly strain the transmission grid.

Available short-term storage technologies for heat and power, e.g. batteries, are currently able to balance production and consumption peaks. However, issues of cost and reliability remain to be addressed in order to make the installation of short-term storage facilities more attractive.

In future, long-term energy storage systems will become necessary to reduce reliance on energy imports and lower electricity costs in winter. Such storage systems, e.g. power-to-gas or compressed air storage plants, are currently at development stage but will be critical to meeting climate targets. This applies to Switzerland as well as all other countries committed to achieving their climate objectives.

### Implications for Switzerland

Some energy system scenarios make do without long-term storage options. However, such scenarios take as their starting premise a power grid in Switzerland and neighbouring countries that is firstly dimensioned to handle peak loads and secondly reliant on sufficient power imports from countries generating production surpluses even in winter. Heavy dependence on neighbouring countries' energy policy, potentially high costs and the vulnerability of such a system amount to considerable risks for Switzerland, which long-term storage technologies can help mitigate.

It is strongly recommended to keep researching and assessing options for the long-term storage of energy and to scale them up from laboratory to industrial scale. With the *Swiss Competence Centres for Energy Research (SCCERs)* and other support schemes, Switzerland has laid strong foundations for the successful development of the required technology. Going forward, research networks must be allowed to remain intact and keep growing. In this light, the current lack of business models in the field of long-term energy storage is cause for concern. It makes it difficult to find industrial partners willing to invest in long-term developments in order to keep networks going.

## Geothermal energy

Willy Gehrler (SATW and Geothermie Schweiz)

Quadrant: niche technologies



### Present situation worldwide and in Switzerland

Geothermal energy is thermal energy stored in the Earth. It is generated by the decay of natural radioisotopes in the rock of the Earth's crust and by thermal exchange with deeper layers of the planet. The term "geothermal" originates from the Greek roots "geo" (earth) and "thermos" (hot). Over 99% of the globe's mass are hotter than 1000° C and only one thousandth – its uppermost 3 km – is cooler than 100° C. Geothermal energy thus provides 24/7 carbon-free energy. Availability is practically unlimited, as radioactive decay inside the Earth produces constant heat.

At a depth of 10-20 meters, earth temperatures in Central Europe are around 12° C. This is the depth up to which temperatures are influenced by the climate. In deeper layers, the geothermal gradient applies, meaning that on average temperatures rise by around 1° C every 33 meters. Hydro-geothermal energy uses natural resources of hot water in the sub-surface. For petro-geothermal energy (hot dry rock geothermal energy), cold water is pumped deep underground. In order to allow the water to circulate, the hot, compact rock is cracked open through high-pressure water injection. The water flowing through these joints in the rock captures the rock's heat and can be put to different uses depending on depth. Up to 440 meters, shallow geothermal energy is used for heating (heat pumps) and cooling buildings including warm water processing, or as process heat for plant nurseries and swimming pools. Medium-depth geothermal energy (up to 3000 meters and around 100° C) is used to heat entire neighbourhoods, office buildings and industrial sites (district heating). Deep geothermal energy (more than 3000 meters and over 130° C) is used to generate electricity.

### Implications for Switzerland

Switzerland has the highest per capita percentage of geothermal probes with heat pumps. The number of new installations has been rising sharply for many years. Around 5% of thermal energy is currently obtained using geothermal probes and heat pumps. No statistics are yet available on the substitution of air conditioners by the use of shallow earth temperatures of around 12° C. To date, deep hydrothermal and petrothermal installations have only been realised in other countries. In Switzerland, projects planned for the years ahead include the following: Haute Sorne, canton/city of Geneva, La Côte, Triengen, Horgen, Avenches. Throughout the world, the technology is still in its infancy. Based on the new Swiss Energy Act, Switzerland is investing heavily in research. Around 80 researchers are currently working at the *Grimsel Test Site* and the *Bedretto Deep Underground Lab*. Commercial projects in Basel, St. Gallen and Zurich have not yet proven successful. In Geneva, however, medium-depth boreholes are being drilled to feed into the district heating network. Worldwide, the use of geothermal energy is growing rapidly. This is especially true of deep geothermal energy for electricity generation (e.g. in the US, the Philippines, Indonesia, Mexico or Turkey) and for heat generation (in China, the US, Sweden, Turkey and Japan).

## Photovoltaics

**Christophe Ballif** (EPFL and CSEM)

**Quadrant:** star technologies

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### Present situation worldwide and in Switzerland

Photovoltaics (PV) is the direct conversion of light into electricity using semiconductors, solar modules and solar cells as well as electric components such as maximum power point trackers and inverters. PV also includes other aspects such as installation (assembly systems and building integration), areas of application (stand-alone or grid-connected systems, mobility), planning, monitoring, maintenance, and forecast. In 2017, 98 gigawatt (GW) of new PV peak power were installed worldwide. R&D and mass production are turning PV into the most cost-effective source of electricity. Large-scale systems are currently generating electricity at less than 4 euro cents per kWh, i.e. more cheaply than any other new power plant (including coal). Smaller-scale systems generate electricity at typical end user rates of 8 to 30 cents/kWh or even less. PV has the potential to become the most important source of electricity in the world. Combined with hydropower and wind power, at times with a high-voltage direct current transmission grid, with short and long-term storage options such as batteries, heat, water, power-to-gas as well as with demand-side management, it can become an effective part of the energy system.

Taking serious action to fight climate change would require a yearly 600 to 1000 GW of new PV installations worldwide, i.e. a multiple of current installation rates. The solar era is thus only just beginning. More widespread use of PV calls for a further 20-40% decrease in component costs as well as a significant increase in efficiency. Efficiency currently stands at 17.5% for average modules using crystalline silicon cells, which cover 95% of the market, and should be improved to reach 22-24% over the next

ten years. So-called multi-junction cells combining semiconductors made of different materials should enable module efficiencies of 25-30%. With greatly extended lifespans well in excess of 25 years as well as customer-specific and local manufacturing, PV is likely to play an increasing role in the building sector. PV applications in the field of mobility, e.g. on car roofs, are also expanding. All these improvements will make PV even more inexpensive and create more options for power management, justifying efforts to further improve the technology.

### Implications for Switzerland

In Switzerland, 2 GW of installed PV cover 3% of yearly power requirements (estimate as of mid-2018). A slight increase in installation rates (from 250-300 MW/a in recent years to 400-450 MW/a) would make it possible to achieve an annual production of 12 TWh by 2040, meeting minimum requirements for the contribution of PV to the Swiss Energy Strategy 2050 (20% of electricity). Yet this is only a fraction of photovoltaics' technical potential in Switzerland. The country numbers many research institutes and businesses working along the PV value chain, and many PV systems throughout the world contain components produced in Switzerland. Both Switzerland's research institutes and high-tech PV sector hold leading technological positions. Major pressure exerted by the Chinese industry means that Swiss firms must innovate on a constant basis in order to maintain their market share, and have to focus on developing products and services displaying higher added value. These include special stand-alone systems, building-integrated PV products, measurement solutions, software and mobility applications to capture niche markets in Switzerland and in Europe.

## Alternative protein sources

Erich Windhab (ETH Zurich)

**Quadrant:** niche technologies

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### Present situation worldwide and in Switzerland

Over the past three to five years, new sources of protein such as insects and microalgae have gained ground next to traditional sources such as grains, pulses and tubers. Assessing the sustainability of such new resources requires comprehensive life cycle assessments (LCAs). However, these only make sense once production and processing methods, detailed product characteristics and initial reactions by food consumers are available.

In parallel, an interesting trend toward sustainability has developed for some conventional resources, especially proteins in pulses and oilseeds. It finds its roots in the “flexitarian” movement, which is gaining increasing traction among “Millennials”, whose diet is mostly vegetarian or vegan with only occasional meat intake. Texturised vegetable proteins used as meat analogues are therefore generating growing market interest. Such products, where necessary complemented with nutritional fibres, have a sustainable environmental footprint and are likely to be in increasing demand. In addition, these proteins can often be derived or recovered as by-products of other food production processes.

### Implications for Switzerland

Protein texturisation technologies such as high-pressure moist extrusion, multiscale 3D printing or multijet powder fusion are likely to develop greatly in coming years. High growth rates are expected for their resulting products, if need be enriched with nutritionally relevant fibres. Switzerland is well positioned in terms of research to successfully pick up on this trend.

## Drones in precision farming

Frank Liebisch (ETH Zurich)

Quadrant: technological hopefuls

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### Present situation worldwide and in Switzerland

Automated and precise agricultural processes are increasingly in demand, including in Switzerland, with a view to cutting costs and using resources more efficiently. The term “precision farming” describes the combined use of electronic and mechanical devices in order to improve agricultural efficiency. Precision farming makes it possible to secure yields, boost revenue and reduce harmful environmental impacts, e.g. due to the runoff of crop protection products. Citizens are increasingly calling for the minimisation of such environmental impacts. Robots and drones will play an important role in the future: they are optimised for specific tasks and make it possible to carry out field assignments more efficiently in terms of both time and space.

Today, drones are used in agriculture mostly for monitoring and product application purposes. Drone monitoring provides up-to-date, high-resolution information and images of partly poorly accessible locations (e.g. meadows, treetops), which can be used for farm advisory and mapping services. The rescue of fawns using thermal imaging cameras is one such example. The use of maps for intra-field crop management, as practised extensively in some neighbouring European countries, is not yet commonplace in Switzerland. Possible reasons include very low fertiliser costs (e.g. nitrogen), official fertilisation guidelines devoid of technological measures for in-

tra-field fertilisation management, and legal regulations. Drones for the application or spraying of agricultural adjuvants are used mainly in crop protection. One successful example is the dropping of trichogramma capsules to fight the European corn borer, i.e. biological pest control using antagonistic insects. This has by now become a standard method in Switzerland and in the EU, and its robust automation has greatly improved efficiency. The spraying of liquid crop protection products is subject to stricter legal constraints and is more difficult to carry out; it is technically and legally still at development stage. In the field of viticulture, Switzerland has developed internationally groundbreaking drone applications, especially for steep hillsides. These technologies are likely to gain ground and become relevant in other fields such as fruit and vegetable cultivation or preventive precision application in the fields.

Switzerland operates at the global forefront in the development of drone technologies. This applies in particular to the fields of sensor technology, drone control systems and data processing, in which the country is setting new standards. Even though the use of drones in Swiss farming is currently still limited, the technology holds significant potential for the country's diverse and highly structured agriculture. Drone-based technology is oftentimes more flexible and sometimes also more cost-effective than e.g. tractor-based systems.

### **Implications for Switzerland**

Conditions in Switzerland for the development of agricultural drone technology are good, as know-how is available in almost all relevant fields, from basic to applied and practical research. The aim should be to establish links with farming practitioners, promote solutions directly on farms, and improve usability. Appropriate research promotion and technology transfer schemes should be put in place. The integration of such technologies in actual agricultural processes will tend to be slow. Compared to other countries,

adverse factors include relatively low fertiliser and commodity prices as well as agricultural subsidies that are only loosely tied to production efficiency. Also, the legal and regulatory framework for the use of drones is currently being overhauled. And finally, drones play almost no role in the training and education of farmers, agricultural consultants and agricultural engineers. There is a need for clear and favourable framework conditions as well as capacity building in order to extend technological leadership in the field of drones to the realm of agriculture within five to ten years.

## Sustainable food production

Erich Windhab (ETH Zurich)

Quadrant: star technologies

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### Present situation worldwide and in Switzerland

With its 17 Sustainable Development Goals (SDG), the *UN's 2030 Agenda for Sustainable Development* sends a clear signal in favour of a sustainable food system. SDG 2 and SDG 12 in particular address this issue (SDG 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture; SDG 12: Ensure sustainable consumption and production patterns). Industry-oriented European research in the food sector has derived six strategic goals for implementation (see e.g. *EIT Food* and *Food 2030 Programme*). By adopting the *Agenda 2030*, the international community has established a new global frame of reference, which also guides sustainable development in Switzerland. A first analysis shows that the *Agenda 2030* and its goals are well anchored in Switzerland and identifies remaining challenges to achieve the SDGs by 2030.

### Implications for Switzerland

There is a need for action in Switzerland as regards food research along the entire value chain as well as SDG 2 and 12, which are especially likely to benefit from technological developments. Key challenges include: (1) Growing use of resources far beyond our planet's capacity and resilience, shifting the environmental burden to supplier countries; (2) Nitrogen pollution and loss of biodiversity caused by heavy use of crop protection products and antibiotics that do not yet meet environmental goals in agriculture; (3) Malnutrition favouring diseases such as diabetes, obesity or cardio-vascular disorders, which are responsible for around 80% of Swiss healthcare expenditures. The "Foresight Study" published by the *ETH Zurich's World Food System Centre* has identified key issues in working toward a sustainable food system, which food technological measures may contribute to solving:

- Energy and nutrient use efficiency along food value chains
- Reducing food waste and losses in food value chains
- Sustainable diets
- Resistance to antibiotics
- Impact assessment of local vs. global food production

The Swiss food sector numbers around 2200 businesses (98% of which are SMEs). Almost all of them acknowledge and address issues of sustainability in their targets and objectives. With around 62'000 direct jobs and annual sales of roughly 25 billion CHF, they represent 5.3% of Swiss GDP.

## E-mobility: electric vehicles and infrastructure

Andrea Vezzini (BFH)

Quadrant: self-propelling technologies

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### Present situation worldwide and in Switzerland

Complying with the climate targets of the Paris Agreement requires a shift from our current fossil fuel-based transportation system to a sustainable system featuring minimal carbon emissions and primary energy use as well as largely pollutant-free emissions. In Switzerland, transportation is responsible for one third of overall greenhouse gas emissions. When considering only carbon emissions due to heating and motor fuels, this figure rises to 44% (15 million tonnes in 2017). The necessary transition will rely on the development of e-mobility, which aims to answer mobility needs while also meeting imperatives of sustainability through vehicles with electric drive and energy storage. A comprehensive study published by the *SCCER Mobility* shows that the medium to long-term decarbonisation of mobility can only be achieved through technological developments focussed on powertrain electrification. There are two competing pathways to electrification: battery-electric vehicles and fuel cell vehicles powered by hydrogen. The timely development of carbon-free power generation for the mobility sector and of an efficient charging infrastructure will be critical factors. Other global mobility trends include growing urbanisation (megacities), advancing digitalisation (autonomous driving) and changing attitudes (sharing economy).

### Implications for Switzerland

In the short and medium term, it will be important to set up the necessary infrastructure for the electrification of mobility. Over the next five years, the number of battery-electric vehicles is projected to increase as a percentage of new vehicles, reaching 10-20% by 2025. A sizeable charging infrastructure will need to be set up: in this context, a key role can be played by the Swiss energy, financial and technology sectors. Throughout Europe, traditional automobile manufacturers are displaying growing interest in developing their own networks of fast charging stations. Legislators should hasten to establish a suitable framework for such activities. The Swiss automotive industry is traditionally a supplier industry. Around two thirds of sales are generated by the supply of parts and materials. Over the long term, the production of parts for internal combustion engines is likely to decrease and give way to e-mobility components, creating opportunities for new market players.



## Mobility concepts

**Thomas Küchler** (Schweizerische Südostbahn AG)

**Quadrant:** technological hopefuls

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### Present situation worldwide and in Switzerland

When it comes to the development of new mobility concepts, the megatrend is the automation of road and rail vehicles. For road vehicles, automation is likely to be gradual, from today's partial automation to full automation after 2030. As for rail vehicles, major efforts are currently being undertaken to significantly increase capacities using digital technologies. Another strong trend is the development of new solutions based on existing vehicle technologies. In most cases, these are designed to solve "last mile" issues by replacing individually owned vehicles or complementing public transportation. Research is being carried out to develop new on-demand solutions using fully automated road vehicles. A third trend is to combine all mobility solutions into one continuous, multi-link chain providing easy-to-use door-to-door transportation services. It is interesting to note that service providers external to the field of mobility are trying to complement their product range with mobility solutions: such developments are driven mainly by sector-specific goals, giving only limited consideration to the potential of multimodal mobility.

### Implications for Switzerland

Two challenges can currently be identified in the field of mobility: first, the way in which we use mobility will change significantly. Second, the strict boundaries between mobility options, e.g. individual and public transportation, will blur. It remains to be seen which requirements this will give rise to in terms of infrastructures and spatial planning. The availability of mobility data is a key issue in this context. Unlike public transportation, individual transportation data is highly decentralised, often privatised and not accessible to third parties. However, a reasonable combination of data sources is indispensable in order to develop and steer future mobility as well as provide intelligent solutions to issues of capacity.

## Automated vehicles

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

**Quadrant:** technological hopefuls

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### Present situation worldwide and in Switzerland

Automated – or largely assisted – mobility is a key technological topic; as part of the digital transformation, it impacts many areas. Already today, vehicles with ever more high-performing driving assistance features are technologically capable of self-executing specific driving tasks (level 3 of *SAE International's* J3016 standard). The next stage is high automation, in which the vehicle drives autonomously from A to B while still equipped with pedals and a steering wheel (level 4 of SAE J3016). Significant further progress is still needed on both the technical and the legislative fronts for fully automated vehicles without wheel and pedals (level 5 of SAE J3016) that are not limited to driving on defined routes or circumscribed road networks; they shall therefore be given no further consideration in this context.

The path to level 4 and the initial deployment of such vehicles are already causing controversy. Rather than slow and steady progress, “quantum leaps” may take place in the foreseeable future, probably with the groundbreaking deployment of truck and taxi fleets. The development of vehicles with unlimited driving range should not be confused with the deployment of autonomous taxis and buses in peripheral zones and other limited urban areas. In Switzerland, small shuttle buses are already operating in pilot mode at low levels of complexity, i.e. on pre-practised routes and road networks, in Sion, Fribourg and Neuhausen, with other cities to follow. In Singapore, an entire fleet of autonomous taxis was launched. In Califor-

nia, *Waymo* was the first to obtain permission to operate driverless taxis. These pilot projects are much less demanding in terms of environmental perception, interpretation and decision-making capacities than level 4 vehicles for extensive and general use.

The trend toward automated mobility is of great significance, last but not least owing to the (at times unrealistically) high expectations it carries, such as improved road and vehicle utilisation rates, facilitation of new mobility concepts and business models, cost reductions especially in the field of logistics, new mobility services for the young and old, as well as time gains made possible by the elimination of bothersome driving tasks. Yet fear and scepticism are also rife, making the technology vulnerable in terms of public and political acceptance. Issues being raised include the following: the reliability and validation of computer-controlled systems, the protection of huge volumes of accruing data, controllability, liability, and licensing practice. Software that together with sensors and other hardware (e.g. new micro-chips) renders drivers largely superfluous is already at development and testing stage. This includes necessary algorithms for machine learning and pattern recognition, i.e. artificial intelligence. Successful rollout would require an optimisation of the overall system and its integration in wider mobility concepts, e.g. weighing up cost minimisation and safety when it came to sensors. The parallel deployment of human-driven and automated vehicles (“mixed traffic”) raises issues that need to be addressed, last but not least via licensing.

### Implications for Switzerland

Automated systems are an R&D focus at the *EPFL* and the *ETH Zurich*, at various universities of applied sciences and at leading car manufacturers and large systems suppliers. Increasingly, many innovative SMEs are also getting involved. As a highly developed country with high traffic density, Switzerland stands to benefit from automated/ autonomous transportation systems for goods and pas-

sengers. The country is well positioned to take an active part in testing and implementing such systems. Even though Switzerland has no automotive industry, the expertise and track record of its automotive supply industry, large companies (logistics, goods and passenger transportation, insurance) and SMEs (sensor technology, system and software development) create new business opportunities.

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## Smart living environments

### Smart cities

**Andrew Paice** (Lucerne University of Applied Sciences and Arts)

**Quadrant:** star technologies

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### Present situation worldwide and in Switzerland

Technological change and digitalisation are posing major challenges for cities. This applies in particular to the provision of resources (e.g. water, electricity, light) and infrastructure services (e.g. mobility, waste disposal), as well as to the direct interaction of citizens with their municipal authorities. All these areas can be transformed by digital technologies. Key technologies such as big data analytics or the Internet of Things (IoT) are available and can be harnessed to optimise urban traffic. Cost-effective, wireless communication technologies, e.g. long range wide area networks (LoRaWAN), the easy usability of sensors with long battery

life as well as cloud-based data management and analytics software make it possible to create a citywide smart environment. Throughout the world, several municipalities and cities have availed themselves of these technologies to implement different aspects of the smart city concept. Lighting management often constitutes a first step, followed by parking guidance and information systems and traffic management. In the meantime, smart sensors are being integrated in the utility grid to enable intelligent network management. The advent of artificial intelligence allows for many new applications, while also giving rise to new risks such as “profiling” of individual buildings or citizens.

Even though relevant technologies are to a large extent available, creating a smart city remains a major challenge due to the system's complexity and the sheer range of possible applications. Typically, pilot projects are carried out to establish a scheme's feasibility and benefits. Yet considerable issues remain to be solved as regards data security and data protection before public acceptance can be ensured.

### **Implications for Switzerland**

There is a strong interest in smart cities in Switzerland. St. Gallen initiated pilot projects in 2015. Basel has developed a strategy and takes a broad approach with a combination of demonstration and research projects. Other cities such as Geneva or Zurich are either developing a strategy or launching pilot projects that often tie in with international research projects. Examples include a lighting project in Winterthur, a living lab to investigate social aspects in Bellinzona, or smart parking guidance and information systems and mobility in Geneva. It is interesting to note that municipal utilities are often major drivers of smart city technologies. They view them as opportunities to lower costs and to develop service-based business models. There are also interest groups such as *Smart City Hub Switzerland* or *CityZen*, and the *Swiss Federal Office of Energy (SFOE)* runs a research programme on energy management in "Buildings and Cities".

The main technological drivers for the rollout of smart city solutions are the coverage rates of IoT network technologies and communication networks such as 5G. The economic potential of smart cities is enormous and is further enhanced by their possible convergence with smart home and smart building technologies. Key obstacles include costs and (political) decision-making processes, the complexity of integrating all aspects within a functioning system, and finally the search for persuasive benefits to promote acceptance by all concerned. In this highly complex environment, a central decision for cities will be their choice of technology partner: should they favour established partners who often operate on an international scale or should they choose local partners? While local partners offer greater flexibility, they might struggle to ensure operational continuity. There are many ways for Swiss startups and SMEs to provide technological support and innovative service models. The challenge they face is to gain the city's trust and to then establish a going and lasting concern in order to ensure the necessary continuity. The challenge faced by the city will be to create a digital identity and to push ahead with smart city initiatives for the benefit of its inhabitants. In the next five to ten years, we will likely witness strong growth in the rollout of smart city and service innovations.

## Smart homes

**Peter Richner** (Empa)

**Quadrant:** star technologies

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### Present situation worldwide and in Switzerland

Buzzwords such as “smart home” or “smart building” have no exact definition: broadly speaking, they refer to buildings that have been connected and upgraded with information and sensor technology. Developments such as the Internet of Things or cloud-based services have a potential for application in the buildings sector. Passive systems and intelligent planning can also contribute to making a building smart. Smart solutions must perform the desired action with as little user input as possible. One good example is the use of algorithms to manage heating and air conditioning based on continuously updated forecasts as to weather conditions and building use. Other fields of application include monitoring systems that enable the elderly to extend independent living. In a modern, technological society, smart solutions for accessible buildings, fire safety, energy, earthquake proofing and general comfort matter enormously. The greatest potential lies in the intelligent reaction to short, medium and long-term changes in use and/or environmental factors.

### Implications for Switzerland

In a modern, technological society, there is huge potential for smart solutions in building construction and operation. The challenge lies in practically implementing new concepts. The integration of solutions that are strongly tied to the rest of the building must be ensured from planning to installation and operation. The necessary interaction between rather traditionally-minded buildings professionals and new players steeped in information technology can be challenging. For pure add-on solutions, i.e. extension packs or additional programmes such as voice-operated home appliances, user acceptance and the creation of tangible added value are key. Academic and industrial research in Switzerland are well positioned and very active; it should therefore be possible to successfully keep up with the trend.

A bundle of glowing blue fiber optic cables is shown against a dark blue background. The cables are arranged in a fan shape, with their ends pointing towards the top right. The light from the cables creates a series of bright, glowing spots and streaks, giving the image a sense of depth and movement. The overall color palette is dominated by various shades of blue, from deep navy to bright cyan.

# **Manufacturing processes and materials**

## Material development for additive manufacturing

Christian Leinenbach, Lars Sommerhäuser (Empa) and Adriaan Spierings (inspire)

Quadrant: technological hopefuls

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### Present situation worldwide and in Switzerland

The development of materials for additive manufacturing (AM) includes plastics, metals, ceramics and composites whose composition makes them ideally suited to additive manufacturing process requirements and thereby enables new, better performing products. The objective is two-fold: on the one hand, the goal is to expand the portfolio of materials suitable for additive processing. On the other hand, additive techniques are to produce new materials that cannot be obtained with conventional manufacturing techniques. The special conditions of additive processing make it possible for example to freeze unstable states in metals, combine various materials or locally modify material properties.

There is therefore a growing trend toward producing specific materials for additive manufacturing processes. These materials make it possible to produce parts and components featuring new functionalities or improved properties that are unavailable in conventionally produced parts. Tapping the full industrial potential of additive manufacturing requires specifically optimised materials.

### Implications for Switzerland

With its expertise in the field of materials research and technology development, Switzerland is well positioned. On the research side, institutions of the *ETH Domain*, research organisations such as *inspire* as well as some universities of applied sciences play an important role. Switzerland's industrial sector also numbers various firms that hold the necessary competences to develop such materials and associated processes. While in past years additive manufacturing has been driven mainly by firms specialised in mechanical and plant engineering (especially in Germany and in the US), in future greater emphasis will be placed on materials and processes. This field is still in its infancy but developing fast, providing Switzerland with an opportunity to attain international technological leadership. However – akin to other European countries or the US – Switzerland must establish appropriate schemes for research promotion and technology transfer.

## Additive manufacturing processes

Lars Sommerhäuser (Empa) and Adriaan Spierings (inspire)

**Quadrant:** technological hopefuls

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### Present situation worldwide and in Switzerland

Additive manufacturing (AM) processes encompass the full scope of AM processes that are currently available or still in development, including various upstream and downstream processes that are necessary to produce ready-for-use components and products. Examples include powder-based technologies such as selective laser sintering (SLS) and selective laser melting (SLM) for plastic and metal parts, filament processing techniques such as fused deposition modelling (FDM) for plastics, and liquid-based technologies such as stereolithography (SLA). Examples of promising new processes that are still at development stage include the printing of metal parts using binder jetting (BJ), technologies for the additive production of large structures in the metre range, and new micro and nano applications.

An overarching trend is the industrialisation of additive manufacturing processes, meaning in particular their stronger automation and integration in conventional production process chains, the assurance of process and product quality, and the lowering of production costs. The implications of this trend should not be underestimated. Additively produced applications and parts have significant innovation potential, which must be implemented in a cost-effective and high-quality manner. Application-oriented examples that are relevant for Switzerland include the plastics industry, lightweight engineering (aviation and space sectors), mechanical engineering, medical technology and the turbine industry, i.e. fields that contribute to Switzerland's prominent global standing when it comes to innovation.

### Implications for Switzerland

Compared to other countries – especially Germany, the United Kingdom, the US and China – Switzerland has not been very active in promoting industry and research for the development of industrial AM processes. And yet the trend toward increased industrialisation is of great significance, as it calls for new ideas and know-how in the further development and implementation of technologies as well as innovative quality assurance concepts. These are fields that play to Switzerland's traditional strengths. An opportunity to bring its competences to bear in a fast-growing market is given in the development of new AM technologies, the greater industrialisation of additive manufacturing and the qualification of AM technologies for specific applications. Switzerland can and should help bring additive manufacturing technologies to the next level in terms of quality and costs. Mastering these challenges will keep Swiss research and industry busy for the next five to eight years. In order to approach these tasks with success, it is crucial to ensure firm political commitment to promoting manufacturing technology in Switzerland, also setting up appropriate support structures, programmes and priorities.



## Bioplastics

**Urs Mäder** (SATW), **Roger Marti** (HES-SO Fribourg) and **Hans-Peter Meyer** (Expertinova AG)

**Quadrant:** technological hopefuls

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### Present situation worldwide and in Switzerland

Bioplastics are derived from renewable biomass. They should not be confused with biodegradable plastics, as bioplastics are not necessarily biodegradable.

Next to so-called drop-in materials – biobased plastics that are chemically identical to plastics derived from fossil resources – a growing number of novel monomers or polymers are derived from renewable resources. They are increasingly replacing classic, petroleum-derived products. One such example is polyethylene furanoate (PEF), which can be derived entirely from plants. One of its components, furandicarboxylic acid, is a base chemical for many bio-derived plastics and can be produced from vegetal waste matter in a multi-step process. PEF is similar to PET, but has better barrier properties for oxygen and CO<sub>2</sub>, which makes it interesting for the packaging industry. High-grade and functional biopolymers are used increasingly for special applications, e.g. in biomedicine, for 3D printing of new organs and in the packaging industry.

In the near future, biobased plastics will become more present on the market, but their share of the steadily growing total market will remain low (a few percentage

points only). On the one hand, regulatory measures are needed to change things. On the other hand, more research is necessary to accompany a wider rollout of bio-based plastics especially in the packaging industry. One textbook example is the EU project *BioSmart*, carried out in partnership with the *School of Engineering and Architecture of Fribourg*, which aims to develop smart, bio-based and compostable packaging. Other interesting monomers derived from natural resources are still at research stage. Active research is being carried out on functional biopolymers, especially for high-tech applications that interact with their environment or react to external factors. Polyhydroxyalkanoates, which can be tailored to specific applications in terms of structure and properties, are one such exciting development.

### Implications for Switzerland

Applications using biopolymers in medical technology, in formulation and in packaging represent opportunities for the Swiss industry. The automotive industry and the field of agriculture should also be taken into account. Research and industrial partners as well as regulatory bodies should be brought together to identify key issues and solutions. Public awareness of biobased and/or biodegradable plastics must also be raised.

## Functional fibres

**Manfred Heuberger** (Empa), **Paul Keller** (Avery Dennison Materials Europe) and **Urs Mäder** (SATW)

**Quadrant:** self-propelling technologies

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### Present situation worldwide and in Switzerland

Functional fibres are already being used for a wide range of practical applications, especially for the production of functional sports and leisure wear, and as an insulation, composite and reinforcement material in the construction sector and paper industry. Other applications that are still being tested or are already being implemented in practice include the following:

- Fibres with antimicrobial properties (through absorption or the release of antibacterial substances)
- Superabsorbent fibres with high water absorbency for medical and cosmetic products
- Fibres with controlled water absorption and release for food packaging
- Fibres for the selective removal of heavy metals from wastewater

For many technical applications, additives are mixed in with the fibres during the spinning process to achieve new properties, or a finish is applied. During the production process, it is also possible to change the fibres' structure, producing conventional round fibres or hollow, flat or other fibres.

Combining new production methods and new materials such as nanoparticles could enable the development of functional fibres with hitherto unattainable properties. Such possibilities should be explored more precisely to assess their potential and encourage them as necessary. Promising applications include:

- Composite fibres made from a combination of different materials with specific surface properties, e.g. bi-component fibres with a sheath that melts at lower temperatures than the core and dissolves into the surrounding material (matrix)
- Fibres with nanoparticles such as silver for new textiles with a protective effect against mechanical or electromagnetic impacts such as electricity, radiation or heat
- Fibres with microencapsulated liquid agents or with a liquid core
- Biodegradable fibres as a substitute for synthetic non-wovens e.g. in the household, in cosmetics or in agriculture
- High-tolerance fibres for medical applications, e.g. as vascular substitutes, for wound healing in case of extensive burns, or for the measured release of medication via the skin or inside the body

A major technological trend is the development of a new generation of flame-retardant fibres with high-grade mechanical properties such as tensile strength. Both in the US and in the EU, efforts are being undertaken to ban brominated and halogenated flame retardants from various products, especially plastics and textiles. The past ten years of research have yielded new phosphorous organic compounds, which are environmentally sound yet highly potent. They can be used in such small quantities that the fibres' mechanical properties remain largely intact. In the next five years, this trend is expected to produce new fibres made of various polymers with improved flame retardant properties.

#### **Implications for Switzerland**

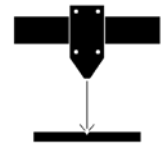
Switzerland is at the forefront of research on flame retardants: the country's industry is therefore in pole position to secure intellectual property rights and to develop markets with high added value. In addition, these developments are likely to have a stimulating effect on other polymer processing sectors (compounding, films, injection moulding).

## Laser surface treatments

**Andreas Conzelmann** (TRUMPF Schweiz AG)

**Quadrant:** technological hopefuls

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### Present situation worldwide and in Switzerland

The term “surface treatment” covers a multitude of processes that alter the properties of a material or texture its surface to apply markings. Surface treatment is typically carried out using laser beam sources with medium output power. These lasers operate in continuous wave mode, in pulsed mode (micro- resp. nanosecond pulses) or in ultrashort pulse mode (pico- resp. femtosecond pulses). In the past five years, the development of laser beam sources with high output power resp. with ultrashort femtosecond pulses, combined with the availability of associated optical components, beam steering systems and sensors, has enabled new processes as well as improved quality and reduced processing times for existing processes. These past years, photonics has been the decisive enabler for the successful industrialisation of many innovative products. In 2017, the global market for laser beam sources used for surface treatment was worth roughly 2 billion USD, which amounts to around 20% of the total laser market.

Surface treatment plays a role in almost all sectors, e.g. car manufacturing, battery technology, screens and displays, electronics, communication, aerospace technology, medical technology, food, security systems, watchmaking and jewellery, consumer electronics and defence technology. Key drivers in the field of surface treatment are:

- the need for new production processes with high energy and power density
- rising requirements in terms of surfaces’ functionality or resistance to wear due to increases in productivity
- the need for traceability of parts and products along the entire process and logistics chain using codes or text
- new regulations in the fields of aviation and space technology, medical technology and other sectors imposing highly resistant labelling along the entire process chain

New surface treatment processes include crystallisation processes to produce OLED or LCD displays, the detachment of flexible displays from substrate materials, or tempered glass processing. Laser markings with conventional nanosecond lasers tend to trigger structural changes in high-grade steels, with the risk of corrosion. The use of ultrashort pulsed lasers has enabled a technological leap and highly corrosion-resistant markings. The short time-scale in which a pico- or femtosecond laser pulse interacts with a material makes it possible to create unusual surface structures, e.g. enhancing absorption or emission properties, or providing catalytic support to electrochemical processes. Significant progress in the coating of various materials with sub-nanometer precision enables the production of new compounds and coatings. In combination with optically active materials and special waveguide structures, it is possible to produce smart and active optical components, sensors or switches. Appropriate

micro-texturing enables the use of innovative joining techniques, for example to achieve specific thermal or tribological properties.

Megatrends such as digitalisation, globalisation, individualisation and security will lead to rising requirements regarding the traceability of components, products and parts along the entire process and logistics chain. Further trends such as connectivity, mobility and neo-ecology mean that surface texturing of metals, semiconductors and polymers, layer ablation and display production processes will gain ground. In the field of electric mobility, thousands of lasers will be used to strip wires for the production of electric motors.

### **Implications for Switzerland**

The Swiss photonics market, which comprises laser beam sources and systems as well as optical components, coatings and sensors, is worth around 4 billion CHF, of which roughly 400 million CHF are generated by surface treatment lasers and laser systems. This market segment displays average annual growth of 8% and has an export rate of more than 90%. According to experts, over the next ten years the share of photonic components in all products developed and produced by Switzerland's MEM industry (mechanical and electrical engineering) will increase from currently 40% to over 60%. These figures highlight the major role played by Swiss industry in the global photonics market. Photonics' share of GDP is significant and set to grow further. In order to retain a leading position in the field of surface treatment, next to basic research Swiss institutions of higher education must increase their focus on enabling technologies such as photonics. Almost all of roughly 20 Swiss academic research institutes in photonics have therefore joined the *National Thematic Network (NTN) "Swissphotonics"*. Their research activities are underpinned by educational courses at bachelor, master and doctoral level. Specialised photonics degree courses have now been on offer for four years.

## Optical space communication

Reinhard Czichy (Synopta)

**Quadrant:** technological hopefuls

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### Present situation worldwide and in Switzerland

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, unlocking wholly new bandwidth resources.

In Europe, testing of optical space communication with high data rates (> 1 gigabit/s) between satellites in low Earth orbit began in 2007. In 2016, the *European Space Agency (ESA)* launched the first satellite carrying an optical terminal for operational use in geostationary orbit. Beginning in 2019, other such satellites will go into operation as part of the *European Data Relay Satellite (EDRS)* programme: operating as relay stations, they will enable the optical data transmission from Earth observation satellites. Following the successful demonstration of this technology in space, international plans are currently being developed for commercial satellite constellations with optical links, geared toward mobile services with very

high data rates and global coverage. These constellations feature optical data links between satellites and with ground stations. Given the steadily growing need for transmission capacity and the trend toward improved mobile services, in coming years optical space communication will keep developing at a fast pace across all segments. This encompasses systems (setup/operation of satellite networks), equipment and component development (optical terminals for satellites and ground stations), as well as the development of applications and services.

### Implications for Switzerland

Optical space communication combines a number of complex technologies that are available in Switzerland. It stimulates innovative applications and furthers the industrial and the service sectors in the field of telecommunication. From the very beginning, Swiss research and industry have successfully brought their relevant skills to bear on developments in this field, establishing a good starting position. However, strengthening international competitiveness and developing marketable products requires continued and strong political commitment as well as long-term strategic planning.

# Photonics as an enabling technology

René Dändliker (SATW)

Quadrant: star technologies

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## Present situation worldwide and in Switzerland

Photonics combines two areas of physics: optics and electronics. Photonics provides the basis for the development of significant technical and industrial applications. According to the European Commission, it is one of six “Key Enabling Technologies (KETs)”. Photonics paves the way in fields such as image processing, displays, light sources (laser, LED), medical technology and life sciences, optical components and systems, communication technology, photovoltaics, production and measurement technology, information technology, security and defence technology. Swiss industry (especially SMEs) is already active in many of these areas, which display persistent annual growth rates of 6-8%.

Photonic measurement technologies enable non-contact, real-time process monitoring. These are crucial features for industry 4.0 and the Internet of Things. Big data acquisition and processing also create new fields of application for optical connections and networks (optical fibres, integrated optics). Applications such as the real-time generation of three-dimensional spatial data are based on multidimensional data and image acquisition using high-resolution cameras or optical scanners (lidar) and produce extremely large quantities of data that need to be processed in real time using smart algorithms. New methods of representation such as virtual and augmented reality create interesting opportunities for the Swiss photonics industry and its globally unique know-how in the production of miniaturised optical components and systems. Photonics today holds the same significance as electronics in the mid-20<sup>th</sup> century.

## Implications for Switzerland

Swiss industry is already present on the market with many products that rely on photonic technologies. Swiss industry and research are well positioned in this field. However, global competition is strong and other countries have been promoting photonic innovation at a very high level for years, with clearly visible effects (especially Germany, but also China, Korea and the US). Support programmes of this kind are lacking in Switzerland. Nonetheless, Swiss institutions of higher education are very active in the field of photonics, including basic research at universities, the *ETH Zurich* and the *EPFL*, projects funded by the *Swiss National Science Foundation (SNSF)* and the *National Centres of Competence in Research (NCCRs)*, as well as applied and industry-oriented research at universities of applied sciences, mostly with short-term *Innosuisse* projects and industry assignments. As a crucial pillar of Swiss industry, SMEs are successful innovators; however, due to the current lack of funding for photonic technologies, they are increasingly falling behind compared to international competitors.



# Life sciences

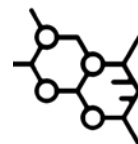


## Biocatalysis and biosynthesis

Rebecca Buller (ZHAW)

Quadrant: technological hopefuls

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### Present situation worldwide and in Switzerland

In future, public pressure on the chemical sector will increase greatly: long-term corporate planning should take into account not only economic objectives but also social and environmental demands. In the past decade, scientific and technological advances have established biocatalysis and biosynthesis (the use of enzymes and microorganisms in synthetic chemistry) as serviceable and environmentally sound complements to traditional organic chemistry. Enzymes are used for example to produce chiral molecules (i.e. molecules that are non-superposable on their mirror image) and, wherever possible, to avoid resorting to protecting groups. The use of biocatalysts thus makes it possible to shorten processes and thereby lower costs. Using inexpensive resources or (agricultural) waste products in biosynthetic processes is another way to create value. Biocatalytic process steps are used in the production of pharmaceutical blockbuster molecules. Biosynthetic approaches are used to derive fine chemicals such as aromas, fragrances and nutraceuticals as well as commodity chemicals from sustainable resources.

Future areas of application include the development of new chemicals. Improving the technological maturity of a greater number of enzyme families will allow the chemical industry to carry out reactions that are complementary to organic chemistry and to extend the range of molecules that can be produced. Next to the industrial establishment of little researched enzyme families, it is possible to use enzymes produced via computer-aided design or enzymes whose reaction spectrum has been expanded by the integration of artificial cofactors.

In future, as we strive for independence from fossil energies, biocatalysis is likely to play a significant role. Concerns over climate change and the volatility of fossil energy costs have become global drivers to use biomass as a production resource. However, the efficient development of a bio-based economy depends largely on establishing a comprehensive biocatalytic and biosynthetic toolbox allowing us to transform available biomass into a wide array of products.

### **Implications for Switzerland**

In Switzerland, large pharmaceutical companies, fine chemical firms as well as the fragrance and flavour industry are devoting significant parts of their enzyme-based research to process development. Contract manufacturers such as *CordenPharma Switzerland*, *RohnerChem* and *Siegfried* are increasingly interested in complementing their chemical synthesis expertise with biocatalytic competences, as know-how development in the field of biocatalysis is viewed as a crucial factor for future customer acquisition. However, large companies are the main active beneficiaries of the opportunities created by biocatalysis. SMEs are not yet fully harnessing the potential of this promising approach. This is due mainly to soft factors such as

the limited availability of trained personnel and the more restricted R&D capacities of smaller-size companies. In order to strengthen Switzerland's position in this high-tech sector, it is therefore crucial to promote a dialogue between the research and business communities. The networking programme *Innovation in Biocatalysis*, funded by the Swiss Confederation, promotes this exchange and contributes to establishing a dynamic biocatalysis community in Switzerland. More such programmes are needed for biocatalysis and biosynthesis to deploy their full industrial potential.

## Continuous manufacturing processes

**Djordje Filipovic** (Novartis)

**Quadrant:** technological hopefuls

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### Present situation worldwide and in Switzerland

Pharmaceutical products are traditionally produced in batch mode, which remains the dominant production technique: defined materials are processed for a defined period of time before being released as a production unit (batch). This usually involves several separate and consecutive processes. Products are analysed off-line and released for further processing. In recent times, “continuous manufacturing” has gained ground. Materials undergo all process steps in a single flow: materials are added and finished products are released on a continuous basis. Product release takes place in real time based on on-line and in-line process analytics and control algorithms.

Compared to batch production, the continuous approach presents several benefits: safer and more cost-effective production on highly specific and customised systems, shorter time to market, smaller and thus more environmentally friendly production facilities, lower requirements in terms of scaling and maintenance as well as the possibility of “auto-tuning”. Integrated real-time quality control, a fundamental prerequisite for continuous manufacturing, is another major advantage. Continuous manufacturing production facilities are flexible platforms: new processes can be developed faster on existing continuous manufacturing lines, as the same lines can be used for process development and for production. This makes it possible to massively reduce costs and time required for scaling. In addition, the range of chemical solutions expands: since reaction volumes are smaller, it becomes possible to apply more “risky” exothermic reaction steps or higher pressure, enabling the synthesis of new molecules. It is furthermore possible to vary the production volume as needed on a continuous scale. Such platforms are also better suited for implementing customised medication-based patient solutions.

A key obstacle facing continuous manufacturing concepts was the lack of regulatory framework for this new production paradigm. In recent years, under the leadership of the *US Food and Drug Administration (FDA)*, many uncertainties have been removed, greatly boosting research and testing activities in the field of continuous manufacturing. Many equipment manufacturers have also undertaken major steps toward developing continuous manufacturing solutions. Several companies now also provide solutions for process monitoring and analysis as well as integrated process control platforms. New manufacturers have recently entered the market, leading to more competitive and better solutions for industry.

Large pharmaceutical companies are leading the way in implementing this new paradigm. Yet SMEs have also begun to assess the opportunities and benefits of continuous manufacturing. In the meantime, products developed specifically for continuous manufacturing have received regulatory approval, e.g. *Orkambi* by *Vertex Pharmaceuticals*. Recently, a switch from batch to continuous manufacturing was approved for the first time. Close collaborations between academic institutions and industrial partners, such as the *Novartis-MIT Centre for Continuous Manufacturing*, are also increasing in number.

### **Implications for Switzerland**

Switzerland is well positioned, although application is largely limited to large producers. Key aspects to be considered are concept development, equipment and automation. There is room for improvement as regards cooperation with Swiss institutions of higher education on concept development: such endeavours often fail due to intellectual property issues. There are also opportunities for collabora-

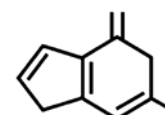
tion with niche suppliers on the development and application of technical equipment with subsequent commercialisation by the industrial partner. Expanding activities in the field of continuous manufacturing should prove significant for Switzerland, as the emerging shift in paradigm can only be accelerated by further innovation. This also creates opportunities for smaller academic and private sector players.

## Synthetic biology

Sven Panke (ETH Zurich)

**Quadrant:** technological hopefuls

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### Present situation worldwide and in Switzerland

The term “synthetic biology” is used to describe activities that aim to turn biotechnology into a “real” engineering discipline. It covers processes that enable the application of biological systems such as cells or tissues to chemical, diagnostic or medical problems following classic engineering methods. The underlying assumption is that by doing so, prototype cells can be built significantly faster, more complex new properties can be built into cells, and the prospects of such activities can be greatly improved. Such methods include the mathematical simulation of biological prototypes ahead of construction, the introduction of norms and standards for the use of biological components and measurement methods, or the dissociation of design and execution tasks. This last aspect applies in particular to the fast evolving possibility of chemically synthesising genetic sequences of unprecedented length (up to entire chromosomes in unicellular organisms). Bioengineers are thus spending more and more time planning prototypes and are outsourcing time-consuming biological programming tasks to others. Indeed, the biological properties controlled, modified or even newly construed by bioengineers are becoming ever more complex. There is a constant stream of new applications for synthetic biology, especially in the fields of chemical production, diagnostics, medicine and pharmaceuticals. The range of applications is a wide one and includes genetic circuit engineering, greatly improved diagnosis and therapy of diseases such as gout, diabetes and even cancer, more sustainable production of ever more complex chemicals, or wholly new approaches in areas such as biologically produced high-performance materials.

### Implications for Switzerland

Switzerland plays a key role in the young discipline of synthetic biology. With its *Department of Biosystems Science and Engineering* in Basel, the *ETH Zurich* has established a hotspot that benefits greatly from its proximity to major pharmaceutical players and has become a global leader in medical applications and simulations. Rooted in Switzerland’s tradition of biotechnological excellence, other institutions also play a prominent role. The *ETH* and others have given rise to various startups. Even though Switzerland is very well positioned in terms of education and implementation, it must remain attentive to future developments. Infrastructure requirements are growing at a fast pace and it is likely that Switzerland’s economy will soon be too small to fully meet these needs. In Europe, only the United Kingdom is investing comparable energy to Switzerland into promoting synthetic biology. Switzerland’s neighbouring countries are much less advanced. New developments in the synthesis of large DNA molecules, which in the long run is likely to prove crucial for sustained success in synthetic biology, are almost exclusively limited to the US.

## Surgical robots

**Bradley Nelson** (ETH Zurich)

**Quadrant:** technological hopefuls

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### Present situation worldwide and in Switzerland

Medical robotics provides a good example of the growing use of ever more advanced technologies in healthcare. Human skills and computer-assisted technologies are combined to improve the quality of medical treatments. Artificial intelligence is harnessed for diagnosis, clinical findings are analysed in greater detail, and smart medical products are used to achieve therapeutic improvements. Next to surgical procedures, medical robotics covers therapies, drug administration and physiotherapy. The most noteworthy commercial success in this field is *Intuitive Surgical's* Da Vinci surgical system. Since 2000, more than three million surgical procedures have been carried out using the system, and the company's market capitalisation is valued at around 60 billion USD. Overall, the medical robotics industry is known for its high profit margins. However, it is important to keep in mind that no randomised controlled trials have yet shown improved clinical outcomes. To date, this has not had any negative repercussions. Various important healthcare players have recently entered the market, among them *Johnson & Johnson* and *Medtronic*. New, complex technologies that interact directly with the physical environment need years or even decades to mature. As soon as they become established, however, they can become significant long-term economic drivers. Their wider economic impact consists in the fact that they give rise to high-precision industries operating as key suppliers.

### Implications for Switzerland

As is the case all over the world, Swiss citizens are demanding better medical care at lower costs. These contradictory demands are currently manifesting among others in the guise of decreasing reimbursements for often performed treatments, which has been one of the main drivers for robotic solutions. Over the past ten years, the demand for intravitreal injections to treat retinopathies has increased sharply, while reimbursements fell from 630 CHF per injection in 2017 to 150 CHF in 2018. Ophthalmic surgeons are not willing to risk treatment quality, and hospitals are less motivated to carry out the procedure, even though it stops the progression of blindness for 10% of the population. The obvious solution is the use of robotised procedures, allowing highly qualified medical practitioners to carry out more interventions with usual quality yet at lower costs. The same applies to several other medical procedures, e.g. echocardiography and catheter ablation. Yet the robotisation of such procedures faces significant hurdles both from a research and from an industrial standpoint.

Despite clear trends in the number of robot-assisted interventions, the sector's high profitability and the prospect of long-term economic benefits, Switzerland has been slow to identify medical robotics as a major driver. Stronger public and industrial investment in medical robotics would benefit Switzerland both medically and economically. Any other approach would be tantamount to increasingly outsourcing our healthcare to Silicon Valley and to Asia.

## Personalised nutrition

**Erich Windhab** (ETH Zurich)

**Quadrant:** technological hopefuls

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### Present situation worldwide and in Switzerland

Personalised nutrition aims to meet consumers' individual needs and requirements in terms of preferences, acceptability, diet and health. Individual health-related requirements can be determined in ever increasing detail owing to advances in individual genome decoding with the identification of specific risks or intolerances, self-monitoring using at-home diagnostic tools (e.g. "wearables" for physiological measurements), the expected mapping of the gut flora composition as well as findings regarding the gut-brain signalling axis. Industrial production, however, will struggle to cater to this degree of differentiation. The food value chain will therefore display increasing personalisation in direct proximity to sites of food preparation and intake (kitchens, catering services, restaurants). There is a technological trend toward the development of kitchen processes and appliances with an emphasis on "co-creation": industrial production supplies modular base components, which consumers then prepare and combine at their individual convenience. This in turn generates new requirements in terms of coordinated industrial production and kitchen technologies ("kitchen of the future") as well as packaging, storage and retail options.

### Implications for Switzerland

Switzerland numbers many firms along the food value chain when it comes to industrial production technologies. Local consumers display a pronounced preference for quality and individuality, as well as the willingness to pay for such features. Conditions are therefore excellent for an industrial leadership role in the coming five years.

## Point-of-care diagnostics

Daniel Gygax (FHNW)

Quadrant: niche technologies

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### Present situation worldwide and in Switzerland

In vitro diagnostic tools are medical products used to diagnose diseases and monitor therapeutic measures in hospital or specialised private-sector laboratories. Analyses of this type are concerned with biomolecules such as proteins and lipids, human cells and microorganisms. Samples are derived from blood, saliva, urine or other biological material. Diagnostic data collecting of this kind is organised in a highly professional manner and provides data of the highest quality. The downside is that patients must go to the hospital or to their general practitioner for sample taking.

Point-of-care diagnostics (POC diagnostics) is a subfield of in vitro diagnostics. It aims to bring testing procedures closer to patients. The best-known application is the monitoring and treatment of blood sugar levels in patients suffering from diabetes. Self-monitoring or self-testing requires a simple and robust testing system, which in future will be combined with mobile health services (mHealth, telemedicine). The key advantage is the time gained between carrying out a test and implementing therapeutic measures: in future, it will be possible for measurements to be taken in pharmacies, by home care providers and in care and nursing homes. To do so, testing procedures must be integrated in an overarching mHealth concept. Technically speaking, a measuring device basically consists of three elements: a biosensor, a signal converter and a signal processor. The aim is to present the data in a user-friendly form. Current devices already make it possible to represent data over time using charts or graphs. Deviations from target values become easy to spot. Such formatted data can be directly forwarded for interpretation to general practitioners, clinics, *eedoctors* or other telemedical service providers such as *Medgate*. Next to these purely technical considerations, the following aspects

must be taken into account when developing POC diagnostics: detection of genetic predispositions, diagnosis and monitoring of diseases and their progression, patient-appropriate handiness and manageability of devices, and costs.

### Implications for Switzerland

In 2016, around 430'000 persons (i.e. one in twelve employees) were working in the healthcare sector or in the pharmaceutical industry. As a sector, the pharmaceutical-diagnostic industry features high innovation and high added value. Its export ratio is in excess of 40%. Next to *Roche* as a global supplier of diagnostic solutions, Switzerland numbers a series of SMEs which provide appliances, IT solutions, medical laboratory services or reagents. In the context of digital transformation and in combination with mHealth schemes, POC diagnostics has the opportunity to enable fully mobile monitoring of patients' state of health, increasing their autonomy and responsibility as well as improving treatment efficacy and productivity. For Switzerland, the production of integrated solutions based on interdisciplinary competences (device engineering, information technology, life sciences, applied psychology, training & education, marketing and distribution) is an opportunity to compete globally by offering new treatment modalities.



## 3D bioprinting: printable organs

Michael Raghunath (ZHAW)

Quadrant: technological hopefuls

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### Present situation worldwide and in Switzerland

In the field of tissue engineering, 3D bioprinting – the additive manufacturing of tissues and organs – has established itself as a promising forward-looking technology. 3D bioprinting differs from standard biomaterials printing in that live cells are either deposited on printed structures in a targeted manner or printed onto a substrate in biomaterials called bioinks following a precise spatial arrangement. In this way, artificial tissues can be produced layer by layer, enabling greater tissue complexity than standard methods of non-oriented cell seeding onto a substrate material. More complex tissue structures are able to better reproduce the physiological activity of human tissue. This is increasingly relevant for the pharmaceutical industry, as it allows it to improve predictive in vitro tests and reduce animal testing. In the EU, animal testing for cosmetic products and their ingredients has now been banned. Biologically relevant artificial skin and eye tissues are therefore of great importance. In regenerative medicine, 3D bioprinting enables the vascularisation of tissue constructs, which was previously impossible.

### Implications for Switzerland

Switzerland is strongly positioned in all fields that stand to benefit from 3D bioprinting technologies, namely the pharmaceutical and cosmetics industries as well as clinical medicine. Switzerland also numbers many firms working on aspects relevant to 3D bioprinting: automation (electronics, control software), machine parts (printer nozzles, valves, robotic arms) and cell culture (media, plastic). If Switzerland promotes this development by integrating the technology in existing industrial and medical processes and by fostering a network of relevant industry and research partners, it will be able to hold its own in global competition. Asian countries such as Korea and Singapore have already developed national strategies in this field. In the US, the public-private partnership *BioFabUSA* has been promoting projects in the field of bioadditive manufacturing since 2016 with a total funding volume of 300 million USD. Even though Switzerland boasts a global market leader in bioprinting (*regenHU*), the country currently has no comparable national strategy geared toward global technological leadership. Current funding schemes for additive manufacturing exclude the field of biomaterials/bioadditive manufacturing using living cells. In order to remain globally competitive, national research programmes and initiatives must be established at the level of strongly application-oriented basic research.

## Mass cultivation of stem cells

**Gerrit Hagens** (HES-SO Valais-Wallis)

**Quadrant:** niche technologies

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### Present situation worldwide and in Switzerland

With advances in organ and tissue transplants, the shortage of organs and a rising demand for donors have become major hurdles. Scientific research has therefore begun to develop alternatives and suggested therapies based on human stem cells (HSCs). It is now generally acknowledged that the use of HSCs shows promise for biotechnological, pharmaceutical and medical applications such as cell therapy, tissue engineering or regenerative medicine. HSCs are able to self-renew and differentiate into specialised cell types. They are defined by their origin and their potency: pluripotent stem cells (PSCs) have the capacity for unlimited self-renewal and can differentiate into any of the body's more than 200 cell types. There are two sources of PSCs: embryonic stem cells (ESCs) and induced pluripotent stem cells (iPSCs). There are also multipotent stem cells, isolated from sources such as mesenchymal stem cells, and which unlike PSCs can differentiate only into a limited amount of cell types. Given the wide range of R&D and industry applications, the demand for stem cells is rising steadily. Many efforts are being undertaken to cultivate stem cells on a large scale and to differentiate them into cell types of interest in an efficient and homogenous manner. Most laboratories multiply stem cells on level surfaces in two-dimensional cultures, so-called monolayers. The production of large amount of cells is carried out by multiplying culture dishes: a highly time-consuming, expensive and labour-intensive method.

### Implications for Switzerland

The challenge for stem cell producers is to develop lawful and cost-effective large-scale production processes. Such processes require automated, controlled and scalable production systems. The current trend is moving away from two-dimensional cultures toward suspension cultures (3D cultures) that grow in single-use bioreactors under controlled conditions. Such systems are a prerequisite for affordable stem cell-based therapies and require collaboration between biomedical researchers and engineers. The global market for stem cells is growing and should reach 5–10 billion USD by 2022. The large-scale production of stem cells is still in its infancy. In Switzerland, public and private research institutions are training leading scientists and engineers. Switzerland is therefore well positioned to play a significant role in developing relevant production processes using bioreactors.

**Abbreviations**

BFH Bern University of Applied Sciences

CSEM Centre suisse d'électronique et de microtechnique

FHNW University of Applied Sciences and Arts Northwestern Switzerland

HES-SO University of Applied Sciences and Arts Western Switzerland

PSI Paul Scherrer Institute

ZHAW Zurich University of Applied Sciences



**satw** it's all about  
technology

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