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1 Introduction

For three consecutive years – 2011, 2012 and 2013 – Switzerland has been judged to be the most innovative country by Cornell University, INSEAD and the World Intellectual Property Organization (WIPO) in their joint Global Innovation Index report [1]. Reassuring as this ranking might seem, one has to understand that a relentless innovation competition is taking place in our globalized world where no achievement and position can ever be taken for granted.

When we look at the details below the shining surface, we find that Switzerland has to be very careful to take the right decisions in the future to maintain its competitiveness in the industrial sector. A few observations may illustrate this.

1. Switzerland ranks 1^{st} in patenting activities [2]. However, Switzerland is clearly underperforming in the economic exploitation of its intellectual property where it is ranked only in the middle of the field with countries such as Ireland, Belgium, France, Denmark and Iceland [3]. Furthermore, in terms of innovation efficiency, it was only placed as no. 12, its business environment ranks 31^{st}, its knowledge absorption 34^{th}, and the education framework ranks only 56^{th} [4].

2. The past dozen years have seen a dramatic change in the way Swiss companies are implementing their innovation activities. In the time frame 2000 to 2008, the number of full-time equivalent R&D personnel in Swiss enterprises has fallen from 16’275 to 10’332 researchers, an impressive reduction of 37% [5].

3. Over the past thirty years, startup companies in the United States have regularly created about 3 million new jobs annually. In Switzerland, every year about 12’000 startup companies are founded (ex nihilo), creating about 23’000 new jobs annually [6]. Per capita, this corresponds to a job creation rate of Swiss startups that is more than three times lower than by startups in the United States.

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[1] S. Dutta and B. Lanvin. The Global Innovation Index 2013 – The Local Dynamics of Innovation. Cornell University: INSEAD and WIPO; 2013. Available on-line at http://www.globalinnovationindex.org/content.aspx?page=gii-full-report-2013.

[2] S. Dutta and B. Lanvin. The Global Innovation Index 2013 – The Local Dynamics of Innovation. Cornell University: INSEAD and WIPO; 2013. Available on-line at http://www.globalinnovationindex.org/content.aspx?page=gii-full-report-2013.

[3] M. Neville, P. Tischhauser and C. Schmid. Creative Switzerland? Fostering an Innovation Powerhouse! Zurich: Swiss American Chamber of Commerce and Boston Consulting Group; December 2008.

[4] S. Dutta and B. Lanvin. The Global Innovation Index 2013 – The Local Dynamics of Innovation. Cornell University: INSEAD and WIPO; 2013. Available on-line at http://www.globalinnovationindex.org/content.aspx?page=gii-full-report-2013.

[5] P. Sollberger, editor. F+E: Ausgaben und Personal der schweizerischen Privatunternehmen 2008. Neuchâtel: Swiss Federal Office for Statistics; February 2010.

[6] Medienmitteilung. 2010, Rekordjahr für Neugründungen. Neuchâtel: Swiss Federal Office for Statistics; July 2012.

4. In 2009, only about 0.3% of the Swiss GDP was available as private equity for investing in new ventures, less than half of what is available by the top-ranking United Kingdom and Sweden [7]. And the situation for venture capital (VC), usually required to finance large and global deals, is even more adverse: In 2005, VC in Switzerland amounted only to 0.11% of GDP, compared with Israel where VC investments were 1.05% of GDP [8].

5. Although Switzerland has a trade surplus over other countries, this trade surplus is primarily due to exports of services rather than exports of manufactured goods. On average, the surplus from trading in services has been more than four times larger than the one from trading in manufactured goods over the past few years [9].

There is now doubt that the future prosperity of Switzerland depends on the ability of retaining an innovative and competitive industrial base. Unlike other economies, Switzerland did not care to formulate a National Technology Strategy up to now. This is surprising since the Federal Council already published its Strategy for an Information Society in Switzerland as early as 1998 since which it was updated in 2006 and restated in 2012.

Switzerland has a rather liberal economic environment where every company has to ensure its own competitiveness. Nevertheless, in a globally competitive situation it may be helpful to identify and discuss the potential of key and cross-cutting technologies in all sectors of our industry.

With this report, the Swiss Academy of Engineering Sciences SATW intends to draw the attention to «emerging and enabling technologies» in order to recognize and realize their full potential for business in Switzerland as early as possible. The aim of the report is to alert the decision makers of our nation about the key challenges lying ahead. There is no intention, however, to propose an interventionist industrial policy. The optimization of framework conditions, specific removal of restraints and fostering of initiatives or incentives is a political decision which is not covered by this report.

[7] Medienmitteilung. SECA Annual Media Briefing. Zug: Swiss Private Equity and Corporate Finance Association (SECA); February 2011.

[8] M. Neville, P. Tischhauser and C. Schmid. Creative Switzerland? Fostering an Innovation Powerhouse! Zurich: Swiss American Chamber of Commerce and Boston Consulting Group; December 2008.

[9] G. Keating and O. Adler, editors. Swiss Issues Macro – Monitor Switzerland. Zurich: Credit Swiss; September 2013.

2 International Review

2.1 Collection and Analysis of International Literature and Sources

The Technology Outlook report (TO) is intended to reflect strategic future directions for technical sciences in Switzerland, well synchronized with the international trends and with high relevance for both the academic and industrial sectors. Moreover, it is of outmost importance that the selected emerging technologies address urgent societal needs and include new businesses, services and job creation.

A collection of information from international publications and databases was performed with the main focus on the following sources:

- **Forbes**[10]: A leading source for reliable business information, encompassing markets, politics, global economy, business & finance with special attention to analysis of future technology trends. Technically, Forbes investigates and publishes trends based on expert analysis that are supposed to be explosive within five years–tough criteria but, often, they might take a decade to develop.
- **IEEE**[11] (Institute of Electrical and Electronics Engineers): The world's leading and largest technical engineering professional society, the core purpose of which is to foster technological innovation and excellence for the benefit of humanity. IEEE has about 425'000 members in about 160 countries and produces over 30% of the world's literature in the electrical and electronics engineering and computer science fields. It publishes well over 100 peer-reviewed journals and is responsible for world-wide standards defined by its standardization committees.
- **McKinsey**[12]: A global management consulting firm providing advice to world's leading businesses, governments, and institutions. Their methodology examines microeconomic industry trends to better understand the broad macroeconomic forces that affect business strategy and public policy. Recently, McKinsey has produced comprehensive reports on 'Disruptive technologies: Advances that will transform life, business, and the global economy' (May 2013) and on 'Ten IT-enabled business trends for the decade ahead'. It is of great interest that their evaluation includes multiple levels, from the individual to the government level (see **Fig. 1**); therefore, this source of information can cover very compressed, different scale angles.
- **European Commission Horizon 2020 Program with focus on societal impact** (**Fig. 2a**) **and Key Enabling Technologies (KETs)**[13]: It is a new integrated European R&D strategy based on growth and innovation in a global context and includes: (i) better focus and more cooperation, (ii) well identified Key Enabling Technologies (KET), (iii) a new innovation policy in Horizon 2020, (iv) focused innovation policies in ICT, and, (v) smart specialization strategies. As part of the European Commission research program (to which Switzer-

[10] http://www.forbes.com/sites/roberthof/2013/05/23/live-the-top-10-future-tech-trends-from-5-top-venture-capitalists/

[11] http://www.ieee.org/about/technologies/index.html

[12] http://www.mckinsey.com/

[13] http://ec.europa.eu/enterprise/sectors/ict/key_technologies/

land is fully associated), one aim is to coordinate Horizon 2020 funding with national funds and an increasing amount of venture capital investments to support innovation (see **Fig. 2b**).

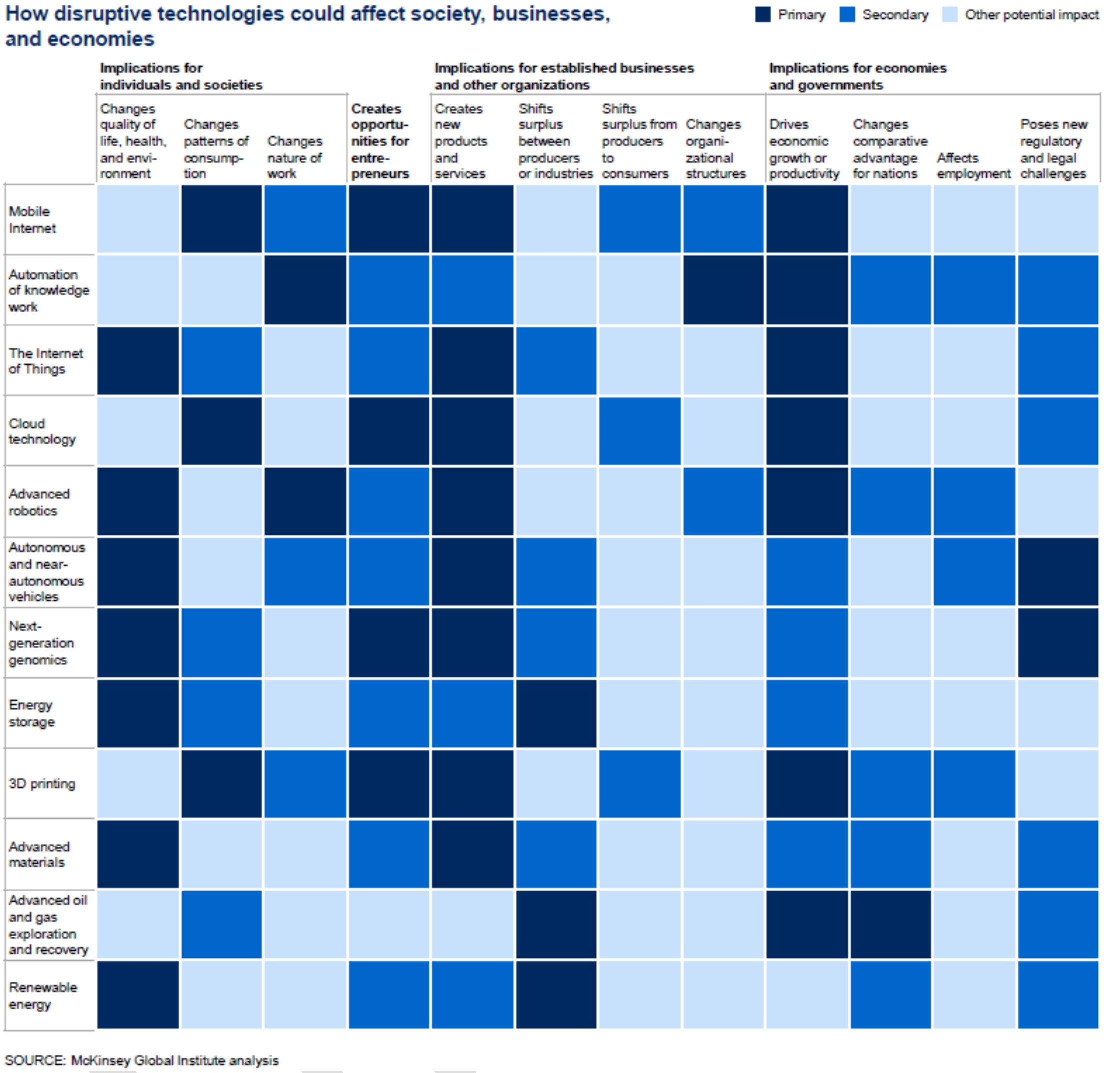
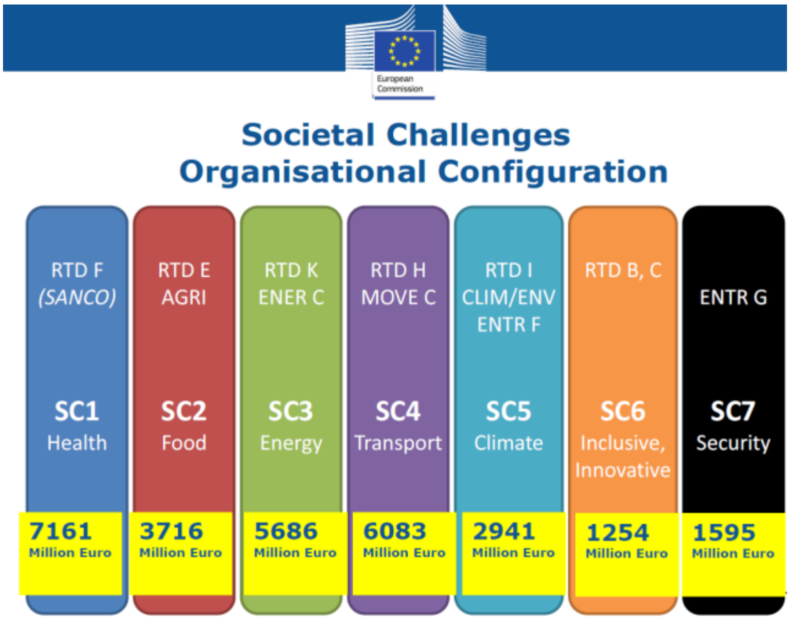
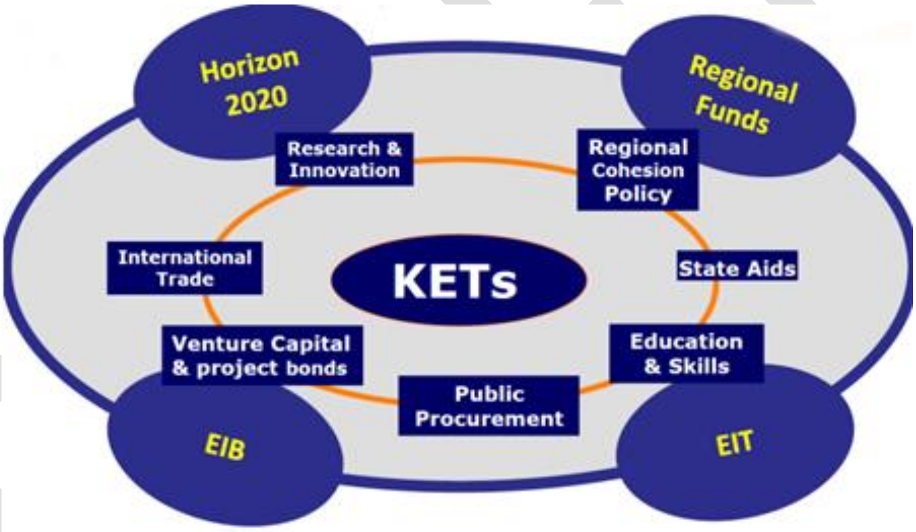


Figure 1: The multi-level impact of future selected disruptive technologies: from individuals to organizations, economies and governments. S*ource: McKinsey report on 'Disruptive technologies: Advances that will transform life, business, and the global economy' (May 2013).*



(a)



(b)

Figure 2: (**a**) Major societal challenges of Horizon 2020 and the budget allocated by the European Commission and (**b**) the new strategy of multiple-funding sources: European Commission and regional funds, with an increasing role of venture capital to support innovation from KETs. *Source: Dirk Beernaert, Reinforcing the competitiveness of Europe Key Enabling Technologies, Micro-nano-electronics and ICT, ESSDERC Workshop on Zero-Power Technologies, 2013.*

- **The Fraunhofer and other networks of institutes internal roadmaps**: It is a summary of the main trends in Europe and reflects the unique position of European research in advanced technologies with three major layers: (i) the technical universities, (ii) the large research institutes with advanced technology platforms connection academic and industrial research and having a key role in technology transfer (Fraunhofer in Germany, CEA-LETI in France, IMEC in Belgium, CSEM in Switzerland, VTT in Finland, Tyndall in Ireland) and (iii) the industrial partners. These partners also operate in specific European organizations or platforms

(ENIAC, ARTEMIS, EPOSS, and others) that have their own roadmaps with particular focus on the European priorities and domains of leadership and in coordination with the European Commission. Swiss institutions maintain strategic collaborations with these partners, therefore their feedback in establishing future TOs is of major importance.

In many of the domains listed by the analyzed sources, Switzerland is already positioned in a leading position and strengthening this position appears strategic for the future. In other domains, Switzerland needs major investments in order to become a major player; the strategic importance and impact on society and economy of these topics can motivate such prioritization in the future.

Swiss Export Figures of Major Economic Branches		Pharmaceuticals and chemical products	Machines and electronics	Watches and jewelry	Precision instruments	Metals and machine parts	Medical technologies	Other
Horizon 2020: societal challenges	**Budget**	74.6 BCHF	26.9 BCHF	25.5 BCHF	14.1 BCHF	13.0 BCHF	10.0 BCHF	44.1 BCHF
Health, demographic change and wellbeing	7.2 BE	X		X			X	X
Smart, green and integrated transport	6.1 BE		X			X		X
Secure, clean and efficient energy	5.7 BE		X					X
Food security, sustainable agriculture and bio-based economy	3.7 BE	X						X
Climate action, resource efficiency and raw materials	2.9 BE		X		X	X		X
Secure societies	1.6 BE		X			X		X
Inclusive, innovative and reflective societies	1.3 BE				X		X	X

Table 1: Contribution of the Swiss major economic branches (based on the export figures in 2011) to the main societal challenges as defined by the European Commission in Horizon 2020, and the associated budget figures in Billion Swiss Francs (BCHF) and Billion Euros (BE), respectively.

Table 1 suggests that the major Swiss economic branches, as identified by their contribution to the overall export budget, are addressing the societal challenges as defined by the European Commission under Horizon 2020 rather well, with an apparent emphasis on '*Health, demographic change and wellbeing*' and '*Climate action*, *resource efficiency and raw materials*'. The scope of this TO is to objectively identify the strengths (leadership) of the Swiss economy and industry in strategic societal domains and to state where an increased effort is needed. An additional aim is identification of new opportunities of industrial development in the most promising areas to which Swiss players should potentially contribute more. This report considers both the international (European) context and the local Swiss reality, with feedback from main industrial and research players.

2.2 Consolidation and Selection of Topics

Careful analysis of the international topics shows a rather high convergence of opinions on the most promising future technologies but also some alternate particular choices, depending on the source of information. There are certain domains of global technologies in which Europe, the USA and Asia have convergent interests, even if there is a competition for markets and leadership among the industrial players. A key filtering aspect appears to be the societal impact of the new technologies and the ability of addressing the problem of sustainability in crucial domains such as health or energy. Both Europe and Switzerland are characterized by highly developed industrial societies in which the quality of life for the ageing society and an increased willingness for energy independence are of major importance. Both Europe and Switzerland are particularly concerned by the combined societal and economy impact of emerging technologies.

A first consolidation of emerging topics at the international level can be achieved based on the previous table, focusing on six major categories:

- **ICT and cross-cutting aspects** – A major convergence concerning the key role of technologies such as ***Internet-of-All-Things*** and related technologies (e.g. ***wireless technology***, ***portable devices***) with the collection and interpretation of ***Big Data*** is predicted for the future. The cross-cutting aspects involve applications of the internet of things, sensing technologies, energy harvesting for autonomous sensor nodes, energy efficiency, and use of ***wearable computing*** in health and for services thereby increasing the quality of life. Also, interest in ***cyber security*** (also connected with wireless and internet technologies) is growing steadily not only regarding security policies but also citizens' protection and privacy.
- **Sustainable energy** – ***Smart grids***, ***new sustainable sources of energy*** (like wind energy) and ***energy storage*** are topics of high importance on all technical and political agendas and should be considered very carefully for future developments in Switzerland.
- **Sustainable health for a highly demographic and ageing society** - Personalized medicine and genomics can be the basis of a revolutionary change in the health policies; Switzerland already is successfully in-

volved in life sciences. In the medical field, the role of smart autonomous systems in a prevention-based paradigm change can serve as a nice connection of this field with ICT technologies.

- **Sustainable transportation technologies for smart cities** – In general, smart transportation is a hot topic for Europe and there are many active and leading industries to which Switzerland is highly connected. This topic includes full ***electric vehicles*** and is of major importance for mobility, sustainability and climate.
- **Human-centric technologies with high societal components (including education)** – A major change is observed in this field, with human-centric services that could be personalized in real time and could have real-time impact on the economy and on the quality of life at the hub of activities. These technologies encompass major challenges regarding citizen security and acceptance by the public. They can, however, induce dramatic changes in the future of social networking, behavior and education that, for instance, can cause a shift from diplomas to certification. For this, a future balance between the role of MOOCs and other modernized but more traditional education methods should be analyzed. The impact of ***e-commerce, e-money, e-work*** and ***e-services*** is still difficult to evaluate.
- **New production technologies** – Novel production technologies and materials can induce dramatic changes in terms of personal manufacturing and very high levels of product customization. 3D-printing, at the heart of the revolution in micro-manufacturing, is quickly becoming accessible to everybody. As 3D printing, and therefore rapid prototyping, reaches our desktops, millions of people are building what they want whenever they want it and innovation is moving at lightning speed. However, the growing revolution in 3D printing is paralleled by growing waste, a problem which should be carefully addressed.

In principle, the Swiss economy has major interests and players in almost all these fields; therefore, for the final selection it is recommended to consider in depth at least one leading technology in each of these major topical categories. Additionally, the international analysis should be crossed with the national analysis of the next chapter that highlights the strengths, weaknesses and opportunities of Swiss industry and research and their adaptability and willingness to follow the path to new emerging technologies.

3 National Review

3.1 Economic Situation in Switzerland

Despite certain drawbacks and worrisome facts and developments, Switzerland has recently been judged to be the most innovative country [14]. What is it that makes the Swiss economy one of the most innovative and competitive in the world, and what needs to be done that Switzerland does not lose its competitive edge over other countries in view of the worrisome developments indicated in the Introduction? According to the landmark publication [15], the two key indicators for a country’s long-term, sustainable prosperity are (1) a society that creates incentives, rewards innovation and allows everyone to participate in economic opportunities, and (2) a government that is accountable and responsive to its citizens. This, obviously, is clearly the case for Switzerland, but many other countries have open, inclusive, pluralistic and empowered societies. What is so special for Switzerland is not the concentration on particular products but rather how different kinds of innovations are linked [16]. In a manner of speaking, the Swiss speciality is integration! Swiss products excel where complexity reigns, collaborations between many specialized professionals is required, and several innovations from different fields have to come together simultaneously. This is well illustrated also in the Swiss export statistics shown in **Fig. 3** [17], [18]: The export drivers are pharmaceuticals, fine chemicals, machines, electronics, watches, precision ments and MedTech products, all typical examples of highly interdisciplinary fields requiring extensive technical and collaboration skills.

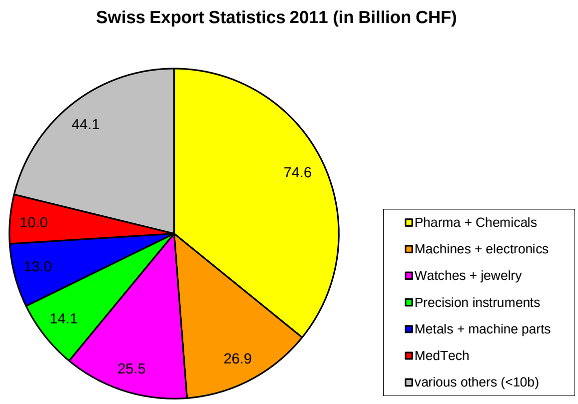


Figure 3: Export statistics of Switzerland for the year 2011 in units of billion Swiss Francs

This strength of the Swiss economy has an obvious consequence: Many of the Swiss industries are strongly interdependent of other sectors. As an example, the MedTech branch simultaneously integrates know-how and products from life sciences, precision instrumentation, machine engineering, electronics, material science and other industries. This interdepence is not only a strength, it could also pose a danger to the Swiss economy, because shortcomings in a particular sector may

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[14] S. Dutta and B. Lanvin. The Global Innovation Index 2013 – The Local Dynamics of Innovation. Cornell University: INSEAD and WIPO; 2013. Available on-line at http://www.globalinnovationindex.org/content.aspx?page=gii-full-report-2013.

[15] D. Acemoglu and J.A. Robinson. Why Nations Fail – The Origins of Power, Prosperity, and Poverty. New York: Crown Business; 2010.

[16] G. Schwarz und R.J. Breiding. Wirtschaftswunder Schweiz – Ursprung und Zukunft eines Erfolgsmodells. Zurich: NZZ-Libro; 2011.

[17] Daten – Aussenhandel, Ausfuhr wichtiger Waren 1990 – 2011. Neuchâtel: Swiss Federal Office for Statistics; 2013Available at http://www.bfs.admin.ch/bfs/portal/de/index/themen/06/05/blank/data.html.

[18] Swiss MedTech Report 2012. Bern: MedTech Switzerland; 2012.

adversely affect several other important branches concurrently. Hence, particular care needs to be taken that none of the key branches of the Swiss economy misses a major technological trend and lags behind.

As the major branches for the Swiss economy, we have identified the six industrial sectors with an annual turnover of more than CHF 10b, i.e.

- Pharmaceuticals and chemical products
- Machines and electronics
- Watches and jewelry
- Precision instruments
- Metals and machine parts
- Medical technologies (MedTech)

Additionally, we have identified four cross-sectional domains that are of central importance for the proper working of the Swiss economy:

- Energy
- Transportation
- Information and Communications Technologies (ICT)
- Photonics (one of the six KETs of the EC, as mentioned before)

In total, ten key industrial branches for the Swiss economy have been determined where particular care needs to be taken, in order not to miss any disruptive innovations, groundbreaking technological advances or seminal changes of the field.

3.2 Pharmaceuticals and Chemicals

3.2.1. Challenges for the Global and Swiss Pharmaceuticals (and Chemicals) Sector

The Pharmaceutical industry is an innovation driven and technology interdependent industry in which human capital, scientific knowledge, and disruptive ideas are sourced globally to gain competitive advantage. Hence, the challenges of the Swiss pharmaceuticals sector are largely a reflection of international ones as companies try to seize opportunities arising from changes in the increasingly complex and globalized health care environment.

The ultimate goal of pharmaceutical enterprises is to provide the right medicine for the right patient at the right time, an endeavor governed primarily by three inherent factors: time, risk, and costs. Besides these three elements that determine a company's profitability the following more specific challenges have been identified that will significantly affect the economic prosperity of the industry in the near future [19], [20]:

- **R&D productivity** – the attrition rates of late stage drug candidates have been rising and the number of new molecular entities reaching the market has plateaued on a comparatively low level [21].
- **Speed of the R&D process** – the drug development time has increased by several years to a total of 10-15 years, leaving a shorter active patent life. This is paired with increased regulatory stringency thereby weakening the output of R&D engines. The current regulatory processes for targeted therapies are suboptimal and limit an effective delivery of novel medicines.
- **Delivering shareholder and stakeholder value** – soaring development costs have reached unsustainable levels [22]. In addition, increased demands in the clinical trials area, for lawsuits and financial penalties and for royalty payments of licensing deals, are observed.
- **Growth in economic adverse conditions** – the financial meltdown has led to uncertainty across the industry that may lead to pharmaceutical companies changing their business mode [23]. Current trends indicate that growth will primarily come from the emerging markets as the developed markets look anemic.
- **Pricing and reimbursement frameworks** – the burden introduced by healthcare reforms and austerity measures worsen the already present pressures on pricing and reimbursement.

[19] The Pharmaceutical industry and global health, facts and figures 2012. Geneva: International Federation of Pharmaceutical Manufacturers & Associations; December 2012.

[20] G. Finnegan, editor. Review of 2012 and Outlook for 2013. Brussels: European Federation of Pharmaceutical Industries and Associations; 2013.

[21] S.M. Paul et al. How to improve R&D productivity: the pharmaceutical industry's grand challenge. Nat Rev Drug Disc 2010; 9: 203-214.

[22] M. Herper. The Truly Staggering Cost Of Inventing New Drugs. New York: Forbes; February 2012. Available at http://www.forbes.com/sites/matthewherper/2012/02/10/the-trulystaggering-cost-of-inventing-new-drugs/.

[23] S.M. Paul et al. How to improve R&D productivity: the pharmaceutical industry's grand challenge. Nat Rev Drug Disc 2010; 9: 203-214.

In addition to these global challenges a number of issues have emerged that directly impact the Swiss Pharma sector [24]:

- Mechanism for determining the price of medicines in order to limit increasing costs without negative impact on R&D while preserving the attractiveness of the Swiss market [25].
- Increasing the national talent pool in life sciences as well as the promotion of entrepreneurship at the universities.
- Improvement of patient oriented clinical research through state of the art research centers.
- Societal attitudes towards the treatment of diseases and the overall image of pharmaceutical enterprises, including the general political landscape, which is increasingly hostile to multinational corporations: e.g. governance, management compensation, migration, taxation, and others.

3.2.2. Emerging Disruptive Technologies

As the complexity of health problems is rising, it has become increasingly difficult to find solutions that can meet those medical challenges and, consequently, the role of emerging technologies is even more critical to the progress of scientific developments. While incremental improvements in technology help to evolve innovations and expand its applications [26], it is the disruptive technologies that revolutionize the way we do things. Breakthrough innovations have the ability not only to change the practice of medicine itself but also to directly impact the relationship between the drug maker and the patient.

Although it is difficult to predict the areas that will give rise to the most disruptive discoveries, they often occur at the trajectory of interfacing scientific disciplines. The convergence of the following technological fields has already started to have a fundamental scientific and sizable economic impact:

- **Consumer electronics and clinical trials** reduced the burden of trial participation and enhanced health data capture. Developments in this area include eHealth, mHealth, telemedicine, 24h/day patient monitoring and regimen compliance as well as eRecord data management [27].
- **Medical devices and drug delivery** led to more targeted and specific therapies. Developments in this area include: tissue/cell specific delivery systems, tableting technologies and stent technologies.

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[24] Pharma Markt Schweiz. Basel: Interpharma, Verband der forschenden pharmazeutischen Firmen der Schweiz; 2013.

[25] Bericht Gesundheit 2020. Bern: Bundesamt für Gesundheit; January 2013.

[26] Incremental innovation : adapting to patient needs. Geneva: International Federation of Pharmaceutical Manufacturers & Associations; January 2013.

[27] Health at your fingertips, A collection of mHealth initiatives from the research-based pharmaceutical industry. Geneva: International Federation of Pharmaceutical Manufacturers & Associations; July 2013.

- **Genomic deep sequencing and bioinformatics** provide us with access and insights into the genetic backgrounds and help decipher biochemical pathways underlying today's pathophysiologies of common and rare diseases. Some of the advances include bioinformatic approaches based on cloud computing and next generation sequencing devices.
- **Gene and cell therapies** captured the multitude of possibilities brought by using stem cells to create novel medicines. More specifically, this includes immunotherapy and iPS cell reprogramming [28].
- **Diagnostics and biomarkers** have impacted patient selection and prediction of treatment outcomes. This includes companion diagnostics, *in vitro* diagnostics (just sold this unit) and point of care diagnostics.
- **Regenerative medicine and bioengineering** altered the way we can grow tissues *ex vivo*. Related fields are 3-D bioprinting, organotypic screens, tissue engineering, bioelectronics and sensors, nanomaterials, orthobiologics and organ-on-a-chip approaches.
- **Social media and mobile applications** have changed how we share health care related knowledge and information.

3.2.3. Potential Impact of Emergent Technologies and Recommended Actions

As the understanding of arraying disruptive technologies and its applications unfolds, it will be necessary for pharmaceutical companies, policy makers and society to work together to understand how best to deploy these advances for positive patient outcomes that exceed the current standard of care and lead to an improved quality of life.

The recent economic climate has severely dried up resources and is likely to render stake- and shareholders more risk averse. This will force decision makers to choose carefully on which disruptive technologies to rely on to build their future capabilities and differentiation from the competition. This is likely to go along with portfolio prioritizations to focus on products and services with more immediate return on investment. Nevertheless, it will be a prerogative not to avoid technological risks and work collaboratively to balance precaution and proportion in relevant regulatory processes [29].

One area of potential is the exploration of alliance models with the academic sector and with governments and their health services to seek solutions in the pre-competitive space (e.g. multi-stakeholder co-operations such as Europe's Innovative Medicines Initiative [30]). In addition to new R&D funding models, this will bring new methodologies in sharing risks in the pursuit of creating new therapies.

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[28] D. A. Robinton and G. Q. Daley. The promise of induced pluripotent stem cells in research and therapy. Nature 2012; 481: 295-305.

[29] The Innovation Principle – Stimulating Economic Recovery. Open letter to Mr Jose Manuel Barroso by twelve chief executives of multinational companies (Bayer AG, BASF SE, Curis GmbH, The Dow Chemical Company, Dow Corning Corporation, Dow AgroScience LLS, Henkel AG&Company, IBM Europe, Novartis AG, Royal Philips, Solvay S.A., Syngenta AG), October 2013.

[30] The Innovative Medicines Initiative. Available at http://www.imi.europa.eu/.

Whether you choose to specialize in a single or a combination of disruptive technologies, they will be paramount to the advancement of the various disciplines in the pharmaceutical industry. Those that embrace these technologies and learn to adapt quickly will continue to be successful in the short and long-term.

Last, but not least, society should be made aware that they cannot get the benefits of new technologies without accepting the risks as well. Investing in the foundations of such technologies, from education (promoting MINT subjects in school) to general framework conditions that are favorable for companies which would like to invest in R&D, are of highest importance.

3.3 Machines and Electronics

3.3.1. Challenges for the Global and Swiss Machines and Electronics Sector

3.3.2. Emerging Disruptive Technologies

3.3.3. Potential Impact of Emergent Technologies and Recommended Actions

3.4 Watches and Jewelry

3.4.1. Challenges for the Global and Swiss Watches and Jewelry Sector

The global watchmaking industry is one of the most competitive, dynamic and noticeable industries in the business world – and Switzerland, still the world's largest exporter of watches, plays a central part in it [31]. Our fast-paced world forces everybody to keep accurate time, and for this reason, watches are a pure necessity today. Beyond that, watches are also worn as luxury attributes and, in this function, watches can be also considered a form of jewelry. For this reason, watchmaking is revolving around the different characteristics of quality: precision, reliability, longevity, elegance, tradition, reputation and value. For a long time, "Swiss Made" has been a guarantor for these qualities, and anything threatening this situation is a vital threat to this key industrial branch of Switzerland. Currently, the biggest menace is perceived in the following challenges:

- The **iWatch concept**, although an extension of the SmartPhone revolution and not formally a watchmaking product, represents a huge potential threat to traditional watches, because an iWatch occupies the same space on a human's wrist as a traditional watch. The enormous additional functionality of an iWatch may lead many users to prefer iWatch-type products over conventional watches in the long term.
- Incipient **regulatory actions** could harm the watchmaking industry in two ways: On one hand, the current regulatory plans concerning both "Swiss Made" and the obligations of compulsory delivery of components and movements may lead to a severe quality problem of the finished products. On the other hand, new regulations regarding environmental protection entails risks for the use of certain, traditionally employed materials and fabrication processes of the watchmaking industry
- Insufficient law enforcement in key markets, leading to a surge of counterfeit products, piracy problems, parallel distribution and gray products in regions where **intellectual property rights** are weakly protected [32].

3.4.2. Emerging Disruptive Technologies

- Novel high-precision, yet cost-effective **machining technologies** are rapidly being adopted in other industrial branches, in particular (femtosecond) laser cutting and water-jet cutting. These technologies promise micrometer-accuracy fabrication precision and excellent surface quality without requiring expensive tooling, for metallic as well as ceramic materials.

[31] S.T. Anwar. Selling Time: Swatch Group and the Global Watch Industry. Thunderbird Int Business Rev 2012; 54: 747-762.

[32] S.T. Anwar. Selling Time: Swatch Group and the Global Watch Industry. Thunderbird Int Business Rev 2012; 54: 747-762.

- It is not yet clear whether additive fabrication (**3D printing**) has the necessary precision and surface quality. Nevertheless, these emerging techniques may open the way to novel ways of designing and fabricating watches, and they may play a key role in the future in the fabrication of decorative parts in watches.
- The emergence of **novel materials** such as ultra-hard metals, ceramics or monocrystalline constituents creates at the same time new challenges in the required fabrication technologies as well as opportunities for novel types of high-quality, super-reliable yet cost-effective watch products.
- Despite the amazingly low power consumption of quartz watches, it is still necessary to change a **quartz watch battery** every few years. Novel technologies allowing the harvesting of the required energy from the environment, such as mechanical energy or temperature differences, may change the way electronic watches are "lifetime-powered" in the future [33].

3.4.3. Potential Impact of Emergent Technologies and Recommended Actions

The Swiss watchmaking industry increasingly has to cope with two types of threats: Firstly, the industry must stay at the innovation forefront by adopting all novel materials and fabrication technologies thereby allowing the Swiss watch products to stay competitive in the global marketplace. Secondly, the Swiss watchmaking industry is particularly exposed and vulnerable to regulatory actions that are beyond its control. As described above, this concerns regulatory actions of the Swiss authorities (regarding "Swiss Made" and obligations to fabricate and deliver to third parties), as well as the weak protection of intellectual property rights of foreign authorities (leading to increasing problems with counterfeiting, piracy, parallel distribution and gray products).

[33] K.A. Cook-Chennault. Powering MEMS portable devices – a review of non-regenerative and regenerative power-supply systems with special emphasis on piezoelectric energy harvesting systems. Smart Mater Struct 2008; 17: 1-34.

3.5 Precision Instruments

3.5.1. Challenges for the Global and Swiss Precision Instruments Sector

The broad industrial branch "Precision Instruments" covers the product classes „Mechanical instruments for measuring and testing", "Optical appliances" and "Survey instruments". The bulk of the precision instrument (PI) sector is made up of small and medium sized companies which are highly specialized in a particular area of activity. Many are global players in a dedicated market niche. The global megatrends such as e.g. "urbanization" and "sustainable resources and energy management" lead to an ever higher need for measurement and monitoring of critical workflows, processes and assets. In this context, the Swiss PI Industry will play a crucial role for the future development if it is capable of mastering the current challenges:

- **Internet of things (IoT)**: The IoT revolution is leading to a much higher level of integration in a complex, top-down designed system [34]. This implies, among others, that market acceptance of any measurement equipment and/or sensor system, which is used for construction or is permanently installed, requires interaction with a specific digital model of the system.
- **Smart sensors**: By making use of the amazing progress in fabrication offered by microtechnology, lower cost sensors of a large number of physical parameters become possible. However, these low-cost sensors often have lower accuracy, which needs to be compensated by elaborate software and calibration procedures. This implies increased complexity of the resulting precision "smart sensor systems", leading to an increasing importance of the software component in such systems.

3.5.2. Emerging Disruptive Technologies

- Many different industries are following today a similar track of **interconnected subsystems and systems** that could be all summarized under the term "internet of things". The building and construction industry for instance is currently exploring and implementing "Building information modeling" (BIM). It is basically a process involving the planning, generation and management of a digital representation of physical and functional characteristics of an asset like a building, plant, dam, and others. The resulting digital models become a shared resource for supporting the whole process from earliest conceptual stages through design and construction as well as through its operational life to eventual demolition. This also means that all the measurement equipment and sensor systems, which are used for construction or are permanently installed over the lifecycle, need to permanently interact with the model and update it.
- Another example refers to a present initiative entitled "**Industry 4.0**". The whole manufacturing process of industrial goods is accompanied by a digital model that helps to plan, control and document the workflow

[34] L. Atzori, A. Iera and G. Morabito. The Internet of Things: A Survey. Comput Netw 2010; 54: 2787-2805.

over the full supply chain. All involved measurement and control systems need to be connected to the model. This requires adequate communication means and the application of common standards (i.e. EtherCAT) for all involved PIs. Full process documentation is another requirement which implies that measurement data need to be stored together with other relevant information (such as time, location, temperature, picture of the environment).

3.5.3. Potential Impact of Emergent Technologies and Recommended Actions

For pure volume reasons, the PIs industry rarely is capable of developing next generation technologies or of driving it into the required direction. On the other hand, advanced components developed for mainstream markets such as telecom, smart phones, automotive, entertainment and gaming industry need to be continuously observed, tested and evaluated. An early and deep understanding of such technologies followed by an optimization and tight integration leads to competitive products and solutions for the PI industry. An example might be inertial sensors developed for the smart phone industry. By a tightly coupled integration into existing positioning systems, such performance can be augmented. This finally requires the development of advanced algorithms which are implemented in the device's firmware.

Traceability requirements for the measurement results of PIs need more and more digital documentation to an ever increasing degree. The measurement environment also needs to be adequately represented. For such purposes, imaging technologies will play an increasingly dominant role. Measurement instruments will be equipped with cameras and other additional monitoring sensors.

3.6 Metals and Machine Parts

3.6.1. Challenges for the Global and Swiss Metals and Machine Parts Sector

3.6.2. Emerging Disruptive Technologies

3.6.3. Potential Impact of Emergent Technologies and Recommended Actions

3.7 Medtech

3.7.1. Challenges for the Global and Swiss Medtech Sector

A deep disruptive change is currently transforming the health care systems world-wide, forcing a shift from a late curative paradigm to an early preemptive one, known as **4P medicine** (Personalized, Predictive, Preventative, Participatory) [35]. The enormous progress in genomics and metabolomics of the past decades have led to a deep understanding of the fundamental causes of diseases on a molecular scale. It is therefore increasingly possible to recognize the onset of a disease, its dependence on environmental conditions and its development in each individual patient. This will make it possible to precisely adapt the treatment for each patient with a personalized therapy, to predict the efficacy of this therapy and to prevent side effects while maximizing the therapeutic effects. Obviously, a key prerequisite for 4P medicine are highly specific and sensitive diagnostic capabilities, both for the initial recognition of a disease as well as the continuing monitoring of the effectiveness of a therapy.

Successful implementation of the 4P medicine paradigm requires overcoming several huge obstacles in various domains, including

- the complexity of the needed highly interdisciplinary technologies (biochemistry, microelectronics, nanotechnology, microtechnology/miniaturization, robotics, chemical/physical sensing, digital imaging, systems engineering and others)
- the pervasiveness of IT (internet of things, smart sensing, eHealth)
- the creation of effective and secure interfaces between man and machines
- the necessity of producing clear evidence of the increased value of a novel solution at lower cost, in a rapidly changing health care environment ("health economics")
- the enormous price pressure of a globalized, highly competitive economy
- liability problems emerging as a consequence of the complexity of the novel systems
- national and international regulatory challenges, caused by the increasing speed with which health care innovations are created

3.7.2. Emerging Disruptive Technologies

There is a clear trend towards health care solutions bringing more complexity and blurred distinctions between the several involved disciplines. As a consequence, the most important disruptive technologies are all merging various domains:

[35] E.A. Zerhouni. A Vision For Transforming Medicine in the 21st Century. Bethesda: US National Institute of Health; 13 September 2006. Available on-line at http://www.nih.gov/about/director/slides/vision.pdf.

- The combination of diagnostic with therapeutic nano/microsystems, also called **theranostics**, makes use of key elements from the pharmaceutical, the Medtech and the chemical materials industries. Often, this involves "smart materials" whose properties are adaptively changing as a reaction to altered environmental conditions, in particular in the human body; see for example [36]].
- **Regenerative medicine** promises the growth at will of complete replacement organs using a patient's own or foreign biological material. Promising results have already been shown for teeth, cartilage, bone, skin, blood vessels and various kinds of tissues [37]. It is quite possible that special variations of additive manufacturing techniques ("3D printing") could play a key role in regenerative medicine.
- Both the precision and the speed of surgical interventions could be significantly improved with **robot-assisted surgery** [38]. In combination with conventional and novel digital imaging modalities, it is quite feasible that robots may even carry out complete operations autonomously, without any human intervention. However, this entails huge ethical, liability, legal and regulatory questions, making it doubtful if and when such autonomous robot surgeons will be commonplace.
- Many diagnostic methods are still based on chemical reactions, restricting their use to centralized laboratories. The increasing pressure to provide simple and cost-effective **point-of-care (POC) diagnostics** has led to the development of microfluidics-based, easy-to-use miniaturized diagnostic solutions. In the near future, these methods may be replaced with physical, so-called **fingerprinting diagnostic techniques**, either based on infrared spectroscopy, mass spectrometry, micro-NMR, Raman (or SERS) spectroscopy or mechanical-resonator based "electronic noses", see for example [39].

3.7.3. Potential Impact of Emergent Technologies and Recommended Actions

The increasing complexity and interdisciplinarity of the life sciences – the Medtech as well as the pharmaceutical industries – poses not only a challenge but a huge opportunity for Switzerland, due to its traditional capability of integrating several different technologies from various disciplines, see also **Fig. 4**. The authorities and the university system should do their utmost to develop the innovative force of each individual industrial sector, and to foster and to improve the required "cross industry innovation". This implies strengthening of the dual education system (vocational or academic education), simplified access to technologies from any industrial branch, and the explicit promotion of world-class research at universities and clinics.

[36] K.H. Bae et al. Nanomaterials for Cancer Therapy and Imaging. Mol Cells 2011; 31:295-302.

[37] G.C. Gurtner et al. Progress and Potential for Regenerative Medicine. Annu Rev Med 2007; 58: 29-312.

[38] G.I. Barbash and S.A. Glied. New Technology and Health Care Costs — The Case of Robot-Assisted Surgery. N Engl J Med 2010; 363: 701-704.

[39] R.A. Shaw. Toward point-of-care diagnostic metabolic fingerprinting: quantification of plasma creatinine by infrared spectroscopy of microfluidic-preprocessed samples. Analyst 2009; 134: 1224-1231.

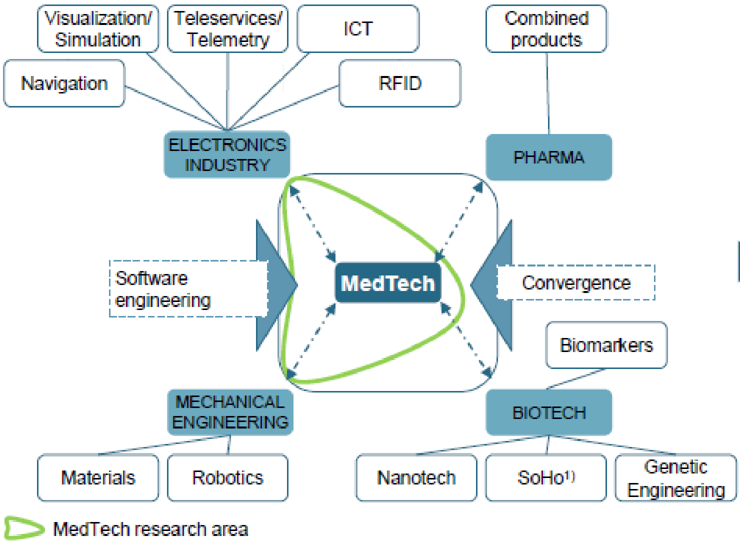

Figure 4: Illustration of the complexity and interdisciplinarity of today's Medtech industry [40]

[40] P. Dümmler and B. Hofrichter. Swiss Medical Technology Industry Survey 2010. Bern: Swiss Medical Cluster; 2010.

3.8 Energy

3.8.1. Challenges for the Global and Swiss Energy Sector

The international and national supply systems for electricity are currently undergoing a radical change, induced by the rapid growth of fluctuating renewable energy sources. It is estimated that renewable energies are already providing 19% of the global final energy consumption [41]. The integration of renewables with their almost inexistent marginal costs into the national and international power grids is a huge challenge, requiring novel technical means for grid frequency and voltage stabilization and corresponding regulatory standards – the pan-European grid frequency will not suffice any more as joint carrier frequency, and simply switching on and off additional production capacity will be impractical in the future. There are two immediate consequences and key challenges for the industry:

- On all levels in the power generation and distribution chain, the production and consumption of electrical energy must be controlled – also called the "**smart grid challenge**"; this increases the pressure on efficient use of energy by all consumer groups, leading to a huge demand of bi-directional information flow and the acceptance of "remote control" of energy consumption. The smart grid problem is an enormous challenge, starting with proper, cost-effective sensing, and leading up to close international cooperation and coordination.
- A comprehensive, huge addition of **storage capacity** must be obtained, installed and efficiently operated. This revolution will force utilities to convert their business model from "kWh delivery" to "energy services and power management", in order to satisfy the demands of today's energy-conscious but simultaneously energy-hungry society.

3.8.2. Emerging Disruptive Technologies

Huge capacities of energy storage facilities are required for the efficient implementation of the energy turnaround. In particular, the cost-effective and sustainable storage of large amounts of electrical energy is a tremendous problem. This includes invention and elucidation of the fundamental principles, the technological realization of these principles, large-scale production of affordable solutions, as well as the lifespan-extending, economical operation of these storage facilities. Although a range of novel storage solutions are currently under development, promising to increase the "round-trip" (overall) efficiency and the storage density, disruptive low-cost technologies for distributed high-capacity energy storage are expected in three domains:

- The direct conversion of incoming radiation into liquid (or gaseous) combustible materials can be achieved with **photoelectrochemical converters** (**PEC**) [42]. This so-called "photon-to-fuel" technology is under intense

[41] REN21. Renewables 2013 – Global Status Report. Paris: REN21 Secretariat; 2013.

[42] G. Ghadimkhani, N.R. de Tacconi, W. Chanmanee, C. Janaky and K. Rajeshwar. Efficient solar photoelectrosynthesis of methanol from carbon dioxide using hybrid CuO-Cu2O semiconductor nanorod arrays. Chem Commun 2013; 49: 1297-1299.

research, in particular in the United States, see for example [43]. Conversion efficiencies of more than 10% were achieved, and the primary research goal today is to transform the research insights into reliable, robust and sustainable processes based on cost-effective catalytic materials.

- The gratifying growth of renewable energies, in particular solar and wind power, has also some undesired consequences: The availability of this power source is varying rapidly with time, potentially destabilizing the grid, and causing a significant loss in the worth of Europe's utilities, optimized for providing a stable flow of electrical power [44]. A highly promising way of coping with the rapidly varying oversupply of renewable energies is **power-to-liquid** (**PTL**) technologies, capable of converting electric energy into liquid fuels directly and efficiently [45]. Since many of these processes can be made CO_2-neutral, PTL technologies are seen as the optimum, environmentally friendly "missing link" between renewable sources of electric power and time-shifted consumption of the generated energy.
- Our society commits terrible waste when employing high-quality combustible fuels (in particular fossil fuels such as oil or natural gas) just for raising the temperature of a certain medium by the sole act of burning these fuels. The key is cogeneration of electrical/mechanical energy while heating, also called **combined heat and power** (**CHP**). A particularly promising solution is **thermophotovoltaics** (**TPV**) [46], i.e. the use of combustible fuel for generation of radiant energy with a particular wavelength spectrum (using selective emitters) and the ensuing direct conversion of these photons into electricity. High energy conversion efficiencies reaching 80% are theoretically possible but practical systems are not exceeding 10%. It should be remarked that the wide adoption of CHP technology will also necessitate regulatory adaptations and the clear directive of employing CHP in heat-led mode, in order to prevent new fashions of wasting the world's precious fossil fuels.

3.8.3. Potential Impact of Emergent Technologies and Recommended Actions

The wide-spread use of renewable energies is not an option for our world's society – it is a must! Regulatory processes are therefore necessarily trans-national, and Switzerland can at best contribute to these processes. Unfortunately, Switzerland is virtually absent in the fundamental research and industrial application of innovative large-scale energy storage solutions (as an example, the only remaining large battery maker of Switzerland, Leclanché SA, is currently fighting for its survival [47]). At most, Switzerland could develop and market the required "smart" sensor

[43] US Department of Energy. Project "Helios" at Berkeley. Available at http://www.lbl.gov/LBL-Programs/helios-serc/html/goals.html.

[44] European Utilities – How to Lose Half a Trillion Euros. Available at http://www.economist.com/news/briefing/21587782-europes-electricity-providers-face-existential-threat-how-lose-half-trillion-euros?frsc=dg%7Ca&fsrc=scn/tw_app_ipad.

[45] R. Blanck, P. Kasten, F. Hacker and M. Mottschall. Treibhausgasneutraler Verkehr 2050: Ein Szenario zur zunehmenden Elektrifizierung und dem Einsatz stromerzeugter Kraftstoffe im Verkehr. Berlin: Öko-Institut e.V.; February 2013. Available at http://www.oeko.de/oekodoc/1829/2013-499-de.pdf.

[46] L. Fraas, J. Avery, E. Malfa, J.G. Wuenning, G. Kovacik and C. Astle. Thermophotovoltaics for Combined Heat and Power Using Low NOx Gas Fired Radiant Tube Burners. Proceedings of the 5th International Conference on Thermophotovoltaic Generation of Electricity. Melville: American Institute of Physics; 2003.

[47] Precept will Aktienmehrheit bei Leclanché – Der Westschweizer Batterienhersteller kämpft ums Überleben. Handelszeitung, 2 August 2013.

technology including innovative logistics solutions for the required intensive data exchange, load balancing and optimized “remote control” of decentralized energy production facilities and consumers.

3.9 Transportation

3.9.1. Challenges for the Global and Swiss Transportation Sector

3.9.2. Emerging Disruptive Technologies

3.9.3. Potential Impact of Emergent Technologies and Recommended Actions

3.10 Information and Communication Technologies (ICT)

3.10.1. Challenges for the Global and Swiss ICT Sector

Data Privacy and Security:

One of the main challenges that the ICT industry faces today and will have to address in the near future is how to ensure the privacy of the personal data and its secure management. The amount of generated personal data is increasing and will increase tremendously, due to the growing use of social media, mobile applications in smart phones and portable devices, sensors, the introduction of electronics medical records and genomic sequencing tools, etc. On the one side, analytics and data mining on this large amount of generated personal data may be used to improve people's quality of life, by offering personalized services to the customers, improving medical diagnosis and treatments, redirecting heavy traffic and others. On the other side, however, lot of effort needs to be done to ensure that this data are handled in a secure way so that privacy is respected over all. This is further complicated by the increased use of cloud technologies in which data are not stored locally and third party manage and even own the data. Not only new data encryption methods and technological solutions will be required for appropriate data governance (privacy, security, etc), but also specific law and policies.

End of Moore's Law:

Over the past years, by shrinking device dimensions and increasing wafer size, CMOS technology had benefited from an increase in performance at decreasing costs per die. This had generated an economically viable microelectronic technology based on Moore's law. Faster and better performing products could be produced at affordable costs. Lately, however, miniaturization has started to be more and more complicated due to the fact that the size of the devices is reaching physical limits. Dynamic and static power consumptions in the chips have become almost unacceptable. In addition, not only it has become more difficult to develop the tools to fabricate such nano-devices (i.e. EUV lithography) but also these tools are becoming more and more expensive. These issues had been solved so far by the introduction of new materials, novel system- and device-designs, new fabrication solutions, etc. The implementation of these new solutions was so far economically viable and physically possible but in the next years this will become extremely challenging. This will imply a total rethinking of the so called "Moore's law" (if not its end).

Towards non-von-Neumann Computing Architecture:

We will also assist to the paradigmatic shift from a so-called von-Neumann architecture to a non-von-Neumann type of computation.

3.10.2. Emerging Disruptive Technologies

Cloud Services and Solutions:

Although not a new trend, cloud computing is becoming the predominant way of delivering and consuming IT infrastructure (computation and storage), middleware and applications. Cloud Computing is one of the fundamental transformations that will change how people communicate, do business and offer services. Not only private Swiss companies are embracing cloud solutions due to their flexibility, low cost, availability, but also Swiss public offices and institutions. Cloud solutions are desirable at all levels in public institutions, from the administration to education. Still under debate are the definition and agreement on the best architecture, meta-architecture and operational models to foster cloud enablement, and appropriate governance mechanisms, billing and accounting models and support structures. A discrete numbers of swiss companies is working on providing solutions for cloud computing: AdNovum, Netcetera, Swisscom, Swisstopo and others.

Big Data Analytics:

Many recent cases show what is the benefit from deployment of Big Data analytics and predictive analytics such as improved business decisions, decrease in traffic congestion and accidents, improved customer experience, costs saving, improved medical treatments, etc. At the moment some ecosystems of technologies have been defined, that can be used to implement and support Big Data solutions, by complementing legacy investments with new technologies (Map-reduce framework Hadoop like, massive parallel processing data warehousing). However new tools for data management and analytics, able to address increasing data complexity and velocity are still being developed. Furthermore advanced computing technologies that can effectively process large volumes of different types of data are needed (the amount of generated data is steadily increasing). Also solutions addressing appropriate security, governance, privacy, and risk management in Big Data deployment are still being explored. New models able to encourage data sharing and collaborative data sciences efforts are required (i.e. semantic web and linked data). With some delay with respect to other fields, health care starts embracing big data services/analytics due to cost pressure and the need for evidence-based medicine (holistic, patient-centered framework, genomic). For example, the adoption of big data solutions in health care coupled to genomic medicine is extremely interesting and appealing for Switzerland due to the large density of pharmaceutical and biological companies. Small local companies, such as Teralytics AG, Basis 06, c-knox GmbH, Quantinum AG, and bigger companies such as Cisco, SAP, IBM offer commercial Big Data solutions. The interest towards Big Data is also demonstrated by the foundation in July 2013 of the Swiss Data Value Forum (SDVF). In addition, the Swiss Big Data User Group, founded in 2012, aims to bring together people from all industries who are interested in dealing with large amounts of data, offering talks, hands-on advice and a forum for exchange and networking. At academic level ETH is very active (see Prof. Kossman's group) and applications of Big data solutions in biology (SyBit) and sociology are also explored. The eX-ascale Infolab is a new research group at the University of Fribourg, Switzerland who designs, builds and deploys next-generation infrastructures for Big Data, with a focus on social, scientific, and linked data. The „Berner Fachhochschule, Informatik/SWS“ has recognized the potential of "Big Data" und is offering a new study course "CAS Big Data" (CAS BGD) starting in April 2014. That Big Data implementation may be important in healthcare has been recognized by the Akademien der Wissenschaften who have submitted an a+ project proposal “Big Data im Gesundheitswesen“.

Internet of Things and Cyber Physical System:

An increasing number of assets including people and places can be linked to deliver and share information, enhance business value and competitive advantage (20 billion devices permanently and 200 billion devices intermittently connected to the web by 2015). This is driven by recent improvements in devices/sensors/actuators technology (miniaturization, integration, self-powering, reduced power consumption, RFIDs, wireless networks of sensors). Many applications of these smart systems of interconnected objects are generated by real needs:

- monitor/maintain aging infrastructures (buildings, bridges, roads)
- contain the exploding health-care costs (digital hospital)
- smart grids
- smart home (interconnected and smart appliances, energy savings)
- retailers: inventories, visibility and traceability of goods
- make transport systems green/efficient/safe (interconnected cars)
- food/agriculture/water distribution systems
- manufacturing/ oil and gas industries

In addition interesting business cases are generated when IoT/mobile/cyber-physical systems are coupled with Big Data analytics/predictive analytics/Cloud technologies. At the moment there are different major visions: the Industrial Internet, the Web of Things, ubiquitous use of adaptable, autonomous and mobile Cyber-Physical Systems. Also in this respect security, privacy and standardization are still extremely important issues.

Small local companies such as Yaler GmbH, Oberon and other big companies such as Cisco and Bosch offer commercial IoT solutions. Also one of the main Swiss giant companies, ABB, has realized the need “for a unifying corporate initiative that explains to the world why it will be a major player in this burgeoning sector” [48]. The “Bosch Internet of Things and Services Lab”, formally opened in September 2012, is a cooperation between the University of St. Gallen and the Bosch Group [49]. The Prof. Mattern and Prof. Fleisch [50] groups and the distributed system depart-

[48] http://www.smartgridnews.com/artman/publish/Delivery_Transmission/The-Big-6-How-ABB-stacks-up-against-the-other-giants-in-the-smart-grid-race-5532-page2.html#.Ul1VgBDNH1I.

[49] http://www.iot-lab.ch/.

[50] http://www.nzz.ch/aktuell/wirtschaft/wirtschaftsnachrichten/wie-viel-schweiz-steckt-im-internet-der-zukunft-1.18101449.

ment at ETH [51] work on IoT related topics. In addition, Qipp and Amphiro are ETH spin offs working on IoT technologies. Cosibon is also an ETH-University of St. Gallen spin off and works on mobile applications and data analytics. The interest towards smart and better organized cities is proven by the Smart City Schweiz initiative, a project of the "Bundesamtes für Energie" and "EnergieSchweiz für Gemeinden" [52].

Cognitive Systems/ Machine Learning:

Advances in artificial intelligence and machine learning applications (natural language processing, image/pattern recognition, computational neuroscience).

Increasing interest for contextually aware, intelligent personal assistants. Use of a cognitive system like Watson in healthcare (cancer diagnosis and treatment).

Neuromorphic cognitive systems or brain inspired computing.

Machine Learning Laboratory at ETH Zurich and the Artificial intelligence and machine learning at EPFL [53]. Regarding neuromorphic cognitive systems: Institute of Neuroinformatics at ETH and Blue Brain Project. Cognitive computing IBM: Watson.

3.10.3. Potential Impact of Emergent Technologies and Recommended Actions

The projected market sizes for the above mentioned trends are significant. Forecasted is a worldwide revenue for Big Data solutions and services of about $23.8 billion in 2016. McKinsey estimates the potential economic impact of the Internet of Things to be $2.7 trillion to $6.2 trillion per year by 2025 through use in a half-dozen major applications [54]. From a pure business perspective, it is then clear that all the mentioned trends are extremely important to the economical development and competitiveness of Switzerland and its enterprises. In addition the capability of deploying smart solutions in different fields (government, cities, healthcare, use of resources, energy management, and education) represents an important possibility for advaning the quality of life of Swiss citizens and the welfare of the Swiss State. Adoption of these technologies would reinforce Switzerland's position as global ICT player. However, barrier entries typical to the Swiss reality such as its Federalism and the different maturity stages of these topics in different application areas will have to be considered. A complex and fragmented landscape may indeed slower the adoption and the penetration of the discussed smart technologies.

[51] http://www.vs.inf.ethz.ch/publ/papers/mayersi-semant-2013.pdf, http://www.vs.inf.ethz.ch/publ/papers/mayer-extensiblediscovery-2011.pdf.

[52] http://www.smartcity-schweiz.ch/de/, http://www.bkw.ch/verein-smart-grid-schweiz.html.

[53] http://ic.epfl.ch/artificial-intelligence-and-machine-learning.

[54] http://www.mckinsey.com/insights/business_technology/disruptive_technologies.

3.11 Photonics

3.11.1. Challenges for the Global and Swiss Photonics Sector

Photonics was identified as a EU key enabling technology with components, sensor and systems providing a large potential for the European photonics market. Today, the assembly of optical systems is moving to the Far East due to reduced costs of personnel. On the other hand, as photonic components and systems are becoming smaller and smaller, miniaturization integration solutions are essential and will require increased automated assembly; this leads to a reduction of the dependence on man-based assembly and opens the possibility of relocating and regrowing this industry back to Europe and Switzerland [55].

All aspects of photonics, from device to system architecture, need to be addressed. The integration of heterogeneous materials has to be considered as a higher level of integration (hybrid packaging of electronics and optics) and is becoming more and more important. This also means that the design for assembly has to be included in the development of new devices and that a variety of materials (Si (CMOS), III-V semiconductors (lasers), glass, plastics and others) has to be taken care of. The compatibility of different design methodologies has to be ensured, e.g. for the optical design in new configurations. The trade-offs in terms of costs, complexity and performance, e.g. optical SiP versus optical SoC, has to be taken into account. Finally, reliability and testing continue to play a major role and are often a challenge given the variety of materials, processes, and devices in Photonics. In general, the applications are manifold and also include image sensing, biosensing, 3D measurements of components and objects, fiber-optic sensors for harsh environment and medical applications, medical diagnostics, high-power lasers for marking, cutting and welding, and industrial process control.

There is a need to address new fields including biophotonics and medtech that have very high potential for innovation and breakthroughs. Interdisciplinarity needs to be fostered to develop such innovative products. Photonics need to be brought to large application areas and to low cost, leading to a potential paradigm shift from the “rich-man photonics” (e.g. photonic crystals in semiconductors) to the “poor-man photonics” (e.g. optical films/devices with interferential/diffractive/plasmonic effects).

Today, photonics education programs are rarely available in Switzerland. Therefore, the attractiveness of (photonic) technologies for young people needs to be further developed and people need to be adequately trained.

[55] European Technology Platform Photonics21. Towards 2020 – Photonics Driving Economic Growth in Europe. Dusseldorf: Photonics21; April 2013.

3.11.2. Emerging Disruptive Technologies

Disruptive technologies emerge in a variety of fields:

- **Plasmonics** and new materials are appearing as an opportunity for bringing photonics to the daily-life [56].
- **Quantum cryptography/communication** technology is already entering the market [57].
- Technologies such as micro and nano-fluidics (**"optofluidics"**) will provide an interface allowing photonic devices to communicate with the environment, thus opening more and more opportunities e.g. for biophotonics and medical applications.
- Flexible photonic devices, as standalone devices or interfaced with traditional CMOS or glass devices, open up new routes towards cost-effective innovative photonic devices.
- Progress in **photonic integration**, less disruptive but also of great importance, is based on miniaturization, an increase of optical power output for light sources and automated assembly. For this, novel technologies dealing with heat removal, reduction of stress-induced failure during the assembly, and high-precision assembly of the different components are needed. Moreover, the technologies should be generic in such a way as to improve the current lack of standardization in many domains of photonics.
- Photonic manufacturing requires detailed competences in light – material interactions in view of new manufacturing structures. **3D manufacturing** is an exciting new emerging technology where lasers are used as tools.

3.11.3. Potential Impact of Emergent Technologies and Recommended Actions

Photonic technologies are enabling technologies since they provide devices and systems with advanced function for a large variety of industries: sensing devices, communication systems, lighting systems, displays, light management systems, or material processing. As a consequence, the potential impact of photonics is enormous since Swiss industry is renowned for precision instrumentation. Due to the diversity of photonics, the fragmented/SME based structure of the Swiss economy can be better served. Industrial sectors that can strongly leverage and profit from such technologies including medtech, pharma, automation, energy generation, consumer goods, environment and security [58].

The needs for adaptation, in particular in areas such as flexible photonics as stand alone or with an interface to the traditional materials (glass or CMOS), is required. This could have an impact on the industrial extension of a number of traditional SME, which could modernize their business. Companies traditionally focused on telecommunication or classical device applications will have to adapt to the new paradigm/application fields and learn how to discuss with new players (the requirements for a fiber router are not the same as those for a medical device). There is a

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[56] Focus Issue. Plasmonics. Nat Photonics 2012; 6

[57] N. Gisin et al. Quantum Cryptography. Rev Mod Phys 2002; 74: 145-195.

[58] European Technology Platform Photonics21. Towards 2020 – Photonics Driving Economic Growth in Europe. Dusseldorf: Photonics21; April 2013.

need for demonstrating the potential of new photonics applications addressing the main current societal challenges (e.g. cleantech, medtech).

Photonics is traditionally “technology-push”. In the future, it will be more “application/market-pull”. The need for innovation and opening to new fields of application will be an opportunity for Swiss industries with a high potential for innovation.

Equal opportunities for Swiss SMEs are very important. Whereas in many other countries, in particular in Europe (research framework programmes), in the USA and in Japan, companies can get financial support for their research through a variety of funding agencies, such means do not exist in Switzerland.

Thematic think tanks understanding the potential of photonics and informing the industrial players should be created. These think tanks can be linked with international clusters in Europe, both thematically as well as geographically. In Switzerland, the SWISSPHOTONICS NTN, a national thematic network, is actively working on this and is strongly supporting the founding of a “Fachgruppe Photonics” within SwissMEM.

“Photonic engineers” should be educated who can address the need in new emerging fields (biophotonics/medtech/energy and more). A tool that has been proven to be excellent in Switzerland in the 90’s was the implementation of a Priority Program for Optics (PPO). The level of knowledge and commercial exploitation has been largely improved due to this R&D program. A reprise of PPO2 can only be beneficial for the growth of this key enabling technology and its integration in the Swiss industry.

4 High Priority Selected Topics

This section will list the series of selected technologies to be included in the TO, shortly describe each of them in terms of global and national importance as well as the position of Switzerland in the respective domain.

A possible distinction can be made between the following categories: (i) technologies in which Switzerland is very strong and its leadership needs to be reinforced, (ii) new emerging technologies that are strategic for the future, have potential of innovation, can create new industries and jobs and fit very well with the Swiss profile and priorities. Switzerland should, however, have little current involvement in these technologies, but there is a clear must for investment, (iii) key enabling technologies for Europe, motivated by the high social impact.