European Commission

Foresight

100 Radical Innovation Breakthroughs for the future

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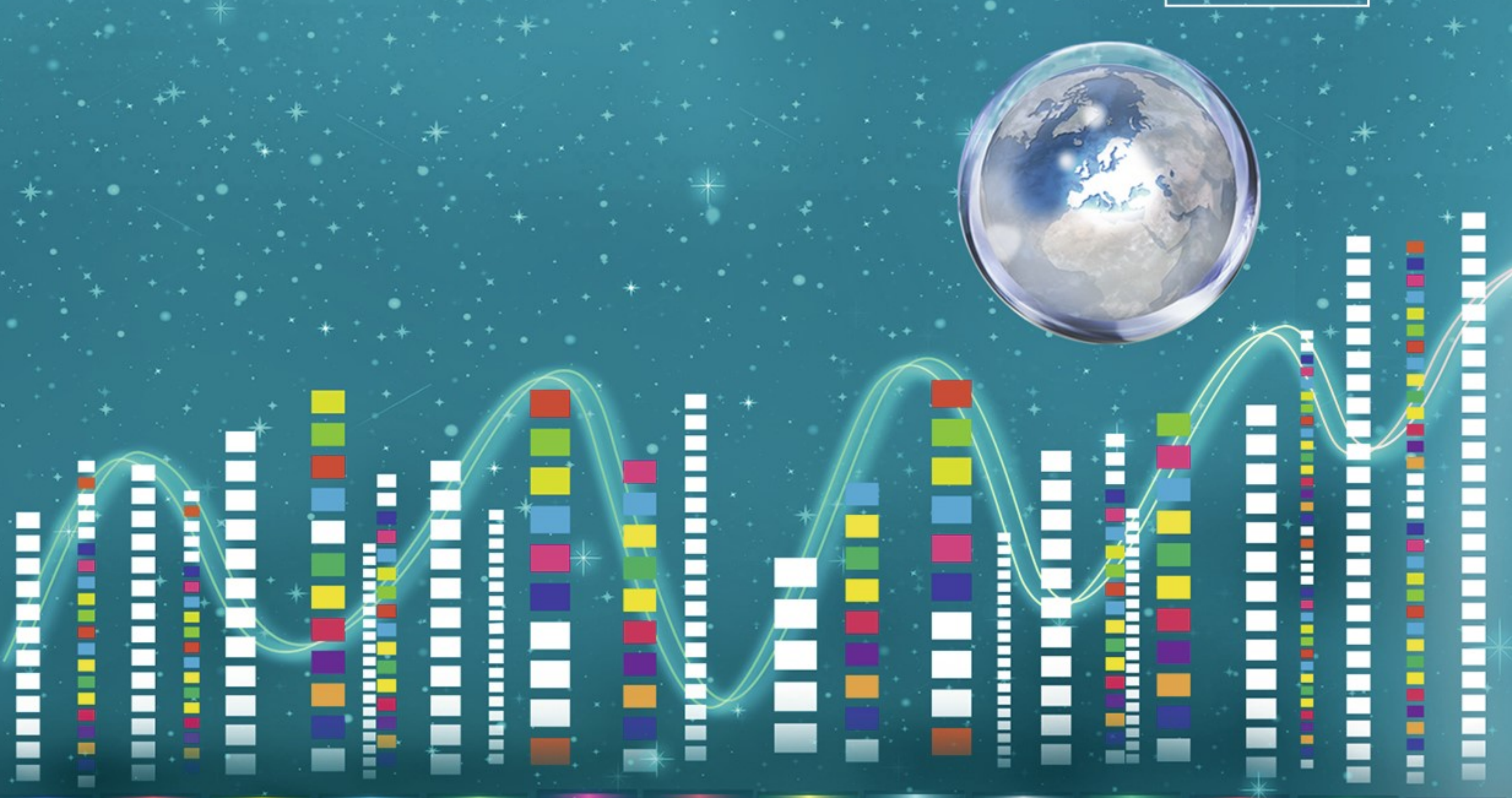

Research and Innovation

100 Radical Innovation Breakthroughs for the future

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EUROPEAN COMMISSION

100 Radical Innovation Breakthroughs for the future

The Radical Innovation Breakthrough Inquirer

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FOREWORD

Horizon 2020 and Horizon Europe are ambitious EU research and innovation programmes aiming at strengthening science, technology and innovation, fostering European industrial competiveness, and helping to achieve the Sustainable Development Goals. These ambitions will require a step-change in breakthrough innovation in Europe. The proposal for the European Innovation Council is at the heart of our ambitions for breakthrough innovations. But it is not alone. Breakthrough innovations are needed to boost the quality of our science as well as to address the many challenges faced by people today, individually as well as collectively.

Our Horizon Scanning for Radical Innovation Breakthroughs is part of the preparation for Horizon Europe's implementation. A massive automated survey of recent scientific and technical literature filtered through panels of experts has been combined with reviews of important recent foresight projects worldwide. The results have been screened for their potential impact on future global value creation, and assessed in terms of current maturity, long-term diffusion potential and relative strength of the EU in research and innovation.

This report "100 radical innovation breakthroughs for the future" captures the most potentially impactful results. It provides a strategic resource to all those concerned with decisions on science, technology and innovation. For example, in EU research and innovation policy planning we need to understand the potential of breakthroughs as enablers or barriers to sustainability transitions. Such transitions involve interactions and potential synergies between different policies of the Union. The collection of radical innovation breakthroughs can create common references between different policies and facilitate interactions.

With the publication of this report, we hope to also contribute to national and regional strategies, be they on research and innovation priorities or on smart specialization. To improve the lives of people, our reflection about the future should be inspired by the goals of sustainability in order to stretch the boundaries of what is feasible in function of what is desirable for people. Radical innovation breakthroughs are aspirational and inspirational. Scanning the horizon to identify them is a growing part of policy intelligence.

Jean-Eric PAQUET
Director General for Research and Innovation
European Commission

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Global Value Networks (GVNs)
Carbon retention for climate change mitigation
Decent and meaningful life for elderly people
Enabling mechanisms for self-organising communities
Global Capacity for Social Innovation

Global Value Networks (GVNs)
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Peer to peer based consumption decisions
Planning and infrastructure for liveable human settlements
Pro-active health and self-care approaches
Remote interaction with people and machines
Security network against military and criminal attacks
Smart transport
Space as a global commons
Sustainable energy solutions
Sustainable food for all
Sustainable housing
Sustainable tourism
Sustainable use of materials
Sustainable use of water systems and resources
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Virtual citizen interaction for entertainment, art and culture

EXECUTIVE SUMMARY

This report provides insights on 100 emerging developments that may exert a strong impact on global value creation and offer important solutions to societal needs.

We identified this set of emerging developments through a carefully designed procedure that combined machine learning algorithms and human evaluation. After successive waves of selection and refinement, the resulting 100 emerging topics were subjected to several assessment procedures, including expert consultation and analysis of related patents and publications.

Having analysed the potential importance of each of these innovations for Europe, their current maturity and the relative strength of Europe in related R&D, we can make some general policy recommendations that follow.

However, it is important to note that our recommendations are based on the extremes of the distributions, and thus not all RIBs are named under the recommendations. Yet, the totality of the set of Radical Innovation Breakthrough (RIBs) and Radical Societal Breakthrough (RSBs) descriptions and their recent progress directions constitute an important collection of intelligence material that can inform strategic planning in research and innovation policy, industry and enterprise policy, and local development policy.

Policy recommendations:

1. Position Europe strategically for the forthcoming AI wave

Artificial Intelligence is a cluster of innovations that will have huge impact on the future world economy and society. The EU should position itself strategically vis-a-vis these innovations. The following RIBs are either directly contributing to AI by providing new software or hardware solutions or by tailoring AI approaches for specific applications:

- Artificial intelligence (advanced deep learning algorithms)
- Computational creativity
- Artificial synapse/ brain
- Brain functional mapping
- Computing memory
- Neuromorphic chip
- Chatbots
- Speech recognition
- Emotion recognition
- Touchless gesture recognition
- Swarm intelligence
- Driverless
- Flying Car
- Humanoids
- Precision farming
- Automated indoor farming

Emotion recognition

Emotion recognition has been traditionally applying advanced image processing algorithms to images (or videos) of the human face. But recent developments have extended the field to include other means of gauging emotions (text analysis, tone of voice, heartbeat and breathing patterns, etc.), and even extending them to other species. Applications cover areas like marketing (detecting minute, subconscious reactions to advertising or products), smart devices that adapt to our mood, and law enforcement (improved lie detectors).

In some of these areas, such as chatbots, Europe is already strong. These strengths should be fully exploited. In other areas, especially computing memory, capacities in Europe are weak and therefore efforts should be stepped up. At the same time, consolidating the application pathways emerging from the surge of innovations in algorithms and hardware in sectors like mobility, health, education and food seems at least as important as fostering the further emergence of newly upcoming innovations. Especially for Europe, it will be vital to pursue trajectories that unlock the potential of these technologies to support better solutions, which meet the needs of its citizens.

2. Fast emerging innovations

According to our results, there are 45 technologies (listed in table 7) that are currently at a low level of maturity, but are expected to develop fast and find important use in the coming 20 years. Among these, seven RIBs are especially fast moving:

- Neuromorphic chip
- Biodegradable sensors
- Hyperspectral imaging
- Warfare drones
- Harvesting methane hydrate
- Thermoelectric paint
- Neuroscience of creativity and imagination
- 4D printing

Neuromorphic chip

Neuromorphic chips are modelled on biological brains. They are less flexible and powerful than the best general-purpose chips, but highly efficient for specialized tasks. Neuromorphic chips can boost the development of AI based systems for specific purposes such as object recognition, voice and gesture recognition, emotion analytics, health analytics or robot motion, and moderate their power consumption.

In some of the 45 fast moving technologies, Europe's capacities show weaknesses:

- 4D printing
- Bioluminescence
- Automated indoor farming
- Water splitting
- Computing memory
- Molten salt reactors
- Graphene transistors
- Energy harvesting
- Hyperloop

4D printing

4D printing adds an additional element of time to 3D printing/additive manufacturing. 4D-printed objects can change shape or self-assemble over time if exposed to a stimulus – heat, light, water, magnetic field or other form of energy – that activates the process of change. Among the ground-breaking applications expected are drug devices reacting to heat changes of the body, shape memory materials allowing solar panels to auto-rotate towards the sun, and self-repairing infrastructures.

Energy harvesting

Converting energy from the environment into usable electricity involves an ever-expanding set of techniques that draw energy from the sun, the wind, natural heat, and the movement and chemistry of human bodies. Combining solar cells and fibre-based triboelectric nanogenerators, scientists have developed a "hybrid-power textile" that generates electricity from both sunshine and flapping in the wind.

In other such technologies Europe holds a leading position:

- Harvesting methane hydrate
- Underwater living
- Bioplastics
- 3D printing of food
- Lab-on-a-chip
- Chatbots
- Quantum cryptography
- Marine and tidal power technologies

Interestingly in the field of quantum cryptography, the EU leads in terms of patents, but China is taking the leadership in publications.

Bioplastics

Bioplastics use as a source of carbon renewable natural feedstock such as e.g. corn, rice, potatoes, palm fibre, tapioca, wheat fibres, wood cellulose and bagasse. Depending on their chemical composition bioplastics may or may not be biodegradable. Research efforts focus on bioplastics solutions with substantially reduced environmental footprint. Applications include different industries like food and beverage packaging, health care, textiles, agriculture, automotive or electronics.

Lab-on-a-chip

A lab-on-a-chip (LOC) integrates laboratory functions into a single device of small dimensions. Lab-on-a-chip promises better and faster diagnostics, especially in areas with poor healthcare infrastructure, a more active role of patients in monitoring their own health, as well as enabling citizens to engage in environmental monitoring.

In the following fast moving areas, Europe's capacities are strong but not world leading:

- Speech recognition
- Neuromorphic chip
- Flexible electronics
- Gene editing
- Exoskeleton
- Swarm intelligence
- Blockchain
- Biodegradable sensors
- Hyperspectral imaging

Biodegradable sensors

Biodegradable sensors can be used as medical implants for temporary in-body sensing, drug delivery, tissue engineering, microfluidics, for tracking food and environmental sensing, whilst contributing to alleviating the problem of mounting electronic waste.

Fast moving areas hold a lot of promise for important applications and positive economic impacts but also involve the potential for controversy and serious unintended social and environmental consequences. They include, for example, gene editing, warfare drones, harvesting methane hydrate and molten salt reactors, which are already controversial.

3. Nourish capacities in highly speculative areas

The expectation of an increasing rate of change and uncertainty of techno-economic patterns means that radical innovations can unfold very fast.

Therefore, we should not ignore capacities in highly speculative areas such as:

- Neuromorphic chip
- Neuroscience of creativity and imagination
- Plant communication
- Spintronics
- Bioelectronics
- Aluminium-based energy
- Airborne wind turbine
- Artificial Photosynthesis
- *4D Printing*
- *Asteroid mining*
- *Thermoelectric paint*
- *Artificial synapse/brain*
- *Flying car*

Bioelectronics

Bioelectronics is the use of biological materials and architectures inspired by biological systems to design and build information processing machinery and related devices. Researchers hope to develop bio-inspired materials (e.g. capable of self-assembly or self-repair) and bio-inspired hardware architectures (e.g. massive parallelism) to be used in new sensors, actuators and information processing systems that are smaller, work faster/better and require less power.

In the first eight RIBs of this list, Europe has promising capacities. In the other five (indicated in italics) its position is unclear or weak. To maintain and further advance the European position as a pioneering actor in newly emerging technologies it is important to create spaces where also highly speculative ideas with yet unclear perspectives find support and nourishment. This seems especially relevant for the three RIBs on this list that may contribute to the high impact AI cluster, namely neuromorphic chip, artificial synapse/ brain and neuroscience of creativity and imagination. The neuromorphic chip also deserves special attention because in spite of its low maturity expectations on its widespread use in 2038 are very high.

4. Review enabling frameworks for mature technologies

Some of the Radical Innovation Breakthroughs identified are quite mature - they have been known for a while, and are quite established in terms of R&D and patenting. At the same time, they have a great deal of unexploited growth potential in the perspective of 2038. Their technological maturity places them at the junction between research and innovation policy and industry policy concerns. These RIBs are especially located in the area of nanotechnology (nano-LEDs, nanowires, carbon nanotubes), but also hydrogels and holograms fall into this category. Their further development is not so much a matter of research and innovation policy but more a subject for industry policy or other policies concerned with the respective domains. It may be worthwhile checking whether appropriate regulatory frameworks and complementary social innovations are in place for successful and beneficial exploitation of these RIBs. Another question is whether an industry policy is needed to foster the European position in the weaker mature areas such as carbon-nanotubes, nanowires and hydrogels.

Hydrogels

Hydrogels are natural or synthetic polymeric networks capable of holding large amounts of water that can replicate the dynamic signalling involved in biological processes, such as cell/tissue development. In the near future, hydrogels will provide the basis for first-aid kits and innovative drug development concepts. In the longer term we can imagine curative soft robots performing surgeries at microscopic and sub-microscopic levels, and hydrogels in mobile phone screens sensing environmental pollutants and informing an app.

5. Understanding and harnessing the waves of change

In the results of our study, we see two distinct but interwoven waves of change. The first is the wave of information and communication technologies, which is still unfolding amidst important technological social innovations and concerns. The second wave is far less clear in its technological scope and is also shaped by substantially broader demand factors, such as the political and social imperatives associated with the UN Sustainable Development Goals (SDGs). We expect the value creating structures and processes of the future to be significantly shaped by the SDGs, often seeking to speed up positive technological transformations and to control negative externalities. The search for newly upcoming innovations in the SDG related arenas should be intensified. Interlinkages of environmental and health technologies with the ICT wave, and in particular the AI cluster, should be systematically explored in order to exploit synergies and avoid conflicts.

To sum up, European strength in science, technology and industry is necessary to ensure that Europe is competitive and able to achieve its objectives for its future. To be competitive, Europe needs to maximise the value and productivity of its investments in R&I, and this requires appropriate intelligence and coordination between relevant policies and strategies at EU, national and regional levels. We hope that the RIBRI study will nudge Europe’s authorities to further develop their intelligence efforts, to identify key innovations of the future and to debate their usefulness and possible trajectories with maximum benefit for its citizens.

The following picture summarizes the results of all 100 Radical Innovation Breakthroughs:

RIB Assessment

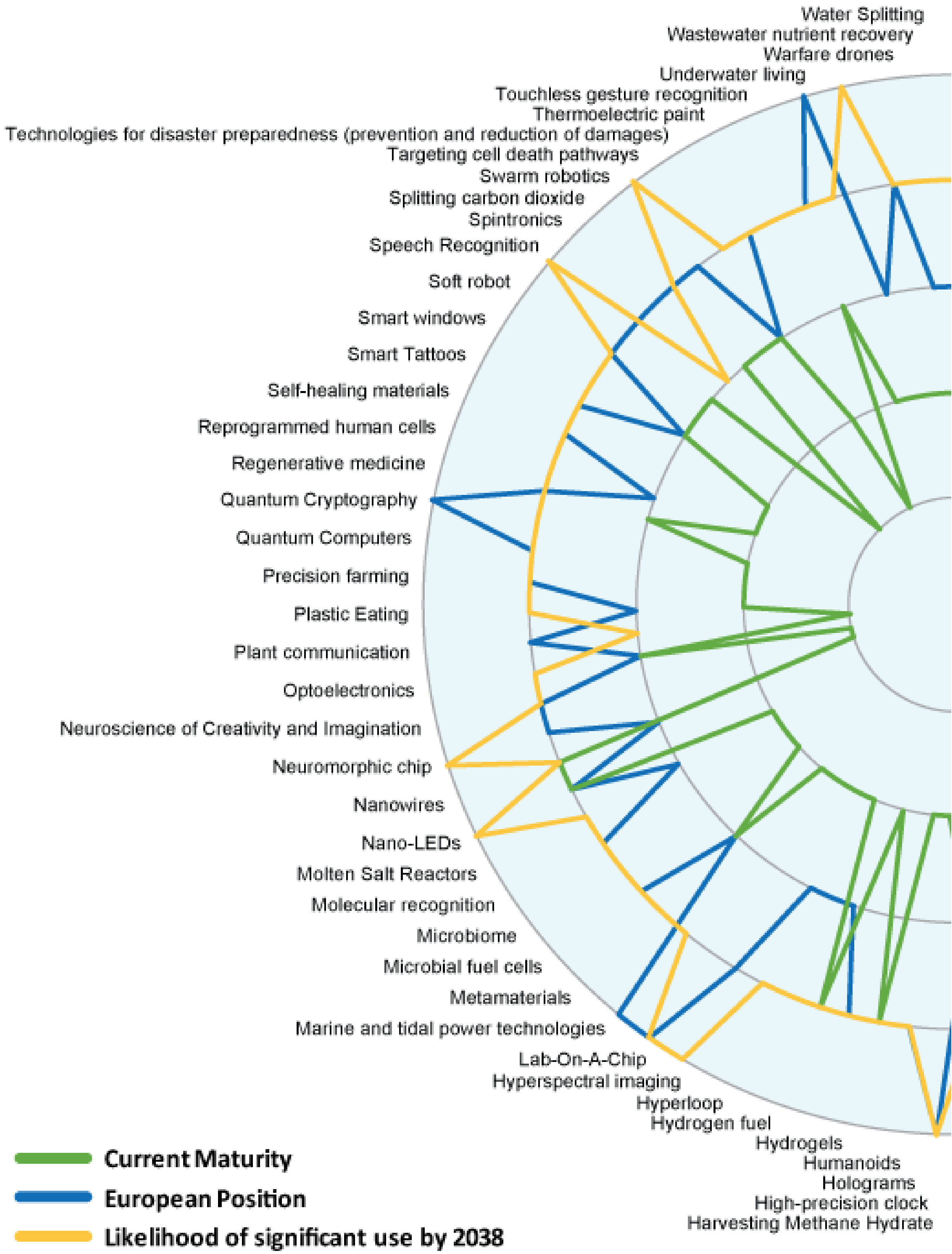
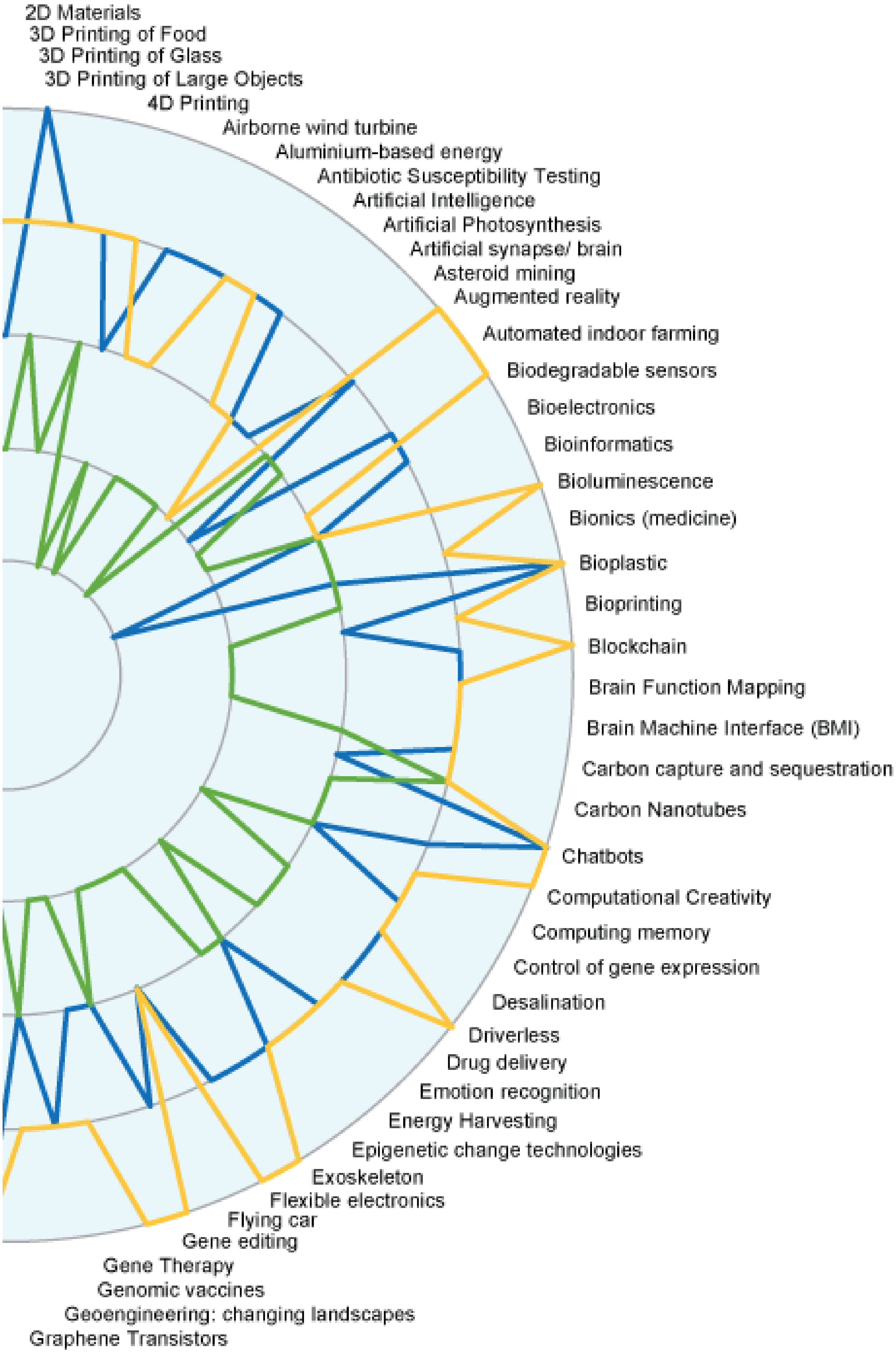


Figure 1: Overview RIB Assessment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Energy Harvesting
Epigenetic change technologies
Exoskeleton
Flexible electronics
Flying car
Gene editing
Gene Therapy
Genomic vaccines
Geoengineering: changing landscapes
Graphene Transistors

1 Introduction

This study set out to identify Radical Innovation Breakthroughs – potentially important cross-cutting, disruptive innovations - that could be usefully considered in the development and implementation of:

- European Union Research and Innovation policy, especially in the implementation of Horizon Europe,
- European Union policies that are supported by the framework programme (e.g. security, environment, agriculture, health, etc. – see Article 179 TFEU) and
- relevant strategies at national and regional level, including smart specialization.

Radical Innovation Breakthroughs are not instant. They result from cumulative processes of multiple inventions and innovations, and their diffusion and adaptation to different circumstances. Their key characteristics are (a) an unusually high impact potential and (b) the potential to disrupt technical, economic and social structures.

This study searched for future Radical Innovation Breakthroughs in literature associated with the continuous efforts of people and society to innovate in technology such as peer reviewed journals from a range of S&T disciplines and platforms sharing cutting-edge S&T news. In this sense, most of the RIBs identified are technological innovations.

People often draw a distinction between technological and social innovations. New movements in society create knowledge about how to do things differently, often emphasizing behavioural aspects rather than the role of technical artefacts. This does not mean that technology does not play a role in social innovations. The continuous effort for social innovation and improvement is part and parcel of human societies, but it is not organized in the same way as the effort for technological innovation. When searching for social innovations in literature, we came across trends that are already well diffused and established. However, some of them contradict fundamental elements of social norms and systems and have thus considerable disruption potential, whilst opening up possibilities to solve important problems plaguing contemporary societies.

The way in which technological and social innovations will combine to shape future industries and sociotechnical regimes can be a matter of considerable uncertainty and speculation. We see so much disruptive potential around us that we are confident that the industries, sectors and value-chains of the future will not be like the ones of today. In order to evaluate the potential impact of future innovations, we considered a number of future global value creating structures, which we termed Global Value Networks, following the approach of the Finnish Radical Technology Inquirer (RTI).[1] These structures represent a mixture of expectations (how things will be), wishes (how things should be) and appreciations of how things are. In each case, the defining characteristic is a network that is associated with a function for

[1] Linturi, Risto, Osmo Kuusi and Toni Ahlqvist (2014) 100 Opportunities for Finland and the World, the Radical Technology Inquirer (RTI), the English edition https://www.eduskunta.fi/FI/tietoaeduskunnasta/julkaisut/Documents/tuvj_11+2014.pdf

which there is a global need, and therefore an actual or potential global market. We believe that the needs underpinning each GVN are significant and will be even more significant in the future. Thus, collectively, our GVNs are likely to represent an important part of the global economy in 20 years' time.

2 Overview methodology

The approach of this study is based on a methodology that was first developed in the context of the Finnish Radical Technology Inquirer (RTI).[2] The first step was to create descriptions of future GVNs from a European perspective. This was carried out through a set of interviews with 35 experts from 22 different European countries, aiming to adapt and enhance the GVN descriptions of the Finnish study to reflect an EU level appreciation of importance. The results were discussed at a workshop with experts and EU policy-makers, and were refined accordingly.

In parallel, and independently from the effort to describe the GVNs, a large set of potential technological innovations was identified through a procedure that combined machine learning algorithms and human evaluation.

After successive waves of refinement, a list of 100 emerging topics has resulted. This iterative process, which is described in depth in section 4, is visualized in Figure 2.

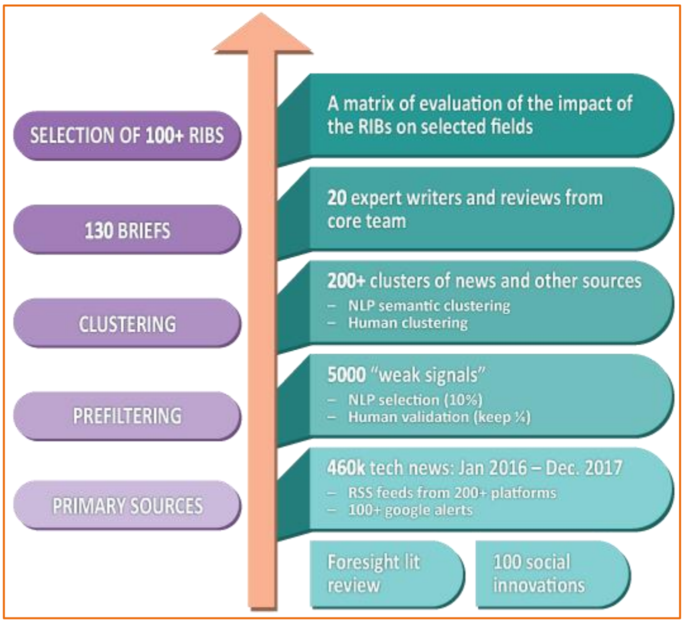

Figure 2: Process of RIB Selection

Simultaneously, a set of potentially disruptive social innovations were identified through a meta-analysis of existing mapping exercises.[3]

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[2] Linturi, Risto, Osmo Kuusi and Toni Ahlqvist (2014) 100 Opportunities for Finland and the World, the Radical Technology Inquirer (RTI), the English edition https://www.eduskunta.fi/FI/tietoaeduskunnasta/julkaisut/Documents/tuvj_11+2014.pdf

[3] The EU Projects CASI http://www.casi2020.eu/ and TEPSIE http://www.tepsie.eu/, OBSERVE https://www.horizon-observatory.eu and the German BMBF Foresight II https://www.zukunft-verstehen.de/application/files/4114/9001/1268/Social_Changes_2030_Band_103.pdf

The resulting technological and social innovations were then submitted to further assessments based on:

1) A consultation of experts from Europe and beyond, in addition to a panel of PhD students specialised in the RIB areas; (for details see Part II, section 1.3)
2) An analysis of the patents and publications; (for details see Part II, section 1.5)

By combining the outcomes of these elements, we formed three key indicators for each technological RIB and three for each societal practice RIB. Table 1 provides an overview of the sources behind each indicator. The details on the calculation of the indicators are provided in the Final Report, Part II, section 1.7 (maturity), section 1.8 (EU position), section 1.9 (likelihood). In addition, we analysed the relationship between RIBs and GVNs. In the Final Report, Part II, chapter 2, we describe the outcomes of this analysis, which allows some conclusions to be drawn in regards to the impact of the RIBs on future value creation and societal needs.

Table 1: Forming of the RIBRI indicators

Indicators RIBs	Sources
Likelihood of reaching market or significant use by 2038	● Online expert consultation ● PhD panel assessment
Current Maturity	● Scientometric Analysis (Level and Dynamics of Publications & Patents)
European Position in R&I	● Expert Consultation, ● Scientometric Analysis (position of EU in Publications & Patents)
Likelihood of significant expansion in Europe (RSB only)	● Expert consultation
Likelihood of significant expansion globally (RSB only)	● Expert consultation

3 How to read the report

Chapter 4 presents the important technological RIBs that form the main body of this study. For presentation purposes, they have been clustered in thematic groups. Most RIBs are combinations of different elements, which form various directions of potential development. These are also described under each RIB.

Chapter 5 presents the 13 emerging important societal practices or "Radical Social Innovation Breakthroughs (RSBs)" that we identified. These practices have implications for the emergence of future value networks, as well as for the direction of technological innovations, and can be supported or counteracted by policy.

Chapter 6 presents the analysis of the societal and technological RIBs. In particular, we assess their likelihood of significant future use, their current maturity and Europe's position in providing policy conclusions and recommendations, which are presented in the concluding chapter.

Chapter 7 presents the 23 descriptions of Global Value Networks (GVNs) used to assess the future importance of the innovations identified. We consider these to be possible future scenarios for important future global value creating structures. While we made considerable effort to create independent scenarios, there are at least two elements strongly present in many of the scenarios. One is the need for sustainability and progress towards the Sustainable Development Goals. The other is the effects of information technology in general, and the combined effects of ubiquitous networks, data and artificial intelligence. We think that these are fundamental characteristics of how value will be created in the future and that they will combine in paradigmatic configurations such as those described by our GVNs.

Finally, in chapter 8, we attempt a bird's eye view on all these elements of possible future techno-economic paradigms and venture into some overarching observations. We conclude with chapter 9.

The final report consists of two parts. Part I gives an overview of the findings and describes the Radical Innovation Breakthroughs in detail. In Part II, we give full details on the individual methodological elements such as the components of the online expert consultation and the approach to scientometric analysis. Readers wishing to go deeper into the findings can refer to the raw results from the consultation, the scientometric analysis and the impact assessment in Part II.

4 Radical Innovation Breakthroughs (RIBs) in technology

In the following sections, we report the identified RIBs in eight thematic groups. The groups emerged from an automatic clustering based on a semantic analysis of the RIB texts. For each RIB, we first show a graph with the values the RIB achieved in the assessments we carried out. Then, the text presents first an overall description of the RIB followed by the more specific directions where the sources claimed recent progress.

The meaning of the indicators is as follows:

- **Likelihood to reach the market or significant use by 2038:** This indicator characterises the expectation of experts regarding the future development of this RIB over the next twenty years. For the social innovations, this indicator was replaced by **Likelihood of significant expansion of this practice in Europe/the world**.

- **Maturity:** This indicator describes the current status of the emerging technology. Low maturity (1) indicates first proof of concept or even first speculations, and very high maturity (5) suggests that a technology is already applied in first products. The assessment rests on the review of related patents and publications. Low maturity has also been assigned in cases where there is already a high level of patents but, a recent steep rise in publications and patents, suggests that important new directionsmay emerge. We did not apply this indicator to the social innovations.
- **European Position:** This indicator captures the strength of Europe's current capability in research and innovation with regards to a technological RIB. Its assessment is based partly on expert assessment from the consultation and partly on the EU's share in patents and publications. We did not apply this indicator to the social innovations

Table 1: Overview Technology RIBs (alphabetical order)

RIB Name	Group
2D Materials	Printing & Materials
3D Printing of Food	Printing & Materials
3D Printing of Glass	Printing & Materials
3D Printing of Large Objects	Printing & Materials
4D Printing	Printing & Materials
Airborne wind turbine	Energy
Aluminium-based energy	Energy
Antibiotic Susceptibility Testing	Biomedicine
Artificial Intelligence	Artificial Intelligence and Robots
Artificial Photosynthesis	Energy
Artificial synapse/ brain	Human-Machine Interaction & Biomimetics
Asteroid mining	Breaking Resource Boundaries
Augmented reality	Artificial Intelligence and Robots
Automated indoor farming	Artificial Intelligence and Robots
Biodegradable sensors	Biohybrids
Bioelectronics	Biohybrids
Bioinformatics	Biohybrids
Bioluminescence	Energy
Bionics (medicine)	Human-Machine Interaction & Biomimetics
Bioplastic	Breaking Resource Boundaries
Bioprinting	Biomedicine
Blockchain	Artificial Intelligence and Robots
Brain Function Mapping	Human-Machine Interaction & Biomimetics
Brain Machine Interface (BMI)	Human-Machine Interaction & Biomimetics
Carbon capture and sequestration	Breaking Resource Boundaries
Carbon Nanotubes	Electronics & Computing
Chatbots	Artificial Intelligence and Robots
Computational Creativity	Artificial Intelligence and Robots

RIB Name	Group
Computing memory	Electronics & Computing
Control of gene expression	Biomedicine
Desalination	Breaking Resource Boundaries
Driverless	Artificial Intelligence and Robots
Drug delivery	Biomedicine
Emotion recognition	Human-Machine Interaction & Biomimetics
Energy Harvesting	Energy
Epigenetic change technologies	Biomedicine
Exoskeleton	Artificial Intelligence and Robots
Flexible electronics	Electronics & Computing
Flying car	Artificial Intelligence and Robots
Gene editing	Biomedicine
Gene Therapy	Biomedicine
Genomic vaccines	Biomedicine
Geoengineering: changing landscapes	Breaking Resource Boundaries
Graphene Transistors	Electronics & Computing
High-precision clock	Electronics & Computing
Harvesting Methane Hydrate	Energy
Holograms	Artificial Intelligence and Robots
Humanoids	Artificial Intelligence and Robots
Hydrogels	Printing & Materials
Hydrogen fuel	Energy
Hyperloop	Breaking Resource Boundaries
Hyperspectral imaging	Artificial Intelligence and Robots
Lab-On-A-Chip	Biohybrids
Marine and tidal power technologies	Energy
Metamaterials	Printing & Materials
Microbial fuel cells	Energy
Microbiome	Biomedicine
Molecular recognition	Biohybrids
Molten Salt Reactor	Electronics & Computing
Nano-LEDs	Electronics & Computing
Nanowires	Electronics & Computing
Neuromorphic chip	Human-Machine Interaction & Biomimetics
Neuroscience of Creativity and Imagination	Artificial Intelligence and Robots
Optoelectronics	Electronics & Computing
Plant communication	Biohybrids
Plastic Eating	Breaking Resource Boundaries
Precision farming	Artificial Intelligence and Robots
Quantum Computers	Electronics & Computing
Quantum Cryptography	Electronics & Computing
Regenerative medicine	Biomedicine
Reprogrammed human cells	Biomedicine
Self-healing materials	Printing & Materials
Smart Tattoos	Human-Machine Interaction & Biomimetics
Smart windows	Energy

RIB Name	Group
Soft robot	Artificial Intelligence and Robots
Speech Recognition	Artificial Intelligence and Robots
Spintronics	Electronics & Computing
Splitting carbon dioxide	Breaking Resource Boundaries
Swarm intelligence	Artificial Intelligence and Robots
Targeting cell death pathways	Biomedicine
Technologies for disaster preparedness	Breaking Resource Boundaries
Thermoelectric paint	Energy
Touchless gesture recognition	Artificial Intelligence and Robots
Underwater living	Breaking Resource Boundaries
Warfare drones	Artificial Intelligence and Robots
Wastewater nutrient recovery	Breaking Resource Boundaries
Water Splitting	Energy

Most of the 100 RIBs and RSBs are collections or 'baskets' of related developments. Since the RIBs were assembled primarily based on news reports, which usually describe one single piece of technology, the main challenge was to group the right technologies under the appropriate headings (the RIB 'title'). Generally, two broad approaches were used for this grouping: RIBs consist of developments related to each other in terms of either the science and technology they are based on (e.g. hydrogels) or in terms of the goals they serve (e.g. drug delivery). One consequence is that a piece of technology occasionally features in two or more RIBs. For example, hydrogels have a dedicated RIB due to the number of diverse solutions using this type of material, but also appear in the context of efforts to build soft robots or to improve the delivery of therapeutic substances (For more details on designing the RIBs, see Part II, section 1.2.). In drafting the RIBs, experts worked, mostly with tech news reports. Since we make no claims as to the originality of the description of these technologies, we have cited our sources copiously. Where we felt it was necessary we also placed text between inverted commas.

AI and Robots

4.1 Group 1. Artificial Intelligence and Robots

4.1.1 Augmented Reality

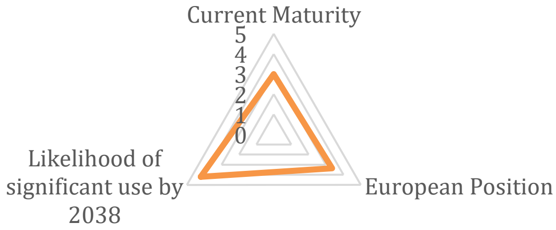

Figure 2: RIB Score of Augmented Reality

Augmented Reality (AR) means overlaying computer generated imagery (or even sound) on our perception of the real world. From a technological perspective, augmented reality is a big challenge as it implies using a complex suite of sensors that can track the user position and points of attention and a good understand of the 3D environment. Currently, the mobile phone acts like a window through which the user can see the world with virtual objects overlaid on top of it, but augmented reality goggles allow the user to see the world through a transparent display that does not redraw the world. Such goggles are expensive and cumbersome but iterative development is improving them every few years.

Recent progress directions

Synchronization with the physical world

The cornerstone of performing AR is the way the virtual projection integrates with the real world. It may sound simple, but it is not easy to completely overlap the human sensory system. Eyes must be tracked to compensate for their movement.[4] The world must be scanned in 3D in order to synchronize[5] the virtual world with it. Some companies are using special cameras for this[6], but others are focusing on using commodity smartphone cameras to accomplish the same task while sacrificing performance.[7] The device must also track people moving through the world.[8] While people tracking augmented reality with facial recognition is controversial from a social perspective, the technology continues to be improved in this direction and police are already deploying it.[9]

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[4] https://www.theengineer.co.uk/sensor-tracks-eye-movements-in-real-time-to-enhance-virtual-reality

[5] https://www.technologyreview.com/s/602091/baidu-is-bringing-intelligent-ar-to-the-masses

[6] https://campustechnology.com/articles/2017/07/24/stanford-team-develops-4d-camera-for-use-in-robots-vr-autonomous-cars.aspx

[7] http://www.3ders.org/articles/20161215-korean-government-announces-affordable-3d-video-capture-technology-for-smartphones.html

[8] http://www.dailymail.co.uk/sciencetech/article-4001734/The-Shazam-faces-World-s-facial-recognition-smartphones-identify-faces-person-print-TV.html

[9] http://abcnews.go.com/International/police-china-wearing-facial-recognition-glasses/story?id=52931801

Live instructions

The most promising professional application for augmented reality are interactive manuals giving live instructions to people working directly with a machine. In order to enable such applications, the AR device must be able to pick up objects from the world and turn them into virtual objects in real time.[10] Instructions can then be projected in relation to these virtual simulacrums. Car companies are already exploring the concept, but the most novel research is happening in the field dealing with the most complex machines of all: human medicine. Doctors are using augmented reality to better guide them during surgery[11], and it is hoped that this will drastically reduce the time spent in the operating room.

Therapy

Improving the health of long-term sufferers is a welcome application for any new technology. AR has already proven that it can help people with sensory issues such as phantom limb patients.[12] This is successfully replacing bulky mirror systems that did not even work for all cases. Another application is to complement the missing sensory processing of autistic children[13] by directly showing them hints of what they should do depending on the social context. Recuperation protocols can be improved by showing patients virtual live models of their own movements[14] allowing them to self-correct.

Displays

Forming an image very close to the eye is not an easy task. While some researchers try to miniaturize conventional very high-resolution displays[15], others are focusing on guiding and projecting the light rays[16] in such a way that a clear image is built inside the eye. Since human eyes have many imperfections, such projection technologies can also be used to improve vision.[17]

Augmented reality with sound

hile most AR solutions generate visual output, a prototype pair of glasses incorporating focused speakers enables different apps to trigger specific audio cues in relation to the objects in the estimated direction of the sight.[18]

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[10] http://www.3ders.org/articles/20170728-purdue-scientists-developing-surfnet-ai-system-that-turns-2d-images-into-3d-models.html

[11] https://www.theengineer.co.uk/augmented-reality-guides-surgeons-during-spine-cranial-and-trauma-surgery

[12] http://neurosciencenews.com/augmented-reality-phantom-limb-pain-5660/

[13] http://www.dailymail.co.uk/sciencetech/article-4900402/Google-Glass-app-tell-autistic-children-say.html

[14] https://www.theengineer.co.uk/ultrasound-augmented-tongue-speech-therapy

[15] http://www.dailymail.co.uk/sciencetech/article-4543270/Get-ready-MegaHD-Experts-reveal-technique-screens.html

[16] http://feeds.nanowerk.com/~/293934432/0/nanowerk/agwb~Engineers-invent-method-to-control-light-propagation-in-waveguides.php

[17] http://www.japantoday.com/category/technology/view/retinal-scanning-display-glasses-developed-for-weak-sighted-people

[18] https://www.theverge.com/2018/3/12/17106688/bose-ar-audio-augmented-reality-glasses-demo-sxsw-2018

Long-term perspectives

The ultimate goal of the currently competing technological solutions is to have an unobtrusive device that seamlessly overlays the virtual world on top of the user's natural senses. This device may be a pair of glasses, contact lenses or even a cybernetic implant to beam the virtual world directly into our nerves. While such devices are still far, companies are cautiously investing in this direction. For productivity, instead of being tied down to a PC monitor, a whole wall could serve as a desktop workspace. Teleconferencing would be as easy as looking across the table to the virtual representation of your colleague. For people working on site, plans for modifications would be overlaid directly in the room. No need to fumble with a manual when augmented reality can show you how to fix an engine by highlighting the components that need intervention. The advertising industry is taking particular interest in augmented reality seeing it as both an opportunity and a threat. There is a great benefit to showing people personalized ads in the real world, but those same people might want to install an augmented reality ad-blocker and stop seeing any billboards at all.

Gaming is another great fit for the technology. No longer would computer games be tied to the living room. We have already seen a glimpse of this with the Pokemon Go mobile app. That game only implemented rudimentary augmented reality but the features garnered a large number of players.

With seamless AR, every human would see his or her personalized version of the world. Imagine all what you see in your field of vision is translated into your language, or personalized signs that point you to your airplane seat, or the colour of the sky changing to fit your mood, or virtual pets following you everywhere. However, with everyone seeing things their own way there is no telling how society would change.

4.1.2 Automated Indoor Farming

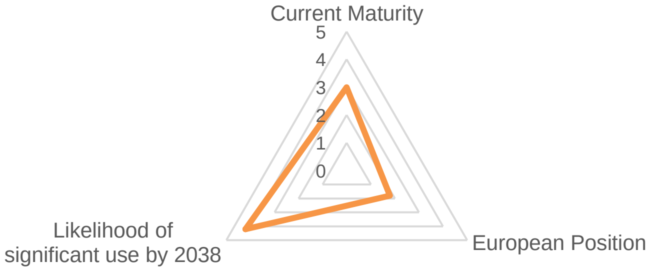

Figure 3: RIB Score of Automated indoor farming

There are a number of reasons to move farming indoors. In areas with high radioactivity – such as those experiencing the aftermath of nuclear disasters –, there are fears that traditionally grown produce could contain radioactive fallout. In other areas, a desert environment, lacking in water resources or other geographical factors, may pose challenges for growing vegetables. In such cases, factory farming, which is mostly indoors, may be viable and scalable.

Recent progress direction

Fully automated farming process

Japanese companies are advancing fast in robotic indoor farming that is stable in any climate condition. More than 200 'plant factories' in Japan are capable of harvesting 20,000 heads of lettuce daily.[19] Their lettuce is grown hydroponically, in a nutrient-rich gelatinous substance in a sterile environment in vertical stacks under LED lights. One example is Spread, a company running "a giant factory farm that grows lettuce" in Kameoka, Kyoto Prefecture and another one at the plant factory at Kansai Science City.[20] The so-called vertical farms allow for a highly efficient use of water.

At the same time, automation of outdoor farming is also progressing quickly. Guided by artificial intelligence systems, machines carry out classical farming tasks such as raising seedlings, replanting and harvesting but also animal husbandry.

Techno farming in extreme conditions

The concept of indoor factory farm is now being exported to the Middle East, where the desert environment, lack of water resources and other geographical factors pose challenges for growing vegetables.

Long-term perspectives

Some people think that, in the long run, agriculture could become fully automatized, first in areas with a lack of human workers and extreme conditions and then around the globe. This could have disruptive impacts areas in like food culture, sustainability, social fabric and, last but not least, employment.

[19] https://www.japantimes.co.jp/life/2017/03/10/food/indoor-farms-next-step-evolution-agriculture/#.Wp8CCE0m52s

[20] https://www.japantimes.co.jp/life/2017/03/10/food/indoor-farms-next-step-evolution-agriculture/#.Wp8CCE0m52s

4.1.3 Blockchain

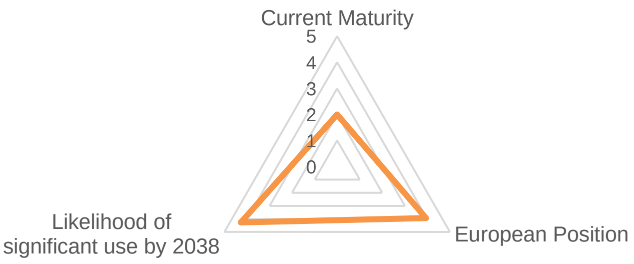

Figure 4: RIB Score of Blockchain

The blockchain is a technology that allows people who do not know each other to organize a network to keep trusted records. Once recorded on a blockchain a piece of information cannot be changed. The most common application is that of a "distributed ledger" that keeps track of transactions. This solves, among others, the problem of double spending digital money (or other information). Using the blockchain, digital data can have an owner recognized by everyone in the network. The blockchain is also the technology at the core of cryptocurrencies like bitcoin. The way this network functions is a matter of debate and different implementations have sparked new ideas and development directions outside the original scope of the concept. At its core, a blockchain is a data structure consisting of a linked list that is cryptographically secured so that its elements cannot be altered after they have been set. Unfortunately, it also comes with a cost, as the energy consumption for Bitcoin mining is estimated to be comparable to that of Ireland and increasing.[21]

Recent progress directions

Trust and notarization

As data registered on the blockchain is immutable, data ("hashes") in any document can be stored there and verified at any point in the future. This is bringing considerable disruption to the field of notarization by removing the human intervention from the loop and providing anonymity.[22] Companies are interested in storing the data about their product in immutable databases.[23] This way they will be able to reliably trace any information

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[21] https://arstechnica.com/tech-policy/2018/05/new-study-quantifies-bitcoins-ludicrous-energy-consumption/

[22] https://guce.oath.com/collectConsent?brandType=nonEu&.done=https%3A%2F%2Ftechcrunch.com
%2F2015%2F09%2F22%2Fstampery-leverages-the-blockchain-to-certify-all-your-documents%2F%3Fguccounter%3D1&sessionId=3_cc-session_69504575-d56c-4d49-a0f5-53f3e3df1d75&lang=&inline=false

[23] https://www.wired.com/2017/05/curious-plan-save-environment-blockchain/

about their products when queried.[24] This has the potential to improve operations considerably and reduce the legal burden considerably.

Smart contracts

Code that transacts the digital assets is being made to be self-executing by registering it on the specific blockchain itself.[25] This means that any transaction that required escrow can now use a smart contract instead. Furthermore, any money processing operation (exchanging currency, routing or even gambling) can be implemented as a smart contract. In practice, every member of the blockchain network gets a readable copy of the code.[26] The validating nodes of the blockchain network then execute the stored code when the prerequisite conditions are met. Transactions executed by smart contracts need to be done in cryptocurrency (Bitcoin, Ethereum and so on). It is hoped that this use case of cryptocurrencies will further legitimize their existence in the financial sector.

Private corporate blockchain networks

Not all networks have to be public and as such business and IT companies are investing considerable resources in developing private blockchain networks[27,28] that can be deployed as easily as cloud infrastructure[29,30] for any need a company might have. These private blockchains could be used for storing data, certification or even some tightly controlled form of cryptocurrency.

Proof of Stake Protocol

Currently, the main method for mining is "proof of work", in which the miners' competition involves a process of generating signatures repeatedly until one guesses correctly a random number, the consumption of energy being immense.[31] An alternative method called "proof of stake", which select validators based in part on the size of their respective monetary deposits (their stake) is currently under review to be adopted by Ethereum, one of the leading cryptocurrency network.[32]

Long-term perspectives

A blockchain-enabled world without central controlling authorities might happen through decentralized networks, providing a neutral and fair result

[24] http://fortune.com/2017/05/30/walmart-blockchain-drones-patent/

[25] https://www.coindesk.com/ethereum-blockchain-homestead/

[26] https://cointelegraph.com/news/trust-but-verify-first-ethereum-decompiler-launched-with-jp-morgan-project

[27] http://fortune.com/2016/10/04/jp-morgan-chase-blockchain-ethereum-quorum/

[28] https://www.prnewswire.com/news-releases/chronicled-launches-quorum-blockchain-integration-at-enterprise-ethereum-alliance-kickoff-300414641.html

[29] https://www.coindesk.com/ibm-goes-big-on-blockchain-unveiling-ambitious-new-service-offerings-and-strategy/

[30] https://techcrunch.com/2017/08/10/microsoft-wants-to-make-blockchain-networks-enterprise-ready-with-its-new-coco-framework/?guccounter=1

[31] https://www.technologyreview.com/s/609480/bitcoin-uses-massive-amounts-of-energybut-theres-a-plan-to-fix-it/

[32] https://cryptoslate.com/ethereums-proof-of-stake-protocol-in-review/

to all possible transactions. Presently, companies are seeing blockchain technology as an opportunity to increase traceability in their own business. Perfect immutable records can be kept without any hassle or risk of contamination. They can be verified at any time by anyone on the network. This can be used to boost the transparency of an endeavour. As such, the blockchain is accepted by public groups and private companies as a future infrastructure for honest business. Most if not all leading companies in technology are interested in deploying blockchain implementations relevant to their fields.

4.1.4 Chatbots

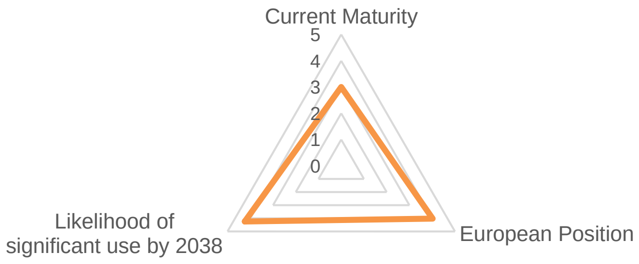

Figure 5: RIB Score of Chatbots

Chatbots, short for "chatting robots", are computer programs which conduct real-time conversations with humans, via written text or live audio.

Designing a chatting machine that would be as adept at conversations as an ordinary person has fuelled computer scientists' imagination and ambition ever since 1950, when British mathematician Alain Turing framed that challenge as a famous benchmark for artificial intelligence. Until recently, software research around chatting programs only progressed at a slow pace and did not yield notable results. During the last years, however, significant software and hardware advances in natural language processing, machine learning, and cloud computing have given rise to a host of widely available chatbots, employed for personalized (albeit still limited) conversations. Some chatbots are standalone applications. Others are integrated in messenger applications, social platforms and larger IT ecosystems, on a range of digital devices. While many chatbots are aimed at assisting with specific tasks (such as placing shopping orders or finding out the weather forecast), the range of chatbot capabilities and uses is quickly expanding, spanning areas such as banking, telecom and entertainment.

Recent progress directions

Unscripted, AI-powered chatbots

Traditionally, chatbots have followed a set of predefined rules and scripts, looking for certain words and providing predefined answers to predefined questions. This paradigm has often led to an underwhelming user experience. Newer chatbots are powered by Artificial Intelligence technologies (such as Natural Language Processing and Machine Learning), allowing them to be more flexible in terms of user input and blurring the line between chatbots and virtual assistants like Siri, Cortana or Google Assistant. Machine learning techniques (and, in particular, Deep Learning models) enable the automatic training of chatbots, mitigating the issue of question variants. Businesses can program AI-powered chatbots to pull information from a trove of available data and self-improve over time: the more they are used, the more they are learning and the better they are getting.

The end result is that an unscripted chatbot has fewer limitations: it is far more likely to understand a question and to provide a helpful answer when a response does not fit a narrow script. Even when a chatbot is unsure about what the user exactly asked, it can attempt to offer multiple options rather than defaulting to the standard (and dreaded) response: "I don't know".[33]

Technology reuse and integration with major platforms

Most major high-tech players have invested significant resources in the development of chatbots and virtual assistants. Having developed competing technologies, the big consumer-facing IT companies have integrated chatbots and virtual assistants in their messaging platforms and ecosystems. Besides deploying chatbot services directly to end users, the companies have also opened up their conversational technologies to outside developers.

In April 2016, Facebook announced support for chatbots in its very popular Messenger system[34], leading to a flurry of Messenger chatbots launched by third parties (jumping from 30,000 to 100,000 within a single year), alongside notable hype. One can use dedicated chatbots to book an appointment or to order a Uber ride, directly in the Messenger platform.[35] Google's 2016 Allo, a smart instant messaging app, allows people to chat directly with Google Assistant and receive, for example, restaurant or movie suggestions.

Besides integrating Cortana, the AI assistant, into its core products, Microsoft launched Bot Framework, a set of programming tools for chatbot developers, in early 2016. Over 130,000 developers have since registered for the service. Microsoft's two chatbots for Chinese and Japanese users, Xiaoice and Rinna, launched in 2014 and 2015, have been used by millions as information providers – but also for interaction at a personal and emotional level, perhaps in part due to techno-cultural proclivities.

Apple and Amazon are also pushing further the development of their own smart assistants, SIRI and Alexa, which embed chat functions. In April 2017, Amazon made Amazon Lex – a set of conversation tools also used by Alexa – generally available to other companies.

[33] http://www.information-age.com/chatbots-more-chit-chat-123469420

[34] There were 1.2 billion registered users in mid-2016 (https://getvoip.com/blog/2017/04/21/the-current-state-of-chatbots-in-2017)

[35] https://getvoip.com/blog/2017/04/21/the-current-state-of-chatbots-in-2017

In Europe, Telia, Scandinavia's largest operator of mobile, fixed and broadband services, announced in the summer of 2018 the launch of A Conservational Engagement (ACE). This customer relations platform adds the latest AI technologies to a pre-existing chatbot ecosystem already in use elsewhere on the continent (such as by electricity giant E.ON).[36]

Enterprise and Customer Service Applications

Chatbots are increasingly used for customer care across a spectrum of fields, including commerce, banking and telecom. In customer service, the focus is on solving a customer query, rather than on personalization and good conversational skills. Generally, chatbots are complementing and assisting customer service representatives (CSR) in order to reduce workload, rather than replace the latter. They are mostly used to handle routine questions, retrieve information from technical databases, and redirect calls or inquiries.

The financial sector is increasingly testing and deploying chatbots. While legacy banks seek to supplement their core products, a number of fintech startups have built chatbots as core products. Supported transactions include balance checking, bill paying and money transfers, such as the daily transfer of small amounts into savings (microsaving).[37] While traditional banks are somewhat slower to adapt, they do not sit still either. In Scandinavia, banking giants SEB, Swedbank and Nordea have introduced Aida, Nina, and Nova, respectively, in 2018, after several years of internal tests. These AI-powered assistants have emotion-sensing and other state-of-the-art capabilities.[38]

Across the oceans, Australian giant NAB has developed a virtual banking assistant powered by AI which is able to answer more than 200 common questions relating to business banking accounts, with 13,000 variants, extracted from real-life customer enquiries. When the bot cannot answer a question, a human banker takes over.[39] In early 2017, a survey undertaken in Australia suggested consumers were warming to bots, although 56 % still preferred to interact with a human.[40]

Long-term perspectives

While a general-purpose chatbot on par with humans is not expected in the foreseeable future, chatbots will likely evolve and enter the mainstream, as they are getting progressively better at understanding and responding to user questions and commands. As chatbots get smarter and smart assistants get chattier, the line between chatbots and smart assistants will further blur.

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[36] https://www.teliacompany.com/en/news/news-articles/2018/the-creators-of-a-grand-new-world/
[37] http://www.businessinsider.com/chatbots-banking-ai-robots-finance-2017-10
[38] https://www.computerweekly.com/news/252434043/Swedish-banks-embrace-rapidly-evolving-chatbots
[39] https://www.cmo.com.au/article/626835/nab-taps-power-ai-chatbots-business-customer-service
[40] https://www.cmo.com.au/article/619915/report-aussies-happy-talking-chatbots

The future of chatbots (as well as virtual assistants) is linked to the future of Artificial Intelligence. Assuming continued advances in AI algorithms and chips (and, particularly, in NLP), AI powered chatbots will get better and better at understanding the intent behind a human's question, as well as at providing meaningful answers in a variety of conversational scenarios. Future chatbots could lead to rich conversational user interfaces, allowing users to naturally interact with a trove of devices (including computers, smartphones, robots, smart homes) rather than using all kinds of graphical interfaces and applications.

4.1.5 Computational Creativity

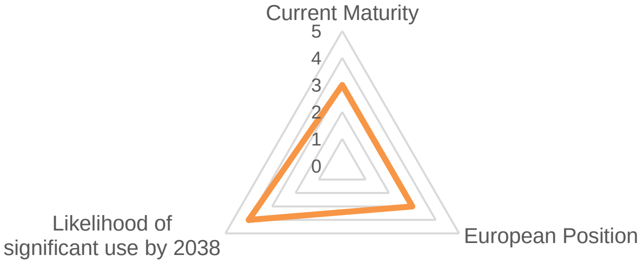

Figure 6: RIB Score of Computational Creativity

Computers are now capable of producing output that is (almost) indistinguishable from human works.[41] They use software, which assesses information, identifies a gap and then uses the best elements at its disposal to create something brand new. In other words, computers are not randomly mixing existing data; instead, they use scientific methodologies and, by merging existing features, produce creative results.

Recent progress direction

Computers are capable of creating original art, ideas and solutions that look as much human-generated as the work appearing at major art fairs or coming out of well-established think tanks.

The semi-autonomous AI systems producing these works are supported by human designers. They are programmed by humans, but identify new avenues, new solutions, and new ideas by having no preconceived limitations and by using massive amounts of processing power. Alongside Machine Learning and Natural Language Processing, as well as computational perception and contextual awareness[42], Computational Creativity is an integral part of finding solutions. "The AI can explore a

[41] https://news.artnet.com/art-world/rutgers-artificial-intelligence-art-1019066

[42] http://telecoms.com/486958/nvidia-software-raises-question-as-to-whether-creativity-actually-exists/

space, identify things that are potentially interesting, and then present them to a designer to follow up on."[43]

Some machines can also teach themselves - a special AI (AutoML) can now pick out specific objects in images better than any other computer vision system.[44] This is an AI form effectively created by another AI, training only on rules and large swaths of data.

In some domains, "ignorance of tradition and precedent is a clear weakness for an AI system"[45], but in finding new designs it represents "a strength that could unlock new creativity. Moreover, it could help managers and designers lower the cost of producing new strategies and products".[46]

Long-term perspectives

Creativity through AI will play an ever-increasing role in the future, augmenting humans in their quests and problem solving, besides the automation of menial tasks. The next frontier is using increasingly sophisticated machine-learning techniques to design entirely new kinds of objects or strategies that have, to date, evaded the human imagination.

4.1.6 Driverless

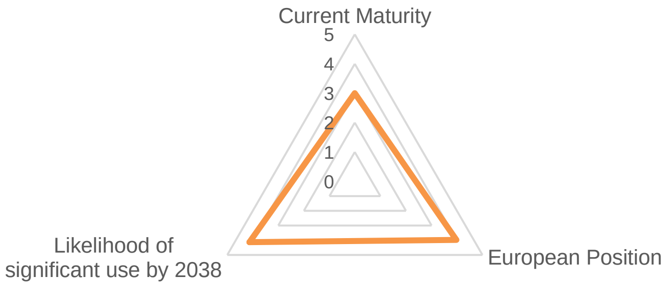

Figure 7: RIB Score of Driverless

For a long time, the driver was thought to be indispensable for any type of vehicle. While an autopilot that can handle long monotonous sections without obstacles was considered standard for water and air vehicles, no solution was available for land vehicles. Autopilots also failed completely when encountering even small disruptive elements. Thus, the driver remained central to the operation of any vehicle. Even fiction did not stray from this idea too much, as most visions of the future lacked any truly self-driving vehicles. This all changed when the DARPA grand challenge proved that driverless vehicles were not only possible, but within our grasp.

[43] https://www.technologyreview.com/s/609482/ai-is-dreaming-up-new-kinds-of-video-games/
[44] http://www.iflscience.com/technology/googles-ai-makes-its-own-ai-children-and-theyre-awesome/
[45] https://www.technologyreview.com/s/609482/ai-is-dreaming-up-new-kinds-of-video-games/
[46] https://www.technologyreview.com/s/609482/ai-is-dreaming-up-new-kinds-of-video-games

Surprisingly, self-driving technology was not descended from autopilot systems. Instead, it was an extension of autonomous robotics research. For decades, roboticists had developed many algorithms for autonomous robots without much thought of practical applications outside the lab. Blue-sky research into small (person-sized) robots, which could roam around on their own, turned out to be relatively easy to scale up. Turning a traditional car into a self-driving car boiled down to equipping it with enough sensors and computers to essentially turn it into a large autonomous robot.

The winners of the DARPA grand challenge were not perfect. In fact, their performance was amusing sometimes. However, they proved to the world that it could be done. Suddenly everyone could envision a world where the driver is not a mandatory part of any moving vehicle. The world braced for the inevitable appearance of self-driving cars and the extinction of driving as a requirement (or even a job) but the revolution has been reluctant to make itself felt.

It turns out that all the sensors and computers needed to make a car self-driving are very expensive. Not only that, but they are very fragile. Nobody wants to equip a car with electronics worth many times more than the car itself and replace the failing ones in a few weeks. Furthermore, real world behaviour of human drivers appears to be hard to anticipate as it varies wildly from day to day and region to region. This set of problems refocused research on creating self-driving vehicles with fewer, cheaper sensors and making the vehicles themselves capable of learning. These efforts are intertwined, as the most efficient way of making a self-adjusting system with few sensors is by making it capable of learning. Unfortunately, this brings us into uncharted territory. "Robodrivers" resulting from learning algorithms are not fully understood even by their designers. Some experts are quick to raise the alarm and deem them unpredictable. Questions have arisen about how self-driving vehicles would handle ethical dilemmas. Although much safer than human drivers, such vehicles might accidentally injure or kill someone. Engineers believe this is a non-issue because systems prefer inaction to making moral choices, but critics are not convinced.

Despite the criticism, industry is moving ahead. Every major company involved in vehicles (land, sea, air or any other kind) is investing significant resources to bring this technology comfortably to market. While the public deployment of the technology will not be as sudden as originally thought, it will slowly start to change things. The long-term effects are still undetermined. As the transportation industry changes, it usually induces significant change in all other fields connected to it.

Recent progress directions

New-generation sensors

Since one of the main obstacles to wide availability of driverless technologies is the relative cost and complexity of sensors, a lot of effort goes into finding new ways to perceive the world. Modulated electromagnetic waves are already omnipresent in our world so maybe they can also be used to guide[47] driverless vehicles. The general idea would be to cover the blind spots and imperfections of GPS and other traditional navigation signals so that fast moving driverless signals do not have to always rely on them.

Instead of building a perfect representation of the environment in the computer memory, several companies are trying to train the computer to think using more limited data. Car companies will try to outfit regular cars with enough sensors to build a rough understanding of the driving environment[48] and then train a computer[49] to link the environment to what the human driver is doing.

Even the "traditional" LIDAR (laser radar) is being augmented[50] in order to see through foliage and bad weather. Some are looking to replace LIDAR completely with special cameras[51] that capture "light fields". These light feed cameras operate passively and absorb so much information about the light rays entering them that a computer can reconstruct the 3D environment the camera films.

Another novel approach involves turning the sensors inward to allow driverless vehicles to sense themselves and predict breakdowns.[52]

Man-machine synergy

From an interface design point of view, driverless vehicles are unexpectedly complicated. If the vehicle is expected to carry humans, it must communicate with them in an intuitive and clear way. This means outfitting the vehicle with internal sensors[53] dedicated to passenger analysis. The problem is compounded if there is a fall back system allowing a human driver to take control of the vehicle. Direct brain interfaces have been explored as a solution[54] allowing the human to direct the vehicle while the vehicle can monitor the mental state of occupant. Even if it is not expected to carry humans, a driverless vehicle must be able to interact with humans it may encounter in the environment. To this end, algorithms are being developed that can analyse humans instantly[55] in order to understand their movement and intent.

Legislation

Many developers see legislation as an obstacle to the development of driverless vehicles, but many jurisdictions have proven to be supportive

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[47] http://www.azosensors.com/news.aspx?newsID=11583%20

[48] http://www.techradar.com/us/news/car-tech/toyota-plans-to-use-self-driving-car-cameras-gps-to-make-more-accurate-road-maps-1311730

[49] https://www.seeker.com/a-way-for-driverless-cars-to-see-the-road-and-react-1770642552.html

[50] https://www.eurekalert.org/pub_releases/2017-06/tos-stf062717.php

[51] https://campustechnology.com/articles/2017/07/24/stanford-team-develops-4d-camera-for-use-in-robots-vr-autonomous-cars.aspx

[52] https://www.springwise.com/startup-using-ultrasonic-sensors-revolutionise-automobile-industry/

[53] http://www.azosensors.com/news.aspx?newsID=12074

[54] http://venturebeat.com/2015/12/07/chinese-researchers-unveil-brain-powered-car/

[55] https://www.eurekalert.org/pub_releases/2017-07/cmu-act070617.php

rather than disruptive. When it comes to land vehicles, it has been decided that the definition of driver is outdated[56], as it does not describe who may be in control of the car. California, with its many tech companies, has gone a step further by allowing driverless cars to operate without any human inside[57], while making the owner of the vehicle responsible for the actions of the computer in control of the vehicle.

The high seas continue to enjoy a special status even in this new age. There is currently no legislation governing autonomous ships[58] and companies are eager to take advantage of this.

Connectivity

When a vehicle is continuously moving through a landscape at high-speed, connectivity becomes a true problem. Traditional data connections become hard to maintain and the driverless vehicle cannot broadcast or receive the data it needs. State of the art telecom infrastructure is being developed with this in mind.[59] The complete opposite approach is to have many autonomous vehicles communicate with each other[60] to create a mesh network. In this way, only a few vehicles at a time would be able to relay all the data to the outside world. Of course, the last resort is to develop a vehicle that can operate completely autonomously[61], but even such a vehicle would benefit from a means to connect reliably to the internet if needed. As for the occupants, turning the vehicle itself into a communication hub[62] would mean the devices inside will connect to it using standard protocols, while the special antennas of the vehicle handle outside connections.

Long-term perspectives

The concentrated effort to create fully autonomous driverless vehicles continues. However, despite the transnational resources devoted to developing the technology, the vision is not as clear as many originally thought. The promise of having wide scale deployment of completely autonomous driverless vehicles by 2020 is unlikely to be realised. Instead, companies are focusing on creating almost-autonomous vehicles that can safely let a human take control during unforeseen situations. This might be an attractive option, but several groups have pointed out that people will slowly be deskilled by self-driving systems. As a consequence, humans might not be able to react better than a computer. In the commercial sector it is precisely this conundrum that is keeping jobs moderately secure. Professional drivers are still expected to perform better than computers.

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[56] http://robohub.org/nhtsa-redefines-driver-of-self-driving-car/

[57] http://robohub.org/california-proposes-driverless-car-rules/

[58] https://singularityhub.com/2017/07/30/the-worlds-first-autonomous-ship-will-set-sail-in-2018/

[59] http://www.telecomstechnews.com/news/2017/feb/22/5g-edges-closer-china-mobile-announces-large-scale-testing/

[60] http://www.aerotechnews.com/blog/2015/12/02/lockheed-martin-conducts-collaborative-unmanned-systems-demo/

[61] https://techcrunch.com/2017/02/21/exyn-unveils-ai-to-help-drones-fly-autonomously-even-indoors-or-off-the-grid/?ncid=rss

[62] http://techcrunch.com/2015/12/23/meet-kymeta-the-company-that-could-bring-high-speed-wi-fi-to-cars/

One can envision a future in which self-driving vehicles handle most of the tasks while human drivers are available to step in whenever needed.

In the long term, once completely self-driving vehicles become the norm, society will start to experience paradigm shifts. Workers will be able to use the time usually wasted on commuting. Private car ownership might not be attractive to many people anymore. Transportation is set to become a commodity regardless if it is by land, air or sea. Businesses owners envision many possibilities. Food trucks may roam the city serving food by app. Innovative package delivery systems would combine trucks and drones to deliver shopping without human intervention. Fully unmanned container ships that are impossible for pirates to attack may become a reality. Some are even looking to flying driverless cars as a possibility.

The impact on the broader society is likely to be major, and most likely impossibly to fathom at this point. At the least, urban infrastructure will adapt to better-fit self-driving vehicles. Plans include roads dedicated to self-driving, zero signal intersections, or even subterranean tunnel networks in which no human would be allowed to drive.

The real-estate market will also be amongst the first to react to such changes, but the direction of change is not well understood. The question many are asking is how will housing prices be impacted if it’s easier to commute. One scenario is that easy accessibility for the suburbs will drive up prices by drastically raising demand. Another possible scenario is that increased accessibility to more land will mean supply of suburban space will outstrip demand, leading to a sharp drop in housing prices.

It is truly hard to pinpoint an industry that will not be affected by ubiquitous driverless vehicles. As such, it is tempting to prepare legislation in advance in an effort to safeguard against radical changes. However, this might hamper development. Overregulated societies will miss out on the massive growth technology brings. To avoid stagnation, governments of many countries have chosen to support companies in this sector and ensure a harmonious evolution of legislation alongside technology.

4.1.7 Exoskeleton

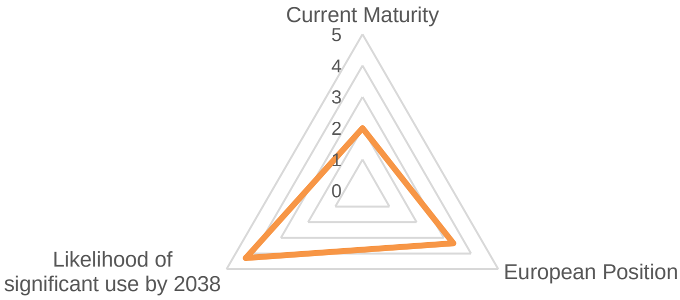

Figure 8: RIB Score of Exoskeleton

An exoskeleton is an external, artificial structure designed to be worn in order to compensate or enhance natural (i.e. biological) physical abilities. It is built using robotics and biomechatronics and consists of a wearable device that works in tandem with the user. Being placed on the person's body and acting as an augmenting amplifier, it reinforces or restores human mechanical performance.

Materials for building exoskeletons can be rigid, such as (light) metals, plastics or carbon fibre, or the framework can made out of elastic and soft components. "Exoskeletons can be powered and equipped with sensors and actuators, or they can be passive (non-powered)".[63] Depending on the intended use, exoskeletons "can cover the entire body, just the upper or lower extremities, or even a specific body segment such as the ankle or the hip."[64]

Recent progress directions

Medical applications

One of the main fields of applications is in the medical field, where exoskeletons are used to help restore patients' limb movement. For example, by exercising in an exoskeleton linked to a brain-computer interface, paralyzed patients were able to regain partial movement and muscle control.[65] Scientists discovered that an exoskeleton "could restore multiple sclerosis patients' balance and some of their walking capability."[66] In addition, it seems that an exoskeleton may help children with cerebral palsy overcome crouch gait.[67] For the elderly, a waist-down exoskeleton

[63] https://exoskeletonreport.com/what-is-an-exoskeleton/
[64] https://exoskeletonreport.com/what-is-an-exoskeleton/
[65] https://www.popsci.com/paralyzed-patients-regain-partial-movement-using-brain-controlled-device?dom=rss-default&src=syn
[66] https://multiplesclerosisnewstoday.com/2017/08/07/study-suggests-that-the-restore-exosuit-can-improve-ms-patients-ability-to-walk/
[67] https://www.upi.com/Health_News/2017/08/23/Exoskeletons-may-help-children-with-cerebral-palsy-avoid-crouch-gait/6881503517705/

learns the wearer's stride and can detect and counteract the loss of balance.[68]

Other "proofs of concept" include: a wearable robotic leg with natural knee movement[69], and regular fabric coated with an electroactive material that acts as muscle fibres and could be incorporated into clothes.[70]

Military applications

While Sci-Fi fans and video game players are excited to see "full body armor suits" looking like those in Star Wars[71] or Iron Man[72], for now they are far from useful military devices. On the other hand, it seems that something that could be really used on the battlefield is an exo-suit "with pulleys and gears designed to reduce the musculoskeletal stress typically experienced by soldiers."[73]

Industrial applications

Physical stress, fatigue and the danger of injury also affect civil workers. Companies are beginning to explore the benefits of exoskeletons – for example a spring-loaded vest designed to reduce shoulder injury.[74] A team of researchers developed a modular exoskeleton for heavy physical work that comes with three components: one supports the back of a man, another – the shoulders, another – his legs. Tests have shown it reduces the load on back muscles by up to 60 %.[75] Also promising is a passive, non-powered exoskeleton that transfers the weight of heavy tools to the ground, helping relieve workers' fatigue.[76] Ford employees in 15 plants globally who perform repetitive overhead tasks now have assistance from an upper body exoskeleton, which provides lift assistance from five pounds to 15 pounds per arm.[77]

Long-term perspectives

The most mature applications of exoskeletons seem to be medical: they will help patients recover from paralysis, multiple sclerosis, cerebral palsy and other debilitating conditions. Gradually the exoskeletons could become widely used by the elderly.

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[68] https://newatlas.com/exoskeleton-balance-prevents-elderly-falls/49592/
[69] https://www.theengineer.co.uk/wearable-exoskeleton-mimics-human-knee/
[70] https://phys.org/news/2017-01-muscles-power.html
[71] https://www.engadget.com/2017/07/06/russian-exoskeleton-suit-turns-soldiers-into-stormtroopers/
[72] https://defensemaven.io/warriormaven/land/special-ops-advances-iron-man-suit-2018-ER6wHPJ9WUq_PJaBOyI0Kg/
[73] http://www.aerotechnews.com/blog/2017/07/17/prototype-exoskeleton-suit-would-improve-soldiers-physical-mental-performance/
[74] https://www.theverge.com/2017/12/5/16726004/verge-next-level-season-two-industrial-exoskeletons-ford-ekso-suitx
[75] http://cwt.top/en/news/1274/modular-exoskeleton-for-heavy-physical-labor
[76] http://www.dailymail.co.uk/sciencetech/article-4444224/The-Iron-Man-arm-workers-superhuman-strength.html
[77] https://media.ford.com/content/fordmedia/fna/us/en/news/2018/08/07/ford-rolls-out-exoskeleton-wearable-technology-globally-to-help-.html

New industrial equipment could become closer to exoskeletons, increasing the integration of human decision and body action. Military full-body armours, however, are very challenging because of their power problem: they need a lot of power, and thus huge batteries[78] which are inconvenient on the battlefield. In the near future, we will probably see only light military exo-suits that offer modest assistance/ support.

4.1.8 Hyperspectral Imaging

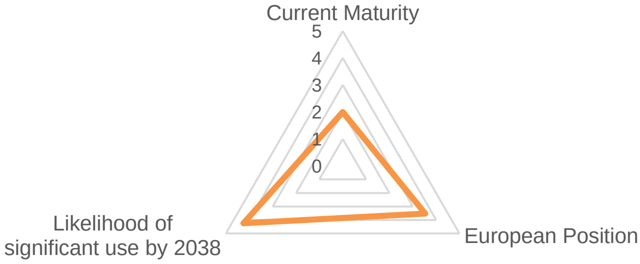

Figure 9: RIB Score of Hyperspectral imaging

"Hyperspectral Imaging (HSI) is one of these powerful analytical imaging tools based on the detection of both spatial and spectral information within a single data set, referred to as a HSI cube. Originally conceived for remote sensing, HSI has impacted fields as diverse as food inspection and forensics. The power of HSI lies in the ability to determine the chemical composition of a sample based on characteristic spectral signatures."[79]

"The goal of hyperspectral imaging is to obtain the spectrum for each pixel in the image of a scene, with the purpose of finding objects, identifying materials, or detecting processes."[80]

„Hyperspectral imaging holds promise for use in fields ranging from security and defence to environmental monitoring and agriculture. Conventional imaging techniques, such as digital photography, capture images across only three wavelengths of light, from blue to green to red. Hyperspectral imaging creates images across hundreds of wavelengths. These images can be used to determine the materials found in whatever scene was imaged – sort of like spectroscopy done at a distance."[81]

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[78] http://warisboring.com/the-japanese-military-is-building-a-robotic-exoskeleton/
[79] https://www.advancedsciencenews.com/low-cost-hyperspectral-imaging-improve-cancer-diagnosis
[80] https://en.wikipedia.org/wiki/Hyperspectral_imaging#cite_note-Chang2003-1
[81] https://www.sciencedaily.com/releases/2016/02/160218133405.htm

Recent progress direction

Medical

Hyperspectral imaging is an attractive technique in medical treatment and diagnosis thanks to its non-contact and minimally invasive nature. Searching for cancer tumours, researchers obtained a very good correlation between the real positions of the tumours seen by clinicians and the automatic predictions made by a hyperspectral imaging system.[82] Hyperspectral imaging could also improve in vitro fertilization (IVF) success rates, by providing a more objective assessment of the health of early-stage embryos.[83]

Researchers tested an SRDA-based (Spectrally Resolved Detector Array) HSI camera for fluorescence imaging, well suited for use in an endoscopy suite or operating theatre. SRDA's are extremely compact, robust, and "have the potential to be produced at very low cost."[84] "Early applications of snapshot SRDA have shown promise in neurosurgery and ophthalmology."[85]

Food Quality

"Fruit quality represents a combination of properties and attributes that determine the suitability of the fruit to be eaten as fresh or stored for a reasonable period without deterioration and confer a value regarding consumers' satisfaction."[86] Until now, internal qualities such as firmness, soluble solids content, and acidity could only be measured using destructive, time-consuming and inefficient methods. Scientists have demonstrated that hyperspectral imaging, combined with image processing algorithms, is a fast and non-invasive method to accurately predict the quality attributes of kiwifruits.[87]

Using a combination of digital imaging, spectroscopy and machine learning, food companies can take a picture of food, analyse the unique spectral reflections of the light, and determine nutritional content, fat and protein content and freshness level. With this automated and non-invasive technique, researchers hope to improve the quality and freshness of food available and reduce food waste. Systems that can work with beef, white fish, bananas and avocados are already available.[88]

Mining

„With known sources of some essential metals facing depletion within the next few decades, there is more pressure on pursuing alternatives to

[82] http://optics.org/news/9/1/14
[83] http://optics.org/news/8/8/43
[84] https://www.advancedsciencenews.com/low-cost-hyperspectral-imaging-improve-cancer-diagnosis
[85] https://www.advancedsciencenews.com/low-cost-hyperspectral-imaging-improve-cancer-diagnosis
[86] https://www.nature.com/articles/s41598-017-08509-6
[87] https://www.nature.com/articles/s41598-017-08509-6
[88] https://thespoon.tech/impactvision-raises-1-3m-to-combat-food-waste-with-hyperspectral-imaging

existing mining exploration technologies. Hyperspectral imaging makes use of the fact that all objects possess a unique spectral fingerprint based on the wavelengths of visible and invisible light that they absorb and reflect."[89] Some companies approach mineral discovery using high resolution hyperspectral imaging and machine learning.[90]

Recycling

Conventional vision systems often fail to sort items that have similar colours or appearances. In these cases, hyperspectral data combined with spatial pattern recognition algorithms can detect a wide range of materials, patterns, coatings, defects and contaminants. Hyperspectral vision systems generate data for quality control and also transmit information to robotic actuators, enabling automated picking and sorting of commodities.[91] For example, a new generation of multispectral and hyperspectral cameras are capable of increasing the purity of many recycled materials to close to 100%.[92]

Security

A company developed a "standoff hyperspectral imaging technology and analytical software to detect explosive, narcotic or chemical residues that may have transferred to a particular item (such as a vehicle or backpack) during illicit activity like bomb-making or drug smuggling."[93]

New Hardware & Software

Since the data gathered by a HSI system is richer than a regular colour image, we cannot interpret it by simply looking at the pixels. Interpreting the images involves sophisticated machine learning algorithms. Researchers have "developed an algorithm that can quickly and accurately reconstruct hyperspectral images using less data".[94]The capturing instrument uses "compressive measurements" to mix spatial and wavelength data, and the combination of algorithm and hardware makes it possible to acquire hyperspectral images in less time and to store those images using less memory.[95]

Another team has integrated graphene into a CMOS integrated circuit, then "combined it with quantum dots to create an array of photodetectors, producing a high resolution image sensor. When used as a digital camera this device is able to sense UV, visible and infrared light at the same time. The development of this monolithic CMOS-based image sensor represents a

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89 https://www.photonics.com/wpp1672/Hunting_New_Mining_Deposits_with_Hyperspectral

90 https://www.geologyforinvestors.com/northern-sphere-mining-corp-optimizes-mineral-targets-on-its-sudbury-nickel-belt-and-arizona-porphyry-copper-properties

91 https://www.photonics.com/a63241/Hyperspectral_Machine_Vision_Enables_Smart

92 https://www.vision-systems.com/whitepapers/2018/04/how-multispectral-and-hyperspectral-imaging-are-improving-recycling.html

93 http://www.armyrecognition.com/dsa_2018_news_official_show_daily/verovision_threat_detector_showcased_at_dsa_2018.html

94 https://www.sciencedaily.com/releases/2016/02/160218133405.htm

95 https://www.sciencedaily.com/releases/2016/02/160218133405.htm

milestone for low-cost, high-resolution broadband and hyperspectral imaging systems."[96]

"In a new study, researchers used 3D printing and low-cost parts to create an inexpensive (700 USD) hyperspectral imager that is light enough to use on-board drones. They offer a recipe for creating these imagers, which could make the traditionally expensive analytical technique more widely accessible."[97]

Long-term perspectives

Despite the clear advantage of providing more detailed data than conventional imaging systems, hyperspectral imaging is still in its infancy. There are a few limitations for hyperspectral machine vision applications. A critical factor is speed, which is limited by the large data volumes inherent in hyperspectral data. Speed limitations have only recently been overcome for real-world applications, and research and development are still required to make this technology widely installed.

Cost and a means to interpret the information have been other major barriers to adoption of hyperspectral imaging, but coupling state-of-the-art hyperspectral imaging engines with classification and machine-learning algorithms promise to solve these problems.

4.1.9 Speech Recognition

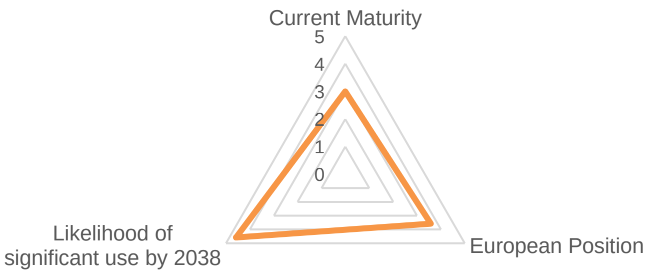

Figure 10: RIB Score of Speech Recognition

Speech recognition is the field that develops methodologies and technologies enabling computers to recognize spoken language and to translate it into text. It is also known as "automatic speech recognition" (ASR), "computer speech recognition", or just "speech to text" (STT). Although not new - the first commercially successful speech recognition technologies date from the 1990s -, recent increases in computing power and the development of new algorithms have made possible spectacular advances in recent years.

[96] https://www.sciencedaily.com/releases/2017/06/170605150305.htm
[97] https://phys.org/news/2018-02-lightweight-hyperspectral-imagers-sophisticated-imaging.html

Currently, several drivers push speech recognition forward: the fast growing field of home and personal "intelligent assistants"; the extended use of smartphones/computers in cars (connected and autonomous vehicles); a greater demand for speech-based biometric systems for multi-factor authentication; and the miniaturization-driven need for an input method requiring less space than keyboard or touch.

"Since 2014, there has been a lot of research interest in "end-to-end" automatic speech recognition. Traditional phonetic-based approaches required separate components and training for the pronunciation, acoustic and language model, while end-to-end models jointly learn all the components of the speech recognizer"[98], thus simplifying the training and deployment processes.

Recent progress directions

Dedicated chipsets and algorithms

Researchers have built a low-power specialized chip for automatic speech recognition, drawing 100 times less power than the multi-purpose chips in mobile phones.[99]

A new voice processor supports stereo-AEC (acoustic echo cancellation) and far-field linear microphone arrays. It has been designed for developers working in the growing voice-enabled smart TV, sound bar, set-top box and digital media adapter markets. Commands are accurately captured from across the room for processing by a cloud-based speech recognition system, even in complex acoustic environments.[100]

Researchers have found that children's speech pitch and behaviour are vastly different from those of adults. They have developed special datasets and algorithms for speech recognition technology targeted at children.[101]

Latent Sequence Decompositions (LSD), a framework in which the decomposition of sequences into constituent parts is learnt during model training, was proposed by Carnegie Mellon University, MIT and Google Brain to directly emit sub-word units which are more natural than English characters.[102] The University of Oxford and Google DeepMind extended LAS to "Watch, Listen, Attend and Spell" (WLAS) to handle lip reading, and it surpasses human-level performance.[103]

Systems and devices

An ASR that listens in to air controllers' radio conversations and suggests instructions for pilots has been developed. The number of incorrect commands was reduced to a fourth of the original figure.[104]

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98 https://en.wikipedia.org/wiki/Speech_recognition
99 http://news.mit.edu/2017/low-power-chip-speech-recognition-electronics-0213
100 https://www.eetimes.com/document.asp?doc_id=1332788
101 https://techcrunch.com/2018/01/13/soapbox-labs/
102 https://arxiv.org/abs/1610.03035
103 https://arxiv.org/abs/1611.05358
104 https://www.eurekalert.org/pub_releases/2017-03/su-cl030717.php

A deep neural network speaker recognition engine running in the background of other tasks can perform voice matching using short utterances and identify customers more efficiently before they are connected with a human representative. This can reduce call times by up to 55 seconds, and call centre operations costs by up to $1 per call.[105]

Some automakers will ship in 2019 vehicles with a voice-powered virtual assistant with built in artificial intelligence. The AI voice assistant will leverage the connectivity in the car combined with voice recognition software and will tap into calendars, mapping platforms, and other services to both respond to and anticipate users' needs. It will be able to remind the driver, for instance, of an upcoming meeting, and could suggest when to depart for it based on traffic conditions. The AI assistant will also respond to voice queries about things like weather or messaging, and even control factors in the car such as the heating systems or door locks, giving the driver safe and hands-free control over many parts of the vehicle.[106]

Long-term perspectives

Speech recognition and conversational platforms are expected to be one of the top 10 strategic technology trends for 2018. Systems are increasingly capable of answering various questions of users, in different contexts (from "How's the weather?" to "What is the difference in features between coffee machine A and B") – ComScore projects that "50 % of all searches will be voice searches by 2020."[107]

In the longer term, the shift will be more profound as voice will become an invisible interface that allows us to interact with the intelligent, connected devices around us. As AI and Natural Language Processing become more sophisticated, devices will be able to learn about their users and then anticipate intent, even if not explicit in a person's voice command. In this world characterized by "ambient intelligence", a simple utterance like "it's movie time" will elicit various responses from smart devices in the house – dimming the lights, turning off the music, locking the door, turning on Netflix, etc.[108]

One barrier is the lack of accuracy in speech and voice recognition systems in noisy and harsh working environments, but recent advances are making strides in overcoming this shortcoming.

[105] http://www.biometricupdate.com/201801/pindrop-launches-voice-recognition-engine-and-solution-to-combine-customer-experience-with-security
[106] http://www.businessinsider.com/hyundai-and-kia-developing-ai-assistants-for-cars-2017-12
[107] https://www.campaignlive.co.uk/article/just-say-it-future-search-voice-personal-digital-assistants/1392459
[108] http://samsungnext.com/whats-next/the-disappearing-user-interface/

4.1.10 Swarm Intelligence for undertaking practical tasks

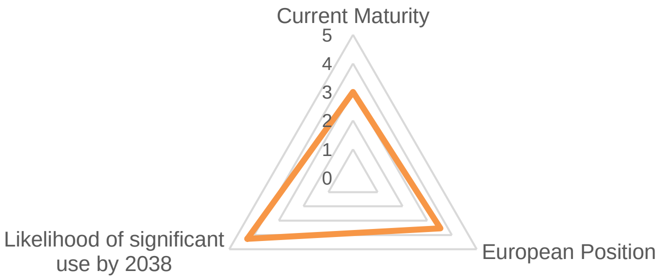

Figure 11: RIB Score of Swarm Intelligence for undertaking practical tasks

Swarm intelligence refers to the collective behaviour of various objects, each performing a number of simple functions and interacting with others in the process. Like insects or a flock of birds, information systems designed based on this principle manage processes in a decentralised way, through self-organising operation of all their elements.

Such systems' development prospects are connected with application in driverless cars, energy grids with distributed energy sources, search and rescue robots.[109]

Swarm intelligence and swarm robotics explore the design of a system where a desired collective behaviour emerges from the local interactions among large numbers of relatively simple physical agents and between the agents and the environment.

Recent progress directions

The Swarm-Organ project

The Swarm-Organ project[110] studies "how systems containing large numbers of autonomous, but relatively simple agents could collectively organise themselves into complex spatial arrangements, despite each agent having only local awareness"; or how a fleet of small, cheap robots is able to coordinate and will transform into a variety of different shapes and sizes.[111] The Swarm-Organ project is funded by the EU's research programme on Future and Emerging Technologies (FET).

Unmanned Aerial Vehicles

A recent report by Canada's Security Intelligence Service[112] shows that the "Chinese defence industry has achieved significant advances in swarm intelligence. In June 2017, the China Electronics Technology Corporation

[109] https://issek.hse.ru/en/news/204251974.html
[110] http://www.swarm-organ.eu/, accessed 17/9/2018
[111] http://www.fetfx.eu/story/harnessing-power-swarms/
[112] https://www.ainonline.com/aviation-news/defense/2018-06-02/canada-prc-threat-more-partner

(CETC) demonstrated progress by testing 119 fixed-wing UAVs (unmanned aerial vehicles), almost doubling the previous record of 67.[113] In one exhibit, China's Military Museum depicts a UAV swarm combat system with swarms used for reconnaissance, jamming, and a 'swarm assault' targeting an aircraft carrier.

Long-term perspectives

The military is very much interested in swarm intelligence, especially for vehicles of any kinds[114], but other applications are imaginable. The investments are already high, so that further improvements and new applications can be expected in the medium term.

4.1.11 Warfare Drones

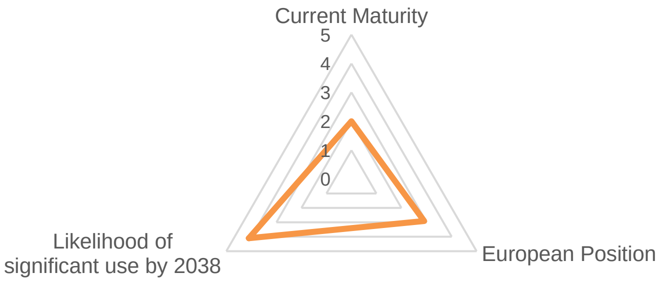

Figure 12: RIB Score of Warfare drones

The word "drone" has come to define any kind of vehicle (air, land or sea) that is mostly controlled by autopilot algorithms computing how the necessary controls need to be tweaked in order to carry out an operator's orders. While the operator may assume direct remote control of the drone, algorithms have evolved to cover almost any situation the drone may encounter, making the device a favourite in the warfare domain. A trained soldier is hard to replace, but s/he may direct ten identical drones rolling off the assembly. This has radically changed the face of war. The relative ease of deploying drones has shifted the intervention policy of major governments. Meanwhile, the people facing the remote-controlled guns have grown resentful, as drones can descend on peaceful areas with no warning. Surgical strikes have proven to be problematic since the targets might be chosen in a rush based on uncertain information. Because of this, research has been focusing on improving information-gathering capabilities and on making drones even more precise. One eventual target is to create miniaturized drones that can identify and strike individuals. Of course, this type of tiny superweapon is stirring up controversy, so a number of groups are developing anti-drone technology and defensive drones.

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[113] https://jamestown.org/program/swarms-war-chinese-advances-swarm-intelligence/

[114] https://www.military-technologies.net/2018/05/09/global-swarm-intelligence-market-2018-application-analysis-size-trends-status-segments-and-forecast-to-2023/

Recent progress directions

Sensing the world

Drones have to navigate the world on their own therefore special attention is being devoted to their sensing abilities. All drones operate by building an internal map, based on sensor data, to allow their algorithms to make decisions, from navigation to weapon deployment and mission parameters. Incredible advances have been made in the field to allow drones to use a single consumer camera to build their internal map.[115]

Extensive progress has been made in the field of sensors that can analyse a substance from a distance by using multi-wavelength laser.[116] These sensors are being developed especially for drones and can reliably detect explosives providing critical mission data.

Combine drone and wing-born flight

A prototype drone system developed by DARPA uses fully-autonomous drones that in flight transition to wing-borne flight at medium altitude. The system can be used as a surveillance and striking capability for ships with a greater range as a traditional helicopter.[117]

Intelligence

In order to allow drones to accomplish more and more complicated tasks on their own, they must be endowed with the ability to not only perceive the world, but also to understand it. Researchers are developing techniques to use the fuzzy data provided by telephoto lenses to make drones reliably discriminate between armed combatants and civilians.[118]

Once drones get close, they should be able to identify their targets with a high degree of accuracy. This can mean facial recognition, but other biometric data can be used, including gait and behaviour patterns.[119] As drones are supposed to execute surgical strikes, their target identification and discrimination abilities are amongst the most important functions. We can expect this domain of research to affect all drones regardless of size or specific purpose.

Fuel autonomy

To accomplish longer and longer missions, drones require energy autonomy beyond what standard sources, like batteries and kerosene, provide. This is why researchers have started to create lighter fuel cells that can be used in

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[115] https://hackaday.com/2016/04/02/insanely-quick-3d-tracking-with-1-camera/
[116] https://www.extremetech.com/extreme/239512-spectrodrone-system-uses-lasers-detect-explosives-afar
[117] https://www.businessinsider.com/darpa-building-drone-provide-persistent-surveillance-2016-11
[118] https://www.inverse.com/article/22753-darpa-military-drone-ai-identify-armed-people
[119] https://www.popsci.com/technology/article/2011-09/army-wants-drones-can-recognize-your-face-and-read-your-mind; https://motherboard.vice.com/en_us/article/8qxe93/this-drone-zoom-lens-can-identify-your-face-from-1000-feet-away

drones[120] and are investigating ways to quickly recharge them[121] with abundant elements such as hydrogen. There is also research into drones using bio-matter to recharge.[122] The hope is that the drones could use whatever bio-matter is encountered in the field in order to power themselves and successfully carry out long-term missions without depending on resupply from base.

Micro drones

Size is a special consideration in warfare drones. Microdrones are smaller than a person and their applications are completely unique, as are the requirements imposed on them. Roboinsects[123] are an extreme case, being developed to accomplish reconnaissance missions in urban environments without detection. One day they might even carry small explosives in order to target a specific device (like a laptop) or person.

Of course, insects can only carry micro payloads, so drones the size of small animals are also being developed. To navigate the extreme height differences found in urban environments, DARPA has made a jumping chassis.[124] And if the mission requires no stealth and speed is essential, a slightly larger drone can be used to map out large areas in minutes.[125] While they are conspicuous, such drones could work in swarms and allow an operator to completely dominate an indoor space.

Microdrones are a peculiar area of research built from organic components.[126] Cells and organs are harvested[127] from living creatures and become integral parts of the drone. The idea is that these biodrones could be deployed in swarms that biodegrade harmlessly into the environment after they have accomplished their mission.

Defence against drones

Of course, there are drones specifically made to be stealthy, hard to see and invisible to radar. Considerable effort is being devoted to creating defensive systems against drones. One avenue of research is using the on-board cameras of drones to detect and track other drones.[128] However, video cannot be used at night or in adverse weather conditions. Other

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120 https://www.entrepreneur.com/article/272337
121 http://feeds.feedblitz.com/~/136682957/0/gizmag~Drone-flight-powered-by-lightweight-hydrogenproducing-pellets/
122 https://paleofuture.gizmodo.com/remember-eatr-the-military-robot-that-was-supposed-to-172486832
123 http://edition.cnn.com/2015/01/14/tech/mci-drone-robohawk-robofly/index.html
124 https://www.tomsguide.com/us/Sand-Flea-Robot-DARPA-Jumping,news-14652.html
125 http://www.businessinsider.com/watch-this-tiny-darpa-drone-fly-45-mph-through-a-warehouse-2016-2
126 http://www.technology.org/2016/07/09/using-cardiac-cells-rats-scientists-developed-robotic-stingray/
127 https://phys.org/news/2016-07-robot-sea-slug-d-body.html
128 https://cvlab.epfl.ch/research/unmanned/detection

groups are focusing on developing radar systems capable of spotting drones[129] and on equipping drone-hunting-drones with them.

Shielding drones against electronic jamming is impractical because of the weight restrictions, as electromagnetic shielding is particularly heavy. A drone gun[130] has been developed that can jam electronics. The concentrated electromagnetic emissions of this gun can disable drones without reloading time, consumables or maintenance.

While some rely on technology to protect themselves from technology, others are turning to more traditional methods. Falconry has proven to be effective against small and medium drones.[131] While this technique is attractive to police departments and civil authorities, militaries are worried that less technologically developed opponents might employ birds of prey to destroy expensive military equipment.

Long-term perspectives

Drone warfare has already changed the landscape of war. The ease of deployment coupled with the lack of accountability has made some experts warn about as a new category of weaponry. There is a hypothetical threat of an autonomous army fighting completely without human control, sent out into the world with encrypted orders that nobody can change. Though currently cost prohibitive to manufacture and prone to run into maintenance issues very quickly, mutually assured destruction through autonomous precision weapons is not impossible in the future. In response to this threat, anti-drone technology has diversified, with birds of prey and jamming technologies, while some believe in creating defensive drones that only serve to hunt other drones, thus creating a stable artificial ecosystem. Whichever the path, drone technology is not something that can be controlled by laws alone.

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129 http://www.xconomy.com/seattle/2016/11/08/echodyne-demonstrates-detect-and-avoid-radar-on-a-small-drone/

130 http://defense-update.com/20170301_dronegun.html

131 https://www.wsj.com/articles/bold-eagles-angry-birds-are-ripping-80-000-drones-out-of-the-sky-1506701429

4.1.12 Artificial Intelligence

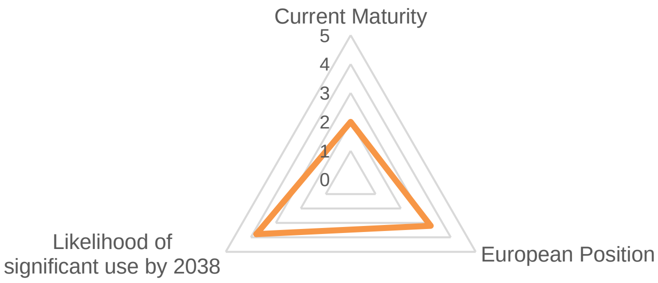

Figure 13: RIB Score of Artificial Intelligence

Artificial Intelligence has exploded over the past several years, as powerful graphical processing units (GPUs) have enabled the intensive computations required for machine learning (particularly, deep learning), drastically reducing the running time of training algorithms. Although convolutional neural networks have been a mainstay of deep learning, in computer vision especially, a number of design innovations (including capsule networks and duelling networks) have emerged, raising new prospects as well as fresh challenges.

Recent progress direction

Duelling Networks

Duelling networks, also called *generative adversarial networks* (GANs), are emerging as the key software model for automated generation of realistic media, including images, sounds and text.[132] The GAN design involves two neural networks with opposite goals: for instance, while one network (the generator) learns to generate realistic photos, the other network (the discriminator) plays the adversary by trying to determine which input photos are real and which are fake (i.e. machine generated). The discriminator's judgements are fed back into the generator network, thus pushing it to get better at generating realistic photos. In turn, the discriminator gets better at spotting the fakes.

Since the GAN concept was first proposed and implemented in 2014, hundreds of research papers have explored it. One overarching aspiration is that AI systems which learn to generate realistic representations do so by getting a better understanding of real world structures, pushing AI systems to become more adept at both understanding the real world – or, more precisely, *our* perception of the world – and emulating its traits. Many researchers believe GAN's could eventually lead to unsupervised learning (that is, machine learning which does not require direct human help), a goal widely regarded as the Holy Grail in machine learning. (Yet, a functional

[132] https://www.wired.com/2017/04/googles-dueling-neural-networks-spar-get-smarter-no-humans-required/

GAN system currently involves the training of two neural networks – the generator and the discriminator –, which still requires significant human effort.)

Experimental applications of duelling networks have targeted computer-generated images[133], poetry[134], and video games[135], while an AI start-up hopes to employ GANs and Reinforcement Learning techniques for drug discovery.[136] Along with their significant promise, GANs are also raising fresh concerns[137,138,139] regarding the AI-assisted generation and proliferation of fake media (the so-called *deep fakes*) for malicious purposes.

Capsule Networks

Unveiled in late 2017 (albeit incorporating older concepts and ideas)[140], the Capsule Network architecture is an important software innovation in artificial neural networks and deep learning, which could solve some of the problems associated with convolutional neural networks (CNNs). Although they have been very successful in solving a range of machine learning and computer vision tasks, such as automated image classification and tagging, CNNs are nevertheless prone to notable limitations and drawbacks. Generally, a CNN does not account for important spatial relations between simple and complex objects (e.g. between a face and the relative positions of the mouth, nose and eyes) and it has problems recognizing the same object viewed from different perspectives.

A capsule network (briefly, CapsNet) is a neural network with an enhanced hierarchical structure, which could better resemble the way humans process information. While a regular neural network is organized in multiple layers of neurons, a capsule network is a nested collection of neural layers: each layer comprises multiple capsules and each capsule groups together a small group of neurons. Functionally, a capsule is a specialized software module which learns to detect a particular pattern – or object – in an image. The capsules in the lowest layers are called *primary capsules* and detect general patterns such as rectangles, while the *routing capsules* in higher layers detect larger and more complex objects, such as cats or boats, based on the input from the lower level capsules. Notably, a primary capsule is able to recognize a rectangle regardless of its pose (e.g. position, orientation, size, etc.) and it encodes and feeds the detailed information to the higher layers.

In principle, the capsule network design has a number of advantages: it can account for relationships between objects, it can generalize object

[133] https://www.scientificamerican.com/article/spot-the-fake-artificial-intelligence-can-produce-lifelike-photographs/
[134] https://www.technologyreview.com/the-download/611021/ai-is-a-poet-and-knows-it/
[135] https://techxplore.com/news/2018-05-adversarial-networks-unleashed-video-games.html
[136] https://www.eurekalert.org/pub_releases/2018-05/imi-cga050918.php
[137] https://www.economist.com/science-and-technology/2017/07/01/fake-news-you-aint-seen-nothing-yet
[138] https://qz.com/1230470/the-hottest-trend-in-ai-is-perfect-for-creating-fake-media/
[139] https://www.technologyreview.com/s/609358/ai-could-send-us-back-100-years-when-it-comes-to-how-we-consume-news/
[140] https://www.wired.com/story/googles-ai-wizard-unveils-a-new-twist-on-neural-networks/

recognition to new viewpoints and it can achieve very good performance by using much less data than a convoluted network. Although capsule networks have achieved state-of-the-art performance in at least two prototype systems[141,142] , the CapsNet architecture is still very recent and awaits further research and assessment in real-world applications. In the short to medium term, convoluted networks are expected to remain the mainstay of deep learning systems, although Capsule networks and other designs could eventually render them obsolete.

One-shot Image Recognition

Currently, one drawback of deep learning systems is that they are generally data hungry: they require a significant amount of training on labelled data (e.g. thousands of tagged photos per category) before they can learn well how to classify new data. One- learning or few-shot learning is a paradigm which aims for much faster and efficient learning: the goal of such an AI system is to learn how to classify data from a single sample, or from a very small training set, just like the human brain is often able to recognize an object after seeing it only once or twice. Zero-shot learning models set an even higher bar: they require the ability of inferring a new category without any previous example.

Although presently one-shot learning is more of an open problem rather than a well defined set of algorithms, AI researchers have already proposed and trialled a number of techniques and models. In one-shot models, the common emphasis is on knowledge transfer from learnt categories to new categories. Model variations include knowledge transfer by model parameters and knowledge transfer by sharing features - *relying on "the similarity between new object classes* and the previously learned classes" – as well as knowledge transfer by contextual information, which "appeals to global knowledge of the scene in which the object is placed". Generally, one-shot models rely on a family of probabilistic techniques called Bayesian programming learning and on neural networks augmented with working memory, such as the Neural Turing Machine (NTM) model designed by Google DeepMind.[143]

In 2015, university researchers implemented a one-shot learning system which could recognize a handwritten character after seeing just a single example, achieving human-level accuracy.[144] In 2017, Google DeepMind researchers tweaked a deep-learning algorithm and added a memory component, enabling the system to recognize new objects categories from a single instance.[145] They demonstrated the system capabilities on ImageNet, a public database of labelled photographs, as well as on handwriting and language. Their system still needs to be trained on a large set of data to analyse several hundred categories of images or characters – but it could

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141 https://papers.nips.cc/paper/6975-dynamic-routing-between-capsules.pdf
142 https://openreview.net/pdf?id=HJWLfGWRb
143 https://blog.acolyer.org/2016/03/09/neural-turing-machines/
144 https://www.technologyreview.com/s/544376/this-ai-algorithm-learns-simple-tasks-as-fast-as-we-do/
145 https://www.technologyreview.com/s/602779/machines-can-now-recognize-something-after-seeing-it-once/

subsequently learn to recognize new objects or characters from a single example.

Despite the early promise, significant challenges remain in both advancing the theoretical models and proving their feasibility in practical applications - the main problem is how a neural network to use its memory to achieve fast learning.

Long-term perspectives

While Artificial Intelligence in its current incarnations has already been touted as a technological revolution, the AI revolution has most likely only started. Over the next couple of decades, advances and radical innovations in machine learning, computer vision, natural language processing and robotics will reshape entire fields of science and economics, such as medicine or the automotive industry.

In the next decade and beyond, one can expect significant research around one-shot and zero-shot learning models involving knowledge transfer. If the research translates into practical advances, it will lead to real-world applications capable of handling new concepts and categories even when only limited or even no relevant data is available. Assuming the concept gets further validated, capsule networks and other neural network designs will significantly increase the power of learning systems, while also accelerating their development and deployment. Generative techniques such as duelling networks could lead to an explosion of computer-generated media and multimedia, including text, music, pictures and video – and perhaps virtual reality worlds too. The cultural impact will be significant, provided that computers and software programs eventually turn from mere tools assisting humans to expert creators of realistic (i.e. human-like) art and artefacts. Although fake media proliferation is already a hot topic, generative AI could turn it into a much bigger problem. Ironically, AI could become the main tool for both the creation and the detection of fake media and content.

In a particularly ambitious (and perhaps concerning) scenario, future advances in AI software and hardware infrastructure could lead towards unsupervised learning and some incipient forms of general artificial intelligence. This would entail super-smart systems which are able to self-improve and outperform humans not only in specialized applications (such as chess playing or car driving), but also in a wide range of domains and circumstances, including the handling of novel problems and ad hoc situations.

4.1.13 Holograms

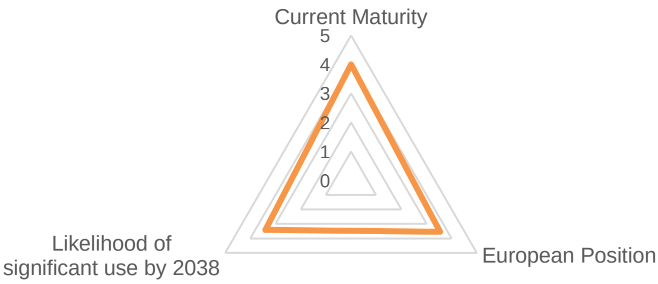

Figure 14: RIB Score of Holograms

Displaying 3D images in a realistic manner without using glasses represents one of the fascinations for fields ranging from entertainment, design to medicine or intelligence.

Optical holography was invented by physicist Dennis Gabor in 1948. Technically, holograms are three-dimensional recordings of wave fields. "A holographic image can be seen by looking into an illuminated holographic print or by shining a laser beam through a hologram."[146] Such a holographic image achieves three-dimensional perception and changes according to the relative position of the viewer, as if the objects displayed are actually present. Acoustical holography, originating in the 1960s, is an outgrowth of optical holography. It involves reconstruction of the sound field that arises due to radiation of sound at a boundary.

Although holograms already have some widespread uses (for example, as security markings in credit cards and currencies), researchers currently explore many other applications. The focus of recent research includes 3D holographic displays, acoustic holography, touchable holograms, as well as holographic microscopes and printers. Although a number of recent studies and initiatives have yielded bold claims and exciting demos, virtually all prototypes still have practical limitations that need to be removed (or, at least, reduced). Optimistic scenarios predict only a few years until the next generation of holographic products, such as 3D holographic displays, becomes widely available.

Recent progress directions

Acoustic holograms

Acoustical holography involves reconstruction of the sound field that arises due to radiation of sound at a boundary, such as the vibrating body of a violin, the fuselage of an aircraft, or the surface of a submarine.

[146] http://holocenter.org/what-is-holography

Acoustic holograms are now produced with the help of a 3D printed metamaterial matrix[147], which distorts in intricate ways a single origin soundwave, transforming it into a sound hologram. This technique is less time consuming and inexpensive at the same time.

"Where older methods of producing acoustic holograms involved precisely tinkering with the speakers and electronics used to manipulate the source sound itself, the new 3D printed brick technique changes the sound when it's already on its way by placing the brick structure in front of the source to manipulate the transmitted sound into new shapes."[148]

The new acoustic holography techniques could be useful in fields such as entertainment, electronics, medicine, ultrasound imaging.

Meta-surface holograms and nano-based, volumetric displays

Recent progress shows promise towards the use of meta-surface holograms for nano-based, volumetric displays. Meta-surfaces are special interfaces that can manipulate the wave front of light. Unlike conventional displays, which simulate depth through a number of visual effects, volumetric displays enable the visual representation of objects in three physical dimensions.

"Holograms modulate the phase of light to give the illusion of three-dimensional depth."[149] However, conventional holograms are not suitable for volumetric displays, since they are limited by large pixel sizes and the difficulty of modulating the phases of light. In practical terms, standard holograms feature very narrow viewing angles (less than 3') and poor colour reproduction.

Researchers have been working on overcoming the existing technical limitations by designing and using metamaterials with special optical properties. To generate enough phase shifts for 3D displays, holograms need to be at the thickness of optical wavelengths. The recent crop of experiments involve holographs with nanoscale films, which enable nanometric pixels, smaller than the wavelength of visible light.

Japanese researchers at the Toyohashi Institute of Technology used magneto-optic spatial light modulators (MOSLMs) to develop 3D holographic displays with nano-sized pixels and viewing angles over 30', suitable for reproducing 3D movies.[150] A team of researchers from China and Singapore created a metamaterial that resulted in nanometric pixels and pushed the projection angles to over 90 degrees across the full colour spectrum. The researchers claim their method leads to a remarkable image quality, with a signal-to-noise ratio five times better than those of the previous meta-hologram designs.[151] Researchers at Missouri University of Science and Technology developed a new approach to reconstruct 3D full-colour

[147] http://www.3ders.org/articles/20161103-3d-printed-lego-bricks-create-sound-holograms-for-better-home-audio-medical-imaging-wireless-charging.html
[148] http://www.3ders.org/articles/20161103-3d-printed-lego-bricks-create-sound-holograms-for-better-home-audio-medical-imaging-wireless-charging.html
[149] https://www.sciencedaily.com/releases/2017/05/170518083031.htm
[150] https://www.sciencedaily.com/releases/2016/04/160419100006.htm
[151] http://www.nanowerk.com/spotlight/spotid=45011.php

holographic images by using just one layer of nanoscale metallic film[152], 35-nanometer thick.[153] The world's thinnest hologram was produced by an Australian-Chinese team using a topological insulator material. The 25 nanometre hologram is 1000 thinner than a human hair and can be seen without 3D goggles. Still, a rigid thin film that could be laid onto an LCD screen to enable 3D holographic display would involve further shrinking the nano-hologram's pixel size, making it at least 10 times smaller.[154]

Recently published research from Brigham Young University shows how the scientists manipulate dust-like particles – "nearly unseen specks in the air" – and use them to create 3D, volumetric images that are more realistic and clearer than conventional holograms. People standing around such an image would be able to see the image from their own perspective. Their prototype still produces tiny images – a limitation shared by virtually all the competing prototypes.[155]

Touchable holograms

Japanese researchers from Tsukuba University have created holograms that respond to human touch, using femtosecond lasers.[156] (Earlier hologram experiments used nanosecond lasers, but the generated plasma burned human skin.) The prototype holograms, called Fairy Lights, are very small (less than 1 cm^3), but they could be scaled up using larger optical devices. In the future, the technology could be used for three-dimensional communication, such as on construction sites or for medical instruction.

Printed Holograms and Hologram Printers

The conventional process for producing rainbow holograms, like those used to protect credit cards and banknotes, is time consuming and involves multiple stages, starting with the creation of a laser-recorded master hologram. Russian researchers at ITMO University in St Petersburg developed an innovative process that could slash production time and cost.[157] The process involves an ordinary inkjet printer loaded with colourless ink made of nanocrystalline titanium, deposited on micro embossed paper. The holographic images could be printed in a matter of minutes, while conventional methods require several days.

Not only can holograms be printed, but holograms could themselves be used for 3D printing, as demonstrated by an American start-up. It designed a hologram-based printer using a complex DLP-style curing system. The prototype printer is currently capable of printing only tiny objects like paper clips -but it can print them in about five seconds, compared to at least a

[152] http://news.mst.edu/2016/10/researchers-create-3-d-full-color-holographic-images-with-nanomaterials
[153] http://news.mst.edu/2016/10/researchers-create-3-d-full-color-holographic-images-with-nanomaterials
[154] https://www.rdmag.com/news/2016/10/scientists-create-3d-full-color-holographic-images-nanomaterials
[155] https://phys.org/news/2018-01-holograms-d-thin-air.html
[156] https://newatlas.com/touchable-mid-air-holograms/40845
[157] https://www.photonics.com/a58079/Injket_Method_Cuts_Hologram_Production_Costs_Time

couple of minutes for a regular 3D printer.[158] Also, the printed objects have structural advantages, as they are smoother and stronger. To scale the printing for larger objects, the researchers must find a way to control the heat energy produced by the hologram system in a way that stops the printed object from melting.

Long-term perspectives

Acoustic holograms could significantly improve ultrasound imaging, as well as medical treatment options.

3D holographic displays of the future could deliver an unparalleled level of motion picture realism, without requiring the viewer to wear any 3D glasses or VR-style headcase. Flexible and elastic ultrathin films could be embedded in a whole range of surfaces, leading to innovative smartphones and everyday devices that would pop-up 3D holograms, rendering their screen size irrelevant. In addition, if touchable holograms become truly functional, we could see holographic interfaces allowing new ways of interacting with devices, as well as a wholly new (and, quite literally, sensational) dimension added to virtual reality experiences.

4.1.14 Humanoids

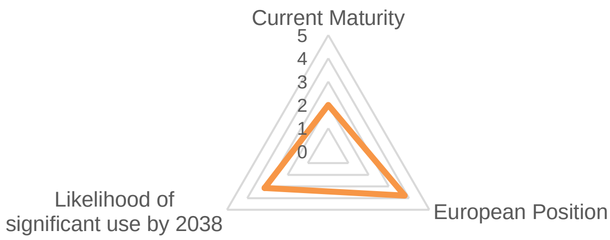

Figure 15: RIB Score of Humanoids

Humanoids are machines designed to resemble humans in form and features, regardless of their intended use. There is something about the human shape that makes us give it special consideration. In practical terms, humanoids have a distinct advantage in situations where a machine needs to accomplish the same general tasks as a human. Opening a door, climbing a ladder and moving a box might seem like trivial tasks and a machine could be built to do any one of those tasks. However, a humanoid would be well suited to accomplish these tasks when some of their parts presuppose a human-like form of capability.

Currently, humanoids are too expensive and complex to be an option for most robotics applications. Replicating the human shape requires extremely complex mechanics and algorithms. As a result, humanoids are only built to go where biological humans cannot. The most common target are disaster

[158] https://www.3ders.org/articles/20170220-ar-startup-daqri-builds-incredible-3d-printer-than-can-print-with-holograms.html

areas where hostile environmental conditions have forced humans to evacuate. Sending a humanoid robot through an unstable building, to open a water valve or drive to a reactor to shut it down, may be the only option. Any other type of robot would not be able to deal with the wide range of tasks required to accomplish the mission.

This being said, the limited field of applications does not limit research. Various labs push their work forward without regard to a very specific application, preferring instead to improve humanoid robot platform performance overall.

Recent progress directions

Mimicking humans

Since humanoids are expected to be as similar to humans as possible, many projects focus on direct mimicry. Dexterity is treated as a special type of motion problem and advances have been made in recent years that bring robotic limbs close to human ones.[159] The hope is that this kind of research will be applicable in the prosthetics fields too.

Replicating human motion on a large scale has fewer short-term practical applications but more impressive demonstrations. Robots are being built that can perform athletic exercises[160], do acrobatic motions such as backflips[161], and even martial arts.[162] The degree of biomimicry goes as far as replicating human cooling through sweat[163], which was found to be effective for humanoid robots too.

Probably the most impressive characteristic of human motion is, however, fault tolerance. Companies are creating robots with the express purpose of understanding how humans recover from falls[164] and hits.

Application demonstrators

The immediate need that humanoid robots will fill is that of replacing humans in practical roles. DARPA organized a robotics grand challenge to see how humanoid robots would fare in a scenario similar to the Fukushima disaster. The tests included opening doors, operating faucets and even answering phones.[165] Numerous teams compete in such challenges and the hope is that they will continue development so that solutions can be deployed when the next disaster strikes.

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[159] http://www.dailymail.co.uk/sciencetech/article-4444366/Next-generation-robots-dextrous-human.html?ITO=1490&ns_mchannel=rss&ns_campaign=1490

[160] https://www.inverse.com/article/39627-humanoid-robots-exercise-tokyo-japan

[161] https://www.wired.com/story/atlas-robot-does-backflips-now/

[162] http://www.3ders.org/articles/20170801-meet-surena-mini-irans-new-3d-printed-humanoid-robot-that-can-dance-and-do-karate.html

[163] https://www.3ders.org/articles/20171221-university-of-tokyo-researchers-create-3d-printed-humanoid-robots-that-can-do-pushups-and-sweat.html

[164] https://spectrum.ieee.org/automaton/robotics/humanoids/lifesize-humanoid-robot-is-designed-to-fall-over-and-over-and-over

[165] http://www.betaboston.com/news/2015/05/21/watch-atlas-turn-a-valve-answer-a-phone-before-darpa-robotics-challenge/

Not all teams focus on such hazard scenarios when they develop human replacements. Making well-behaved robots for regular environments such as shops[166] is likely to be more profitable for companies than disaster intervention.

Control

Autonomous systems are not yet advanced enough to take full advantage of the humanoid configuration. Humans are inserted in the control loop as direct controllers of motion. There are two approaches: copying the motions of the human controller[167] or interpreting brain signals as commands from the human controller.[168] Neither of these[169] is a definitive solution to the inherent limitations of a humanoid. Regarding the first approach, mapping human motions to robot motions is cumbersome because the robots are not custom designed for each human controller. Direct brain interfaces are still very primitive, allowing only very simple commands to be used.

Long-term perspectives

Humanoid robotics is one field of research where the long-term direction differs radically from the short-term one. Right now, humanoids are expensive to build and burdensome to deploy to such a degree that it is not worth using them in places where they are not required. Once humanoid robots reach a certain level of performance, there might be a radical shift in acceptance. The humanoid shape would allow a robot to work seamlessly in the same environments as humans. A cheap, reliable, safe, low-power humanoid robot body would rapidly become the standard robotics platform for an unimaginable number of applications ranging from military to the entertainment industry and even inside the home. But this would require the confluence of multiple technologies which, for now, do not seem to be converging. The consensus is that bulky electrical motors and hydraulics would have to be replaced by polymer muscles[170] akin to the biological ones that power our movements. Even with highly power-efficient muscles, a humanoid would still need batteries that are an order of magnitude better than what the market currently provides. All this must be coupled with an impressive array of sensors backed by immense processing power. It is a complex machine and, in the end, owning a humanoid robot might prove to be as difficult as owning an airplane.

[166] https://www.digitaltrends.com/cool-tech/ocado-armar-6-robot/
[167] https://www.geek.com/tech/toyotas-new-humanoid-robot-mimics-your-movements-1723719/
[168] http://www.dailymail.co.uk/sciencetech/article-4287036/New-MIT-controls-robots-using-brain-signals-alone.html?ITO=1490&ns_mchannel=rss&ns_campaign=1490
[169] https://spectrum.ieee.org/automaton/robotics/humanoids/darpa-robotics-challenge-amazing-moments-lessons-learned-whats-next
[170] https://colorado.ourcommunitynow.com/2018/01/12/artificial-muscles-cu/

4.1.15 Neuroscience of Creativity and Imagination

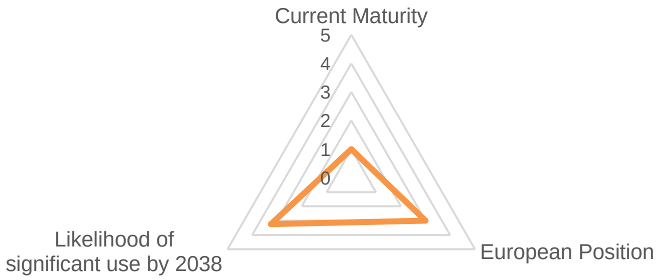

Figure 16: RIB Score of Neuroscience of Creativity and Imagination

The neuroscience of creativity and imagination is still restricted to basic research aiming to find out how creativity and imagination work. Early approaches try to find a way to measure, to predict and to systematically influence the capacity for imagination, which can be seen as a basis of creative thinking and central to human progress.

Recent progress directions

Test for imagination or creativity

By attempting to quantify a person's imagination, neuroscientists and psychologists at the Imagination Institute (a non-profit based at the University of Pennsylvania's Positive Psychology Center) hoped to provide an alternative to traditional IQ-oriented standardized testing. The 3 million-dollar research effort (2014–2017) was funded by the John Templeton Foundation.[171]

Other results are now available.[172] For example, the Hunter Imagination Questionnaire (HIQ) was put forward as an instrument designed to assess imagination over an extended period of time, in a naturalistic manner.[173] According to the researchers who created it, "HIQ was found to be a reliable and valid measure of imagination in a cohort of normal human subjects and was related to brain volumes previously identified as central to imagination including episodic memory retrieval (e.g. hippocampus)".

Long-term perspectives

The broader hope is that the neuroscience of creativity[174] would allow us not only to measure, but also to predict and to systematically influence imagination capacity.

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[171] https://www.templeton.org/grant/advancing-the-science-of-imagination-toward-an-imagination-quotient
[172] http://imagination-institute.org/publications
[173] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4834344
[174] http://www.pnas.org/content/early/2018/01/09/1713532115

4.1.16 Precision Farming

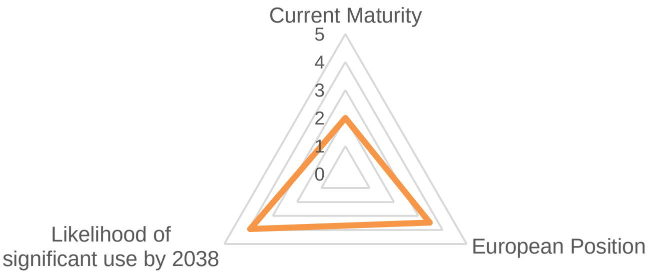

Figure 17: RIB Score of Precision farming

Precision farming, also known as precision agriculture, relies on the latest information and technologies available – GPS, satellite imagery, control systems, sensors, robots, variable rate technology, telematics, software, etc. – to improve crops in every step of the growth cycle: soil preparation, seeding, and harvesting. The ultimate goal of applied technology in agriculture is to proliferate yields, reduce harvest times, and reduce costs and environmental impact.

Recent progress directions

Agrobots

Driverless machines are already being used to spread fertilizer or plow the terrain. Agricultural robots, also known as Agrobots, already exist, but the new machines that identify weeds and kill them with a dose of herbicide are brand new. The Blue River Technology robot "is towed behind a tractor and uses its cameras to automatically identify, target, and destroy weeds with nearly perfect accuracy".[175] It significantly reduces the quantity of pesticide needed and could result in cost reductions.[176] Other innovations include a machine equipped with sensors useful for site-specific crop protection. Chlorophyll-detecting sensors differentiate between green plants and bare ground, while sensor-nozzle systems scan the paddock to spray precise applications of herbicides on individual plants. This new machine is cost-effective and environmentally friendly, as it will spray herbicide only on weeds and not on the soil or on other plants.[177]

The Internet of things in precision farming

The Internet of things represents a network of physical objects equipped with electronics that creates prospects for direct integration of the physical world into computer-based systems. In precision farming, it permits the

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[175] https://www.greenmatters.com/food/2018/01/08/Z2a3sFE/john-deere-ai-lab-sustainable
[176] http://www.greenmatters.com/food/2018/01/08/Z2a3sFE/john-deere-ai-lab-sustainable
[177] http://www.precisionag.com/regions/amazone-set-to-release-weed-detecting-sprayer-in-australia/

detection or remote control of entities across an existing network/internet infrastructure, via sensors and farm-management software and hardware. For example, farmers can now make use of a cloud-based platform for driverless tractors which, "along with the tractor automation kit, is a plug-and-play system that automates a grain cart tractor"[178] (regardless of manufacturer) and provides farmers with assistance during the harvest season. "The system allows a combine operator to set staging and unloading locations in a field, adjust speed, monitor location and command the grain cart to sync precisely to the speed and direction of the combine".[179] Various all-in-one auto-steering kits have entered the market.[180]

A new cloud-based handheld device will allow farmers to test DNA from crops and weeds. This new technology instantly tells farmers if their crops are drought- or insect-resistant or if weeds in their fields resist herbicides. Farmers need only crush a leaf or a seed and put the resulting liquid into the cartridge of the handheld device. The results of the genetic test are uploaded to a digital cloud, which can store several years' worth of data, so farmers will know how the seed compare to what they planted years previously. The device will also send the farmer's GPS location with the sample data, so there is no need to write down which field the DNA sample came from.[181]

Another innovative software solution can detect in-field stress just by taking a photo with the smartphone camera. This mobile application can determine weeds, classify and count insects, recognize diseases, analyse leaf damage and show the nitrogen status. Moreover, it notifies the user when risks are rising on fields and gives access to day-to-day information about disease and pest pressure.[182]

In-field devices

An in-field automated solar-powered laser was created to be a deterrent to birds feeding on blueberry fields. This innovative laser system relies on birds' natural instinct to avoid trouble. They perceive the approaching laser beam as a predator and take flight to seek shelter.[183]

A group of researchers introduced sensors-on-tape to be attached to plants. The plant sensors are so tiny that they can sense plant transpiration and will not affect plant growth or crop production. "The plant sensors measure the time it takes for two kinds of corn plants to move water from their roots

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[178] https://www.precisionag.com/specialty-crops/roboticslabor-savers/smart-ag-announces-driverless-tractor-automation-platform

[179] https://www.precisionag.com/specialty-crops/roboticslabor-savers/smart-ag-announces-driverless-tractor-automation-platform/

[180] http://markets.businessinsider.com/news/stocks/finally-an-all-in-one-autosteering-solution-for-every-farm-has-arrived-1012666305

[181] https://www.precisionfarmingdealer.com/articles/3174-agtech-start-up-dnp123-to-launch-handheld-device-tests-seeds-genetics-weed-id

[182] http://www.precisionag.com/regions/perspective-is-bayers-highly-anticipated-xarvio-app-the-next-uber-for-ag/

[183] http://www.farmindustrynews.com/technology/using-lasers-deter-avian-pests

to their lower leaves and then to their upper leaves."[184] With this tool, one can start breeding plants that are more efficient in using water.[185]

Grain unloading will be soon improved by eliminating the need to shovel, sweep, or enter a bin. A new tool integrated in bins provides complete, efficient and safe zero-entry cleanout. "The innovation uses liners at the base of a bin that inflate sequentially to eliminate the last bit of grain by "rolling" it into a central unload auger."[186] The unloading job, often taken on during late summer, is unpleasant due to heat, sweat and dust. The same device aerates grain.[187]

Long-term perspectives

The farms of tomorrow may no longer need people to grow crops at all. Autonomous robots have already been used to perform tasks like planting seeds, tending crops, and harvesting. Planters, tractors, weed-eating harvesters will grow into all-in-one robots controlled by a central artificial intelligence - and become the mainstream in agriculture. These robots, not subject to human error, will adapt to conditions in the field so as to maximise yield, drastically cut down time, and increase efficiency.

4.1.17 Soft Robot

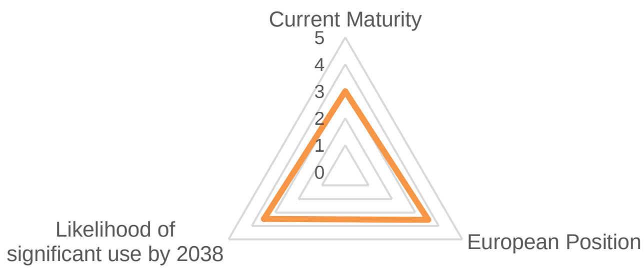

Figure 18: RIB Score of Soft Robot

Soft Robotics is a subfield of robotics concerned with building machines out of materials similar to or mimicking those of living organisms. Soft robots strive to be similar to living creatures in other ways, most prominently in movement and the ability to adapt to the changing physical structure of their environments. The robots are called "soft" to highlight the contrast with those built out of rigid materials, as well as their flexibility and adaptability.[188] Soft robots made of materials such as hydrogel, latex or silicone, "are able to squeeze through tight openings, handle fragile objects,

[184] https://www.precisionfarmingdealer.com/articles/3188-engineers-make-wearable-sensors-for-plants-enabling-measurements-of-water-use-in-crops
[185] https://www.precisionfarmingdealer.com/articles/3188-engineers-make-wearable-sensors-for-plants-enabling-measurements-of-water-use-in-crops
[186] https://www.farmindustrynews.com/technology/update-grain-handling-tool
[187] http://www.farmindustrynews.com/technology/update-grain-handling-tool
[188] https://en.wikipedia.org/wiki/Soft_robotics

and interact with humans far more safely than their rigid, metal-and-plastic counterparts."[189] These features recommend soft robots for use in medicine and manufacturing, among other fields.

Recent progress directions

Pneumatic

The natural compliance of inflated balloons makes them ideal candidates for soft robots. A team of researchers has already developed soft robots with muscle-like actuators made of silicone and rubber and powered by air pressure.[190] Scientists have developed "a method to automatically design soft actuators based on the desired movement."[191] They used it to design a soft robot that bends like an index finger and twists like a thumb when powered by a single pressure source.[192] Inspired by natural organisms that cover distance by growing – such as vines, fungi and nerve cells –, engineers also built a soft robot that can grow across distances without moving its whole body.[193]

Robotics researchers made a hand that can touch delicate items and sense the shape and texture of what it touches. The hand "was able to scan three tomatoes and determine, by softness, which was the ripest".[194]

Another team has developed a soft robotic sleeve that envelops a living heart and twists/compresses in synch with it, augmenting cardiovascular functions weakened by heart failure.[195] In another application, artificial muscles looking like strange little worms were packed into bundles to make a credible analogue to human muscles, helping in the physical rehabilitation of stroke victims.[196]

The Octobot is the first 3D-printed, entirely autonomous robot with no rigid parts. Each of the components within the soft robot body was 3D-printed, including the fuel storage, power and actuation. The researchers are currently looking into flexible sensors that allow for navigation.[197] Another team has developed the first 3D-printed, soft, four-legged robot that can climb over obstacles and walk on different terrains, such as sand and pebbles.[198]

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189 https://www.economist.com/science-and-technology/2016/07/09/flight-of-fancy
190 http://www.technology.org/2016/10/12/soft-robots-mimic-human-muscles
191 https://www.sciencedaily.com/releases/2016/12/161219161606.htm
192 https://www.eurekalert.org/pub_releases/2016-12/hjap-mbm121916.php
193 https://www.eurekalert.org/pub_releases/2017-07/su-srd072017.php
194 https://www.sciencedaily.com/releases/2016/12/161219161606.htm
195 http://scitechdaily.com/engineers-develop-soft-robotic-sleeve-to-help-the-heart-beat
196 https://techcrunch.com/2016/10/12/these-soft-robotic-muscles-could-help-with-physical-therapy
197 http://www.3ders.org/articles/20160825-pneumatic-octobot-worlds-first-autonomous-entirely-soft-robot-3d-printed-by-harvard-scientists.html
198 http://www.technology.org/2017/05/20/3d-printed-soft-four-legged-robot-can-walk-on-sand-and-stone

Living muscle tissue

By combining robotics with tissue engineering, researchers are building robots powered by living muscle cells. "These devices can be stimulated electrically or with light to make the cells contract to bend their skeletons, causing the robot to swim or crawl."[199] A team has built a soft robotic stingray propelled by living cells (rat muscle) fed with glucose and activated by flashes of light. It could swim almost 10 cm per minute. After six days, it retained 80 % of its original speed.[200] Researchers have developed a type of walking "bio-bot" powered by skeletal muscle cells that can be controlled by light.[201]

Mechanical

Some soft robots involve also rigid parts and pure mechanical connections. Scientists have created a "lightweight, low-profile soft robotic ankle support that could help stroke patients walk with less difficulty and more normal strides."[202] A team of engineers has developed "a hybrid soft-rigid robot arm for endoscopic surgery that includes integrated sensors".[203]

New materials/techniques

Scientists have created a dielectric elastomer that requires low voltage and no rigid components. It could be used in wearable devices, soft grippers, laparoscopic surgical tools, entirely soft robots or artificial muscles.[204] Using Liquid Crystalline Elastomers (LCEs), researchers have demonstrated "a bioinspired micro-robot capable of mimicking caterpillar gaits in natural scale".[205] A team of engineering researchers has used "magnetic fields to remotely manipulate microparticle chains embedded in soft robotic devices".[206]

A hydrogel-based robot inspired by jellyfish is capable of enough force to catch and release live fish. Its inventors describe it as "a clever little robot that is not only made mostly from water, but is powered by water as well, meaning that if used underwater they appear almost invisible, like a jellyfish."[207] Studying the gelatinous jaw of a sea worm, a team of scientists has developed muscles for soft robots made from a hydrogel-like synthesized protein. When the salt concentration in the environment changes, the material expands or contracts.[208]

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199 http://www.nanowerk.com/news2/robotics/newsid=44202.php
200 http://www.economist.com/news/science-and-technology/21701746-robotic-stingray-powered-real-muscles-and-guided-light-flight-fancy
201 http://www.dailymail.co.uk/sciencetech/article-4224446/The-BIO-BOT-skeletal-tissue-muscle-cells.html
202 https://www.eurekalert.org/pub_releases/2017-07/aaft-sre072417.php
203 https://www.theengineer.co.uk/soft-medical-robot-endoscope-arm
204 https://www.sciencedaily.com/releases/2016/07/160721143907.htm
205 http://www.eurekalert.org/pub_releases/2016-08/fopu-nsc081816.php
206 https://phys.org/news/2017-03-soft-robots-magnetic-fields.html
207 http://newatlas.com/mit-hydrogel-robot-fish/47683
208 http://feeds.nanowerk.com/~/301938416/0/nanowerk/agwb~A-material-inspired-by-a-sea-worm-changes-according-to-the-environment.php

(For soft robots that can heal parts of themselves, see 'Self-healing Materials'.)

Long-term perspectives

In medical and personal robotics, soft-matter machines will enable safe and biomechanically compatible interactions with humans. At a smaller scale, "miniature soft robots promise to help in medical applications such as drug delivery and surgery. For field exploration and disaster relief, soft robots can navigate challenging terrain and penetrate tightly confined spaces by adapting their shape and locomotion strategy in ways similar to natural organisms."[209] Soft robots will further help fields such as food handling and agriculture to become highly automated, bringing down costs.

4.1.18 Touchless Gesture Recognition

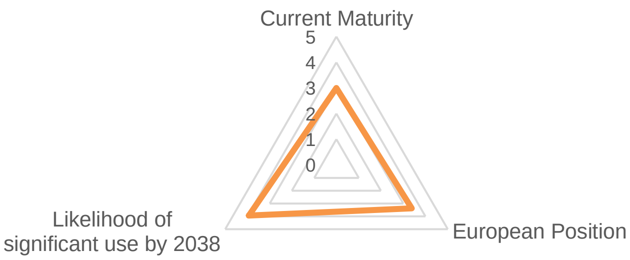

Figure 19: RIB Score of Touchless gesture recognition

Touchless gesture recognition refers to a family of information technologies allowing people to interact with electronic devices and gadgets via gestures performed outside touchscreens, usually in mid-air.

Recent progress directions

Ultrasonic gesture sensing

The underlying principle of ultrasonic gesture sensing resembles the echolocation system used by bats and dolphins. A sonar system emits ultrasound, inaudible signals which are reflected by the user's hand, head or body and subsequently captured by microphones and interpreted by time-of-flight algorithms. The latest ultrasonic technologies employ acoustic microelectromechanical systems (MEMS), such as microphones and speakers in existing smartphones; or special-purpose ultrasound transceivers incorporating piezoelectric transducers.[210]

[209] https://www.researchgate.net/publication/275605108_Soft_Robotics_A_Perspective-Current_Trends_and_Prospects_for_the_Future

[210] https://spectrum.ieee.org/semiconductors/devices/beyond-touch-tomorrows-devices-will-use-mems-ultrasound-to-hear-your-gestures

Ultrasound technology successfully replaced the infrared proximity sensor in a first-of-its-kind smartphone released at the end of 2016.[211] But the main advantage of sonar solutions, besides very low power, is that they do not depend on direct line of sight or lighting conditions. A key question concerning the future adoption of ultrasonic gesture recognition is whether the technological solutions are able to deliver sufficient accuracy in real-world scenarios. Additionally, sonar echoes are weak and typically not accurate enough to precisely track finger motion. However, error correction algorithms led to a gesture recognition prototype featuring 0.8 cm finger tracking accuracy for smartphones and 1.2 cm accuracy for smartwatches.[212] Chirp Microsystems claims its ultrasonic chips are able to recognize tiny "micro gestures" with 1mm accuracy.[213]

Optical cameras and sensors

Image-based gesture recognition employs conventional or depth sensing cameras to track and then interpret hand and body gestures. Visual gesture recognition systems (such as Microsoft Kinect) have been prototyped, tweaked and even commercialized for many years already, but they have so far had limited capabilities, applications and user appeal. Nevertheless, current and medium-term innovations, along with breakthroughs in speech recognition, virtual reality and augmented reality, could soon lead to a much broader use of touchless interfaces.

On the hardware front, there is a trend towards miniaturization, with an eye towards embedding gesture sensing cameras into smartphones, wearables and IoT devices. As an alternative, optical proximity sensors can recognize air gestures and hover manipulations. For example, German and Canadian university researchers have put together a smartwatch prototype called WristWhirl, featuring 12 infrared proximity sensors and a piezo vibration sensor in the watch strap. Four custom apps demonstrated the control of different functions (such as music playing and scrolling) through wrist movements and directional marks performed by the hand wearing the watch.[214]

Gesture decoding gloves and hand tracking controllers

Gesture decoding gloves are fitted with sensors that follow the motion of someone's hands. While older glove prototypes were wired, the newest proof-of-concept prototypes transmit the glove sensor data via wireless protocols (i.e. Bluetooth). In a recent project, University of California researchers created a low-cost glove prototype which could recognize and translate American Sign Language gestures, suggesting potential uses for biomedical devices.[215]

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[211] http://www.smart2zero.com/news/xiaomi-phone-replaces-proximity-sensor-ultrasound-software
[212] http://www.eurekalert.org/pub_releases/2016-03/uow-scn031516.php
[213] https://finance.yahoo.com/news/chirp-microsystems-introduces-high-accuracy-163429249.html
[214] https://www.eurekalert.org/pub_releases/2016-10/dc-dt101416.php
[215] http://www.cbc.ca/news/technology/wearable-tech-asl-glove-1.4195429

Hand tracking controllers for virtual reality, such as Valve Knuckles or Oculus Touch, are handheld wireless accessories that allow the manipulation of virtual objects. Other controllers, such as the newly released LeapMotion, perform hand tracking without any handheld accessory. While multiple hand tracking products and upgrades for virtual reality are on the market, touchless gesture recognition tech for augmented and mixed reality poses additional challenges and is still in research and development.

EMG

Multi-channel electromyography (EMG) sensors measure the electrical potential generated by muscle cells. Since EMG can be performed through non-invasive surface electrodes, several companies have developed wearable armbands, which incorporate such electrodes.

Gesture recognition software

While spatial gesture recognition has generally relied on specialized hardware and dedicated software, wider-ranging software frameworks which support both depth-aware cameras and the typical RGB cameras in existing smartphones are now merging.[216] There is a shift towards streamlined integration with established mobile platforms and software libraries for virtual, augmented or mixed reality.

Since the hand gestures recognized by sensors are inherently noisy and uncertain, they need to be interpreted in real time by software algorithms, which aim to identify the most likely gesture in a given context. The gesture algorithms use broader statistical methods and will directly benefit from advances in machine learning.

Long-term perspectives

Just as nowadays, we routinely interact with smartphones, tablets and laptops via touchscreens; in a couple of years we could begin to complex hand gestures.

Touchless gesture recognition constitutes a Natural User Interface (NUI) with a great scope to alter the way we interact with everyday tech - all it would take is naturally moving and hovering our hands and fingers to issue commands to nearby devices, such as phones, computers, wearables, gaming and VR consoles, infotainment systems, robots and home appliances. Touchless interfaces could enhance professional devices as well, such as medical or military equipment. It would also revolutionize domains that rely on deep consumer engagement, like media & communication, retail, entertainment.

Moreover, there is a wealth of data garnered from recognizing and interpreting gestures, in terms of speed, motion, emotional reaction, that translates into a very sophisticated understanding of users engaging with tech. In this context, our environment will be able to "learn" from our

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[216] https://www.forbes.com/sites/charliefink/2017/09/08/ar-gesture-control-arrives/#5da0d8b3495b

reactions and become reactive to us, increasing depth and relevance of engagement by an order of magnitude.

The gesture-based market (excluding competing areas such as speech recognition) is predicted to grow to 24 billion USD by the year 2024, at an annual compound growth rate from 2017 to 2024.[217]

4.1.19 Flying Car

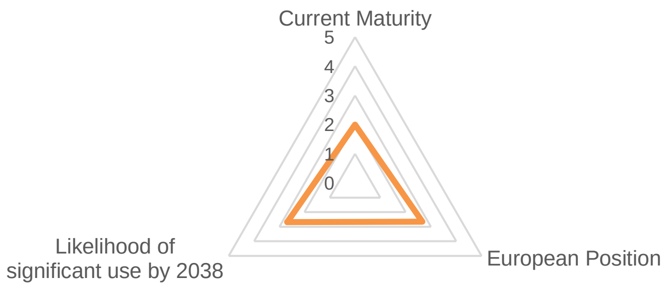

Figure 20: RIB Score of Flying car

The idea of flying cars has been appealing to humans even before automobiles existed. As the means of transportation evolved and congestion became an issue, the dream itself evolved. The flying car went from providing an effortless way to surmount the difficulties of the landscape to an effortless way to avoid the traffic caused by other people. Urban helicopter services tried to fill this niche by ferrying wealthy customers between destinations, but they proved both too disruptive and too limited in capacity. A small, safe, low-impact personal flying car seemed to always remain a dream of the 20th century. Today, advances in the miniaturization of sensors, power storage, electric motors and artificial intelligence are seemingly aligning to finally bring the flying car close to reality. As a result, smart cities are preparing for deployment of personal autonomous transportation in the hope of resolving their traffic issues.[218]

The technologies currently being developed target market niches that can be filled in the proximate future, such as one-person or utility vehicles. Drone manufacturers are adapting existing technology to these uses. On the other hand, traditional manufacturers of vehicles and aircraft are entering the market by buying up companies that already have expertise in building flying cars.[219]

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217 http://www.digitaljournal.com/pr/3538708

218 https://www.dailystar.co.uk/news/world-news/662430/flying-car-news-china-ehang-e-184-singapore-saudi-arabia-europe-62mph

219 https://spectrum.ieee.org/cars-that-think/aerospace/aviation/flyingcar-company-terrafugia-is-bought-by-chinas-geely;https://www.theverge.com/2017/11/13/16643342/volvo-geely-terrafugia-flying-car-acquisition; https://spectrum.ieee.org/view-from-the-valley/aerospace/aviation/hax-and-airbus-want-to-help-you-build-your-flying-car-company

Recent progress directions

Large autonomous drones

The one-person vehicle is a product amenable to scaled-up drone technology. Multirotor drones started out as toys and high manoeuvrability micro aircraft. However, as the number of applications increased, there was an ever-increasing demand for higher payloads, leading to oversized versions of existing products.[220] An alternative that maximises the drones' payload envisages utility vehicles. The first applications contemplated at this point are fire protection and emergency transports.[221]

Algorithms and batteries for coordinated flying taxi fleets

Extremely crowded cities with multiple high-density areas connected by low-density sprawl[222] are prime candidates for companies that want to deploy flying cars as a service.[223] While an obvious application for a personal flying car, a taxi service entails considerable effort. Controlling a fleet of autonomous vehicles is a much more complicated task than standard air traffic control, given that requests can come at any time, with no flight-plan. This has led to the development of management algorithms.[224]

Additionally, since a taxi service needs to run without interruption, electric vehicles are attractive because they entail no extra pollution in the city. Conversely, their batteries are slow to recharge. Several companies are therefore developing solutions that can work on multiple fuels to improve flight times.[225] Regulators have not yet expressed themselves on the emission standards for flying taxis, but this is sure to become an issue in the near future.

Personal rockets

Some projects seek to adapt technologies developed for other purposes to new uses. Elon Musk, hoping to find additional applications for the SpaceX reusable rocket[226], suggested a self-guided rocket that can deliver the ultra rich anywhere on earth in under an hour. While the idea itself is not new, it is not being pursued systematically at this time. Critics point out that there are many outstanding safety concerns with this type of rockets. Moreover, regulators will not allow this level of freedom of movement because of

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[220] https://www.recode.net/2016/1/6/11588556/a-chinese-dronemaker-built-a-one-seat-self-driving-flying-vehicle

[221] http://www.dailymail.co.uk/sciencetech/article-5115609/Russia-unveils-SKYF-heavy-lift-drones.html

[222] https://www.theverge.com/2017/4/25/15417506/uber-flying-taxi-elevate-dallas-dubai-bell-helicopter

[223] http://fortune.com/2017/04/26/uber-dallas-dubai-2020-flying-taxi-launch/

[224] https://www.theguardian.com/technology/2017/nov/08/uber-signs-contract-nasa-develop-flying-taxi-software

[225] https://spectrum.ieee.org/cars-that-think/aerospace/aviation/workhorse-offers-yet-another-flying-taxi-the-surefly

[226] https://www.theverge.com/2017/9/29/16383048/elon-musk-spacex-rocket-transport-earth-travel

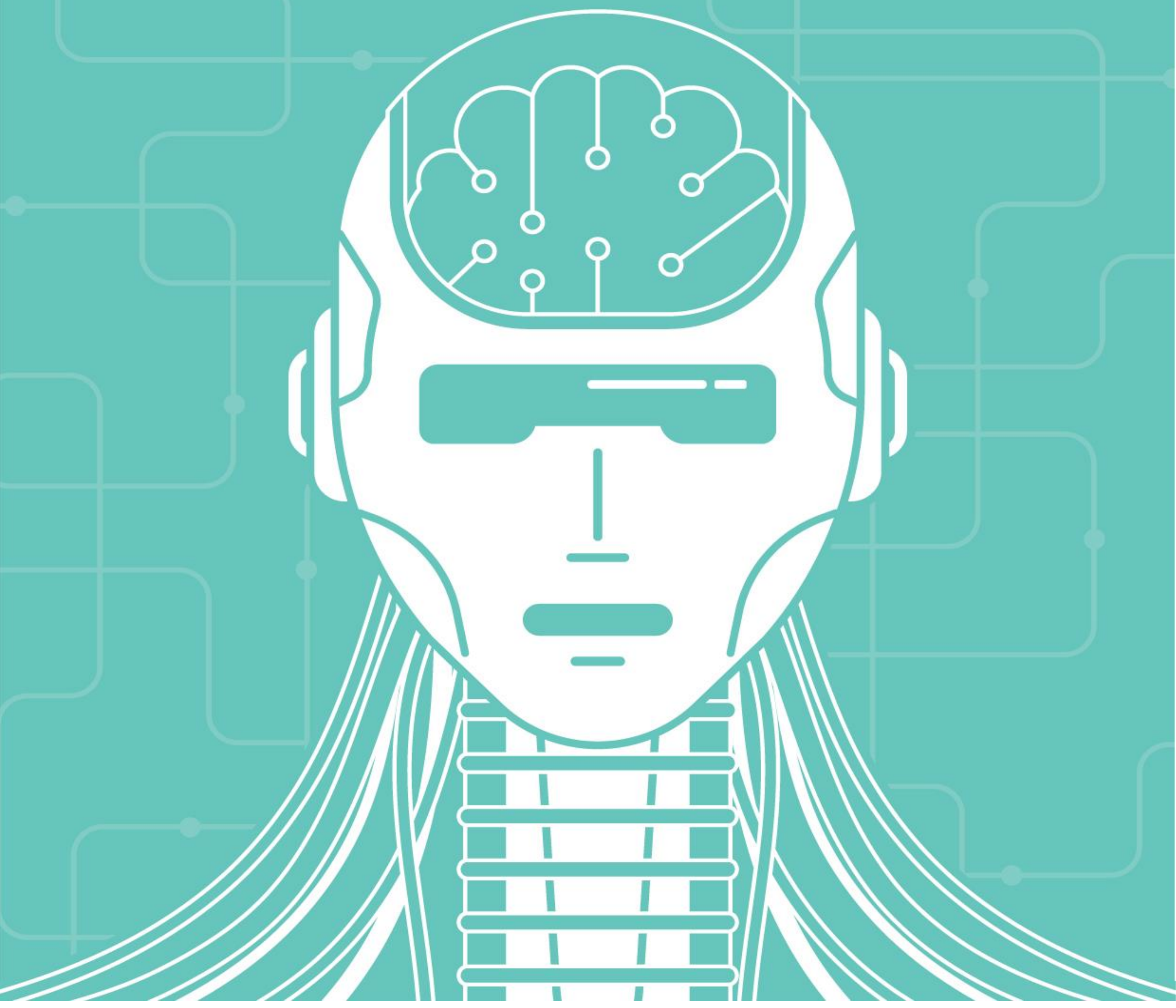
security concerns.[227] However, if the safety and security issues are resolved, many companies developing reusable rockets will likely rush to fill this market niche.

Long-term perspectives

As most approaches are focused on short- and medium-range transportation (under 60 km), cities will be the primary target of flying-car-type products. Initially, the latter will be deployed into highly developed congested cities, but they will also offer advantages to cities with difficult geography. If flying cars prove to be a success, they will eventually start to influence the basic infrastructure of cities as well as their development more generally. New neighbourhoods might be built in areas that were previously inaccessible by road (mountainous regions, waterscapes and others); old neighbourhoods would dedicate less space to land cars, re-gifting roads to bicycles, pedestrians, and social activities. On the very long term, entire urban planning initiatives might develop on the idea that flying cars are common. The hope is that commuting without a road infrastructure will decongest our metropolitan areas allowing for a freer and more dynamic use of land.

[227] https://www.wired.com/story/elon-musk-spacex-rocket-travel-plan/

Human-Machine Interaction & Biomimetics



4.2 Group 2. Human-Machine Interaction & Biomimetics

4.2.1 Neuromorphic Chip

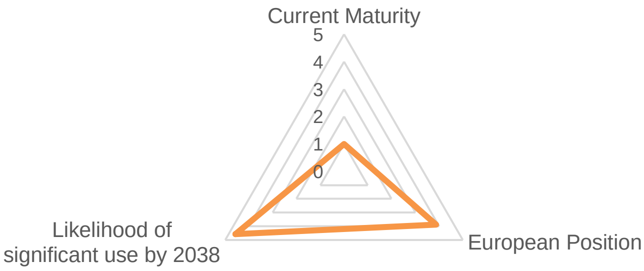


Figure 21: RIB Score of Neuromorphic chip

"The best AI algorithms already use brain-like programs called simulated neural networks, which rely on parallel processing to recognize patterns in data—including objects in images and words in speech. Neuromorphic chips take this idea further by etching the workings of neural networks into silicon. They are less flexible and powerful than the best general-purpose chips, but being specialized to their task makes them very energy efficient, and thus ideal for mobile devices, vehicles, and industrial equipment."[228]

The technology behind ranges from simple emulation of the electrical spikes generated in the brain on digital chips to massive parallel computing up to networks of artificial synapses.

Recent progress directions

Object recognition

In 2018, Intel announced a neuromorphic chip that "learns to recognize objects in pictures captured by a webcam".[229] "It integrates a wide range of novel features for the field, such as hierarchical connectivity, dendritic compartments, synaptic delays, and, most importantly, programmable synaptic learning rules".[230]

"The Air Force Research Lab (AFRL) reports good results from using a "neuromorphic" chip made by IBM to identify military and civilian vehicles in radar-generated aerial imagery. The unconventional chip got the job done about as accurately as a regular high-powered computer, using less than a 20th of the energy."[231]

[228] https://www.technologyreview.com/s/609909/intels-new-chips-are-more-brain-like-than-ever/
[229] https://www.technologyreview.com/s/609909/intels-new-chips-are-more-brain-like-than-ever/
[230] https://ieeexplore.ieee.org/abstract/document/8259423/
[231] https://www.technologyreview.com/s/603335/air-force-tests-ibms-brain-inspired-chip-as-an-aerial-tank-spotter/

Brain simulation

The first full-scale simulations of a cortical microcircuit (80 thousand neurons and 300 million synapses) with biological time scales has been achieved in 2018 with the help of massively parallel neuromorphic computer. The simulation is comparable to the one made by a standard supercomputer but with considerable less power consumption.[232]

Long-term perspectives

The development of neuromorphic chips can boost the development of AI based systems with specific purposes such as object recognition, voice and gesture recognition, emotion analytics, health analytics or robot motion. With reasonable power consumption, they can become key components of diverse interactive devices, from toys to humanoids.

4.2.2 Bionics

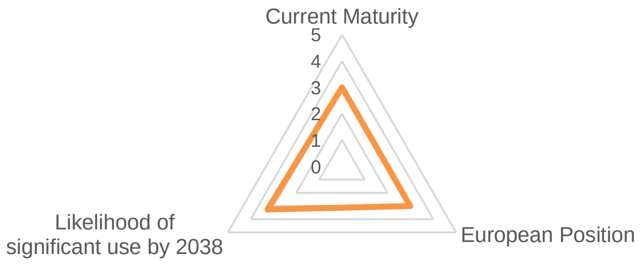


Figure 22: RIB Score of Bionics

The term "bionics" is generally used in medical contexts to describe either replacing or augmenting various body parts with machinery. The artificial – or bionic – organs and limbs are not to be confused with ordinary prostheses, since they are designed to perform as closely as possible to the original function of the replaced body part (sometimes even demonstrating superior performance).

Recent progress directions

Exoskeleton

Designed primarily to assist injured or debilitated patients, an exoskeleton copies from insects and crustaceans the idea of external strong structures sustaining the internal soft body parts. A secondary use of bionic exoskeletons is augmenting the natural human locomotor system, enabling people to run easier/faster. Researchers have developed the first robotic legs that allow patients to move about "hands-free".[233] "Lightweight"

[232] https://www.top500.org/news/neurmorphic-computing-breaks-new-ground-in-brain-simulation/

[233] https://www.eurekalert.org/pub_releases/2016-05/uok-cto051216.php

pneumatic exoskeletons are also in the making, using predominantly plastic and high-strength fabric[234], which is lighter, cheaper and uses less power than traditional designs.

Upper limbs

Patients with various degrees of amputation (hand, forearm, arm) can benefit from enhanced prostheses: a bionic hand that "sees" with a webcam and instantly decides what kind of grip to adopt for grabbing objects[235] or a hand that can feel rough/smooth textures using an electronic fingertip connected to electrodes that were surgically implanted above the stump.[236] Scientists have reported the first successful effort to wiggle the fingers of a mind-controlled prosthetic arm individually and independently of each other, without extensive training.[237] The US Army has developed a bionic arm that "provides amputees with mechanical strength and dexterity far surpassing anything seen before: it incorporates advanced motors, materials and electronics and can be tweaked to fit users with varying degrees of amputation."[238]

Internal organs

Bionics is not limited to visible limbs or organs: researchers have developed a bionic heart patch that combines electronics and living tissue, which "contracts and expands like human heart tissue, but regulates itself like a machine".[239] The patch can also deliver drugs directly to the heart, and it can be remotely monitored.[240] Another team of scientists works on a bionic pancreas: a smartphone receives data from a glucose monitor, calculates the right dose and drives two pumps to administer either insulin or glucagon.[241]

Long-term perspectives

In a broader, more audacious view, bionics aims at "merging organism and machine". This approach would result in a hybrid system that merges biological and mechanical parts, into what is called a "cyborg"[242] (short for "cybernetic organism"). Bionic organs will augment biological functions, enabling people to use superhuman force, run faster, see farther, hear better, live longer and maybe even think better.

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[234] http://newatlas.com/roam-robotics-pneumatic-exoskeleton-lightweight-otherlab/47413/
[235] http://www.dailymail.co.uk/sciencetech/article-4469698/Bionic-hand-sees-objects-grips-revealed.html?ITO=1490&ns_mchannel=rss&ns_campaign=1490
[236] http://feeds.feedblitz.com/~/142844786/0/gizmag~First-bionic-fingertip-implant-delivers-sensational-results/
[237] http://www.dailymail.co.uk/sciencetech/article-3449344/Futuristic-bionic-arm-lets-users-control-individual-fingers-using-just-thoughts-without-need-hours-training.html?ITO=1490&ns_mchannel=rss&ns_campaign=1490
[238] http://www.dailymail.co.uk/sciencetech/article-4069290/The-Pentagon-s-Luke-Skywalker-inspired-bionic-arm-FINALLY-ready-DARPA-begins-fitting-veterans-prosthetic-limb-powered-muscle-twitches.html?ITO=1490&ns_mchannel=rss&ns_campaign=1490
[239] https://english.tau.ac.il/news/cyborg_cardiac_patch
[240] https://www.sciencedaily.com/releases/2016/03/160314140743.htm
[241] https://www.eurekalert.org/pub_releases/2016-12/mgh-bps121916.php
[242] https://en.wikipedia.org/wiki/Bionics

4.2.3 Brain Functional Mapping

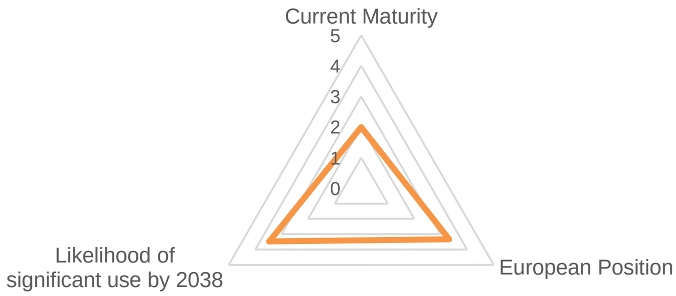

Figure 23: RIB Score of Brain Functional Mapping

Brain has not only an impressive number of neurons and connections, but it is also far from being homogenous, having an estimated 500 different parts, many functionally and anatomically distinct, connected together in very dense networks.[243] Mapping these brain areas and their interconnections is progressing rapidly, laying promises for treatment of neurological diseases, and for understanding cognition and replicating it in artificial environments.

Recent progress directions

Brain electrical activity mapping

Communication between neurons is based on electrical activity that is transmitted from neuron to neuron. In an attempt to better map these communication pathways scientists are developing electrodes that can record this electric activity under various conditions, using a computer to interpret the collected information. The information collected can provide a complex view of how neurons connect functionally, through electrically created "pathways" that define brain functions. This is also a starting point in creating computer-controlled brain stimulation procedures and developing support devices for patients that have lost either the ability to get information from their surroundings or are unable to react to such information.[244]

To make such recordings without the risks in implanting electrodes directly into the brain, new types of electrodes are being developed that can be inserted in the brain through less invasive methods, such as stentrodes (prosthetic devices that reach the brain through a vascular approach)[245] or injectable mesh electrodes.[246] These new types of electrodes have proved to

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243 https://www.youtube.com/watch?v=Ecvv-EvOj8M
244 http://www.eurekalert.org/pub_releases/2016-01/uowh-sdb012716.php
245 http://feedproxy.google.com/~r/Medgadget/~3/OYQ4tktEJP0/stentrodes-for-recording-electrical-activity-within-the-brain-without-craniotomies.html
246 http://www.dailymail.co.uk/sciencetech/article-4668722/Radical-brain-mesh-make-Matrix-reality.html?ITO=1490&ns_mchannel=rss&ns_campaign=1490

be as effective as surgically implanted electrodes and can be used for both recording and stimulation.

Another important development in this field is the concomitant use of imaging and electrical activity recording. This method will allow scientists to correlate structural and vascular changes with changes in electrical brain activity, also enabling experiments with various types of stimulation in order to better understand brain activity.[247]

Biomarker mapping

Brain mapping can also be used as a diagnostic or staging tool in neurological diseases, through the use of disease-specific biomarkers. Biomarkers can be either neurotransmitters measured at the level of synapses and/or within the neurons, brain structures volumes, variations of other substances within the brain or the accumulation of substances resulted as anomalies in normal brain functions. They provide a picture of the brain as a complex network of communicating structures supported by a highly complex metabolism.

For Alzheimer's disease, scientists have developed a specific tracer – a substance able to bind to specific proteins accumulated in the brain during the disease's progression. It is used during a PET (positron emission tomography) evaluation in order to provide visual support for early diagnostic and progression of the disease.[248]

Biomarkers can also be used in the process of understanding the mechanisms whereby drugs act to control symptoms. In the case of depression, using a specific marker attached to serotonin (which becomes visible via MRI when serotonin is removed from the synaptic gap), allows scientists to map serotonin reuptake throughout the brain. It also enables them to evaluate how new serotonin influencing medication acts in the brain and thus estimate its efficacy in a more direct and precise manner.[249]

Specific MRI techniques, such as T1-weighted MRI and diffusion-tensor imaging, can be used to obtain such biomarkers (altered white matter structure, reduced grey matter thickness, etc.) for specific diseases such as cognitive impairment.[250]

Sensors can also be used to monitor various biomarkers in the brain. A new optical nanosensor is being developed to provide spatiotemporal mapping of potassium levels as a marker of neuronal activity.[251] Similarly, transient dissolving sensors, able to communicate wirelessly with a recording device located outside the body, are being tested to measure biomarkers such as pressure, temperature, pH, motion, and flow of specific substances.[252]

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[247] https://www.medgadget.com/radiology

[248] http://www.eurekalert.org/pub_releases/2016-05/uosf-piw052316.php

[249] https://www.eurekalert.org/pub_releases/2016-10/miot-itm102016.php

[250] https://www.eurekalert.org/pub_releases/2016-10/miot-itm102016.php

[251] https://phys.org/news/2017-03-optical-nanosensor-brain-accuracy-applications.html

[252] http://www.impactlab.net/2016/03/05/dissolvable-electronics-in-the-brain-monitor-health-and-then-vanish/

Combining existing technologies to correlate two separate biomarkers that reflect a normal function of the brain is the basis for a new technology used to monitor brain function in newborn babies. The technology analyses EEG data in correlation with real-time heat maps of the brain to provide a real-time evaluation of brain function or neurovascular coupling. The new technology can be used both for the evaluation of new-borns at risk of oxygen deprivation, and to assess the efficacy of treatments for these children.[253]

Promising in vitro and laboratory work

New mapping technologies currently developed in laboratory experiments are looking into ways to map the brain starting at cellular or intracellular levels.

A new method of brain mapping uses specific viral RNA sequences connected to proteins that carry them through individual neurons. They map the connections of neurons throughout the brain building connectomes, or neuron wiring maps. This technology also reduces research costs and duration, while providing wiring information down to individual cells.[254]

Another new technique uses specific protein marking in conjunction with an improved method of tissue preservation and expansion, to map brain connectivity or functions by mapping specific proteins disposition down to subcellular level.[255]

Advances in brain imaging

Good quality imaging is vital both for diagnostic and disease progression evaluation in brain pathology. Finding new ways to analyse images or correlate them with concomitant recordings of brain function can provide further insight into the way the brain functions.

New software able to analyse and correlate information from multiple imaging sources allows scientists to rapidly obtain detailed structural and functional data about the brain with vast applicability in clinical and research settings.[256]

Image acquisition under normal functional conditions is an important step in understanding the functioning of the brain. A newly developed, portable, miniaturized positron emission tomography (PET) brain scanner allows associations to be made between brain images and specific movements and activities performed during image acquisition. This technology provides a new research tool with wide applicability in neurology, psychology, psychiatry, social sciences, etc.[257]

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[253] https://www.laboratoryequipment.com/news/2017/04/weather-forecasting-tool-finds-critical-neonatal-application?__hstc=145616811.98f189618e798238c5e9e44c34562662.1504896303329.1504896303329.1504942094162.2&__hssc=145616811.78.1504942094162&__hsfp=3422858294

[254] https://www.genengnews.com/gen-news-highlights/brain-mapped-at-single-neuron-level-of-resolution/8125 3112/

[255] http://www.azonano.com/news.aspx?newsID=34890

[256] http://www.biosciencetechnology.com/news/2017/01/new-software-speeds-medical-and-scientific-image-analysis

[257] http://www.kurzweilai.net/wearable-pet-brain-scanner-enables-studies-of-moving-patients

Understanding memory formation

By combining optogenetics and artificial intelligence, scientists have created a map of more than a billion cell connections of mouse brain, discovering a diversity of synapse types may be key to recalling information.[258]

Improving specific cognitive functions

As a tool for cognitive improvement, brain training has been shown to improve specific areas of cognitive functioning. The improvement comes specifically to cognitive functions as memory, reasoning, or processing speed, as a result of training these functions using specifically created exercises, varying in contents and difficulty. And although some studies have shown improvements in the specific functions that the exercises addressed, these is still no proof that these improvements get transferred to other cognitive functions[259,260].

Long-term perspectives

Understanding in depth how the brain functions both under physiological and pathological situations provides important information in defining both the causes of disease, therapeutic intervention and preventive strategies.

Moreover, progress in brain decoding is strongly supporting the advancement of brain-machine interfaces and brain simulation.

4.2.4 Brain Machine Interface (BMI)

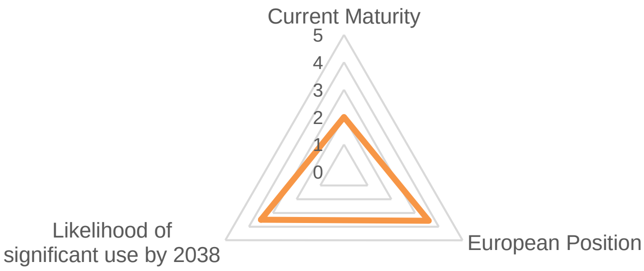

Figure 24: RIB Score of Brain Machine Interface (BMI)

A brain machine interface (BMI), also known in some incarnations as a mind-machine interface (MMI), direct neural interface (DNI), or brain computer interface (BCI), is a direct communication pathway between brain and an external device.[261] A BMI can both collect information from and feed it into the brain (e.g. restoring a lost sense), enabling it to interact with the

[258] https://www.sciencedaily.com/releases/2018/08/180802141619.htm
[259] https://www.theatlantic.com/science/archive/2016/10/the-weak-evidence-behind-brain-training-games/502559/
[260] https://www.medscape.com/viewarticle/882877
[261] https://www.irjet.net/archives/V2/i1/Irjet-v2i161.pdf

environment. An enhanced and more sophisticated is the "bi-directional" BCI, which records brain activity and transmits stimuli to the nervous system, for example in order to strengthen or reroute information from injured areas of the brain.[262]

Recent progress directions

Electroencephalography (EEG) and Electrocorticography (ECoG)

While the non-invasive use of electrodes placed on the scalp (traditional electroencephalography, or EEG) is safe, it has poor spatial resolution. Electrodes surgically implanted on the surface of the brain (ECoG) provide great "spatial resolution and can accurately detect brain activity at high frequencies", but remain expensive and their invasive nature presents risks of injury. Significant steps have made towards improving ECoG. These include "untethered" implants (wires are prone to infections) with wireless power sources[263] and smaller radio antennas.[264]

More broadly, implants have been used to allow communication with paralyzed or locked-in patients[265,266] by deciphering unspoken words from brain waves and enabling fast and accurate typing. They have also empowered paraplegics to move objects "with their mind", enabled individuals who had lost the feeling of touch[267] to regain it, and even restored the ability to move individual fingers.[268] Promising new developments through safer solutions such as an EEG cap placed on the head (complemented by machine learning) made it possible for subjects to control a robotic arm in a complex 3D environment.

Functional Near-Infrared Spectroscopy (fNIRS) and Functional Magnetic Resonance Imaging (fMRI)

Functional Near-Infrared Spectroscopy (fNIRS) allows "functional imaging of brain activity (or activation) through monitoring of blood oxygenation and blood volume in the prefrontal cortex". It proved efficient in measuring the cognitive load of the wearer in order to signal to the computer when to deliver a new piece of information.[269] fNIRS has also been used to detect yes/no responses from completely locked-in patients.[270]

fMRI has been used for biofeedback. Researchers have enabled individuals to visualize the level of activation in the Posterior-Cingulate-Cortex (PCC)

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262 http://neurosciencenews.com/machine-brain-melding-7686/
263 https://www.eurekalert.org/pub_releases/2016-02/tuot-wsp020716.php
264 https://futurism.com/new-mini-antennae-could-pave-the-way-for-brain-computer-interfaces/
265 http://www.dailymail.co.uk/sciencetech/article-3423290/Mind-reading-computer-INSTANTLY-knows-thinking-about.html?ITO=1490&ns_mchannel=rss&ns_campaign=1490
266 http://neurosciencenews.com/typing-paralysis-bci-6140/
267 http://neurosciencenews.com/brain-controlled-robotic-arm-paralysis-5281/
268 https://www.sciencedaily.com/releases/2016/02/160215154656.htm
269 http://www.impactlab.net/2016/02/29/bach-brain-reading-tool-that-can-teach-you-a-new-skill/
270 https://www.popsci.com/new-brain-computer-interface-helps-completely-paralyzed-people-communicate?dom=rss-default&src=syn

area of the brain[271], and learn how to reduce their mental activity, obtaining a meditation-like state.

Long-term perspectives

Communication by simply transferring thoughts has long captivated human imagination, for reasons such as speed, directness, trustworthiness, or capturing the complexity of thoughts.

One long-term pursuit is to increase the effectiveness of carrying out complex tasks (e.g. piloting a fighter plane) through man-machine symbiosis. Progress in brain stimulation may open an era of brain-to-brain communication. Exchanging complex thoughts may not be possible on the medium term, but brain-to-brain communication could enable the constant sharing of emotions, moods, states of mind. Numerous questions loom large, from dependency (in the man-machine scenario) to the individual and social impact of sharing things, which, so far, have fundamentally shaped human societies.

4.2.5 Emotion Recognition

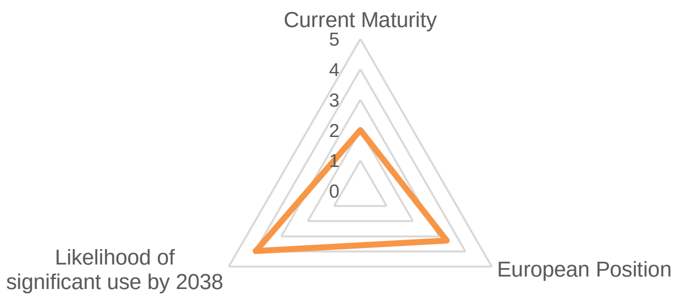

Figure 25: RIB Score of Emotion recognition

Emotion recognition has been traditionally concerned with detecting emotions by applying advanced image processing algorithms to images (or videos) of the human face. But recent developments have extended the field to include other means of gauging emotions (text analysis, tone of voice, heartbeat and breathing patterns, etc.) and even extending them to other species.

Applications of emotion recognition include marketing (detecting minute, subconscious reactions to advertising or products), smart devices that adapt to our mood, law enforcement (improved lie detectors), etc.

[271] https://yalebooks.yale.edu/book/9780300223248/craving-mind

Recent progress directions

Recognizing facial expressions

The main direction in emotion recognition remains "reading" facial expressions. Engineers have developed a chip running AI algorithms that enable it to analyse images of faces in real time and to recognize eight emotions. It requires no internet connection and can be used in toys.[272] Another team has announced a kiosk that can detect changes in physiology and behaviour when a person is lying. The system has been rigorously tested in different environments, including airports and border crossing stations.[273]

Capturing facial expressions is not limited to image analysis: "a temporary "electronic tattoo" can measure the activity of muscle and nerve cells, recording a strong and steady signal for hours on end without irritating the skin. One major application is emotion mapping by monitoring electric signals received from facial muscles."[274]

Turning their attention towards other species, scientists have written an algorithm which uses AI techniques to take as input the facial expressions of a sheep and to output an evaluation of the intensity of the pain it might feel. "This system can facilitate the early detection of painful conditions in livestock, and eventually it could also be used as the basis for AIs that read emotions on human faces."[275]

Interpreting other signals (text, voice, heartbeat, breathing)

After facial expressions, the next big thing in emotion recognition is "sentiment analysis" – applying machine-learning algorithms to written text in order to detect positive or negative attitudes expressed by people. Researchers were surprised to discover that a neural network trained to predict the next character in Amazon reviews taught itself to analyse sentiment. The network classified reviews as either positive or negative, and was even able to generate text with a desired sentiment.[276]

Focusing on spoken language, a team of engineers has developed a wrist-mounted AI device that can detect a conversation's tone. The prototype measures the mood of a story with 83 % accuracy. "It can also provide a "sentiment score" for every five-second interval in a conversation."[277]

Another team has created a device that can pick up emotions (such as excitement, sadness, anger and happiness) with around 87 % accuracy,

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[272] http://www.dailymail.co.uk/sciencetech/article-4625214/Feeling-sad-Soon-DOLL-able-tell.html?ITO=1490&ns_mchannel=rss&ns_campaign=1490
[273] https://www.mnn.com/green-tech/research-innovations/stories/border-security-may-soon-be-staffed-lie-detecting-robots
[274] http://www.nanotech-now.com/news.cgi?story_id=53666
[275] https://futurism.com/researchers-have-created-an-ai-that-could-read-and-react-to-emotions/
[276] https://futurism.com/ai-learns-to-read-sentiment-without-being-trained-to-do-so/
[277] https://www.techradar.com/news/the-siri-of-the-future-could-detect-the-tone-of-your-conversations

using heartbeat and breathing patterns measured with radio waves reflected off the body.[278]

Long-term perspectives

Accurate measurement of emotions could completely change how marketers design their advertising: instead of relying on personal hunches or on subjective focus groups, each idea could be tested scientifically and rigorously on various target groups. Law enforcement will benefit too from a device that can capture micro-expressions and detect subtle emotional changes – lying would become far easier to detect. Applications in healthcare are also very promising: it could be used to help with monitoring and diagnosing conditions that have strong emotional components, including depression and anxiety.

Companies will probably want to embed emotion recognition systems in toys, in smart TVs, in a smart home hub or in mobile phones – imagine a smartphone that can tell how you are feeling and offer up content, communication or app suggestions accordingly. Smart devices are our current reality, but "sympathetic devices" could be the future.

4.2.6 Smart Tattoos

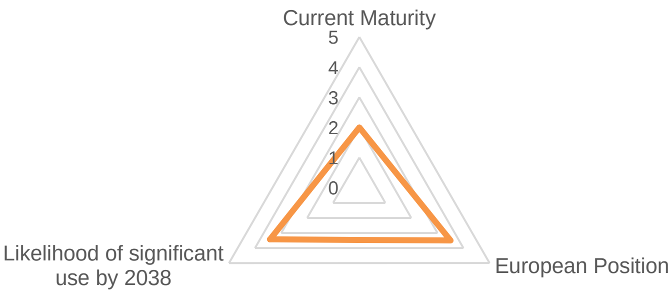

Figure 26: RIB Score of Smart Tattoos

Smart tattoos represent an all-in-one sensing platform, also known as paper skin[279], e-skin[280], or electronic tattoos.[281] They consist of wearable epidermal skin electrodes which enable real-time and simultaneous sensing of various environmental stimuli (pressure, touch or proximity) and physiological data (heart rate, breathing, blood alcohol and oxygen content, muscle activity, emotions). Smart tattoos enable "portable access to the collection, storage

[278] https://techcrunch.com/2016/09/20/this-mit-device-can-tell-if-youre-happy-sad-or-angry-using-wireless-signals/?ncid=rss&guccounter=1
[279] http://www.nanowerk.com/spotlight/spotid=42650.php
[280] http://www.dailymail.co.uk/sciencetech/article-3542072/The-electronic-skin-fitted-disco-lights-Sticky-film-lead-wearable-screens-track-health-FILMS.html
[281] http://www.theengineer.co.uk/electronic-tattoo-collects-physiological-data-for-medical-and-commercial-applications

and analysis of health signals and information".[282] For example, by measuring variations in body temperature one could track healing processes; by monitoring blood content or heart rate, one could gather information about pathological conditions. Key advantages of smart tattoos over conventional trackers include the large degree of skin conformability (skin is flexible and stretchable), the wireless interface for data collection, wireless power, disposability, and inexpensive microfabrication.

Recent progress directions

Improved sensor performance

Paper skin has a scalable fabrication approach using off-the-shelf household items such as aluminium foil, scotch tapes, sticky-notes, napkins and sponges. The intrinsic porosity of cellulose paper, for example, enables good response to and recovery times for humidity sensing. The structure of polypropylene wipes, on the other hand, promotes ultra-high sensitivity in the low-pressure regime, easily detecting the heart pulse waveform via the tip of a finger lightly touching on the sensor's surface. Aluminium foil has paramagnetic properties, improving the detection range in proximity sensing devices.

Medical technologies

Human skin can simultaneously feel touch, pressure, temperature, humidity, strain, and flow. One objective for the electronic skin is thus to mimic the sensations and multi-functionality of human skin, for example to help burn and acid victims. Paper skin promises to be a flexible platform for applications such as health monitoring, where sensing diversity, surface adaptability, and large-area mapping are all essential. The e-skin platform is suitable for measuring instantaneous UV (ultra-violet) exposure (a major risk for skin cancer) and skin temperature, providing precise dosimetry in the UV-A and UV-B spectrum.[283]

Virtual reality

An artificial skin with the thickness of a spider thread (3.5 micrometers) consists of a tiny magnetic field sensor sandwiched between two layers of film. The minute skin patch reacts to proximity to magnets by producing voltage. The latter varies depending on its angle relative to the magnetic field, enabling software to retrace the sensor's movement. Placed on the human body, the skin patch can thus trigger movement in a virtual environment. The technology opens exciting opportunities for interaction with virtual worlds.[284]

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282 https://www.eurekalert.org/pub_releases/2017-08/dgi-st082017.php
283 http://www.theengineer.co.uk/electronic-tattoo-collects-physiological-data-for-medical-and-commercial-applications
284 http://www.sciencemag.org/news/2018/01/watch-wearable-electronic-skin-control-virtual-objects

Emotion mapping (for marketing and other uses)

Given the wide range of potential sensorial readings, electronic tattoos provide a comparatively more convenient and direct solution for emotion mapping. Most solutions currently in use rely on methods based on the analysis of facial expressions. Identifying emotional states and their development by reading a much broader spectrum of physiological data would enable advertisers, pollsters, media professionals, and others to test individuals' responses to a variety of products and situations.[285]

Long-term perspectives

In the future, electronic skin will support interactive telemedicine and treatment systems for patients in areas where medical services are not accessible. "Ultimately, flexible organic optical sensors may be directly laminated on organs to monitor the blood oxygen levels during and after a surgery."[286] Tattoos would help patients under rehabilitation after stroke or brain injury to improve muscle control, or amputees to move artificial limbs.[287] Emotion mapping, on the other hand, heralds a new era of interaction among both individuals and individuals and companies. It also raises fears of addiction and of hacking humans for nefarious purposes.

4.2.7 Artificial Synapse/ Brain

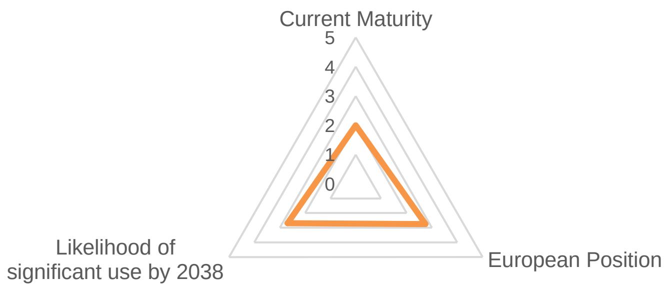

Figure 27: RIB Score of Artificial synapse/brain

Biomimetics is the field that creates technologies which mimic natural systems – including human organs like the brain – in their functioning and design. An example is artificial synapses (a *biological* synapse is an electrochemical system that links two neurons) –one of the approaches to creating brain-like computer systems that would lead to a working artificial brain which would process information in a similar manner relative to the human brain. Recent developments draw on exploring new materials, as well as on efforts to create a standard model of the brain and to design neural networks via software.

[285] https://www.nanowerk.com/nanotechnology-news/newsid=43905.php
[286] https://www.bbc.com/news/health-36055501
[287] https://www.sciencedaily.com/releases/2016/07/160711155817.htm

Recent progress directions

Memristors and atomristors

Researchers from France's National Centre for Scientific Research (CNRS) have designed a so-called "memristor", an artificial synapse which is implemented directly on a computer chip. As reported, this synapse "is capable of learning autonomously. They were also able to model the device, which is essential for developing more complex circuits."[288]

Once the working of such synapses is well understood, more complex systems could be built in which multiple artificial neurons could be linked by such memristors. This may eventually lead to developing intelligent systems capable of learning quickly and efficiently, and, importantly, without external assistance – i.e. autonomously.[289,290,291]

Another team of researchers (at the University of Texas, Austin) discovered a "non-volatile memory effect in atomically thin 2D materials such as MoS2".[292] This durable memory effect is comparable to memristors or RRAM in metal oxide materials. "These devices can be collectively labelled atomristors – referring, in essence, to a memristor effect present in atomically thin nanomaterials or atomic sheets".[293] MoS2 and similar compounds are crystalline and have an electronic barrier which can block electrical currents. Given these properties, working atomristors may be feasible.[294]

ENODe

Another relevant step has been taken by researchers at Stanford University and at Sandia National Laboratories. They designed a new type of "artificial synapse" which, which further development, may lead to circuits which allow for direct brain – artificial system interfaces. This version of artificial synapse consists of an organic transistor, an "electrochemical neuromorphic organic device" (ENODe), to use the team's own terminology.[295]

The team took a path to building brain-like computing systems that differs from the common approach. Typically, a virtual neural network is programmed or simulated by writing appropriate code (i.e. via software). Instead, the researchers built a physical machine that mimics the behaviour of biological synapses. In the process, they "overhauled our traditional idea of computing hardware. The ENODe, may one day be used to create chips that perform brain-like computations with minimal energy requirements.

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288 https://futurism.com/we-just-created-an-artificial-synapse-that-can-learn-autonomously/
289 https://www.sciencealert.com/scientists-just-created-an-artificial-synapse-that-can-learn-autonomously
290 http://www.cnrs.fr/index.html
291 http://www2.cnrs.fr/en/2903.htm
292 http://scipol.duke.edu/content/atomristor-memristor-effect-atomically-thin-nanomaterials
293 http://www.nanoappsmedical.com/atomristor-memristor-effect-in-atomically-thin-nanomaterials/
294 http://scipol.duke.edu/content/atomristor-memristor-effect-atomically-thin-nanomaterials
295 https://thenewstack.io/scientists-create-artificial-synapses-brain-like-computing/

This opens up the possibility of interfacing live biological cells with circuits that can do computing via artificial synapses”.[296,297,298,299]

Junction-based artificial synaptic device

Research in artificial intelligence envisions the development of systems capable of matching human learning, cognition and image recognition. To achieve such goals, laboratory studies are done to build electronic-based artificial synapses. However, such artificial synapses, at the current stage of development, can process just one type of signal.[300] A group of researchers from the US and China sought to create a reconfigurable artificial synapse that can switch between stimulatory and inhibitory signals.[301]

This team sought to develop a device which could manage both types of signals. The solution was to design an artificial synapse system that can change its configuration relative to the voltages its input terminal receives. “A junction made of black phosphorus and tin selenide enables switching between the excitatory and inhibitory signals. This new device is flexible and versatile, which is highly desirable in artificial neural networks. In addition, the artificial synapses may simplify the design and functions of nervous system simulations.”[302]

Epitaxial random access memory, epiRAM

At MIT, another group of scientists built an artificial synapse from silicon germanium. When an electric current is fed to this device, it can regulate with accuracy the intensity of the said current. While other artificial synapse designs use amorphous materials, in this case a new, “epitaxial random access memory” (epiRAM) design was preferred.[303]

An accurate computer model of the brain

Another reason for optimism in the hope to arrive at an accurate computer model of the brain is the progress made by a group of researchers in Switzerland, assisted by IBM researchers. This team was able to demonstrate a computer simulation of the neocortical column, which is the most complex part of the mammalian brain. It seems that this simulation behaves reasonably close to the biological original. The success of this simulation made the team confident enough to advance a term of three years to model a (complete) mammalian brain, and a decade to model a

[296] https://singularityhub.com/2017/03/15/new-artificial-synapse-bridges-the-gap-to-brain-like-computers/
[297] https://news.stanford.edu/2017/02/20/artificial-synapse-neural-networks/
[298] https://spectrum.ieee.org/tech-talk/semiconductors/design/flexible-organic-artificial-synapse-could-one-day-interface-with-the-brain
[299] https://news.stanford.edu/2017/02/20/artificial-synapse-neural-networks/
[300] https://phys.org/news/2017-06-hacking-human-brainlab-made-synapses-artificial.html
[301] https://www.acs.org/content/acs/en/pressroom/newsreleases/2017/june/hacking-the-human-brain-lab-made-synapses-for-artificial-intelligence.html
[302] https://www.acs.org/content/acs/en/pressroom/presspacs/2017/acs-presspac-july-12-2017/Hacking-the-human-brain-lab-made-synapses-for-artificial-intelligence.html
[303] http://www.kurzweilai.net/an-artificial-synapse-for-future-miniaturized-portable-brain-on-a-chip-devices

human brain. "By mimicking the behaviour of the brain down to the individual neuron, the researchers aim to create a modelling tool that can be used by neuroscientists to run experiments, test hypotheses, and analyse the effects of drugs more efficiently than they could using real brain tissue."[304]

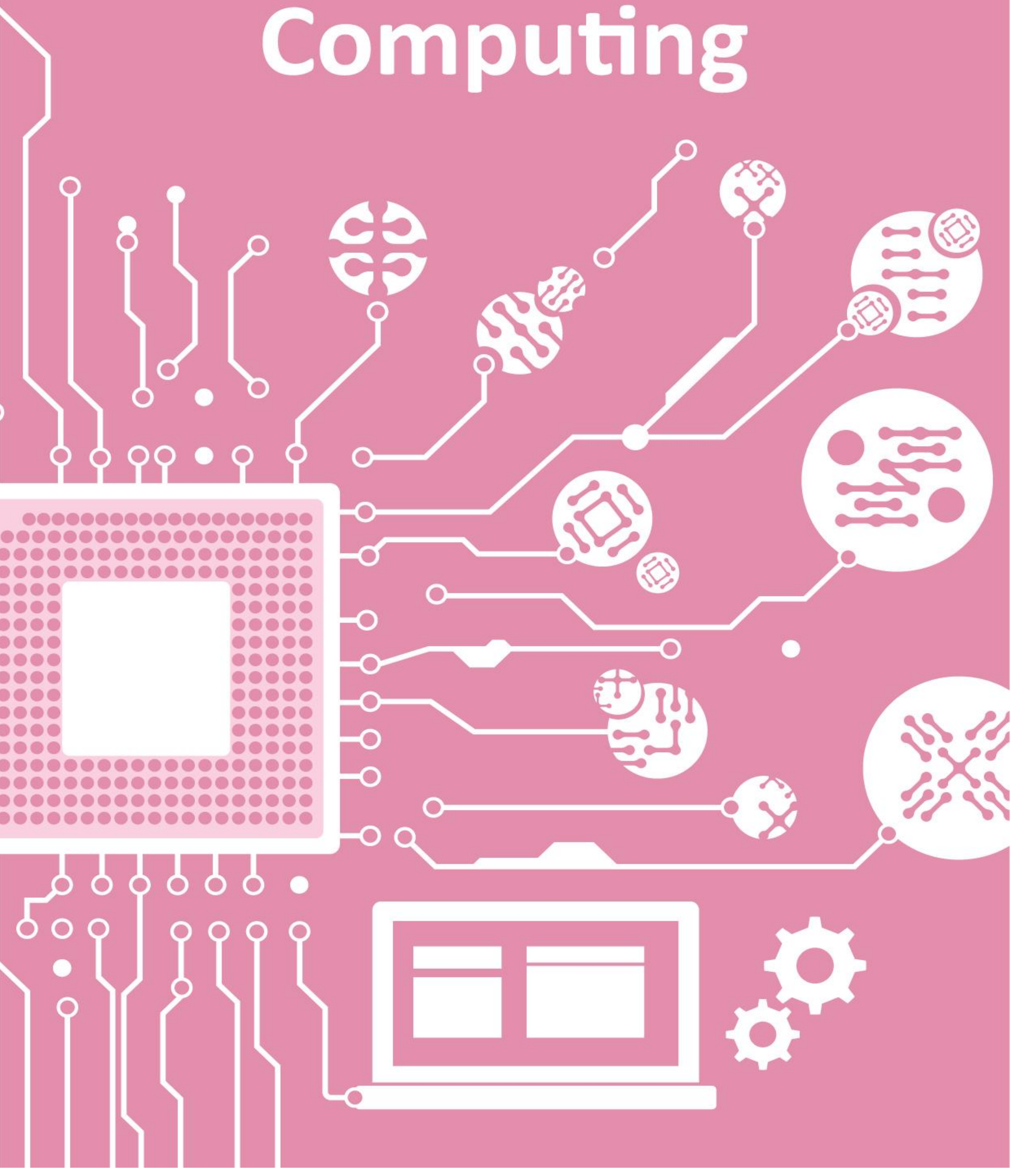
Long-term perspectives

Although different groups of researchers seem to have made breakthroughs, it will be a while until these separate approaches to harnessing the power of the brain or mimicking its structure will become widely functional.

It is to be expected that such technologies will become integral to designing computing machinery. This will be especially the case in contexts where it is productive to mimic biological neural networks, but also for supercomputers with a huge number of connections that would allow a level of computing power previously unattained.

[304] https://www.technologyreview.com/s/409107/a-working-brain-model/

Electronics & Computing



4.3 Group 3. Electronics & Computing

4.3.1 Flexible Electronics

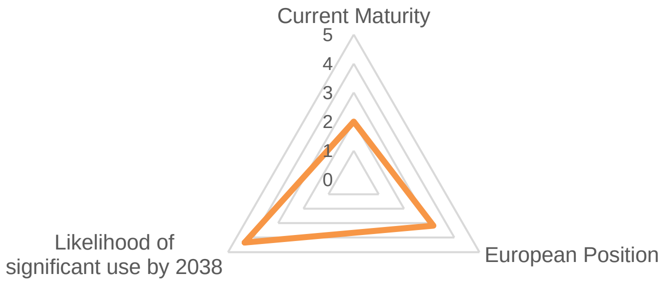


Figure 28: RIB Score of Flexible electronics

Flexible electronics are bendable or stretchable electronic circuits, meaning that at least some of their components (e.g. transistors, displays, batteries, sensors) have these properties. Flexibility enables not only more complex designs, but also new applications, such as wearables, e-tattoos or potentially low-cost solutions based on direct 3D printing of electronic circuits.

The core technology is thin-film electronics, with dozens of variations offering various promising advantages for one application or another. Flexible electronics are employed in fields such as display manufacturing, sensors, energy storage/conversion, healthcare, environmental monitoring, human-machine interaction, and others.

Recent progress directions

Transistors

The most used active electronic component is the transistor, which can act either as an on/off switch or as an amplifier. It is no wonder scientists are trying to make bendable and/or stretchable transistors. A team has succeeded in creating a new flexible transistor that could revolutionize thin-film electronics.[305] Another team designed a transistor that "can be stretched to double its original length without losing much of its conductivity".[306]

These are not theoretical, "lab-only" results: engineers have created one of the most functional flexible transistors in the world, which combines speed, high current and low power dissipation. The process is fast, simple, and cost-efficient enough for commercial scalability.[307] Also promising is a

[305] http://www.technology.org/2016/02/16/researchers-engineer-a-first-in-flexible-electronics
[306] https://www.technology.org/2017/02/22/flexible-transistors-for-wearable-electronics
[307] https://www.medicaldesignandoutsourcing.com/researchers-build-flexible-electronics-quickly-inexpensively

method to manufacture, quickly and at a low cost, high-performance transistors with wireless capabilities on huge rolls of polyethylene terephthalate, more commonly known as PET.[308]

Displays

The classical LCD or OLED technology comprises a sandwich with a rigid sheet of glass (for mechanical strength) and all the other layers flexible. Replacing the glass with a transparent plastic sheet yields a flexible display. Still, the electrical connections of individual pixels on such a screen have to be flexible and transparent. A new 2D semiconducting polymer-blended nano-network material promises exactly that: excellent charge mobility, high flexibility, and nearly 100 % optical transparency.[309] Another approach uses optically transparent, flexible, and conductive gold films.[310] Yet another deposits transparent oxide thin-film transistors (TFT) on glass, and then transfers them onto a skin-like, flexible substrate.[311] Photo-patterning of semiconducting polymers leads to cheaper, high-density, flexible electronics, which can be used as pixels for smartphone displays.[312]

Energy storage

It makes sense that the power source of flexible electronics is also flexible. Researchers have developed a new kind of flexible and thin battery, ideal for use in wearables and implantable devices[313], and a flexible lightweight material that can store energy at high temperatures.[314] A new, bendable lithium-ion battery that can flex and twist[315] or a micro-supercapacitor that exploits 3D porous electrodes[316] can be incorporated into wearable flexible electronic systems.

Power sources can be more than bendable – actually stretchable. A supercapacitor made from a stretchable polyelectrolyte combined with carbon nanotube composite paper electrodes can be stretched to nearly 1000 % in length and compressed to about 50% of its thickness, gaining even more capacity.[317]

Researchers have also engineered bendable batteries that can run on body-inspired liquids such as normal IV saline solution and cell-culture medium.[318]

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308 http://www.eurekalert.org/pub_releases/2016-04/uow-wsp042016.php
309 https://phys.org/news/2017-01-semiconducting-nanonetwork-backbone-transparent-flexible.html
310 https://www.nanowerk.com/nanotechnology-news/newsid=47212.php
311 https://phys.org/news/2016-07-team-ultrathin-transparent-oxide-thin-film.html
312 https://www.ecnmag.com/news/2017/11/honey-i-shrunk-features-low-cost-flexible-large-area-electronics
313 https://futurism.com/researchers-develop-bendable-batteries-that-could-make-implants-and-wearables-safer
314 http://www.plastemart.com/news-plastics-information/energy-storage-solution-combines-polymers-and-nanosheets-for-flexible-electronics-electric-vehicles-aerospace/46154
315 http://www.livescience.com/56514-bendable-lithium-ion-battery.html
316 http://www.azonano.com/news.aspx?newsID=35256
317 http://www.azonano.com/news.aspx?newsID=35679
318 https://www.nanowerk.com/nanotechnology-news/newsid=47707.php

Sensors

For electronic circuits that need input from sensors, making the circuit flexible is only a half-step if the sensor remains rigid. Researchers have developed a flexible pressure sensor that remains accurate even when doubly bent.[319] Another development is a new kind of display: a highly flexible, colour-changing "skin" that senses pressure.[320]

A novel "sheet camera" can be wrapped around objects to capture high quality images over a wide range of sheet deformations.[321] Folding it around any surface (e.g. a lamp post, the outside of a car) would allow taking photos and videos of the object's environment from angles previously impossible. Another team of scientists built a flexible detector for terahertz frequencies, using graphene transistors on plastic substrates.[322]

Researchers have created a semiconductor in a rubber composite format that can stretch and retain functionality. A robotic hand made from this material feels temperature differences and distinguishes between hot and cold.[323] Another team of scientists managed to build a powerful magnetic memory chip on a flexible plastic material.[324]

Health monitoring

A new flexible, elastic electronic device that adheres to the skin[325] resembles a temporary tattoo. Only about five micrometres thick, it is "imperceptible, biocompatible, and as stretchable and flexible as the skin itself."[326] It could be used for clinical sensing of heartbeat, blood oxygen levels, hydration, and blood flow near the surface.[327]

Wearing a sensor on your skin for long periods of time may be a problem. Scientists have developed a hypoallergenic electronic sensor that can be worn on the skin to monitor a person's health continuously. The wearable device is made up of breathable nanoscale meshes that let the skin breathe, preventing inflammation.[328]

3D printing

The traditional thin film deposition technique is photographic, but new advances enable 3D printing of flexible electronics, which could bring advantages such as reduced cost. A new bonding technique for SMD

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319 http://www.dailymail.co.uk/sciencetech/article-3415872/The-rubber-glove-screen-BREAST-CANCER-Pressure-sensors-make-detecting-lumps-faster-easier.html

320 http://www.theverge.com/2016/3/3/11155270/stretchy-electroluminescent-skin-robot-cornell-university

321 http://www.eurekalert.org/pub_releases/2016-04/cuso-afc041216.php

322 https://electronics360.globalspec.com/article/10254/watch-leaning-toward-the-flexible-future

323 https://www.ibtimes.com/researchers-create-artificial-skin-give-robots-sense-touch-2589620

324 http://www.eurekalert.org/pub_releases/2016-07/nuos-rtl071916.php

325 http://www.medgadget.com/medicine

326 https://spectrum.ieee.org/the-h uman-os/biomedical/diagnostics/stretchable-electronic-patch-for-infants-in-clinical-trials

327 https://spectrum.ieee.org/the-human-os/biomedical/diagnostics/stretchable-electronic-patch-for-infants-in-clinical-trials

328 https://nano-magazine.com/news/2017/7/17/new-wearable-e-skin-sensor-to-boost-health-monitoring

("surface mounted devices") uses an inkjet printer with ink that incorporates silver nanoparticles.[329] Scientists have announced the first stretchable circuit made with just an inkjet printer.[330] Another research team has developed an innovative "spray-on" digital memory device employing only nanoparticle inks and an aerosol jet printer. It can be used to construct programmable electronic devices over bendable materials such as fabric, plastic, or paper.[331]

Photonic sintering of silver nanoparticle films (the use of intense pulsed light, or IPL, to rapidly fuse functional conductive nanoparticles)[332] allows printing flexible electronics on substrates like paper and plastic.[333] Alternatively, 3D printing of elastomers might be a solution for cost-effective and scalable fabrication of stretchable electronics.[334] For example, scientists developed UV-curable elastomers, which can be stretched more than 10 times their size.[335]

A new method, called Hybrid 3D printing, "uses additive manufacturing to integrate soft, conductive inks with a material substrate to create stretchable electronic devices. This is the first time a 3D printer has built, in a single process, stretchable sensors with integrated microelectronic components.[336]

A team of researchers has developed a new type of ink that allows electronic circuits to be applied to paper directly from a pen.[337]

New materials and technologies

Versatile and lightweight materials that are both strong and resilient remain key to flexible electronics such as bendable tablets and wearable sensors. Though in principle good candidates for such applications, aerogels have been difficult to imbue with both properties at once.[338] However, researchers have reported making a graphene-based aerogel that meets all these standards.[339]

Biologically inspired proteins "can act as programmable assemblers of 2D materials, like graphene oxide, to form hybrid materials with minute spacing between layers".[340] These are suitable for flexible electronics and

329 https://phys.org/news/2017-03-bonding-chips-inkjet-printers.html
330 http://www.dailymail.co.uk/sciencetech/article-4231712/New-material-make-stretchable-tablets.html
331 https://www.azonano.com/news.aspx?newsID=35499
332 https://www.eurekalert.org/pub_releases/2016-12/osu-aii122216.php
333 https://www.eurekalert.org/pub_releases/2016-12/osu-aii122216.php
334 http://www.3ders.org/articles/20170104-3d-printed-stretchable-electronics-may-be-here-to-stay.html
335 http://www.3ders.org/articles/20170210-researchers-have-developed-the-worlds-stretchiest-3d-printable-elastomer.html
336 http://www.aerotechnews.com/blog/2017/10/18/afrl-harvard-researchers-invent-new-method-of-hybrid-3-d-printing-for-flexible-electronics
337 http://www.nanowerk.com/nanotechnology-news/newsid=43111.php
338 https://www.nanowerk.com/nanotechnology-news/newsid=47148.php
339 https://www.nanowerk.com/nanotechnology-news/newsid=47148.php
340 https://www.eurekalert.org/pub_releases/2017-07/ps-070517.php

energy storage systems.[341] Scientists "have developed organic semiconductor nanosheets, which can easily be removed from a growth substrate and placed on other (flexible) substrates".[342]

Using a new method for making stretchable electronics, researchers have built a prototype that can stretch four times its original shape and relax back without any loss of its electrical properties.[343] A new technique using liquid metals to create atom-thick integrated circuits could produce extremely bendable circuits.[344]

Just as promising is a continuous roll-processing technology that transfers and packages large-scale integrated circuits (LSI) on plastics in order to create flexible electronics.[345]

Long-term perspectives

The field of flexible electronics is quite dynamic, with diverse applications. Discoveries are made at an accelerating pace, with dozens of exciting announcements lately. Researchers promise that the future will bring us smart fabrics, stretchable screens, bendable smartphones, super thin tablets that can be stretched to larger ones, rubber-band sensors worn continuously on the wrist to monitor health-related signals, or wallpapers that can turn your wall into one giant screen. While bendable connectors are already old news and flexible displays seem to be just around the corner, other applications will take more time to mature.

Applications such as flexible solar cells are promising not only for "power your phone from your vest" applications, but also for space exploration. They are lightweight, can be rolled up for launch, and are therefore, in principle, easily deployable in space. Medical and bioengineering applications would profit from truly flexible/stretchable sensors, which could revolutionize brain implants. Eventually, the hope is they would enable seamless communication between our minds and our computers.

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[341] https://www.eurekalert.org/pub_releases/2017-07/ps-070517.php
[342] http://www.nanowerk.com/nanotechnology-news/newsid=46608.php
[343] http://www.eurekalert.org/pub_releases/2016-02/epfd-set022616.php
[344] https://www.eurekalert.org/pub_releases/2017-02/ru-lmn021517.php
[345] https://www.eurekalert.org/pub_releases/2016-08/tkai-crt082916.php

4.3.2 Nano-LEDs

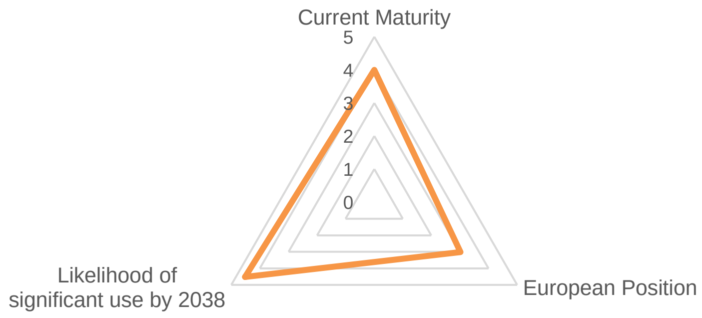

Figure 29: RIB Score of Nano-LEDs

The light-emitting diode (LED) is a two-lead semiconductor light source device that has the ability to convert electricity into light. The main feature of LED lights is that they do not generate heat, in contrast with traditional tungsten bulbs. Furthermore, LEDs require only a small fraction of the energy necessary for regular bulbs to light up and do not contain toxic metals (e.g. mercury, used in fluorescent light bulbs). Nanotechnology integration in almost every step of LED production leads to the creation of nano-LEDs and nano-LED lights as bright as ordinary bulbs.

Recent progress directions

Multitasking LED displays

An LED display is an LCD that uses an array of LEDs as pixels in order to display images – and nothing more. A multi-function nanorod-based LED is able to both emit and detect light, and does so three times quicker than the standard LED refresh rate. This makes the human eye perceive the display as permanently on, even as it executes other functions, such as charging itself via sunlight or responding to touchless commands. An array made of nanorod-based LEDs has been created that responds to a laser stylus.[346] It could be the basis of smart whiteboards, tablets or other surfaces for writing or drawing with light.

Deep ultraviolet (UVC)

Ultraviolet light with wavelengths between 200 and 280 nm is called UVC. This type of light sterilizes infectious pathogens, so it can be used for chemical-free disinfection of surfaces or drinking water. To explore applications of UVC light, one requires suitable UVC-emitting components. Common UV lamps have some limits, including weak action at low temperatures, long warm-up times, and the risk of mercury leakage. To

[346] http://www.moreinspiration.com/article/6312/led-emits-and-detects-light

eliminate these problems, researchers have developed UVC-LEDs on lightweight flexible metal foil for portable UV lights.[347]

Optical Data Communication

An alternative to sending digital data by electric voltage signals is through the use of light signals. Electrical signals from digital circuits may be transformed into discrete optical signals and vice-versa with the help of LEDs or solid-state lasers. Scientists at the Eindhoven University of Technology have designed a nano-LED that is 1,000 times more efficient than its predecessors and capable of conveying data at speeds of several gigabits per second.[348]

Long-term perspectives

Passing electrons through light-emitting nano-semiconductors will have many applications in fields such as biology, computers, medicine and, of course, lighting.[349] The nano-LEDs could produce a wider range of light wavelengths, using only small amounts of energy and allowing warmer and more vivid colours for displays. In a short while, nano-LEDs could be used to paint apartment walls in colours and patterns of choice. On a slightly longer term, new LED arrays that can both emit and detect light could help users control smart devices by touchless gestures, as well as charge these devices using ambient light.[350] One of the most significant next steps will be the progress of ultra-small and power-efficient circuit elements, such as modulators and detectors that use nano-LEDs.

4.3.3 Carbon Nanotubes

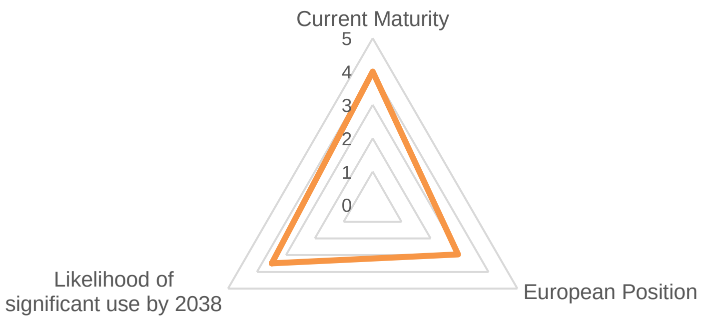

Figure 30: RIB Score of Carbon Nanotubes

Carbon nanotubes (CNTs) are carbon-based, tube-shaped materials with nano-scale diameters. The special properties of these tube-shaped carbon

347 https://www.azonano.com/news.aspx?newsID=35211
348 https://www.eurekalert.org/pub_releases/2017-02/euot-1tm020217.php
349 https://www.azonano.com/news.aspx?newsID=35211
350 https://phys.org/news/2017-02-dual-function-nanorod-multifunctional.html

molecules makes them "valuable in nanotechnology, electronics, optics and other fields of materials science and technology".[351] CNT are added to other structural materials due to characteristics such as exceptional thermal conductivity, but also for their mechanical and electrical properties.

Recent progress directions

Nanotubes with fullerenes

When paired with fullerene molecules – a form of carbon having a large spheroidal molecule consisting of a hollow cage of sixty or more atoms –, single-walled carbon nanotube (SWCNT) semiconductors show a lot of promise for photovoltaic (PV) systems. Using this kind of technology, light to energy conversion would gain in efficiency, because SWCNTs have the capacity to transform sunlight into electricity or fuels without significant loss of energy.[352]

On-chip light sources

By integrating the smallest CNTs into a nanostructured waveguide, researchers "have developed a compact miniaturized switching element that converts electrical signals into clearly defined optical signals. The nanostructures act like a photonic crystal and enable the customization of the properties of light in the carbon nanotube. […] When electric voltage is applied, photons are produced. This compact electricity/light signal converter now meets the requirements of next-generation computers that combine electronic components with nanophotonic waveguides, promising increased speed and better energy efficiency."[353,354]

Liquid biopsy chip

A chip developed by mechanical engineers can target and capture cells originating in metastatic tumours in blood samples of patients.[355] The device "uses antibodies attached to an array of CNTs at the bottom of a tiny well. Cancer cells settle at the bottom of the well, where they selectively bind to the antibodies based on their surface markers. Unlike other devices, the chip can also trap tiny structures called exosomes produced by cancer cells. This "liquid biopsy" could become the basis of a simple lab test to quickly detect early signs of metastasis (the process by which cancer spreads from one organ to others, typically through the bloodstream) and help physicians select treatments targeted at the specific cancer cells identified."[356]

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351 http://agt-international.eu/Carbon-Nanotubes-Presentation-short.pdf
352 http://www.nanowerk.com/nanotechnology-news/newsid=43233.php
353 https://www.sciencedaily.com/releases/2016/04/160419083906.htm
354 http://www.nanowerk.com/nanotechnology-news/newsid=43168.php
355 http://www.nanotech-now.com/news.cgi?story_id=54196
356 https://www.sciencedaily.com/releases/2016/12/161215125924.htm

Long-term perspectives

Silicon has been the material of choice in these areas, but its dominance may be challenged in the future by novel compounds. Such hopes have already been attached to carbon nanotubes by numerous researchers, and the latest innovations brings that horizon into view. "In addition to faster, more efficient chips for laptops and smartphones, tiny but powerful processors could enable new types of technology, such as bendable computers and injectable microchips, or nano-machines that could target cancers in the body. Nevertheless, the industry is still years away from being able to manufacture nanotube-based chips at large scale."[357]

4.3.4 Computing Memory

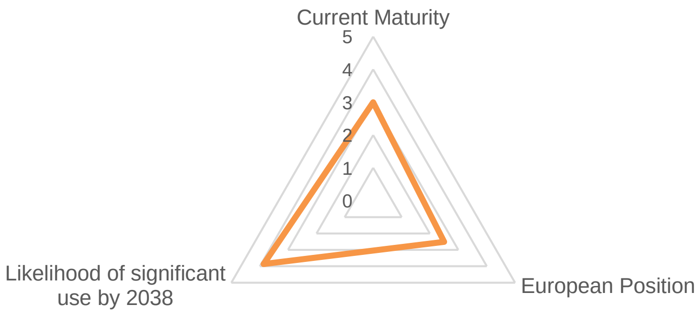

Figure 31: RIB Score of Computing memory

"In-memory computing" or "computational memory" is an emerging concept that uses the physical properties of memory devices for both storing and processing information. This is different from what happens in current von Neumann systems and devices, such as standard desktop computers, laptops and even mobile phones, which shuttle data back and forth between memory and the computing unit, thus making them slower and less energy efficient."[358]

Recent progress directions

In-memory algorithms

IBM scientists demonstrated "an unsupervised machine-learning algorithm, running on one million phase change memory (PCM) devices, which successfully found temporal correlations in unknown data streams. When compared to state-of-the-art classical computers, this prototype technology is expected to yield 200x improvements in both speed and energy

[357] https://www.wired.com/2016/11/ibm-using-tiny-tubes-grow-chips-future/

[358] https://www.ibm.com/blogs/research/2017/10/ibm-scientists-demonstrate-memory-computing-1-million-devices-applications-ai/

efficiency, making it highly suitable for enabling ultra-dense, low-power, and massively-parallel computing systems for applications in AI.” [359]

Faster phase-shifting computer memory

Materials scientists in China have recently found a way to “speed up—by more than a factor of 10—so-called phase-change random access memory (PCRAM), which can hold onto information even when your computer’s power is off.”

Key to the innovation is scandium: “adding the element creates strong bonds with neighbouring antimony and tellurium atoms, forming cube-shaped nuclei that remain intact even when enough electricity is zapped through the material to raise its temperature to 600 K, which promotes a fast switch between the amorphous and crystalline phases. And when the researchers synthesized their[360] new phase change material, they found that the nuclei consistently caused the material to switch between the two states in less than 1 nanosecond. The faster PCRAM must still prove that it can be scaled up, withstand the high temperatures found in standard chip-manufacturing conditions, and still be able to rewrite bits of data many trillions of times to match DRAM’s performance.”[361]

Long-term perspectives

“Memory-Driven Computing is an almost infinitely flexible and scalable architecture that can complete computing tasks faster, using much less energy than conventional systems”.[362] Its relevance increases with the skyrocketing data quantities, recommending it as the solution for a composable infrastructure in big data processing.

[359] https://www.ibm.com/blogs/research/2017/10/ibm-scientists-demonstrate-memory-computing-1-million-devices-applications-ai/
[360] http://www.sciencemag.org/news/2017/11/phase-shifting-computer-memory-could-herald-next-generation-ram
[361] http://www.sciencemag.org/news/2017/11/phase-shifting-computer-memory-could-herald-next-generation-ram
[362] https://community.hpe.com/t5/Servers-The-Right-Compute/The-future-of-computing-Memory-Driven-Computing-security-and-the/ba-p/7018321#.W6Nob2hLg2w

4.3.5 Graphene Transistors

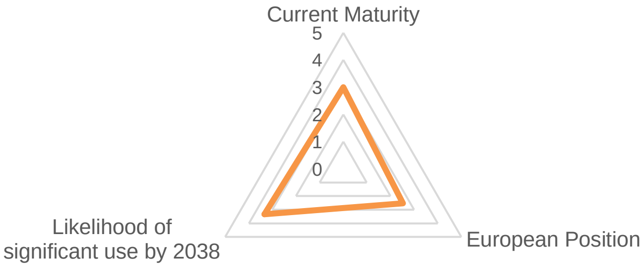

Figure 32: RIB Score of Graphene Transistors

Graphene has been called the nanomaterial of the new millennium. Electrically conductive, chemically stable and the world's strongest material, it consists of carbon atoms that are densely packed and arranged in a two-dimensional hexagonal pattern – a sheet with the thickness of a single atom.[363]

Since it was first isolated in 2004, scientists have found valuable physical and electronic properties that could enable applications, such as more efficient rechargeable batteries, and better and faster electronics. Its "ability to conduct heat ten times better than copper, the most commonly used conductor", makes researchers argue that graphene-based transistors would be far more effective than the silicon transistors we use nowadays.[364]

Recent Progress directions

Microprocessors

Graphene transistor-based logic circuits can solve the processing speed limitations of silicon transistors. They improve microprocessors' clock speed thousand-fold, while needing "a hundredth of the power required by silicon-based computers. Additionally, these circuits are tiny, which could enable smaller yet more effective electronic devices."[365]

Constructing transistors capable of switching at low voltages is a major challenge in electronics. Graphene has proven a perfect platform for low-voltage electronics and was included in an innovative design for a bilayer graphene tunnel transistor.

Neuromorphic chips

Graphene may also prove the solution to building computer chips that operate like the human brain in processing information but faster. That can

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[363] http://feeds.feedblitz.com/~/241257198/0/gizmag~Silly-Putty-smartens-up-with-a-dash-of-graphene/
[364] https://futurism.com/graphene-computers-work-1000-times-faster-use-far-less-power/
[365] https://futurism.com/graphene-computers-work-1000-times-faster-use-far-less-power/

lead to remarkable technological advances "from more accurate image recognition to control systems for hypersonic aircraft".[366] Researchers are currently developing neuromorphic chips that require a network of transistors that interact in a similar way to neurons, that is, faster and more accurately than traditional chips can. This was achieved by placing a small graphene component in a semiconductor laser. Inside the laser, "graphene acts as a 'saturable absorber' because it can take up and release photons at extreme speeds and at any wavelength."[367]

Next-generation electronics

In a breakthrough that opens the way to next-generation electronic technologies, scientists have developed a way to chemically bring together atom-thin transistors and circuits. They "controlled the synthesis of a transistor in which narrow channels were linked onto conducting graphene, while a semiconducting material (transition-metal dichalcogenide, TMDC) was seeded in the blank channels. This assembly yielded essentially two-dimensional electronic structures."[368]

Another innovative pairing that involved graphene and titanium oxide resulted in new memory devices that are excellent in flexible electronic devices such as "bendable" mobile phones or computer and television screens.[369]

Long-term perspectives

There are already technologies in place to mass-produce graphene cheaply from three simple components (hydrocarbon gas, oxygen and a spark plug).[370] This makes it a suitable candidate for large-scale production.

Graphene transistors and chips will make computers smaller and faster. Among others, these "will run bigger and better simulations for climate science or space exploration".[371] Next-generation, graphene-enabled computing technologies will not stop at crunching large amounts of data, however. These versatile materials holds a lot of promise for tech such as paper-thin gadgets and smart biomedical sensors.

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[366] https://spectrum.ieee.org/nanoclast/semiconductors/optoelectronics/graphene-flakes-make-laser-neurochip-superfastb
[367] http://feedproxy.google.com/~r/IeeeSpectrumFullText/~3/Uw5s1bw7Jcc/graphene-flakes-make-laser-neurochip-superfastb
[368] https://www.sciencedaily.com/releases/2016/07/160711121335.htm
[369] https://phys.org/news/2017-03-ultrafast-flexible-transparent-memory-devices.html
[370] http://www.impactlab.net/2017/02/15/we-may-finally-have-a-way-of-mass-producing-graphene/
[371] http://www.impactlab.net/2017/02/15/we-may-finally-have-a-way-of-mass-producing-graphene/

4.3.6 High-precision Clock

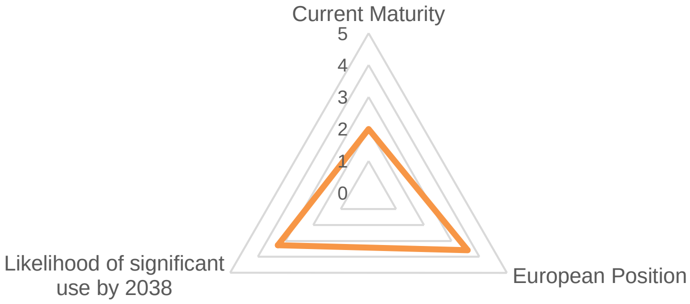

Figure 33: RIB Score of High-precision clock

The clocks of today have their limits, because in many applications, more precision is needed than provided nowadays. Time research is still struggling with a definition of what time really is, but is going ahead with practically measuring time. Central problems of time research beyond basic research include understanding and eventually being able to control time (time efficiency research), precise time measurement, and time resolution (e.g. 4D precision). This could optimize existing technologies or lead to completely new technologies, for example replacing caesium-based atomic clocks.[372]

Recent progress directions

Attophysics - reaching attosecond level

4D-imaging needs high precision clocks to provide a dynamic investigation of structures and microscopy down to the subatomic area. The next step is the application of knowledge from Attophysics, which uses attosecond (10^{-18} s) duration pulses of electrons or photons to probe dynamic processes in matter with unprecedented time resolution. Precision on attosecond level could enable the development of atto-electronics.[373] If researchers could master real-time observation of electrical charge transport and control the movement of electrons in molecules and nanostructures, high-speed electronic systems (e.g. molecular/chemical computers) that could calculate a million times faster than today's computers. Investigations into the dynamics of charge transfer processes

[372] http://www.impactlab.net/2017/02/15/we-may-finally-have-a-way-of-mass-producing-graphene/

[373] assessed as very important in the German BMBF Foresight I (Cuhls, K; Ganz, W. and Warnke, P. (eds.): Foresight Process - New Future Fields, IRB Publishers, Karlsruhe/ Stuttgart 2009, http://publica.fraunhofer.de/starweb/pub09/servlet.starweb; https://www.academia.edu/29635629/Foresight_process_on_behalf_of_the_German_Federal_Ministry_of_Education_and_Research._New_future_fields, p. 55ff., but also emphasized in NISTEP (2015): The 10th Science and Technology Foresight, Report no. 164, Tokyo, http://data.nistep.go.jp/dspace/bitstream/11035/3079/2537/NISTEP-NR164-SummaryE.pdf; and KISTEP (2017): Delphi Survey, Seoul.

would provide a better understanding of intra-molecular energy transport, which could lead to more efficient energy applications.[374] It could also allow new imaging, which is relevant for molecular biology or medical technology.

Ultra-precise time measurement for GPS applications

"Ultra-precise time measurement" announces a new era of time measurement using optical clocks. Today's atomic clocks are already very precise, yet the standard of time measurement now seems inadequate for optimised and improved satellite navigation and localisation (for GPS applications). Measurement and localisation must become increasingly chronologically and spatially precise. Optical clocks are regarded as promising successors to the 50-year-old caesium clock. Examples of potential applications in the GPS context might be very precise navigation in global transport and traffic, navigation over great distances, the positioning and localisation of very remote objects in space travel (space probes, spacecraft), the fertilising of individual plants in precision agriculture, and the remote maintenance and repair of machines. The optimised synchronisation of media and wireless communication, exact process control in production and environmental observation (e.g. using interferometers) could also be further key applications.[375]

Ultra-precise time measurement VoIP

For these high precision technologies, new clocks with ultra-high precision are under development. Special focus is on general new atomic clocks for time standardization and high precision clocks in computers for VoIP.[376]

Long-term perspectives

Optical clocks or new atomic clocks beyond the caesium-based atomic clock are expected to allow much higher precision in time measurement and standardization. This is necessary for a diverse range of applications, e.g. lasers in industry, GPS for precision agriculture on the base of individual plants or synchronizing servers in IT, which can save an immense amount of energy.[377] The synchronisation of devices will be improved over time, step by step as the measurement of time is shifted to a new level by a new technology. Optical clocks are expected to have a role in this and the

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[374] Cuhls, K; Ganz, W. and Warnke, P. (eds.): Foresight Process - New Future Fields, IRB Publishers, Karlsruhe/ Stuttgart 2009,
http://publica.fraunhofer.de/starweb/pub09/servlet.starweb;
https://www.academia.edu/29635629/Foresight_process_on_behalf_of_the_German_Federal_Ministry_of_Education_and_Research._New_future_fields, p. 55ff.

[375] Cuhls, K; Ganz, W. and Warnke, P. (eds.): Foresight Process - New Future Fields, IRB Publishers, Karlsruhe/ Stuttgart 2009,
http://publica.fraunhofer.de/starweb/pub09/servlet.starweb;
https://www.academia.edu/29635629/Foresight_process_on_behalf_of_the_German_Federal_Ministry_of_Education_and_Research._New_future_fields, p. 56f.

[376] http://www.brgprecision.com/products/accuracy.php;
https://www.patton.com/voipnews/v1n1/high-precision-smartnodes.asp;
https://www5.epsondevice.com/en/information/technical_info/pdf/wp_e20130918_rtc.pdf, accessed 17/9/2018.

[377] Monitoring Panel interviews in German BMBF Foresight I

approach of quantum-logic clocks has tremendous prospects[378], whereas new atomic clocks will need much more basic research, completely different ways of thinking and a better understanding of time. When successful, the new approaches and standards will lead to new devices, new applications and energy savings.

4.3.7 Nanowires

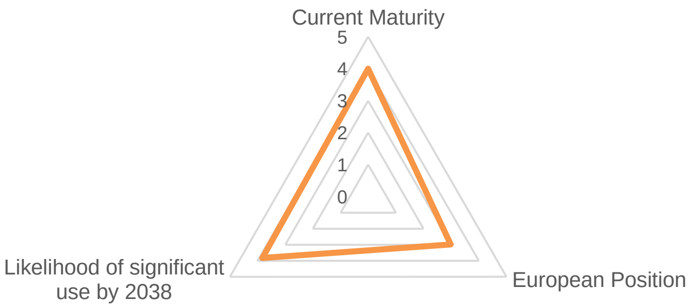

Figure 34: RIB Score of Nanowires

Nanowires are wires with dimensions in the order of nanometres. They can also be described as nanostructures with a breadth in the tens of nanometres or less and a length that is not similarly limited. The reproducible and tuneable properties of nanowires combined with their surface-binding properties provide a novel and powerful approach to nanomedicine. Due to a large choice of materials from which they can be fabricated and to the fascinating properties they display, nanowires have recently emerged as promising building blocks for nanoscale electronics, optoelectronics, as well as for chemical and biological sensing at molecular scale.

Recent progress directions

Batteries

Today, batteries are present in all types of mobile devices, but they have a rather poor lifespan. Lithium-ion batteries currently enjoy supremacy because of their ability to hold a large amount of energy per weight. Nanowires could soon replace lithium-ion batteries. Nanowires are "thousands of times thinner than human hair, very conductive, and possess a big surface area to store and transfer electrons".[379] An experimental battery made from gold nanowires in a manganese dioxide shell covered by a Plexiglas-like gel electrolyte completed 200,000 discharge cycles in few months with no loss of charge capacity.[380]

378 https://www.wired.com/2010/02/quantum-logic-atomic-clock/, accessed 17/9/2018.
379 https://www.azonano.com/news.aspx?newsID=34605
380 https://www.azonano.com/news.aspx?newsID=34605

Nanosensors

Nanosensors are chemical and/or mechanical sensors whose active elements include nanomaterials. They can be used to sense the existence of chemical species and nanoparticles or to monitor physical parameters - all on the nanoscale. In other words, because nanosensors work at a scale comparable to natural biological processes as well as due to the high surface-to-volume ratio, they can have great specificity, enabling functionalization with bio-chemical complexes.

Mostly, nanosensors are based on fabrication methods and materials consisting of nanowires and can be used in healthcare, medicine, and the life sciences.[381,382,383,384] For example, a non-destructive device based on an array of silicon nanowires can simultaneously measure and record the electrical activity of neurons. The nanowires poke inside cells without damaging them and their high sensitivity could measure small potential changes that are critical for understanding neurological diseases.[385]

Electrochromic devices

"Electrochromism" refers to the change of colour produced by a current passing through materials. Electrochromic devices "control optical properties (such as transmission, absorption, reflectance, and emittance) via voltage, in a constant but reversible manner".[386] An electrochromic window comprised of a glass sheet or plastic sandwiched between transparent, soft elastomers sprayed with a coating of silver nanowires was developed to quickly change its opacity. It turns cloudy, clear or somewhere in-between with the flick of a switch.[387]

By utilizing the energy stored in electrochromic devices one can also save energy. "When the coloured state is not necessary, the stored energy can be released through an external circuit", providing an additional resource.[388] This operation can be useful for creating solar cells.[389] Additionally, a property found in the "crystalline nanowires of an organic semiconductor known as 7,8,15,16-tetraazaterrylene could lead to more efficient and cost-effective materials for electrochromic displays".[390]

Field effect transistors

The field effect transistor (FET) is a type of transistor composed of three terminals - the source, the drain, and the gate. By virtue of its construction and biasing, the voltage between gate and source controls the drain current. FETs are widely used as the main active elements in many

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381 https://www.nanowerk.com/nanotechnology-news/newsid=45780.php
382 https://www.azonano.com/news.aspx?newsID=35139
383 https://www.nanowerk.com/nanotechnology-news/newsid=44340.php
384 https://www.azonano.com/news.aspx?newsID=35027
385 https://www.theengineer.co.uk/nanowires-record-notifications-from-neurons/
386 https://en.wikipedia.org/wiki/Electrochromic_devices
387 https://www.nanowerk.com/nanotechnology-news/newsid=42852.php
388 https://www.sciencedirect.com/science/article/pii/S136970211500382X
389 https://www.azonano.com/news.aspx?newsID=35139
390 https://www.sciencedaily.com/releases/2016/02/160225085316.htm

integrated circuits. Semiconductor nanowires made of Si and other materials can also function as FET devices.[391] The most common types of FETs are Metal Oxide Silicon FETs (MOSFETs), where the gate is made from a layer of metal. However, the effort to miniaturize the MOSFET using conventional technology seems to have reached a plateau. “To deal with this issue, a double-layered nanowire, consisting of a germanium core and a silicon shell”[392], has been developed. It is a promising approach to creating small high-speed transistor channels.[393]

Heat dissipators

All electronic devices and circuits produce extra heat and therefore require thermal management to prolong their working life and to prevent failure. There are several cooling methods and systems available, including fans, heat dissipaters, thermoelectric coolers, liquid coolers, Peltier-effect devices, heat pipes, thermally conductive pastes, etc. Miniaturisation in electronics renders controlling the flow of heat through semiconductor materials an important challenge in developing smaller and faster nanodevices. “By spatially confining acoustic phonons in nanowires, one can change the way they carry heat”.[394] Moreover, the design of a cooling system also depends on the characteristics of construction materials. In this respect, a purification method for copper nanowires could open up new possibilities in producing high quality heat dissipators.[395]

Long-term perspectives

Nanowires can be “integrated with microchannels, providing a path from the macroscale to nanoscale that enables researchers to detect and analyse target molecules such as DNA, RNA, and proteins”.[396]

The very small diameter size of nanowires could be used in probe tips to” stimulate and record changes of signals in living cells”[397], for example when subjected to a drug. Moreover, nanowire-based MOSFETs can be combined with tissues to fabricate a flexible nanoelectronic scaffold that holds the promise to create a sensing skin, which would detect chemical and electrical changes.

Nanowire-based “electrochromic energy storage devices change their colour while they store energy”.[398] They could have a significant impact on the building and automobile sectors.

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[391] https://www.azonano.com/news.aspx?newsID=35139
[392] https://www.nanowerk.com/nanotechnology-news/newsid=42310.php
[393] https://www.nanowerk.com/nanotechnology-news/newsid=42310.php
[394] https://www.nanowerk.com/nanotechnology-news/newsid=45043.php
[395] http://www.laboratoryequipment.com/news/2016/09/scientists-purify-copper-nanowires
[396] https://pubs.rsc.org/en/content/articlehtml/2016/lc/c5lc01306b
[397] https://pubs.rsc.org/en/content/articlehtml/2016/lc/c5lc01306b
[398] https://www.sciencedirect.com/science/article/pii/S136970211500382X

4.3.8 Optoelectronics

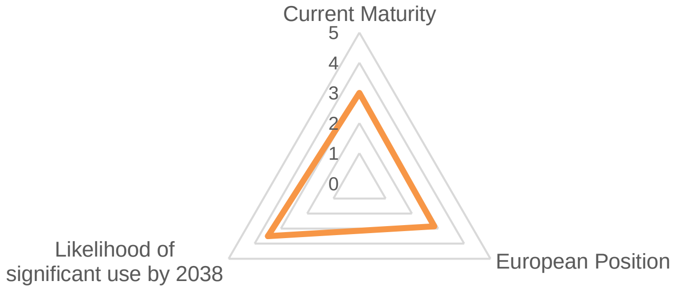

Figure 35: RIB Score of Optoelectronics

Optoelectronics is a subfield of photonics[399] "which is focused on combining electronics and light to transmit data".[400] Light can carry far more data, far more rapidly than standard electronics. "A single fiber in a fiber-optic cable, less than a human hair's width in diameter, can carry tens of thousands of conversations at once."[401] Common optoelectronics devices (e.g. LEDs[402] or solar cells) are capable of converting light into electrical energy and vice-versa.

Recent progress directions

Optical computing

Quantum computing is based on the generation and processing of qubits.[403] Multiple qubits can be linked in „entangled"[404] states, a property which is the basis for quantum information. "Photons have the advantage of preserving entanglement over long distances and time periods".[405] By using on-chip optical frequency combs[406] to generate multiple, stable and controllable entangled qubit states of light, the research brings us closer to practical quantum computing applications, as the device "is compact, inexpensive to make, compatible with electronic circuits and uses standard telecommunication frequencies".[407]

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399 A field focused on using light in a range of applications.
400 https://www.sciencedaily.com/releases/2016/02/160211142008.htm
401 https://www.sciencedaily.com/releases/2016/02/160211142008.htm
402 Light Emitting Diode, a semiconductor p-n junction that emits light when a suitable voltage is applied to its leads
403 Unlike classical bits, which can have a state of either 0 or 1, qubits allow a superposition of the 0 and 1 states, both simultaneously.
404 An entangled state means that a manipulation of a single qubit changes the entire system, even if the individual qubits are physically distant.
405 https://www.sciencedaily.com/releases/2016/03/160310164900.htm
406 Extraordinarily precise light sources comprised of many equally-spaced frequency modes, which have already revolutionized metrology and sensing.
407 https://www.sciencedaily.com/releases/2016/03/160310164900.htm

5D optical data storage

5D data storage process consists of altering the optical properties of fused quartz[408] by first creating 3D nanoscale recordings[409] of information using ultra-fast (femtosecond) laser writing. Each of these recordings ("nanogratings") is written in three layers of nanodots and each dot stores one bit of information. Then, two additional dimensions are added: size and orientation. The storage support is a modified glass disk which is more enduring to climate condition and chemically stable. Modifying the size and orientation of the nanostructures enables each dot to store three bits of information instead of one. That additional capacity allows for storing up to 360TB of data, which is roughly 7000 times the capacity of a 50Gb Blue-Ray discs' capacity[410], with a thermal stability up to 1000 °C - and a practically unlimited lifetime at room temperature.

Photonic chips

"The future of computers, data centres and mobile devices will involve photonic chips in which data is shuttled around and processed as photons (light) instead of electrons. The advantages of photonic chips over today's silicon-based chips are that the former will be much faster and consume less power and therefore give less heat. Inside each chip there are potentially billions of photonic devices, each with a specific function, in much the same way that billions of transistors have different functions in today's silicon chips."[411] Since two of these photonic devices cannot be too close to each other, because the light leakage between them will cause „crosstalk" (like in radio interference); and since they also cannot be far apart, because the chip would be much too large, researchers have developed a special nano-patterned silicon-based barrier. This can be put between the two photonic devices, where it "acts like a "cloak" and tricks one device into not seeing the other. As a result, billions of these photonic devices can be packed onto a single chip. "By going from electronics to photonics we can make computers much more efficient and ultimately make a big impact on carbon emissions and energy usage".[412]

Long-term perspectives

Further research in optoelectronics will open the way to develop many different optoelectronic devices. 5D data storage could soon become an invaluable asset for institutions with extensive historical archives and is expected to be commercialized by industry partners within the next five years. The technology "can preserve documents and information and store

[408] A glass consisting of silica in amorphous (non-crystalline) form, different from traditional glass in containing no other ingredients which are typically added to glass to lower its melting temperature.
[409] A three dimensional nanoscale „etching" of the recorded information
[410] http://spie.org/newsroom/6365-eternal-5d-data-storage-via-ultrafast-laser-writing-in-glass?SSO=1
[411] https://www.nextbigfuture.com/2016/11/nanopatterned-silicon-shields-photonic.html
[412] https://www.nextbigfuture.com/2016/11/nanopatterned-silicon-shields-photonic.html

it in space for future generations"[413] and could "secure the last evidence of human civilisation".[414]

It is expected that photonic-based chips "currently used mostly in high-end military equipment" will be employed in data centres within a few years".[415]

Advances in integrated quantum photonics research "could revolutionize optical quantum technologies, while at the same time maintaining compatibility with existing semiconductor chip technology".[416]

4.3.9 Quantum Computers

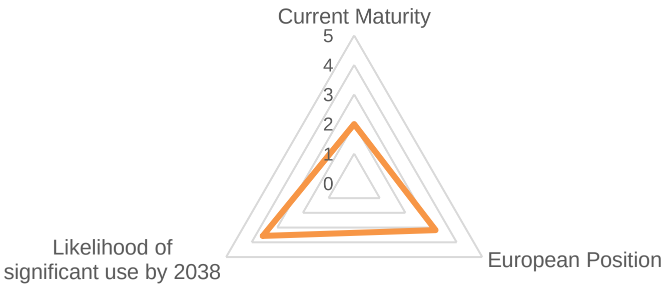

Figure 36: RIB Score of Quantum Computers

A quantum computer (QC) works based on quantum-bits (called qubits), which can be represented as 0, 1 or any quantum superposition of these two states as regulated by quantum mechanics. In general, a QC with n qubits can be in an arbitrary superposition of up to 2n different states.[417] Despite the fact that several companies claimed to produce quantum computers[418,419,420,421] and quantum compilers[422], the present technologies do not offer mature solutions for the manufacturing of QCs and the first

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413 https://www.sciencealert.com/this-new-5d-data-storage-disc-can-store-360tb-of-data-for-14-billion-years

414 https://www.sciencealert.com/this-new-5d-data-storage-disc-can-store-360tb-of-data-for-14-billion-years

415 https://phys.org/news/2016-11-invisibility-cloak-high-tech-chips.html

416 https://phys.org/news/2016-03-team-giant-optical-qubits.html

417 The computing time for the energy of an atomic system scales exponentially with the system size on a classical computer, but it could scale polynomially by the quantum algorithms. A. Aspuru-Guzik, A. D. Dutoi, P. J. Love and M. Head-Gordon, Science 309 (2005) 1704.

418 https://www.pcworld.com/article/3161034/computers/d-waves-quantum-computer-runs-a-staggering-2000-qubits.html

419 https://arstechnica.com/science/2016/05/how-ibms-new-five-qubit-universal-quantum-computer-works/

420 https://www.pcworld.com/article/3176853/hardware/ibms-new-q-program-to-include-a-50-qubit-quantum-computer.html

421 https://www.pcworld.com/article/3194574/hardware/china-adds-a-quantum-computer-to-high-performance-computing-arsenal.html

422 www.theregister.co.uk/2017/10/24/google_we_dont_have_a_quantum_computer_yet_but_we_have_a_compiler

prototypes are only able to operate on specific problems. Thus, QC remains a mostly conceptual model.[423] Conventional supercomputers simulate QCs and analyse the accompanying quantum algorithms. However, conceptual and technical problems remain. For example, the QCs might interfere with electromagnetic radiation or the environment matter, affecting calculation reliability (the "coherence problem"). Therefore, consistent and steady efforts are necessary for the development of the large n-qubits QCs.

Recent progress directions

Quantum systems

Researchers managed to synthesize nanodiamonds doped with nitrogen that are stable at room temperature.[424] A nitrogen-vacancy center is stable in two states and the system can be switched between the two states by an electric current or laser.

Scientists successfully embedded two silicon atoms in a diamond matrix in order to create a quantum bridge to link QCs.[425] "Distributing quantum information on a bridge or network could also enable novel forms of quantum sensing, since quantum correlations allow all the atoms in the network to behave as though they were one single atom."[426]

In another significant development, researchers used a microwave resonator at a temperature near absolute zero to convert the quantum vacuum fluctuations into real photons of microwave.[427] The photons are correlated with each other. Moreover, the photons can be produced at different frequencies and can play a role similar to the registers in classical computers, enabling logical gate operations to be performed between them. The results provide a new approach to quantum computing.

Scientists built ballistic cross-directional quantum communication links.[428] The device "can coherently link multiple functional nanowires for the reliable transfer of quantum information across nanowire (NW) networks. By controlling the size, shape, position and quality of III-V semiconductors integrated on silicon"[429], they obtained ballistic one-dimensional quantum transport without losses. The NW cross-junctions are suitable as cross-directional communication links for the reliable transfer of quantum information as required for quantum computational systems.

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[423] There are some tentative solutions for the quantum hardware for low n-qubits, based on the two quantum-state systems: infrared photon, optical cavities, trapped ions and neutral atoms in electromagnetic fields, electron-spins bound to local defects in crystals and quantum-dots, liquid molecule nuclear spins and superconducting circuits. The hard problems, such as factoring integers and searching databases, are too difficult to be solved by modern computers. The QCs are expected to be more appropriate for such complex problems.

[424] https://www.pcworld.com/article/3139445/hardware/diamonds-could-be-building-blocks-for-quantum-computers.html

[425] https://www.nanowerk.com/nanotechnology-news/newsid=44831.php

[426] https://phys.org/news/2016-10-diamonds-team-quantum-bridge.html

[427] http://www.nanowerk.com/nanotechnology-news/newsid=44368.php

[428] https://www.cemag.us/news/2017/05/scientists-demonstrate-ballistic-nanowire-connections

[429] http://www.sciencetimes.com/articles/15692/20170521/scientists-went-one-step-further-quantum-computer-discovery.htm

Quasiparticle control

For the first time, the chiral magnetic effect that had been theoretically predicted in zirconium pentatelluride was actually observed:[430] when the material was placed in parallel electric and magnetic fields, the spins of charged quasiparticles (electrons and holes) aligned themselves in opposite directions and the electric field moved the two types of particles in opposite directions, triggering an electric current. The separation of the two chiral states could provide a new way of encoding information. The chiral state is very stable compared with other electrical states, as well as more stable under external factors. Thus, it could be a reliable material for quantum computing.

Scientists at Sussex[431] replaced the laser-beam control of trapped ions by individually controlled voltages applied to each logic gate location, in many arbitrarily selected gate zones. Thus, a large number of trapped-ion qubits could be manipulated with a low error rate.

Long-term perspectives

At the moment, the research efforts are focused on the creation of the quantum hardware dedicated to solving specific problems. Nevertheless, more research efforts are necessary to reach a universal QC able to run all existing codes. Massive research efforts are necessary to make QCs more efficient, stable and cheaper and to solve problems related to quantum coherence and working at low temperatures.

4.3.10 Quantum Cryptography

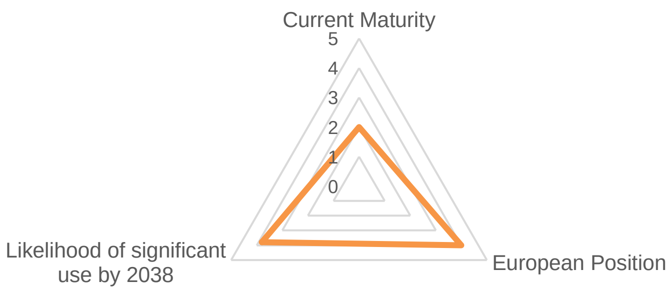

Figure 37: RIB Score of Quantum cryptography

Whether it serves personal communication, e-commerce or online banking transactions, the confidential information exchanged over Internet must be protected against hacking attacks through encryption, using digital ciphers called keys.

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430 http://www.sciencedaily.com/releases/2016/02/160208123826.htm
431 https://www.eurekalert.org/pub_releases/2016-12/uos-cop120216.php

Quantum key distribution (QKD), which lies at the heart of quantum cryptography, uses quantum particles, like electrons or photons, to securely establish a shared key between two parties. A QKD system takes advantage of a fundamental principle in quantum mechanics[432]: observing a quantum particle - the cryptographic key, in this case - automatically changes its property. Therefore, it is always possible to detect if a quantum particle has been previously observed, indicating a security breach. If that happens, the key is discarded and another key is sent, until both parties are sure no other party has observed the key. Once a key has been distributed using QKD, both parties can securely communicate over ordinary channels.

Although QKD was first theorized and implemented three decades ago, the technologies supporting its wide-scale use are still in early development. Several companies inside and outside Europe already sell laser-based QKD systems, with others companies engaged in active research. In a highly publicized experiment, China demonstrated a satellite sending a quantum key to two ground stations located over 7000 km apart. Yet, the main problem with many QKD systems is that they can only transmit the cryptographic keys at low rates (tens or hundreds of kilobits per second), making them too slow for most practical uses, such as encrypted calls or video streaming. Scientists and engineers are researching practical ways to increase bitrates for real-world uses. Although some promising results have already emerged, there is significant work ahead before quantum cryptography gets deployed in real-world scenarios.

Recent progress directions

Quantum key distribution from orbit

In September 2017, scientists reached a technical milestone: they demonstrated the world's first intercontinental video conference using quantum encryption, held between Beijing and Vienna.[433] Technical reasons had previously limited quantum communication to a few hundred kilometres, but the Chinese satellite Micius, launched in 2016, is a game changer. Orbiting 500 kilometres above the Earth, Micius is equipped with all the hardware needed for quantum communication and it communicates to five ground stations, connected to a 2,000-kilometer fiber optic backbone between Beijing and Shanghai. China is touting the infrastructure as the world's first space-ground quantum network.

Faster data rates

Although impressive, the Chinese system has a number of shortcomings, including limited bandwidth. In quantum cryptography, data rates are hampered by the laser techniques used to create indistinguishable particles. Cambridge researchers managed to overcome some limitations by using a "pulsed laser seeding, in which one laser beam injects photons into

[432] Heisenberg uncertainty principle, formulated in 1927
[433] https://www.technologyreview.com/s/610106/chinese-satellite-uses-quantum-cryptography-for-secure-video-conference-between-continents/

another".[434]The laser beam phase randomly changes at very high rates, the new QKD setup makes it possible to distribute cryptographic keys at rates up to 1 megabit per second, representing a ten-fold improvement over the previous attempts. In another experiment, researchers from Duke University "found a way to pack more information onto each photon, making their technique faster. By adjusting the time at which the photon is released, and a property of the photon called the phase, their system can encode two bits of information per photon instead of one. This paired with high-speed photon detectors, powers their system to transmit keys 5 to 10 times faster than other methods."[435]

Quantum blockchain

In 2017, physicists at the Russian Quantum Centre (RQC) in Moscow developed and tested what they claimed to be the world's first "quantum blockchain", an unhackable system for distributed data storage.[436] Using quantum cryptography and quantum data transfer systems, the quantum blockchain is designed to protect databases against the kind of attacks made possible by quantum computers.

Long-term perspectives

China intends to launch additional satellites, with the stated goal of setting up a Asian-European quantum key distribution network by 2020, to be followed by a global quantum network in 2030.[437] Meanwhile, China plans to carry out future demonstrations of quantum communication with Italy, Germany, Russia, and Singapore.

The experimental work currently performed in China and other countries could lay the groundwork for a future quantum Internet, where all transactions are safeguarded by quantum cryptography, by design. It is however too early to safely predict how fast the technological capabilities will progress and when their practical deployment on a large scale will be economically viable. It also remains to be seen how quantum cryptography will play along other technological developments, such as the blockchain or the quantum computers.

In the near future, while access to quantum technology is still limited, quantum keys will likely be used to protect extremely sensitive and critical data. If a quantum communication Internet does indeed become possible, that also raises interesting a crucial dilemma: how well- (or, rather, ill-prepared) is our society prepared to handle the prospect of complete privacy?[438]

[434] http://www.cam.ac.uk/research/news/laser-technique-promises-super-fast-and-super-secure-quantum-cryptography
[435] https://phys.org/news/2017-11-high-speed-quantum-encryption-future-internet.html#jCp
[436] http://forklog.net/russian-physicists-develop-the-worlds-first-quantum-safe-blockchain/
[437] https://www.popsci.com/chinas-quantum-satellite-could-change-cryptography-forever
[438] http://www.firstpost.com/tech/news-analysis/quantum-communication-devices-brings-complete-privacy-dilemma-to-fore-3836375.html

4.3.11 Spintronics

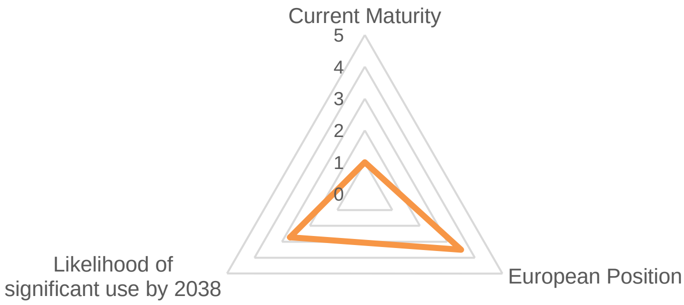

Figure 38: RIB Score of Spintronics

Spintronics, or spin electronics, is a new field of research exploiting the influence of electron spin on electrical conduction.[439] Conventional electronic devices are based on shunting electrons around circuits. Because electrons possess charge, they give rise to electric currents when they move. Spintronics harnesses another property of electrons: their spin. Spin currents are the spintronic equivalent of electric currents, but unlike electric currents, they can flow without the electrons actually moving since spin can be transferred between stationary electrons.

Spintronics covers "the study of the role played by electron (and more generally nuclear) spin in solid state physics" and of the devices that could "exploit spin properties instead of or in addition to charge degrees of freedom".[440,441]

Recent progress directions

Combination with and speeding up other electronic technology approaches

Spin relaxation and spin transport in metals and semiconductors[442] are of fundamental research interest not only for being basic solid state physics issues, but also for the already demonstrated potential these phenomena have in electronic technology[443]. Spintronics may be combined with other

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439 https://ac.els-cdn.com/S2215098615300501/1-s2.0-S2215098615300501-main.pdf?_tid=spdf-c10c627c-79d3-4036-bba3-20a3703082ef&acdnat=1519914810_66c0a01a91284e10868fd3185d622f36, accessed 17/9/2018

440 https://www.physics.umd.edu/rgroups/spin/intro.html, accessed 17/9/2018.

441 NISTEP (2015): The 10th Science and Technology Foresight, Report no. 164, Tokyo, http://data.nistep.go.jp/dspace/bitstream/11035/3079/2537/NISTEP-NR164-SummaryE.pdf; KISTEP (2017): Delphi Survey, Seoul; European Commission/ European Union (2017): New Horizons: Data from a Delphi Survey in Support of European Union Future Policies in Research and Innovation; Report KI-06-17-345-EN-N; doi:10.2777/654172.

442 https://nptel.ac.in/courses/115103039/6

443 https://www.physics.umd.eu/rgroups/spin/intro.html

electronic technologies, e.g. molecular robotics, or even with 'Claytronics'. Claytronics refers to the application of computer science to nano-robots to produce nano-scale computers, also known as ‘claytronic atoms’ or ‘catoms’. The aim is to combine catoms into 3D objects – a notion also known as ‘programmable matter’. Claytronics may also have an impact in many fields, primarily but not exclusively telecommunication, human-computer interaction, or entertainment.[444] Spintronics can be one of the options to make combined technologies more effective and processing faster.

Long-term perspectives

The electron spin can be used to convert between various forms of energy, including electricity, light, sound, vibrations and heat. This ability to switch between different energy forms can lead to a wide range of devices. A potential application of spintronics is audio devices that allow sound to flow in one direction but not the opposite side. It is expected that Spintronics may have an extraordinary influence in electronics, particularly because, in the long run, the technology will be combined with other approaches.

[444] http://i-site.ubfc.fr/en/programmable-matter/; https://en.wikipedia.org/wiki/Claytronics; https://www.academia.edu/3087272/Claytronics-_A_complete_handbook, accessed 17/9/2018.

Biohybrids

4.4 Group 4. Biohybrids

4.4.1 Biodegradable sensors

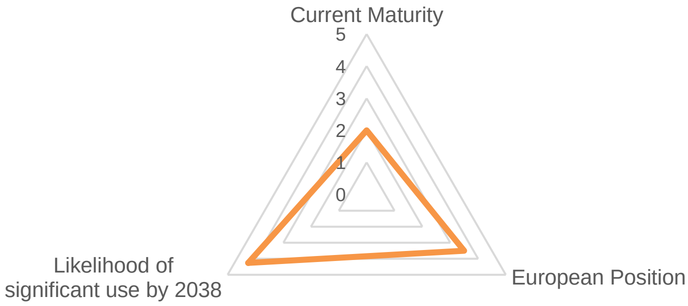

Figure 39: RIB Score of Biodegradable sensors

Biodegradable electronics are electronic components with a limited lifetime subject to disappearing via hydrolysis or biochemical reactions. Such devices can be used as medical implants for temporary in-body sensing, drug delivery, tissue engineering, microfluidics, etc.

Materials which naturally degrade via biological or chemical processes are routinely used in food and medication packaging. Degradable electronics can make such devices smarter and increase their functionalities – for instance for temperature or chemical monitoring.

Temporary environmental sensors could also disappear after they are no longer needed, leaving no harmful traces in the environment.

Recent progress directions

Medical uses

A new semiconductor developed by researchers is "as flexible as skin and easily degradable" by a weak acid like vinegar.[445]

Other researchers have developed a graphene based tattoo-like sensor for monitoring bodily functions.[446]

Another example is a completely biodegradable optical fibre. There are medical uses of fibre optics, as light delivered in this way can help with examining tissues and even in treating tumours. "Many other applications are on the way, including drug release and activation, optogenetics, and new diagnostic modalities."[447]

[445] https://news.stanford.edu/2017/05/01/flexible-organic-biodegradable-new-wave-electronics/
[446] https://motherboard.vice.com/en_us/article/nee8qm/this-tattoo-can-monitor-your-heart-rate-and-brain-waves
[447] https://www.medgadget.com/2017/10/implantable-biodegradable-optical-fiber-stay-body-long-time-stretches.html

In a fresh approach to degradable batteries, researchers at the University of Wollongong used silk to build electrodes and also a solid electrolyte. "The solid electrolyte enables thinner, flatter, and more flexible and robust batteries"[448], stated one of the researchers, Caiyun Wang. This development is promising for medical electronics as silk – "can be made into thin films, is biocompatible, and is sturdy enough to work in electronic circuitry."[449] A flexible battery based on silk films could be used to power implanted electronic devices. At the end of its useful lifespan, it would undergo (pre-programmed) dissolving. In lab tests, the silk battery decomposed almost entirely after 45 days of being immersed in the test solution. There was only a residue of gold nanoparticles, but they would be eliminated by the body.[450,451]

A team of researchers at MIT and Brigham and Women's Hospital, designed a small copper and zinc battery which uses the acid in the stomach as electrolyte. The small electrodes are placed on an ingestible sensor. "The system can generate enough power to run small sensors or drug delivery devices that can reside in the gastrointestinal tract for extended periods of time. This type of power could offer a safer, lower-cost alternative to the traditional batteries now used to power such devices."[452]

Food/medication tracking

A research group in Switzerland proposed "fully biodegradable temperature sensors whose layout and ultrathin format confer a dynamic response of 10ms and high mechanical stability".[453] The use of a polymer capsule prolonged the stable electrical functioning of the device to 24 hours. The sensors are connected via Bluetooth and are capable of a 200mK resolution. They could be used "in food tracking and in medical post-surgery monitoring".[454]

Researchers from Holland designed a small label, invisible and biodegradable, which can be used to ensure the safety of food and medications. The label could also function as proof of the origin of the product (confirming manufacturer). In terms of its utility as a safety check, a "built-in sensor emits a signal if it is insufficiently cooled during transport or storage, another if there is a risk of bacterial spoilage."[455] Dimensions are 0.1 x 0.03 x 0.025 mm, so the label is quasi-invisible. Since the label carries 32 binary digits a code, 4.3 billion unique instances are possible. "In addition, the label is placed on or inside the product itself, rather than on the packaging, making tampering more difficult. The label contains two miniature sensors. One discolours when the acidity of the product changes, which is often caused by bacterial growth. On the other side, the bottom of

448 https://cen.acs.org/articles/95/web/2017/04/Dissolvable-batteries-made-silk.html
449 https://cen.acs.org/articles/95/web/2017/04/Dissolvable-batteries-made-silk.html
450 https://cen.acs.org/articles/95/web/2017/04/Dissolvable-batteries-made-silk.html
451 https://factordaily.com/kashmir-smart-diaper-sensors-predicts-baby-pee/
452 https://www.technology.org/2017/02/07/engineers-harness-stomach-acid-power-tiny-sensors/
453 https://www.nanowerk.com/nanotechnology_articles/newsid=47412.php
454 https://www.nanowerk.com/nanotechnology_articles/newsid=47412.php
455 https://www.elektormagazine.com/news/invisiable-label-protects-against-bogus-medication

the label breaks off if the temperature rises too high."[456] A microscope is necessary to take readings of the code and sensors, but this drawback might be mitigated, since microscope which can be attached to smartphones is under development.

Other examples of progress in relevant areas include biodegradable sensors placed inside objects to measure their temperature. The most important use would be monitoring food safety, but the temperature of other sensitive products, such medications and medical devices, could thus be monitored.[457]

Environmental sensing

A research group at the University of Bath, in the UK, proposed a device which evaluates the toxicity of drinking water. This "cheap, sustainable paper-based sensor"[458] is sensitive to and would warn of toxic components. The well-known litmus test (in which an impregnated paper is used to measure the acidity of fluids) inspired the researchers. They said their paper sensor "could provide some of the world's poorest countries with an affordable and simple way to test a water supply."[459]

Another proposal involves the use of cyanobacteria to synthesize a biological, living ink that can then be printed on paper. These prints could function as biological solar cells. The energy thus generated could power small devices with low and predetermined energy demands, for example "environmental sensing and wearable biosensors. [The sensors] are disposable and biodegradable, and they also work in the dark, releasing electricity from molecules produced in the light."[460]

Long-term perspectives

Recent evolutions have reduced the expected the lifespan of electronics, which now may be as short as several months. A worrying consequence is the ecological impact of discarded electronics. The use biodegradable or organic electronic materials may be a solution to this problem. Materials of this kind could open the way to "fully biodegradable and even biocompatible/biometabolisable electronics for many low-cost applications". These devices could dissolve at the end of their life cycle, which would on the one hand curb the levels of electronic garbage, and on the other would enable "the development of medical implants that after expiration of their operating life are resorbed by tissue, sparing the patient a second surgical intervention".[461]

[456] https://www.elektormagazine.com/news/invisiable-label-protects-against-bogus-medication
[457] https://www.medgadget.com/2017/10/tiny-flexible-embeddable-temperature-sensor-monitor-food-drugs-medical-devices.html
[458] https://www.thechemicalengineer.com/news/cheap-paper-sensor-detects-water-impurities/
[459] https://www.thechemicalengineer.com/news/cheap-paper-sensor-detects-water-impurities/
[460] https://futurism.com/solar-panels-power-small-devices/
[461] https://www.nature.com/news/biodegradable-electronics-here-today-gone-tomorrow-1.11497

4.4.2 Lab-On-A-Chip

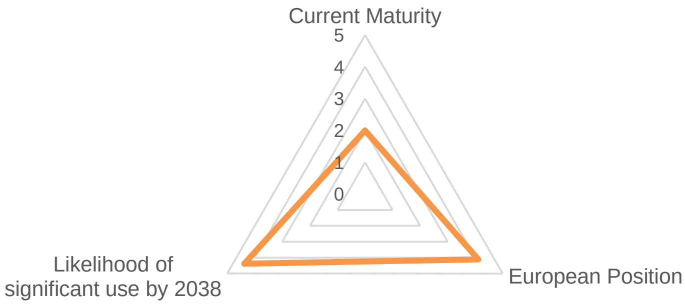

Figure 40: RIB Score of Lab-On-A-Chip

A lab-on-a-chip (LOC) integrates laboratory functions such as chemical analysis within a single device of small dimensions. LOCs, which are a subset of micro-electro-mechanical systems (MEMS), can handle very small fluid volumes and thereby allow for high throughput analysis with fast responses. Microfluidics, i.e. the physics, manipulation and study of minute amounts of fluids, is an important basis of LOC development.

Recent progress directions

Sepsis detection

A very important application in health is rapid sepsis detection. Many people still die of sepsis because the latter is not diagnosed early enough, and every minute is important for antibiotic treatment. Currently, diagnosis and treatment take several days and may be unreliable. LOC systems are being developed to analyse patient blood samples "to detect the microorganisms that may cause sepsis and have the potential to improve patient outcomes and reduce the inappropriate use of antibiotics".[462]

Lab-on-a-stick

A 'Lab-on-a-stick' (LOS) is a plastic ribbon containing an array of multiple micro-capillaries. These test tubes can be used for testing, much like a dipstick, but their microfluidic properties allow high throughput analysis. This promises simple, fast and affordable point-of-care tests such as antibiotic susceptibility testing. The test's results can be read directly or measured via cheap portable equipment such as a smartphone camera.[463]

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[462] https://www.cadth.ca/sites/default/files/pdf/2017_horizon_scan_roundup_part_1.pdf
[463] https://www.sciencedaily.com/releases/2016/08/160823101830.htm

Cheap lab-on-a-chip manufacturing

There are promises for cheap methods for fabricating Lab-on-a-chip devices, in particular through additive manufacturing methods (3D printing).[464]

Long-term perspectives

Lab-on-a-chip technology promises a rapid improvement in healthcare due to better, faster diagnostics, especially in areas with poor healthcare infrastructure. At the same time, the technology may allow for a more active role of patients in monitoring their own health. In a similar way, LOC may enable citizens to engage in environmental monitoring, for example via citizen science projects.

4.4.3 Molecular Recognition

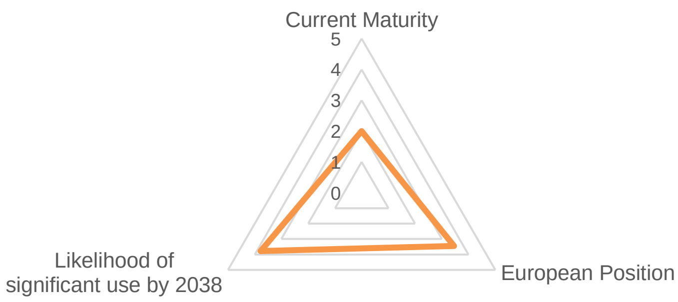

Figure 41: RIB Score of Molecular recognition

Molecular recognition can be thought of as the study of interactions between molecules. "Studies in physical organic chemistry have demarcated and assessed the weak intermolecular forces involved when two molecules meet each other."[465] From a medical perspective, "molecular recognition is a central topic since it determines whether a compound possesses useful clinical properties".[466] Of particular importance for clinical conditions are nanomaterials for biosensing applications based on molecular recognition, where the recognition component could be enzymes, DNA, RNA, catalytic antibodies, aptamers, and labelled biomolecules.

Recent progress directions

Portable diagnostic devices

Portable diagnostic devices play important roles in healthcare strategies, in particular for detection, health management, and monitoring of a medical

[464] https://www.nature.com/articles/srep35111
[465] http://www.pnas.org/content/106/26/10423
[466] https://people.chem.ucsb.edu/kahn/kalju/recognition.html

condition. These devices can be deployed in remote areas and non-laboratory settings. Many biosensing devices for clinical analysis and disease assessment have been produced in recent years. A recent achievement may help introduce portable diagnostic gadgets that rely on attaching nanoparticles to biomarkers such as proteins and determining how many find their targets.[467] Another example is a nanostructured sensor for monitoring a cardiac tissue biomarker known as Troponin. This biomarker is released in the blood from injured heart muscle cells at the beginning of a heart attack. By detecting the presence of "troponins with high accuracy in small volumes of blood drawn from a finger prick"[468], a heart attack may be predicted.[469] A new lab chip of the size and shape of a microscope slide can measure six blood biomarkers, such as CD40 ligand, streptavidin and thrombin, which can indicate certain diseases. For example, thrombin is important for blood clotting.[470] Another AI device composed from a nano-array of carbon nanotubes and gold can identify in breath samples unique chemical signatures of 17 different diseases.[471]

Electrodiagnosis

Electrodiagnosis is used to acquire information about illnesses by recording and/or measuring the natural electrical activity of biological cells and tissues or their responses to external electrical stimuli. One of the experimental holdups in neuroscience in studying synaptic behaviour and degenerative diseases that affect the synapse is performing electrical measurements at synapse level. However, "nanoscale suspended electrode arrays" – a.k.a. nano-SPEARs – can now give researchers access to electrophysiological signals from the cells of small animals without injuring them, and "allows a single animal, such as a worm, to be tested again and again".[472]

Screening (medicine)

In medicine, screening is a tactic used to recognize the potential presence of an undiagnosed disease in individuals without symptoms. Even though screening could lead to earlier disease diagnosis, screening assessments have been prone to over diagnosis and misdiagnosis. For these reasons, a screening test requires good sensitivity and satisfactory specificity. Genetic screening allows for determining the risk of developing specific diseases or disorders. Nucleic acids contain base chains or sequences, which can stretch from a few to millions of elements long. The precise order of bases is associated to their functions and therefore, can be exploited as clear signs of activities inside cells and tissues. For example, microRNAs, a group of nucleic acids, are around 20 bases long, but can offer signals of diseases, such as cancer. New strategies can now recognize a particular sequence

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[467] https://www.medgadget.com/2017/01/tiny-acoustofluidic-chip-separates-nanoparticles-liquid-samples-detect-disease.html?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+Medgadget+%28Medgadget%29
[468] https://phys.org/news/2016-10-bioengineers-sweat-based-sensor-glucose.html
[469] https://www.eurekalert.org/pub_releases/2016-10/uota-tma101316.php
[470] https://www.azonano.com/news.aspx?newsID=34350
[471] https://newatlas.com/different-diseases-different-breathprints/47088/
[472] https://www.nanowerk.com/nanotechnology-news/newsid=46410.php

amongst competing nucleic acids, more precisely microRNA (mi-R155), which signals lung cancer in humans.[473] Another strategy for screening looks for subtle signs that the cells in a culture are starting to defend themselves when they meet a nanoparticle that is introduced in the human body for different beneficial purposes. Furthermore, this technique can detect if a nanoparticle gets noticed and targeted by the immune system and spots whether macrophages are able to swallow the nanoparticles whole.[474]

Long-term perspectives

In the long run, molecular recognition is one of the building-blocks of the processes that build life. As a developing field it can revolutionize medicine.

A functional device, equipped with an array of sensors that would scan and interpret data on the spot, could reshape medicine. As a replacement for expensive machines and long waiting times at doctor's waiting room, data and statistics would be accessible immediately. Physicians could rapidly scan a patient, or patients may possibly scan themselves and receive a list of diagnostic options and recommendations.

4.4.4 Bioelectronics

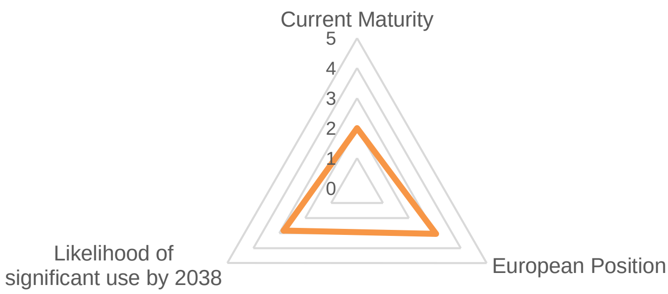

Figure 42: RIB Score of Bioelectronics

Bioelectronics is defined as the use of biological materials or architectures inspired by biological systems to design and build information processing machinery and related devices. This field "seeks to exploit biology in conjunction with electronics in a wider context, encompassing biological fuel cells [see relevant RIB], bionics and biomaterials for information processing, information storage, electronic components and actuators."[475] A crucial dimension of this area of research is the envisaged complementarity and interaction between biological materials and extremely miniaturized electronics.

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[473] https://www.azonano.com/news.aspx?newsID=34367
[474] http://feedproxy.google.com/~r/Medgadget/~3/5dsu4cWmzWY/new-rapid-technique-testing-safety-nanoparticles-body.html
[475] https://www.elsevier.com/journals/biosensors-and-bioelectronics/0956-5663/guide-for-authors

Recent progress directions

Biochips

Biochips are "essentially miniaturized laboratories that can perform hundreds or thousands of simultaneous biochemical reactions".[476] Using biologically derived molecules (such as DNA, RNA, proteins, etc.), these systems perform "computational calculations involving storing, retrieving and processing data".[477]

Researchers built a biological supercomputer that uses parallel networks powered by ATP (adenosine triphosphate, a complex organic chemical found in all forms of life, often referred to as the "molecular unit of currency" of intracellular energy transfer).[478] Also, they assembled a DNA computer that can make calculations and release a drug in response to disease biomarkers.[479]

Other new developments include a system to control in an extremely precise way when and where living cells adhere to some substrate[480]; and a method of printing cheap lab-on-chip devices that can be used to isolate target cells from other cells and count them by type.[481] Another team built a biological computer composed of RNA that functions inside living bacterial cells and tells them what to do.[482]

Biological computer parts

Before building a biological computer, various computer parts are needed. One example is a modified-DNA switch controlling the flow of electricity within a single molecule, which can also be used as a "probe to measure reactions at the single-molecule level"[483]; or DNA memory to store digital files for long time preservation.[484]

Bio interfaces

An active area of research is better biological-computer interfaces. Present implantable electrodes pose a risk of infections, so researchers developed semiconductors related to the indigo pigment which are not only stable when exposed to air, but also under water[485]; or polymers that are

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476 http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.413.9952
477 https://www.omicsonline.org/biological-computers-their-mechanism.pdf
478 https://www.eurekalert.org/pub_releases/2016-02/mu-blb022616.php
479 https://www.medgadget.com/2017/02/dna-computer-can-sense-multiple-antibody-inputs-potential-smart-drug-delivery.html
480 https://www.nanowerk.com/nanotechnology-news/newsid=42315.php
481 https://www.medgadget.com/2017/02/cheap-method-printing-lab-chip-devices-promises-diagnostic-revolution.html
482 http://feedproxy.google.com/~r/IeeeSpectrumFullText/~3/KkFvxa9eNd4/biological-computer-commands-living-cells-to-light-up
483 https://www.genengnews.com/gen-news-highlights/scientists-create-active-controllable-electronic-dna-switch/81253909
484 http://www.japantoday.com/category/technology/view/scientists-work-toward-storing-digital-information-in-dna
485 http://www.nanotech-now.com/news

conducting and transparent and mimic biological tissue better.[486] Also, an implanted memristor (a resistor with memory') could provide real-time processing of neuronal signals leading to efficient data compression and low power requirements of neural probes for implants.[487]

DNA Memory

'DNA memory' refers to memory storage systems that record information in the DNA. The stored information can be retrieved at any moment by sequencing, i.e. converting data back to the binary format. Information can be stored in vitro, using synthetic DNA, or in vivo, using gene editing techniques. DNA advantages for storage include an ultra compact size and durability (in a cool, dry place).

Data can be stored in synthetic DNA by converting nucleotides into digital bits. The resulting strands contain variations of nucleotides that encode for specific pieces of data. In order to make them more identifiable to the device reading them, distinctive markers have placed on certain nucleotides, with a retrofitting computer system retrieving this data.[488]

'Molecular recorders', on the other hand, capture and store practical amounts of real data within the genomes of living cells. Gene editing techniques such as CRISPR-Cas9 are usually employed to this end. The CRISPR-Cas system assures the immune system against viral infections in some bacteria: when a virus infects a bacterium, Cas cuts out part of the foreign DNA and stores it in the genome of the bacterium. The stored DNA (CRISPR) is used to recognize the virus and defend against future attacks. As such, cells can be induced to record different events in their own genomes.[489]

Researchers recorded a short movie into the genomes of a population of living bacteria using the CRISPR-Cas system to encode the pixel values of black and white images.[490] They translated five frames from a racehorse sequence into DNA and subsequently reconstructed the movie with 90 percent accuracy by sequencing the bacterial DNA.[491] The researchers intend to use this system to record a molecular history of the brain throughout its development. The molecular recorder will enable data collection from every cell in the brain at once, while leaving the system undisturbed.

The first mammalian memory storage systems have recorded digital information in living cells using recombinases, a type of enzymes. The cells were programed to flip sections of their DNA when a particular event occurs, for example, in response to exposure to a certain chemical. However, this solution reveals only whether the event occurred, not the length or intensity of exposure. A new technology, Mammalian Synthetic

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486 http://electronics360.globalspec.com/article/9657/conducting-polymer-microcups-for-organic-bioelectronics

487 https://www.theengineer.co.uk/memristors-provide-boost-to-development-of-neuroprosthetics/

488 http://www.iflscience.com/technology/single-drop-synthetic-dna-can-store-all-data-world/

489 https://www.eurekalert.org/pub_releases/2017-07/niom-srm071217.php

490 https://www.nature.com/articles/nature23017?sf96979006=1)

491 https://www.eurekalert.org/pub_releases/2017-07/niom-srm071217.php

Cellular Recorders, can do all of that. The new approach is also based on the CRISPR-Cas9 system.[492]

Long-term perspectives

Researchers hope to develop bio-inspired materials (e.g. capable of self-assembly or self-repair) and bio-inspired hardware architectures (e.g. massive parallelism) to be used in new sensors, actuators and information processing systems that are smaller, work faster/better and require less power. Other uses include molecular manufacturing down to the atomic scale and better interfaces between biological organs and electronics, which could lead to advances in the fields of prosthetics, man-machine integration, bionics, etc.

As a medium for data storage, DNA memory could provide a size-efficient and resilient solution in a world where digital data is expected to reach 16 zettabytes by 2019. Synthetic DNA as a storage medium is millions of times more compact than most cutting-edge contemporary alternatives. On the other hand, in vivo memory storage systems can be used not only to store data, but also to record events and processes in human cells, tissues, or engineered organs. This opens new vistas in health modelling, monitoring, and the study of cell development.

4.4.5 Bioinformatics

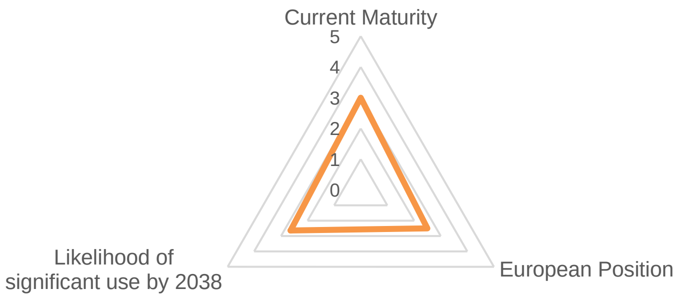

Figure 43: RIB Score of Bioinformatics

Bioinformatics is a recent area of research which combines the methods, interests, and data of several disciplines, such as biology, mathematics and computer science. It aims at developing tools for mapping and understanding data regarding biological organisms. Genetics and genomics are particularly relevant areas of application. "Common uses of bioinformatics include the identification of candidate genes and nucleotides which aims at a better understanding of the genetic basis of disease, unique adaptations, desirable properties (especially in agricultural species), or differences between populations."[493]

[492] http://neurosciencenews.com/analog-memory-human-cells-4873/
[493] https://en.wikipedia.org/wiki/Bioinformatics

Bioinformatics has assisted with developments in synthetic biology biomimetics, supramolecular chemistry and other subfields.[494] This has led some scientists to invest bioinformatics with the promise of delivering breakthroughs in biology, and more specifically in genetics. One cutting-edge area of study, according to Thomson Reuters Research Fronts, is the prediction of protein structure and nucleosome positioning.

Recent progress directions

Biohybrid

A biohybrid typically refers to a combination of artificial components and at least one biological component. This kind of systems can be applied in a large array of domains, from health to nanotechnology, robotics or even consumer goods – such as fresh produce.

The Case Western Reserve University researchers combined a muscle from the mouth of a sea slug with flexible 3D printed components, thus building a biohybrid robot that can crawl on the beach. The muscle is currently controlled by an external electric field, but the researchers are planning on using as future improvements nervous tissue as an organic controller. They also built an organic scaffold by using the collagen from the skin of the sea slug. The researchers are hoping to create robots which could be used to search the ocean floor or detect toxic leaks in water environments.[495]

A start-up company called Biohybrid Solutions uses polymer-based protein engineering to create paint or food packaging that changes colour when a certain toxin is present, or at the same time of the expiration date. This new technology used by the company, is unique, because they "grow" the polymers on the surface of the proteins and not just linking polymers with proteins. They succeeded in controlling the length, density and properties of the polymer, thus making the proteins more stable.[496]

An international team of researchers developed biohybrid magnetic robots for site directed drug delivery. They used microscopic algae that have approximately the same size as red blood cells, called Spirulina platensis. After functionalizing the algae with biocompatible magnetic particles, they tested the micro-robots by magnetically guiding them to the cancer site in the stomach of a rat. The therapeutic substances that the algae released killed only the cancer cells. By controlling the coating of the algae the researchers are able to control the biodegradation process and the release of therapeutic substances. These biohybrid magnetic robots could be used in the future for not only cancer treatment, but for diagnostic or for the treatment of other illnesses.[497]

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[494] https://ec.europa.eu/futurium/en/content/future-research-practices

[495] http://blog.case.edu/think/2016/07/18/researchers_build_a_crawling_robot_from_sea_slug_parts_and_a_3d_printed_body

[496] http://www.post-gazette.com/business/tech-news/2016/11/08/Hamar-startup-Biohybrid-Solutions-LLC-hopes-to-bring-new-developments-to-the-market/stories/201611030014

[497] http://www.sciencemag.org/news/2017/11/robot-made-algae-can-swim-through-your-body-thanks-magnets

Researchers at IIT, Istituto Italiano di Tecnologia, developed a biohybrid device that mimics the blood-brain barrier, an anatomic structure that protect the brain from unwanted substances. They used 3D printing technology and photopolymer resin to create 50 10µm cylindrical channels with 1µm pores, that mimics brain microcapillaries. After fabrication, the polymer structure was covered with endothelial cells, which constructed a biological barrier around the microcapillary system, thus forming a biohybrid system that mimics the natural blood-brain barrier. The researchers intend to use this device to better understand how to design therapeutic strategies against brain cancer and brain disease.[498]

Long-term Perspectives

Biohybrid technologies will develop in the future robots with more precise and softer movements that can be compared with natural movements, which will enable the use of robots in more domains and with wider applications. At the same time by combining technology with biology we could replicate tissues or organs that could help us in better understanding human physiology or to design new drugs or drug delivery methods.

4.4.6 Plant Communication

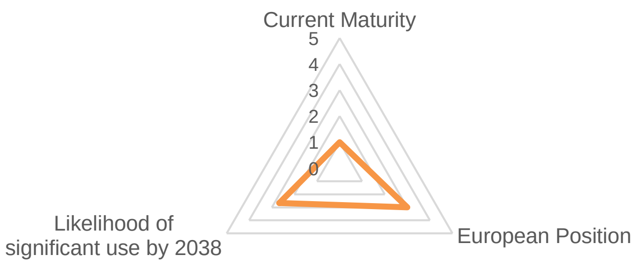

Figure 44: RIB Score of Plant communication

Plant communication refers to communication between plants and other organisms – be they plants of the same or a different type, insects in the soil and in the air, or more sophisticated creatures. Plant communication also involves potential combinations with other, non-plant categories of capabilities. Recently a number of novel and surprising insights on the nature of plant communication have emerged, that could give rise to potentially important innovations. Both artists and engineers experiment with new solutions by combining plant, human and machine capacities. Other research teams are exploring ways to use plants as sensors.

[498] https://www.sciencedaily.com/releases/2018/02/180208104246.htm

Recent progress directions

Parasites involved in plant communication

A team of scientists led by Jianqiang Wu at China's Kunming Institute of Botany and by Ian Baldwin with the Max Planck Institute for Chemical Ecology in Jena have examined the ecological significance of dodder, a parasitic vine. Dodder is a problem because it generates damages in pasture farming with alfalfa and clover, also leading to severe losses in soybean cultivation in China. Therefore, the researchers used soybean plants in their experiments[499], aiming to determine whether this parasite not only taps the hosts' supply system, but also plays a part in the communication between plants. The results show "that plants can communicate through volatile cues and underground mycorrhizal networks … [and] dodder can transmit insect feeding-induced signals among different hosts and whether these signals can even activate defences against insects."[500]

Plant Sensors

According to recent research, "plants have at least 20 different senses used to monitor complex conditions in their environment" including humidity, gravity and electromagnetic fields. Moreover, several studies point out that plants are able to entertain relatively complex social relations and can communicate amongst themselves and with other organisms. They use a variety of means to do so, from electrical signals to vibrations. There is also mounting evidence that plants' intelligence relies at least in part on their complex network of root apexes.[501] The ongoing DARPA Advanced Plant Technologies (APT) program aims at using plants as sensors for defence purposes. The program intends to develop plant sensors that can detect, and communicate chemical, biological and/or electromagnetic threats in the environment. The assumed approach is by having genetically modified plants that would, for example, change colour or size when a threat is detected. Existing surveillance systems like satellite imagery or drones could capture the changes sensed by plants.[502]

Plant robot hybrids

Once plant behaviour is better understood they can be combined with other entities. As an example, the ongoing FET funded project Florarobotica[503] is developing and investigating „closely linked symbiotic relationships between robots and natural plants" and explores "the potentials of a plant-robot society able to produce architectural artefacts and living spaces".

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499 https://www.brightsurf.com/news/article/072517434621/dodder-a-parasite-involved-in-the-plant-alarm-system.html
500 http://www.ice.mpg.de/ext/index.php?id=1379
501 https://www.theguardian.com/environment/radical-conservation/2015/aug/04/plants-intelligent-sentient-book-brilliant-green-internet
502 https://www.darpa.mil/program/advanced-plant-technologies accessed 19/09/2018
503 http://www.florarobotica.eu/ accessed 19/09/2018

Long-term perspectives

Research about the understanding of plant communication is still in its infancy. Judging by the results so far, surprises may be expected once the findings start to accumulate. Deeper insights on plant communication may "grow into" novel solutions for human needs.

Biomedicine

4.5 Group 5. Biomedicine

4.5.1 Gene editing

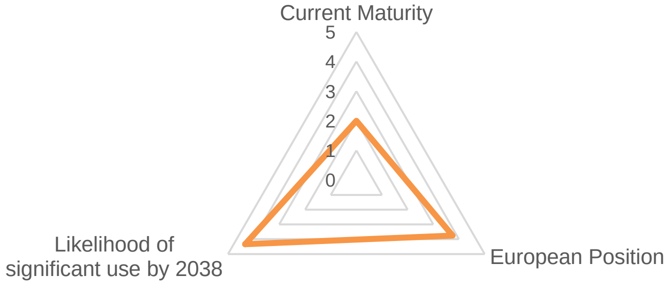

Figure 45: RIB Score of Gene editing

In genome editing, also known by the name of 'genome engineering', DNA is inserted, deleted, modified or replaced in an organism's genome. The usual approach to editing is through engineered nucleases ('molecular scissors') which generate double-strand breaks (DSBs) in the genome at the targeted locations. These DBSs are repaired through nonhomologous end-joining (NHEJ) or homologous recombination (HR). The results are targeted mutations ('edits').[504]

There are 4 families of engineered nucleases in use: meganucleases, zinc finger nucleases (ZFNs), transcription activator-like effector-based nucleases (TALEN), and the clustered regularly interspaced short palindromic repeats (CRISPR/Cas9). The journal Nature Methods selected genome editing in 2011 as the Method of the Year, while Science awarded the Breakthrough of the Year to the CRISPR/Cas system in 2015.[505] The opportunities for the application of gene editing are increasing drastically – and with them the applications and ethical questions.

Recent progress directions

CRISPR as revolution in health

CRISPR generated a revolution in the world of genetic engineering. Although bacteria-based, it works in nearly all living cells and organisms. It promises new possibilities against AIDS, cancer and inherited diseases but also in breeding plants and animals.

Investors are very active in this field. Inscripta (formerly Muse Bio) raised a $55.5 million Series C round led by healthcare investor Mérieux Développement and Washington, DC-based private equity firm Paladin Capital Group. Other investors participated. Inscripta is "building a business based on selling gene-editing tools, such as instruments, reagents, and

[504] http://www.transgen.de/forschung/2564.crispr-genome-editing-pflanzen.html
[505] https://en.wikipedia.org/wiki/Genome_editing

software, and in order to create a market for these tools, the company is giving away CRISPR enzymes for free."[506] CEO Kevin Ness likened his company's business situation to selling pickaxes during the gold rush.[507]

CRISPR in agriculture

Whereas the first applications were in medical health, the next boom is expected in biotechnology and agriculture.[508] There is already a huge ethical debate about the question if these plants and animals are 'genetically engineered' or if they resemble natural mutations.[509]

Long-term perspectives

Gene editing will find its way into many different applications, most of them still unimagined. There is a lot of creativity involved in imagining new uses – and a lot of ethical concerns and regulation to consider.

4.5.2 Gene Therapy

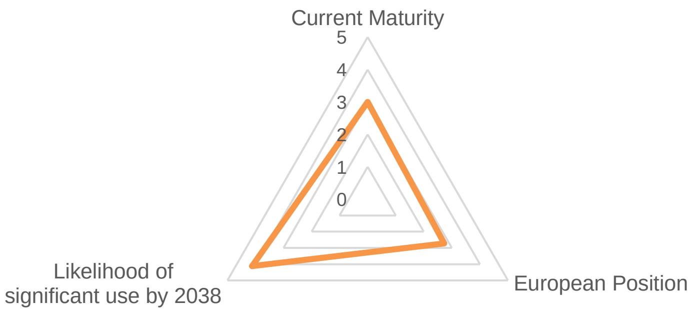

Figure 46: RIB Score of Gene Therapy

Gene therapy (also "gene-based therapy" and "living-drug therapy") is a broad term that captures a wide variety of gene-altering techniques employed for treating or preventing genetically triggered medical conditions. Gene therapy focuses on genes that mutate in such a way that they produce an abnormal protein – or no protein at all. Variations aside, the basic principle of gene therapy is that these defective genes are replaced or inactivated by a therapeutic gene – also known as a 'functional gene' – that is administered into the human body via viruses or as 'naked DNA'.

Numerous in vitro and in vivo trials have been carried out since early 1990s. Successes such as the treatment of Leber's amaurosis (an eye

[506] https://agfundernews.com/crispr-startup-inscripta-raises-55-5m-series-c-open-source-gene-editing.html
[507] https://agfundernews.com/ag-industry-brief-tysons-partners-accelerators-crispr-3-0-gets-patent-unilever-moves-toward-transparency.html
[508] https://www.ncbi.nlm.nih.gov/pubmed/24323919
[509] http://www.transgen.de/forschung/2564.crispr-genome-editing-pflanzen.html

disease), but also failures such as Jesse Gelsinger's death from gene therapy in 1999, have resulted in mixed reactions from policymakers and interest groups..

Recent progress directions

Disease areas

Gene therapy research has attracted the interest of private and public investments in the past 10 years.[510] Research generally focuses on diseases that can be traced to specific gene functions and are not treatable by other, better-known methods. Because of this, around 80% of the funding is directed towards cancers, monogenic disorders (i.e. diseases triggered by a single pair of genes), and cardiovascular diseases.[511] Significant results have been recently announced for retinal diseases[512], immuno-deficiencies[513,514] and epilepsy.[515] In some cases of immunodeficiency, the reconstitution of the immune function came with no adverse effects related to the gene transfer technology. The majority of this research takes place in the United States (63 %), followed by the UK (11 %) and Germany (4.5 %).[516]

Treatments

Some gene therapy treatments such as Glybera or LentiGlobin have already received approval within the United States and the European Union. In 2016, the European Commission granted market approval to gene therapy for the treatment of a severe combined immunodeficiency (SCID), a very rare congenital disorder of the immune system. The clinical trial for this drug started in the early 1990s. In 2017, a treatment for B-cell acute lymphoblastic leukaemia approved tisagenlecleucel, a form of gene therapy which uses the body's own T cells to fight cancer (adoptive cell transfer).

Long-term perspectives

While gene therapy is widely regarded as a promising long-term treatment, it is to date not fully understood. Immune responses, problems with viral vectors and the applicability to multi-gene disorders are yet to be fully studied. Furthermore, the infrastructure needed to produce and deliver functional genes is extremely expensive. One of the drugs mentioned above is the world's most expensive, with estimated costs of around $1.6 million per patient.[517] While technological capabilities that make gene therapy possible are expanding, and the "Statement on Gene Therapy Research" proposed by the Human Genome Organisation in 2001 provides a solid basis for developing it, the complexity of the factors involved in the maturation

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[510] https://www.forbes.com/sites/matthewherper/2014/03/26/once-seen-as-too-scary-editing-peoples-genes-with-viruses-makes-a-618-million-comeback/#3c1332287e92

[511] http://onlinelibrary.wiley.com/doi/10.1002/jgm.2698/full

[512] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2839440/

[513] http://www.sciencedirect.com/science/article/pii/S1471491416000320

[514] https://www.ncbi.nlm.nih.gov/pubmed/21042293

[515] http://www.eurekalert.org/pub_releases/2015-12/lu-ast120315.php

[516] http://onlinelibrary.wiley.com/doi/10.1002/jgm.2698/full

[517] https://www.newscientist.com/article/mg22029412.100-gene-therapy-needs-a-hero-to-live-up-to-the-hype/#.UnUbZXC-068

and large-scale adoption of gene therapy remain dependent on policy and resolution of various ethical dilemmas.

4.5.3 Antibiotic Susceptibility Testing

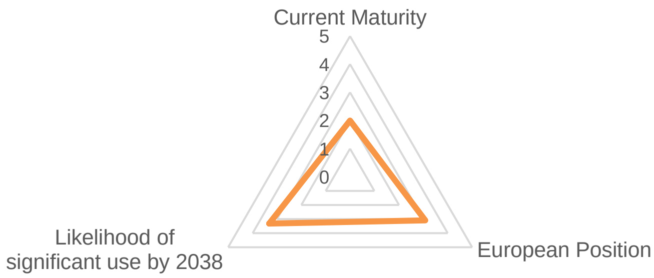

Figure 47: RIB Score of Antibiotic Susceptibility Testing

The emergence of bacterial infections resistant to a very large number of existing antibiotics has been driving the fervent search for Antibiotic Susceptibility Testing (AST) tools. These technologies enable the quick identification of therapies that are still effective for individual patients. Currently, multi-drug resistant bacteria are generally sent to specialized laboratories for analysis, leading to several-day delays before results can guide therapy.[518,519] The development of more effective tests will assist doctors in choosing the appropriate antibiotic treatment, thereby limiting the excessive use of antibiotics and the risk of resistant bacterial strains.[520]

Recent progress directions

AST Micro-assay

The current standard, the microdilution susceptibility test, requires dozens of steps, a complex set of supplies, and significant time. A new modified method using inkjet printer technology has been developed and validated. The new test uses an inkjet printer to print out droplets of an antimicrobial compound, with the printed drops varying in size up to a million-fold. In side-by-side comparisons with the gold standard microdilution method, the digital dispensing method was just as accurate and demonstrated significantly greater reproducibility (precision).[521]

[518] http://www.eurekalert.org/pub_releases/2016-07/bidm-smt071416.php
[519] https://www.google.com/url?rct=j&sa=t&url=https://www.eurekalert.org/pub_releases/2017-08/uu-num080817.php&ct=ga&cd=CAIyGmM0NDk5ZDlhM2YxOGViNTk6Y29tOmVuOlVT&usg=AFQjCNEgFDwCuP3EmLG48D_84GLrw_adcA
[520] http://www.dailymail.co.uk/news/article-4594502/British-device-spot-superbugs-two-minutes.html?ITO=1490&ns_mchannel=rss&ns_campaign=1490
[521] http://www.eurekalert.org/pub_releases/2016-07/bidm-smt071416.php

Microfluidic devices

The microfluidic cantilever is “a device that can rapidly identify harmful bacteria and determine whether they are resistant to antibiotics.”[522] The cantilever was engineered to identify and capture various bacteria and to determine to which antibiotic treatment the infection responds best. The cantilever part, “a plank that resembles a diving board”, has a microfluidic channel coated with biomaterials, such as antibodies, which harmful bacteria in fluid samples stick to.[523] If bacteria are identified by the device, it outputs three different signals, which capture the cantilever's changes in mass, its bend, and its vibration as infrared light is directed at the bacteria. The device allows for adding antibiotic drugs. In such scenarios, variations of the intensity of the cantilever’s minute oscillations will signal whether the bacteria are alive or dead, indicating bacterial susceptibility to drugs.[524]

Another AST device is based on a new plastic microfluidic chip trapping bacteria and on methods for analysing bacterial growth at single-cell level. The "fASTest" method allows for monitoring individual bacterial organisms by deploying subtle optical and analytical instruments. Once it is determined whether individual bacteria are capable or not of developing in an antibiotic environment, their resistance or, respectively, their susceptibility to drugs can be evaluated within minutes.[525]

AST Gadget

Another gadget takes less than two minutes to test if a patient is infected with antibiotic resistant bacteria. It collects samples from a patient and adds them “to a see-through cartridge that contains a cocktail of antibodies, DNA, and other molecules. Bacteria in the sample bind to specific antibodies attached to long, coloured, filament-like molecules in the cartridge”, altering” their alignment and how they absorb a particular colour of light that passes through.[526] The transparent capsule is then illuminated, and the issuing colours and absorbance are measured, with results shown on a display. The system can use filament molecules of various colours, and this allows it to determine “if the bacteria carry genes for certain types of antibiotic resistance. Each cartridge can be tuned to look for a set of bacteria and their antibiotic resistance according to what illness the doctor suspects the patient has.”[527]

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522 http://www.clpmag.com/2016/10/nanoscale-device-detects-antibiotic-resistant-bacteria/

523 https://www.ualberta.ca/pharmacy/news/2016/october/new-device-designed-to-identify-bacteria

524 https://www.eurekalert.org/pub_releases/2016-10/uoa-ndd100416.php

525 https://www.google.com/url?rct=j&sa=t&url=https://www.eurekalert.org/pub_releases/2017-08/uu-num080817.php&ct=ga&cd=CAIyGmM0NDk5ZDlhM2YxOGViNTk6Y29tOmVuOlVT&usg=AFQjCNEgFDwCuP3EmLG48D_84GLrw_adcA

526 http://www.dailymail.co.uk/news/article-4594502/British-device-spot-superbugs-two-minutes.html?ITO=1490&ns_mchannel=rss&ns_campaign=1490

527 http://www.dailymail.co.uk/news/article-4594502/British-device-spot-superbugs-two-minutes.html?ITO=1490&ns_mchannel=rss&ns_campaign=1490

Long-term perspectives

Antibiotic resistance is one of the most serious global risks for human health, and tackling it represents a multi-dimensional challenge with many fronts: infection prevention, development of new antibiotics as well as of alternative ways of fighting infection, limiting overuse and ensuring the effectiveness of treatments. Widely available technologies for antibiotic susceptibility testing will represent a major advance. In the future, once the cause of an infection is determined, doctors will be able to decide practically on the spot whether antibiotic treatment is appropriate; and what antibiotic would be most effective in the case at hand. Ideally, useless antibiotic treatments will no longer be prescribed or, indeed, taken without a prescription.[528]

4.5.4 Bioprinting (of human parts)

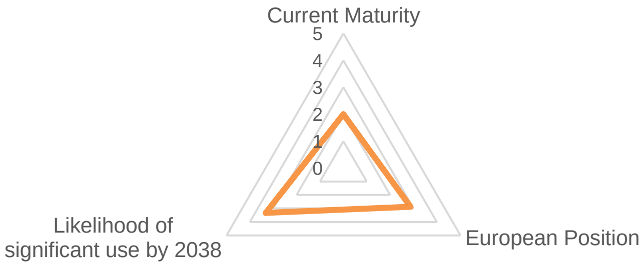

Figure 48: RIB Score of Bioprinting

Bioprinting, sometimes called "organic printing", is a particular application of 3D printing (or 'additive manufacturing', a set of technologies to build 3D objects by adding layer upon layer of material) that uses polymers or genetically engineered biomaterials to produce tissues and organs, some of them implantable in the human body. The advantage of bioprinting is individual adaptation of the material and fewer side effects, including implant rejection. Given the state of the art, only a few attempts of modest scale have been made to print organs or tissue of comparable complexity in terms of cellular structure.

Recent progress directions

3D-printed bones

Bones are 3D-printed from different materials, such as titanium (hips)[529] or bioceramics (implants for bone repair).[530] Researchers have long been interested in using ceramic composite materials for the repair of bones and

[528] https://www.eurekalert.org/pub_releases/2017-08/uu-num080817.php
[529] http://optics.org/news/7/3/7
[530] http://www.3ders.org/articles/20160411-3d-printed-bioceramic-implants-for-bone-repair-to-enter-market-soon.html

musculoskeletal defects, including arthritis, fractures and bone loss. A new resorbable bioceramic material is being developed in Europe, with hopes that a 3D-printed bioceramic implant will soon reach the market and remedy local defects in the joint. It would offer, through a minimally invasive surgical technique, immediate stability for arthritis sufferers (with a global market in joint replacements estimated at over €7 billion).

'Functionally gradient bioceramic composite' cylinders (or plugs) can now be 3D-printed. These devices "have been designed for osteochondral applications in the knee to provide early-stage intervention for osteoarthritis (OA). Requiring only a minimally invasive surgical technique, the plugs would match the mechanical properties of the patient's bone, offer immediate stability, and could be augmented by cells, proteins, growth factors and pharmaceuticals."[531] In addition to printing "new bones", there are new solutions to fix bones, e.g. a "flexible 3D-printed bend splint to facilitate common finger fracture treatment."[532]

3D-printing of tissue, skin, blood vessels and other human parts

Living tissues can be printed to repair damaged body parts[533], for example when the skin is burned in an accident. Different materials are used, including a two-component "bio-ink".[534] Artificial skin can also assist in cosmetics testing to replace live beings[535], especially after the European Union banned the sale of cosmetics tested on animals and other countries around the world have begun to follow suit. Furthermore, 3D-printed "bionic skin" could give robots and prosthetics the sense of touch.[536] Scientists at the University of Minnesota used 3D printing on curved (artificial) surfaces to build "stretchable, flexible, and sensitive electronic sensory devices that could endow robots, prosthetic hands or even real skin with the ability to mechanically sense their environment. Major uses would be enabling surgeons to feel during minimally invasive surgeries (instead of using cameras), or increasing the sensitivity of surgical robots."[537]

Another approach is to print branching vessels that become successively smaller by using a computer model with the desired structure.[538] To test the technique, the team implanted "a network of endothelial cells into skin

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531 http://www.3ders.org/articles/20160411-3d-printed-bioceramic-implants-for-bone-repair-to-enter-market-soon.html
532 http://www.3ders.org/articles/20160411-flexible-3d-printed-bend-splint-to-facilitate-common-finger-fracture-treatment.html
533 http://www.firstpost.com/tech/news-analysis/british-researchers-have-developed-a-new-method-to-3d-print-cells-to-form-living-tissues-3938721.html
534 https://www.biopharma-reporter.com/Article/2016/07/06/Two-component-bio-ink-could-help-advance-3D-printing-of-tissues
535 http://www.3ders.org/articles/20170706-taiwans-industrial-technology-research-institute-creates-3d-printed-chinese-skin-for-cosmetics-testing.html
536 http://www.kurzweilai.net/3d-printed-bionic-skin-could-give-robots-and-prosthetics-the-sense-of-touch
537 http://www.kurzweilai.net/3d-printed-bionic-skin-could-give-robots-and-prosthetics-the-sense-of-touch
538 https://www.theengineer.co.uk/light-activated-3d-printing-produces-branching-blood-vessels/

wounds on mice. After two weeks, they had merged with the mice's circulatory systems and were supporting normal blood flow."[539]

Other developments include a 3D printed trachea implant that enabled an Argentinian woman to talk, eat and breathe normally again[540]; a sternum implant that treated a rare congenital heart condition in a 6-year-old boy[541]; and the world's first 3D printed amphibious prosthetic, allowing amputees to walk and swim without switching prostheses.[542]

3D Bioprinter for life-sized constructs with living cells

A 3D-printing system has been proposed that can print live cells into human-scale constructs representing bone, muscle, and ear tissue.[543] This is considered an important step towards personalized, readily available organs. The objects thus printed are "structurally stable, thanks to the use of a biocompatible synthetic polymer called polycaprolactone".[544]

Bioengineers working with a Boston biotech company have used 3D-printing to construct a patch which contains endothelial cells (a type of cell specific to the inner surfaces of blood vessels). This medical patch stimulates the growth of healthy new blood vessels. "Not only did the patch result in the growth of new vessels – a process known as angiogenesis –, but the researchers were actually able to give structure to the growth, helping the vessels operate more effectively".[545] The experimental method promises to treat ischemia.

3D-printing cells to build living tissues[546] is the next step in this area of research. At Oxford, scientists have developed a new method to 3D-print laboratory-grown cells to form living structures. "The researchers demonstrated how a range of human and animal cells can be printed into high-resolution tissue constructs".[547] Other researchers in the same country "have found a new way to 3D-print living structures from lab-grown cells to be used as human tissue models", removing the need for animal testing.[548]

539 https://www.theengineer.co.uk/light-activated-3d-printing-produces-branching-blood-vessels/

540 http://www.3ders.org/articles/20170724-argentinian-woman-can-talk-eat-and-breathe-normally-again-thanks-to-3d-printed-trachea-implant.html

541 http://www.3ders.org/articles/20170807-6-year-old-boy-gets-3d-printed-sternum-implant-to-treat-rare-congenital-heart-condition.html

542 http://www.3ders.org/articles/20170406-northwell-healths-amphibious-3d-printed-leg-prosthesis-the-fin-helps-veteran-swim-again.html

543 http://feedproxy.google.com/~r/Medgadget/~3/7vdoQmXFdqM/3d-bioprinter-for-making-life-sized-constructs-with-living-cells.html

544 http://feedproxy.google.com/~r/Medgadget/~3/7vdoQmXFdqM/3d-bioprinter-for-making-life-sized-constructs-with-living-cells.html

545 https://www.theengineer.co.uk/3d-printed-patch-helps-improve-blood-flow/

546 http://www.firstpost.com/tech/news-analysis/british-researchers-have-developed-a-new-method-to-3d-print-cells-to-form-living-tissues-3938721.html

547 https://www.sciencedaily.com/releases/2017/08/170815095009.htm

548 http://www.ox.ac.uk/news/2017-08-15-new-method-3d-printing-living-tissues

3D-printed human organs

"3D printing to develop first-of-its-kind implantable artificial kidney based on microchips"[549] is currently on its way. If successful, this project could utterly change the lives of patients under dialysis waiting for transplants.

Since printing a whole organ is very complex, "a more practical alternative is a transplantable bio-hybrid device that almost works as a 'mini' dialysis tool the size of a soda can".[550] The device performs the role of a kidney, and it works by putting together microchip filters and kidney cells powered by a patient's own heart. As the researchers state, this bio-hybrid device, relies on a microchip that revolves around silicon nanotechnology principles, and it "can mimic a kidney to remove enough waste products, salt and water to keep a patient off dialysis".[551]

In a test on mice, ear and the underlying tissues have come to life[552] when baby-sized ear structures 3.8 cm in length were "implanted under the skin of mice in the lab. They showed signs of vascularization one and two months later".[553]

A two-year old child[554] already received a functional 3D-printed ear. While many people with malformed ears can still hear to some extent, in the Microtia (or "little ear") condition the absence of an ear canal causes hearing loss. The child currently wears a headband that transmits sound to her brain, using her skull as a bone conductor. The relevant technologies do not always target full organs or organs meant to be implanted: a scaffold-free 3D printed liver tissue helps in the testing of new drugs.[555]

3D-printed models for humans or human parts

In China, a team of surgeons operated on a nine-month-old baby who suffered from a severe congenital heart defect".[556] The successful intervention used software to convert MRI scan data into a 3D printable model.[557] Other researchers have pioneered a '"person-on-a-chip"' capable of growing human tissues for medical testing and, possibly one day, organ transplantation. The AngioChip consists of a scaffold made from POMaC, a biodegradable and biocompatible polymer, and is meant to wean `the

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549 http://www.3ders.org/articles/20160219-3d-printing-to-develop-first-of-its-kind-implantable-artificial-kidney-based-on-microchips.html

550 https://www.3ders.org/articles/20160219-3d-printing-to-develop-first-of-its-kind-implantable-artificial-kidney-based-on-microchips.html

551 http://www.3ders.org/articles/20160219-3d-printing-to-develop-first-of-its-kind-implantable-artificial-kidney-based-on-microchips.html

552 http://feeds.feedblitz.com/~/138427819/0/gizmag~Dprinted-ear-bone-and-muscle-structures-come-to-life-after-implantation-in-mice/

553 https://newatlas.com/3d-printed-ear-implantation/41869/

554 http://www.3ders.org/articles/20160418-two-year-old-maia-to-become-worlds-first-patient-to-receive-functional-3d-printed-ear.html

555 http://www.3ders.org/articles/20170427-3d-printed-liver-tissue-helps-university-of-tokyo-researchers-test-new-drugs.html

556 http://www.3dmedicalprinting.ch/3d-printed-heart-model-saved-the-life-of-a-nine-month-old-baby-in-china/

557 http://www.3ders.org/articles/20160318-3d-printed-heart-model-saved-the-life-of-a-nine-month-old-baby-in-china.html

pharmaceutical industry off animal testing and get drugs to market more quickly. With the ability to connect different organ tissues, however, they are able to expand upon other initiatives as well".[558]

Long-term perspectives

The number and size of human parts that can be 3D printed – even on the spot – is growing permanently. Some involve "mere" non-living components which can be steered (ears, prosthetic legs)[559,] but the possibilities are expanded by different materials usable in different media (e.g. in water).[560,561] In the longer run, real biomaterials will be used, either through genetic engineering or through cellular components designed in the lab and then integrated into a human body in order to grow there. The 3D-printing of "high-resolution" living tissue "could revolutionize regenerative medicine and allow the reproduction of complex tissue that could replace or repair damaged or severed areas of the body".[562]

According to researchers, one focus in bioprinting is on "designing a high-resolution cell printing platform from relatively inexpensive components; it could be used to produce artificial tissues with appropriate complexity from a range of cells, including stem cells."[563] Another area of interest is developing new scaffoldings for 3D-printed organic matter which no longer collapse but keep their shape.

In the more distant future, the first 3D-printed human organs will be transplanted without rejections, meeting a huge demand from patients waiting for an organ, but also from people who just want to live longer and replace their (somewhat) malfunctioning organs. On the very long terms, "person-on-a-chip" models may generate "complete tissues for implantation, to repair damaged organs with cells from a patient's own body".[564]

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558 http://3dprintingindustry.com/2016/03/08/person-on-a-chip-tech-results-in-working-3d-heart-liver/

559 http://www.3ders.org/articles/20170406-northwell-healths-amphibious-3d-printed-leg-prosthesis-the-fin-helps-veteran-swim-again.html

560 https://nano-magazine.com/news/2017/8/1/3-d-printing-in-water-opens-door-to-advanced-biomedical-materials

561 https://www.laserfocusworld.com/articles/2017/08/rapid-laser-based-3d-printing-in-water-uses-novel-hybrid-nanoparticles.html

562 https://www.rt.com/uk/400157-3d-printing-living-tissue/

563 http://www.ox.ac.uk/news/2017-08-15-new-method-3d-printing-living-tissues

564 https://3dprintingindustry.com/

4.5.5 Control of Gene Expression

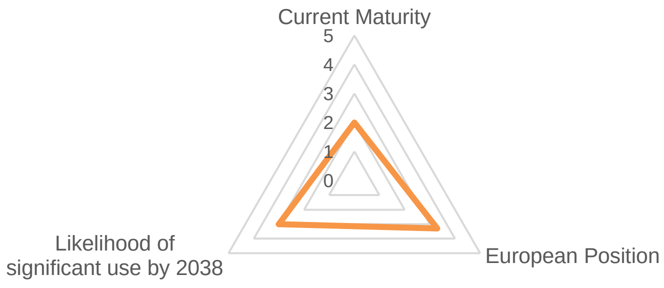

Figure 49: RIB Score of Control of gene expression

Gene expression is the process by which the nucleotide sequence of a gene is used, or "turned on", to direct protein synthesis and produce various cell structures. The structure, or product, could be an enzyme, a structural protein, or a control molecule. "Most of the mechanisms that control gene expression do so by controlling transcription, the synthesis of messenger RNA (mRNA) or, alternatively, the rate of protein synthesis."[565] By understanding how to control gene expression, scientists hope to clarify the role of each gene in human and animal development; detect early on a foetus's susceptibility to diseases and manipulate cells in such a way that the future organism will be healthy; and generally enhance the fields of assisted reproduction and regenerative medicine.

Recent progress directions

Epitranscriptomics

By analogy to the term epigenetics, epitranscriptomics is defined as the process of bringing "functionally relevant changes to the genome that do not involve a change in the nucleotide sequence". Since mRNA is the essential code that changes our biological information from DNA to protein, through transcription and translation, "epitranscriptomics" describes an aspect of molecular genetics that depends on non-mutagenic biochemical modifications of RNA. For example, a new cellular signal describing a "chemical modification that can significantly boost the conversion of genes to proteins"[566] was discovered by a team of scientists.[567] Another mechanism for the production of more proteins has been revealed by another group of scientists in the Drosophila sex determination pathway.[568] These mRNA modifications are "evolutionarily conserved and common, and present in

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565 http://highered.mheducation.com/sites/9834092339/student_view0/chapter16/control_of_gene_expression_in_eukaryotes.html

566 https://news.uchicago.edu/story/rna-modification-discovery-suggests-new-code-control-gene-expression

567 https://www.eurekalert.org/pub_releases/2016-02/uoc-rmd021616.php

568 https://www.sciencedirect.com/science/article/pii/S1097276516000137

humans, rodents or yeast."[569] They could provide a promising new lever in the control of gene expression.[570,571]

Embryo development

Embryogenesis (or embryo development) is a complex process that begins with fertilization. By mitotic divisions (cleavage) and cellular differentiation of the fertilized egg, a multicellular embryo is formed ('embryo' refers primarily to early stages of prenatal development, while 'foetus' describes later stages). A biochemical explanation of the growth "from the fertilized egg to the adult requires an understanding of the proteins and RNAs expressed over time during embryogenesis".[572] Novel methods seek to reveal with spatial and temporal precision the timing and duration of gene expression and/or protein activity. Some of these methods depend on the organism's gene-regulating mechanism and transcribe DNA to mRNA.

A research team developed a method to accurately manipulate gene expression by light illumination, which only acts on mRNAs. To test it, fluorescent protein mRNAs were injected into zebrafish embryos, which were then irradiated with blue or ultraviolet light. Moreover, double-headed zebrafish were created by accurately controlling the expression duration of squint, a gene that regulates body axis formation.[573] Another group produced a reengineered blue-light-activated system for minimal toxicity in zebrafish, while spatially restricting the illumination. Their novel optogenetic system was able to misplace endodermal cells in the presumptive ectoderm of zebrafish.[574]

Long-term perspectives

The study of gene expression will "revolutionize how researchers identify new molecular targets and improve patient care through the identification of "genetic fingerprints or profiles" that might be able to predict responsiveness to therapy or prognosis".[575] Advances in gene-expression control will have a crucial role as a diagnostic and as predictive biomarkers and will translate into a powerful basis for personalized medicine.

Genome instability and gene alteration contributes to disease development, accelerates age-related pathologies and promotes tissue degeneration and organ failure. Through the control of gene expression, it will be possible to foresee how well and how rapidly an individual will age. Controlling gene expression in the phase of embryo development and pluripotent stem cell biology may revolutionize assisted reproduction and regenerative medicine.

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[569] https://news.uchicago.edu/story/rna-modification-discovery-suggests-new-code-control-gene-expression
[570] https://www.eurekalert.org/pub_releases/2016-02/uoc-rmd021616.php
[571] https://www.sciencedirect.com/science/article/pii/S1097276516000137
[572] https://www.ncbi.nlm.nih.gov/pubmed/26555057
[573] https://phys.org/news/2017-01-gene-precisely.html
[574] http://dev.biologists.org/content/144/2/345
[575] https://www.ncbi.nlm.nih.gov/pubmed/19663732

Research in epitranscriptomics combined with high-performance computers may produce large and complex "control panels" that will control and suggest a specific development to a cell.

4.5.6 Drug Delivery

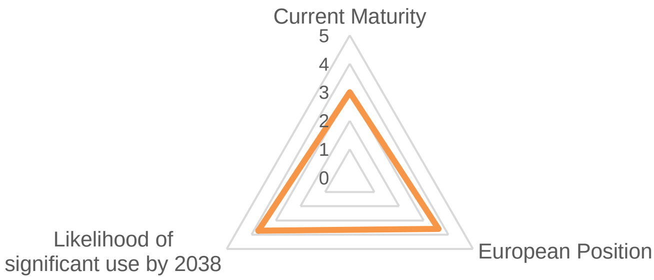

Figure 50: RIB Score of Drug Delivery

Drug delivery represents the administration of a healing agent or pharmaceutical complex to humans or animals in order to reach a therapeutically operative range of medication. Advances in drug delivery technologies generally aim to increase the efficacy and absorption of a drug, while decreasing its side effects. Nanomaterials and new materials are revolutionizing the field.

Recent progress directions

Breaking the Blood-Brain-Barrier

The blood-brain barrier (BBB), a membrane that separates the circulatory system from the fluid around the brain, is impervious to many drugs. But researchers who noted that some venoms can actually penetrate the BBB have been looking for strategies of using these normally toxic substances. A bee-venom peptide, apamin, has been modified to deliver medications to the brain without discharging its poisonous effects.[576]

The BBB has been one of the important obstacles in treating patients with brain cancers or other diseases, such as Alzheimer's. Oxford University researchers and collaborators at the University of Twente developed an in vitro platform – asort of BBB system-on-a-chip – to study how the barrier opens and how it signals this opening – in particular, through sounds. Through sounds, lights, and electrical fields they can now monitor the course and efficacy of treatments and adapt them accordingly.[577]

New- and nano-materials

A sticky and stretchable gel-like material made in MIT can be combined with sensors, light and drugs to act as a 'smart band-aid.' The unique hydrogel

576 https://www.nanowerk.com/nanotechnology-news/newsid=46288.php
577 https://www.eurekalert.org/pub_releases/2017-06/asoa-tb062117.php

matrix which underlies this material is made mostly of water and bonds closely with many types of surfaces, among which skin. Not only does it cover a wound perfectly, but it may deliver the drug as needed by gauging skin temperatures. It may even signal the depletion of the therapeutic agent in the dressing.[578]

Photo-responsive hydrogels – water-swollen polymeric materials that maintain a distinct three-dimensional structure[579] – have been for health scientists "because light is regarded as an ideal tool to control molecules or cell behaviour with high spatiotemporal precision and little invasiveness".[580] In a recent study, entirely protein-based light-sensitive hydrogels were created in order to deliver useful proteins to treat diseases.[581] Other methods include the use of light-sensitive hydrogel coated nanoparticles that convert near-infrared (NIR) into UV light. This induces the coating to release the protein/drug payload at the exact site.[582]

Irish researchers developed 'molecular cages' - metal-organic-organic polyhedra, or MOP, by their technical name – which efficiently convert molecules in chemical reactions and are able to hold various kinds of molecules serving diverse purposes. What makes the 'cages' special is their vast internal surface and thus great storage capacity (reportedly, one teaspoon has the storage capacity of a football field). The advantageous area-to-weight ratio and the ability to take on board various molecules, combined with their ability to react only when specific conditions are present, makes them ideally suited for bio-sensing and drug-delivery. For instance, they could pack drugs that are released only in a specific environment.[583]

3D printing was used at the University of Sheffield to create a powerful drug delivery system via printed 'micro-rockets' made of silk scaffolds. These hair-thin biodegradable devices are self-propelled through bio-fluids and useful as drug delivery devices.[584] Compared to alternative solutions – polystyrene beads, carbon nanotubes or metals covered in a catalyst layer – , these devices are more bio-friendly, simpler to produce, and cheaper.[585]

New- and nano-materials in targeted cancer therapy

Perhaps the most promising field of nano-materials research in health is that of cancer therapy. Modern cancer therapy methods are based on surgery, radiotherapy and chemotherapy, which is considered efficient for advanced stages[586], but also toxic and due to its effects on healthy tissues. Targeted cancer therapy via nanosized platforms aims to release drugs as

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578 https://newatlas.com/mit-smart-bandage-gel-band-aid-hydrogel-electronics/40808/
579 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2212614/
580 https://www.eurekalert.org/pub_releases/2017-07/hkuo-pph070617.php
581 https://www.eurekalert.org/pub_releases/2017-07/hkuo-pph070617.php
582 https://www.photonics.com/Article.aspx?AID=58246
583 https://www.eurekalert.org/pub_releases/2017-06/tcd-smg062917.php
584 https://inside3dprinting.com/news/3d-printed-micro-rockets-fueled-for-thrust-by-enzymes-may-soon-deliver-drugs-in-human-body/40559/
585 https://www.biosciencetechnology.com/news/2016/06/one-giant-leap-future-safe-drug-delivery
586 https://www.eurekalert.org/pub_releases/2016-03/bsp-dni030716.php

close as possible to the interior of a tumour, to intensify its odds of penetrating and killing diseased cells.[587] University of Texas at Austin engineers have developed a new type of nanoparticles, "connectosomes," equipped with a pathway that permits the creation of "a direct channel to deliver drugs to each individual cell".[588] This lowers the dose of chemotherapy and potentially reduces side-effects.

Another unique strategy involved the design of a special "suit" for nanoparticles which tricks the immune system into leaving it alone during its trip to the tumour and allowing it to deal with any hyaluronic acid it comes across when penetrating the tumour.[589]

Nanoparticles have also been used to increase the potency of drugs by combining them. Researchers at the Oregon State University's College of Pharmacy used nanoparticles that migrate to cancer cells – in this case, metastatic melanoma in the lymphatic system –, also reducing the body's resistance to the drug and improving the toxicity profile of chemotherapy. Specifically, the nanoparticles were used to deliver a combination of three anti-cancer agents which acted in synergy. The effect was more powerful than any one drug could achieve separately, while drug resistance and toxicity were minimized.[590] Other research groups focused their efforts on creating nanocapsules as novel vehicles to deliver the medication at the desired site.[591,592]

Finally, scientists developed hydrogel carrier micro-cubes embedded in an anti-cancer drug as a novel drug-delivery platform.[593] A new way to simultaneously test and find the correct therapy for cancer was developed with a new 3D printable hydrogel that mimics or models a tumour microenvironment to test different anti-cancer drugs on it.[594] (For uses outside health, see the separate 'Hydrogel' section.)

Implantable devices

A partnership at The University of Texas at San Antonio and the Department of Nanomedicine at Houston Methodist Research Institute developed a device that might have solved the problem of delivering an effective dose of medicine and clearing it from the body before it has unwanted effects. Unfortunately, the result of this trade-off is that drugs have to be taken periodically, at specific intervals. But the implantable capsule created by the team at the two Texas institutions uses around 5,000 nanochannels to

587 https://www.nanowerk.com/nanotechnology-news/newsid=43090.php
588 https://www.eurekalert.org/pub_releases/2016-10/uota-c100416.php
589 https://www.nanowerk.com/nanotechnology-news/newsid=43090.php
590 http://www.nanotech-now.com/news.cgi?story_id=52696
591 https://www.technology.org/2016/04/09/newly-patented-nist-technique-creates-precisely-sized-nanocontainers-useful-drug-delivery/
592 https://www.nanowerk.com/nanotechnology-news/newsid=42302.php
593 https://www.dddmag.com/news/2017/06/micron-sized-hydrogel-cubes-show-highly-efficient-delivery-potent-anti-cancer-drug?__hstc=20249895.a6e3728a7ff198b6fb98388d566fddf1.1505833936472.1505962152824.1506015912310.4&__hssc=20249895.10.1506015912310&__hsfp=2029326761
594 https://www.eurekalert.org/pub_releases/2016-03/quot-ict032116.php

closely regulate the rate of release of the therapeutic agent. In other words, the drug can be kept in the body without being activated and doing harm.[595]

A novel 6mm device made up of "a silicone sponge with magnetic carbonyl iron particles enclosed in a round polymer layer" was recently created so a drug can be injected into the device. The latter can subsequently be surgically implanted into the area being treated. The device is activated when a magnet is passed over the patient's skin, causing the sponge to deform and triggering the drug release into adjacent tissue through a small opening.[596]

Micromotors and other ingestible devices

American researchers at MIT and Brigham and Women's Hospital developed "an ingestible electronic device powered by stomach acid which can, in its turn, power sensors or drug delivery devices for long periods". This device may soon render ingestible batteries (or battery-powered solutions) obsolete, while also providing a less toxic solution.[597]

Nano-engineering researchers at the University of California-San Diego have successfully tested 'micromotors' in the delivery of a therapeutic agent against stomach bacterial infections. The micromotors have a diameter measuring half that of a human hair, can swim quickly in gastric acid while neutralizing it, and will release a payload of antibiotics that need the reduced acidity.[598]

Evading immune responses

Sometimes, widely used drug-delivery solutions generate immune responses that impede the development or testing of drugs. This is the case of Polyethylene glycol, or PEG, a polymer common in toothpaste, cosmetics, and a variety of drugs due to its thickening, softening, or moisturizing properties. One useful-side effect is its ability to delay an organism's clearing of drugs, thus increasing the latter's effects. Its ubiquity has also generated immune reactions, however, creating problems with PEG's use in drugs. A Duke University team altered PEG so that it evades recognition by the immune system, and successfully proved its ability to prolong several-fold the effects of a drug in mice.[599]

Genetically engineered devices

Genetically engineering red blood cells can now produce specific therapeutic proteins on their surface in order turn them into drug-delivery vehicles. Since mature red cells do not carry genetic material, this would also imply fewer safety risks compared to other gene therapies. Moreover, human red

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[595] https://www.technology.org/2016/12/03/study-describes-new-minimally-invasive-device-treat-cancer-illnesses/

[596] https://www.azonano.com/news.aspx?newsID=35382

[597] https://www.theengineer.co.uk/ingestible-sensor-is-powered-by-stomach-acid/

[598] http://www.digitaljournal.com/tech-and-science/science/micromotors-created-for-drug-delivery/article/500290

[599] https://www.genengnews.com/gen-news-highlights/modified-peg-drug-delivery-method-evades-immune-system-attack/81253483

blood cells circulate in the body over a period of almost four months, meaning they could possibly form the basis for long-term therapies.[600]

By linking the presence of antibodies to a DNA computer, a new method can detect “the presence of each antibody into a unique piece of DNA, whereby the DNA computer can choose on the basis of the presence of one or more antibodies if a drug delivery is needed”.[601] Taking into account that liposomes, with their fragile membrane, are commonly used as capsules for drug delivery, a research group developed an artificial cytoskeletal structure for cell models (liposomes or artificial cells) using DNA nanotechnology. It demonstrated that liposomes with the cytoskeletal structure were almost as strong as living cells.[602]

Long-term perspectives

Dramatically improving drug delivery will lead to drugs that reach their targets faster or better – and little or nothing beyond these targets. They will have fewer and lesser side effects and be de- and re-activated when necessary. Embedded in the right kind of device, they will also provide information to the patient and the therapist. Electronic ingestible pills or injectable devices will one day “enable novel ways of monitoring patient health and/or treating disease”.[603] When a sensor embedded into a transdermal drug-delivery device detects a significant change, like an abnormal variation in temperature, the device will release drugs as programmed, and precisely to the relevant location. It might also select a specific – the most adequate – drug from a reservoir of available therapeutic agents. Such treatment deployment will decrease the time spent in hospitals for patients suffering from cancer and chronic diseases and thus substantially cut the costs of therapy.

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[600] https://www.technologyreview.com/s/544281/turning-red-blood-cells-into-versatile-drug-carriers/
[601] https://www.eurekalert.org/pub_releases/2017-02/euot-dcb021517.php
[602] https://www.eurekalert.org/pub_releases/2017-06/tiot-foa062617.php
[603] https://interestingengineering.com/ingestible-health-tracker-powered-stomach-acids

4.5.7 Epigenetic Change Technologies

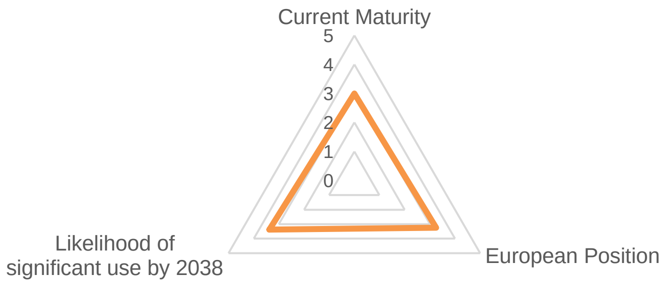

Figure 51: RIB Score of Epigenetic change technologies

Epigenetics refers to the heritable changes in gene function that do not entail changes in the DNA sequence. Epigenetics typically denotes chromosome alterations that affect gene expression, but "can also be used to describe any heritable phenotypic change that does not derive from a modification of the genome, such as prions."[604] Effects occurring at the level of cellular and phenotypic traits may be due to environmental factors or to the normal developmental program.

Although experiments suggest that some epigenetic changes are reversible, the term 'epigenetic' has "evolved to include any process that alters gene activity without changing the DNA sequence" and which leads to modifications that are transmissible to daughter cells.[605]

There is currently some evidence that many diseases and behaviours, as well as various health indicators, are linked with epigenetic mechanisms. The list includes many types of cancer, cognitive dysfunctions, as well as respiratory, cardiovascular, reproductive, autoimmune, and neurobehavioural diseases.[606]

Recent progress directions

Technologies deriving from the knowledge of drivers of epigenetic processes

Potential drivers of epigenetic processes for which there is current evidence involve, among others: heavy metals, pesticides, diesel exhaust, tobacco smoke, polycyclic aromatic hydrocarbons, hormones, radioactivity, viruses, bacteria, and basic nutrients. This, is turn, has driven recent effort into understanding epigenetics and epigenomics – the genome-wide distribution of epigenetic changes – as essential to "work related to many other topics requiring a thorough understanding of all aspects of genetics, such as stem

[604] https://www.whatisepigenetics.com/fundamentals/; https://en.wikipedia.org/wiki/Epigenetics
[605] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1392256/
[606] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1392256/

cells, cloning, aging, synthetic biology, species conservation, evolution, and agriculture."[607]

Epigenetic technologies for diagnosis

It is expected that a diagnostic method will be developed to assess the risk of developing cancer and intractable diseases by monitoring the epigenetic regulation of gene expression. Thus, epigenetic alterations are examined as predictive biomarkers and targets of anticancer therapy.[608]

Long-term perspectives

Fully understanding epigenetic mechanisms will help develop new diagnostics, biomarkers, and therapies. The application of epigenetic technologies may have, in the long run, unalterable, everlasting effects on the human being as such. It would affect human behaviour and lifestyle, and fields such as food, agriculture and others. Health in particular will be most strongly impacted.[609]

4.5.8 Genomic Vaccines

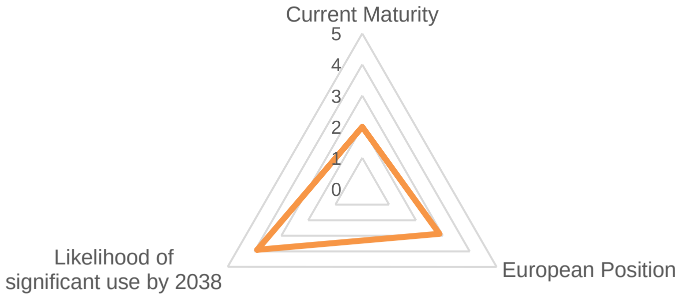

Figure 52: RIB Score of Genomic Vaccines

The typical vaccines deployed against infectious diseases use dead or weakened pathogens or subunits thereof – in the case of cancer vaccines, directly the relevant proteins – to activate the body's immune system.[610] The latter recognizes the foreign pathogen through the antigens it carries (in some modern vaccines, just the antigen is provided in fact) and hits back on the next encounter. Genomic vaccines, also known as "DNA vaccines", take a different approach: they inject genes, specifically DNA or RNA that encode for the needed protein, which then cause cells to produce the protein in question. This has many advantages: producing the genes should be easier than manufacturing the proteins (which need entire cell cultures); more proteins can be crammed in a single vaccine; and they can

[607] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1392256/
[608] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2633440/
[609] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5075137/
[610] http://onlinelibrary.wiley.com/doi/10.1016/j.febslet.2006.04.084/full

be adapted as the pathogen goes through the mutations we are familiar with from, for example, the annual flu.[611]

Recent progress directions

Advances in DNA sequencing and proteomics

Starting the engineering of vaccines from the genetic information, rather than from the offending bug, depends on acquiring this genetic information as easily and as quickly as possible. This has been made possible by new DNA sequencing technologies, which raise hopes that a thorough mapping of the structure of pathogens will be possible. Computational and experimental approaches have shed light on the latter's physiology as well as their genetic history.[612] Simultaneously, advances in proteomics[613] (the study of proteins) through mass-spectrometry and other techniques further contribute to the identification of vaccine candidates.

Clinical trials

While the idea of DNA vaccines itself is not new, with genomic vaccines having been explored and developed for at least two decades[614], dozens of products have recently entered clinical trials.[615] Some trials test the immunogenicity of the vaccines – their ability to generate the desired immune reaction – while others assess their safety. At least one trial is testing efficacy against Zika. Other vaccines undergoing tests target diverse pathogens such as avian influenza, Ebola, hepatitis C, HIV, and various cancers (breast, lung, prostate, pancreas).[616]

The first DNA vaccines have been (fully or conditionally) approved for use in animals, for example in equines and canines, and very recently in chicken.[617]

Better delivery pathways

One way to improve genomic vaccines is through better solutions for getting the genes into the target cells. Traditional solutions for DNA vaccine delivery include viral vehicles, but these may generate other problems, including toxicity. Gene guns, originally used to deliver foreign DNA to plant cells, have been adapted for use in humans, for example via gold and tungsten nanoparticles.[618] As for less high-tech solutions destined for areas where such vaccination devices are not available, nasal administration is being studied as an alternative.[619]

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611 https://www.scientificamerican.com/article/genomic-vaccines/
612 http://onlinelibrary.wiley.com/doi/10.1016/j.febslet.2006.04.084/full
613 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4713355
614 http://www.accessexcellence.org/WN/SUA06/genvax.html
615 http://www.who.int/biologicals/publications/trs/areas/vaccines/dna/en
616 https://www.scientificamerican.com/article/genomic-vaccines
617 https://www.prnewswire.com/news-releases/first-dna-vaccine-licensed-for-chickens-300554855.html ; http://www.mdpi.com/2076-393X/2/4/785/pdf
618 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4950349/
619 https://www.scientificamerican.com/article/genomic-vaccines

Passive immunization

Passive immunization is another promising avenue in DNA vaccination. It relies on the delivery of antibodies rather than antigens: after identifying the antibodies that shield particular individuals from a pathogen, a genomic vaccine would cause persons who are not so lucky to produce those antibodies themselves.[620]

Long-term perspectives

The great promise in DNA vaccination is vaccines that are very stable, easy to produce in great quantity, and quite simple to deliver. When genomic vaccines have become the norm, fewer immunizations are needed, as they last longer, cover a wide spectrum of pathogens, and are easily adaptable to new forms as the latter mutate. Last but hardly least, vaccines tackle some or many forms of cancer, raising a prospect of a world where cancer is a tractable problem.

4.5.9 Microbiome

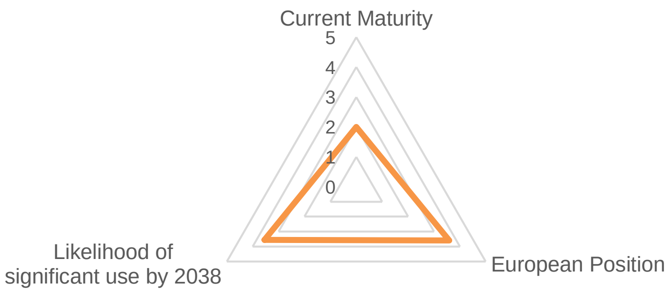

Figure 53: RIB Score of Microbiome

Microbes are everywhere, in our environment, on our skin and inside the human body. They form microbiomes that can have both beneficial and harmful effects on human health. The microbiome's composition can differ substantially from one person to another, under the impact of factors such as one's exposure to microbes in early life and one's diet.[621] Furthermore, different parts of the human body have distinct microbial populations. A variety of microbes lives in the mouth, the gut or the lungs.

Although the bacteria in the human body outnumber human cells by up to 10 to 1[622], a lot of medical research has been done on human cells, whereas our understanding of the microbial ecosystem is still in its early stages. Accumulating evidence suggests that microbiomes play a crucial role in

[620] https://www.discoveryscientificsolutions.com/item/83
[621] http://www.ascopost.com/News/48380
[622] https://www.sciencealert.com/how-many-bacteria-cells-outnumber-human-cells-microbiome-science

human health. Current developments target an improved understanding of microbiomes' biodiversity and of interactions with the human host.

Recent Progress directions

Gut bacteria and immunotherapy

While immunotherapy is increasingly effective for cancer patients, it still works selectively. The causes of that fact are yet unknown. Researchers have found a connection between the microbes in the human gut and the response to immunotherapy. In recent studies, "the ability of patients with advanced melanoma to respond to PD-1 immune checkpoint inhibitors depended on the presence of a diverse microbiome as well as specific bacterial species".[623]

If these findings are validated in bigger numbers across cancer types, they will have "significant implications for cancer prognosis and treatment".[624] Research will continue to better understand the relationship between the microbiome and immune responses, as well as on how the microbiome can be adjusted so that immunotherapy works for more patients.

Probiotic bacteria and depression

Researchers have identified a link between mood fluctuations and the microbiome. Understanding the mechanisms through which bacteria affect mood may provide a better grasp of the connection between the health and diversity of the gut microbiome and mental health.[625]

Recent results show that the amount of Lactobacilus in the gut[626], a probiotic bacterium found in live-cultures yogurt, can affect "the level of a metabolite in the blood called kynurenine, which has been shown to drive depression."[627]

Gut bacteria and gene activity

While we know that the composition of our gut bacteria has an effect on the activity of certain genes, it remains to be proven how this actually happens. A new study[628] has now revealed one potential way that 'good' gut bacteria could control our gene activity and potentially help prevent colorectal cancer. The study describes how chemical messages produced by the gut bacteria can set in motion a process that ultimately turns certain genes on and off.

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623 https://www.asco.org/about-asco/press-center/news-releases/response-cancer-immunotherapy-may-depend-gut-bacteria

624 https://cancertreatment.biz/highlights-from-the-2017-clinical-immuno-oncology-symposium/

625 https://news.virginia.edu/content/uva-reverses-depression-symptoms-mice-using-probiotics

626 https://www.sciencedaily.com/releases/2017/03/170308114709.htm

627 https://news.virginia.edu/content/uva-reverses-depression-symptoms-mice-using-probiotics

628 https://newatlas.com/gut-bacteria-alters-gene-activity/52923/

Microbiome intervention and insulin

A targeted microbiome intervention[629] accomplished through microencapsulated delayed-release niacin was proven to beneficially affect insulin sensitivity in humans. The researchers found that "reduced α-diversity and Bacteroidetes abundance in the microbiome of obese human subjects were associated with a low dietary niacin intake".[630]

Microbiome analysis and monitoring tools

As noted above, technologies are currently being developed to further the understanding of microbiome composition, diversity and action. A team of researchers have built and are now planning phase-two clinical trials for ingestible capsules[631] that can analyze the gas generated by the gut microbiome. The hope is to improve diagnosis of irritable bowel syndrome and to track treatment efficiency.

A new computational tool called MetaGen has been developed to simultaneously identify microbial species and estimate their abundance. The tool sequences "large amounts of DNA … extracted from environmental samples, instead of lab cell cultures. This allows researchers to identify novel microbial species and study their distribution variation in different samples."[632] This could eventually lead to a better understanding of chronic diseases such as diabetes and obesity through the detection of different microbe patterns.

Long-term perspectives

The microbiome has become a major interest for medical researchers. Understanding microbiomes in their variety and discovering new patterns promises an improved grasp of how and why diseases arise and why treatments work much better in some cases than in others. Big data and new computational tools will enable metagenomic analysis of microbiomes on a far larger scale. That knowledge will open the door to new applications.

Future progress in changing the composition of the gut microbiome will lead to enhanced systemic and anti-tumour immune responses. That, in turn, will lead to novel approaches aimed at increasing patients' responses to drugs.[633] In addition to future cancer treatment development, understanding the complicated makeup of the microbes inside our bodies will offer greater insight into the ways gut bacteria can directly alter the activity of our genes. This will enable future therapeutic options for both mental and physical conditions, such as depression, or prediabetes and type-2 diabetes.

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629 https://medicalxpress.com/news/2017-12-microbiome-intervention-niacin-aids-insulin.html
630 https://www.ncbi.nlm.nih.gov/pubmed/29212824
631 http://www.abc.net.au/news/science/2018-01-09/gas-sniffing-capsules-monitor-microbiome-gut-health-human-trials/9299358
632 https://news.uga.edu/microbiome-analysis-tool-will-help-scientists-understand-chronic-disease-environment/
633 https://www.medpagetoday.com/meetingcoverage/additionalmeetings/63388

4.5.10 Regenerative Medicine

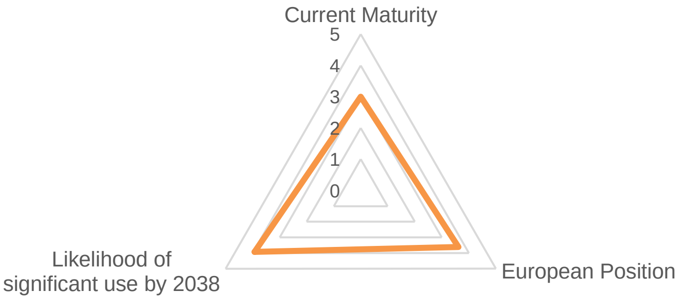

Figure 54: RIB Score of Regenerative medicine

Regenerative medicine is a new medical field which focuses on developing methods to repair or replace cells, tissues, and even entire organs that have been damaged by disease, congenital issues, or trauma. This is achieved by using tissue engineering, cellular therapies with stem cells, and artificially grown tissues or organs.[634],[635]

Recent progress directions

Cellular therapies

Israeli company Pluristem Therapies developed placental-derived adherent stromal cells (PLX-PAD) which can be used for stem cell therapy to increase the body's regeneration and healing capacity. These cells secrete cytokines, chemokines, and growth factors that enhance the damage repair processes. The PLX-PAD is being developed for ischemic tissue damage such as critical limb ischemia (CLI). The company also developed PLX-R18, the second product that aims at treating hematologic disorders and acute radiation syndrome (ARS).[636]

Tissue engineering and artificial tissues or organs

A discovery made by researchers at the Stanford University School of Medicine may open a whole new chapter in regenerative medicine. It enables the production of twelve types of cells starting from human embryonic stem cells, in just five to nine days. The researchers developed sets of chemical and biological signals that differentiate stem cells into twelve types, including heart muscle, cartilage and even bone cells.[637]

Researchers at the Nottingham and Uppsala universities and GE Healthcare discovered a way of mass producing human stem cells that can fix the issue

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[634] http://www.mirm.pitt.edu/about-us/what-is-regenerative-medicine/
[635] https://www.nature.com/subjects/regenerative-medicine
[636] https://www.genengnews.com/gen-news-highlights/pluristem-sosei-set-up-in-japan-to-commercialize-cell-therapy-for-cli/81253583
[637] https://www.sciencedaily.com/releases/2016/07/160714134746.htm

of high demand and high production costs. They discovered a human blood-derived protein called Inter-alpha inhibitor which improves the survival rate of stem cells in harsh environments, as well as cells' ability to attach to plastic culture flasks without prior treatment of the substrate. The researchers state that by combining Inter-alpha inhibitor with hydrogel technology they can enhance cell differentiation. They can also use it for disease modelling, to study rare conditions such as Multiple Osteochondroma.[638]

Scientists at the Laboratoire Adaptation Biologique et Vieillissement and the Centre de Recherche Cardiovasculaire de Paris developed a method for manipulating and building tissues at the same time by using magnetic force. They created cellular magnetic "Legos" that can be assembled by using magnetic nanoparticles and miniaturized magnets. By arranging and stimulating embryonic stem cells in which magnetic nanoparticles were previously incorporated, they could make the cells differentiate into cardiac cells by applying a mechanical movement resembling that of the heart.[639]

A team of researchers from Oxford and Bristol universities developed a new method for 3D printing tissues and organs by using human or animal cells. They printed the cells by isolating them in nanoliter droplets and then wrapping the droplets in a lipid coating. The cell-containing structures can be printed with greater resolution and improved cell survival rate compared to other current techniques.[640,641]

Long-term perspectives

In the future, regenerative medicine will focus on developing more reliable and cheaper methods for cell differentiation, cell culture, and tissue engineering. Tissue and organ creation will focus on improving resolution without the need for external supporting matrices.

638 https://www.eurekalert.org/pub_releases/2016-07/uon-bis071116.php
639 http://electronics360.globalspec.com/article/9790/magnetic-cellular-legos-are-key-to-the-future-of-regenerative-medicine
640 https://www.theengineer.co.uk/3d-printed-cells/
641 https://www.nanowerk.com/news2/gadget/newsid=47752.php

4.5.11 Reprogrammed Human Cells

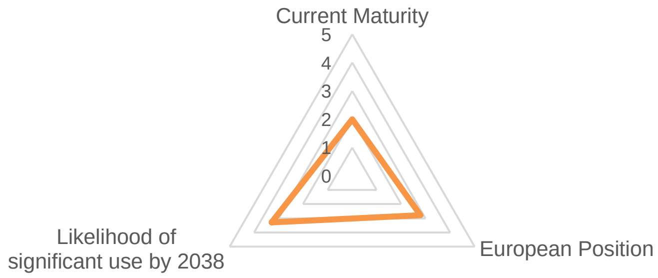

Figure 55: RIB Score of Reprogrammed human cells

This expression commonly refers to either genetically reprogrammed white blood cells of the immune system (macrophages, T cells) or to Induced pluripotent stem cells (iPSCs), which look and behave like embryonic stem (ES) cells. The "pluripotent" cells can develop into skin, nerve, muscle or practically any other cell type.

Recent progress directions

Nanoparticle-programmed immune cells to destroy cancer cells

It has been recently proven that "biodegradable nanoparticles can be used to genetically program immune cells, known as T cells, to recognize and clear or slow the progression of leukaemia in a mouse model -- while the immune cells are still inside the body."[642]

"The nanoparticles carry genes that code for chimeric antigen receptors (CARs), which are proteins designed by scientists to help immune cells target and destroy cancer. Once the immune cells undergo this molecular modification, they turn into an army of cancer serial killers."[643]

These new nanoparticles could be a step further from the current practice, eliminating the need for expensive and time consuming steps: "at present, it typically takes a couple of weeks to prepare these treatments: the T cells must be removed from the patient and genetically engineered and grown in special cell processing facilities before they are infused back into the patient".[644]

Educated macrophages to kill the Tuberculosis pathogen

The Bacillus Calmette–Guérin (BCG) vaccine is primarily used against tuberculosis (TB); its use resulted in generating TB-resistance strains. It has

[642] https://www.sciencedaily.com/releases/2017/04/170417114816.htm
[643] https://futurism.com/in-the-future-cells-reprogrammed-inside-our-bodies-will-fight-cancer-for-us
[644] https://www.sciencedaily.com/releases/2017/04/170417114816.htm

been "shown for the first time that when BCG is administered to mice in a way that enables access to the bone marrow, it can reprogram stem cells.

The innate immune system – via stem cells in the bone marrow – mobilizes macrophages, which are a type of white blood cell that swallows and kills invading bacteria like Mycobacterium tuberculosis (Mtb) that causes TB. However, Mtb disarms the killing program of macrophages and uses them as a kind of "sanctuary" to replicate and grow.

In order to boost the TB-killing efficiency of macrophages. the genomic pathways involved in triggering the enhanced innate immune response against TB had to be dissected, so that the "molecular mechanisms that were involved in the protective pathways" were captured and used to stimulate the stem cells to "proliferate and generate TB slaying macrophages"."[645]

Human Induced pluripotent stem cells (iPSCs) into muscle tissue

"Induced pluripotent stem cells (also known as iPS cells or iPSCs) are a type of pluripotent stem cell that can be generated directly from adult cells." [646]Like naturally-occurring stem cells found in embryos, they can become any other type of human cell.

A recent study aimed to investigate if human stem cells can effectively regenerate lost muscle tissue. To this end, mesodermal iPSC-derived progenitor (MiP) cells were injected into mouse models, resulting in increased heart volume and improved muscle structure compared to controls with untreated muscle degeneration. When a drug to down-regulate the MiPs was introduced, the beneficial effects were reversed, bolstering the evidence that human MiPs have regenerative potential. However, the viability of human-based cells to perform similarly has been largely untested.[647]

In a different endeavour, "the iPSCs were coaxed into becoming skeletal muscle cells, which grew into "functioning human skeletal muscle". The breakthrough was made possible by "unique cell culture conditions" in the lab, and a special 3-D scaffold which allowed the cells to grow "much faster and longer" than in previous attempts. The tissue contracted and reacted to external stimuli such as electrical pulses or chemical signals. Muscle fibres were also implanted into adult mice, where it survived and functioned for at least three weeks, though it was "not as strong" as natural tissue".[648]

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[645] https://www.technologynetworks.com/biopharma/news/innate-immune-cells-reprogrammed-to-fight-tuberculosis-296212
[646] https://en.wikipedia.org/wiki/Induced_pluripotent_stem_cell
[647] https://reliawire.com/stem-cells-muscular-dystrophy
[648] http://www.thehindu.com/todays-paper/tp-life/skeletal-muscle-tissue-grown-from-stem-cells/article22408199.ece

4.5.12 Targeting Cell Death Pathways

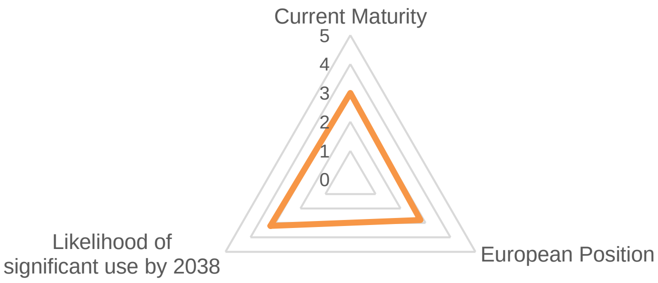

Figure 56: RIB Score of Targeting cell death pathways

Cancer is one of the leading causes of death worldwide. "In 2012, there were 14 million new cases of cancer and 8.2 million cancer-related deaths and these numbers are estimated to almost double in the next two decades".[649] Targeting key regulatory molecules that trigger mechanistically distinct types of cell death might prove, relative to current approaches, a more effective, less toxic and less resistance-prone approach to cancer therapy. Apoptosis, caspase-independent cell death, autophagy, and programmed necrosis are the main forms of programmed cell death (PCD) that are fundamental for maintaining cellular homeostasis and principal mechanisms of tumour suppression. New research has focused on amassing evidence of new pathways involved in cell death and on learning to control these mechanisms by targeting key molecules able to activate them synergistically. This approach has reached a new level in recent years and represents a promising strategy in cancer treatment.

Recent progress directions

Targeting different apoptotic pathways

Apoptosis[650] can be triggered through extrinsic[651] or intrinsic pathways.[652] A two-pronged attack strategy increases the potency of new anti-cancer drugs, as shown by using a combination of inhibitors[653] that prompt apoptosis. This approach[654] showed less toxicity and a much stronger anti-cancer effect than either agent alone.

[649] https://www.cancer.gov/about-cancer/understanding/statistics
[650] Apoptosis is a form of programmed cell death characterised by activation of specific enzymes called caspases.
[651] The extrinsic pathway mostly involves extracellular signals by binding to cell membrane receptors that trigger intracellular signalling leading to cell death.
[652] Intrinsic pathways involve internal cell signalling primarily through the mitochondria.
[653] https://www.eurekalert.org/pub_releases/2016-02/waeh-tai022716.php
[654] That is, inhibiting simultaneously IAPs, a group of proteins that mainly act on the intrinsic apoptotic pathway, and p38 mitogen-activated protein kinases that mediate extrinsic apoptosis.

Future therapies will target oncogenic proteins in the fight against cancer. Mito-priming[655] produces equal amounts of toxic and protective BCL-2[656] proteins in cells, which undergo apoptosis in a rapid and synchronous manner.[657]

Targeting Caspase Independent Cell Death (CICD)

"Current treatments such as chemotherapy, immunotherapy, and radiation, carry risks of side effects, and they frequently fail to kill all cancer cells, which leads to recurrence. The newer treatments work through apoptosis, the process of activating caspases to cause a programmed cell death."[658] However, cancer cells learn fast to resist this attack. Inducing CICD decreases the risk of side effects and recurrence and, as a plus, "cancer cells release inflammatory proteins which alert the immune system to ramp up the body's own natural defences. These then attack any remaining tumour cells missed during the initial treatment".[659]

Targeting cell cycle checkpoints and autophagy

Deregulation of cell cycle checkpoint proteins is a key hallmark of cancer, resulting in uncontrolled cellular growth and tumour formation. Some cell cycle checkpoint proteins inhibitors have shown anti-tumoral potential in pre-clinical and clinical studies. However, the inhibition of these proteins generated tumour cells that escaped inhibition by activating autophagy.[660] Researchers showed that "inhibition of cell cycle checkpoint proteins and autophagy pathways cooperate to induce sustained growth inhibition and senescence (ageing) in vitro and in vivo, in breast and other solid tumours. The study also discovered that combining the current therapy with autophagy inhibitors would result in using one-fifth of the dosage of the standard treatment, which could significantly reduce side effects associated with this therapy."[661]

Targeting anti-oxidative pathways to induce necrosis

Since cancer cells are notoriously power hungry, their metabolism must be altered to provide the additional fuel needed for them to survive, grow and spread.[662] Researchers showed that "the majority of these cancers rewire their metabolism in a way that leaves them addicted to the amino acid

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[655] https://health.economictimes.indiatimes.com/news/industry/new-way-to-kill-cancer-cells-get-them-addicted-to-drugs/50829854

[656] Bcl-2 is an oncogene that may inhibit apoptosis either by directly controlling the activation of caspases, or by disrupting the channels that allow pro-apoptotic factors from leaving the mitochondria.

[657] Cells in this state are very sensitive to inhibition of protective BCL-2 function by BH3-mimetics. BH3 mimetics bind to and inhibit anti-apoptotic Bcl-2 function in a manner similar to pro-apoptotic members of the family.

[658] https://futurism.com/a-new-cancer-treatment-could-be-more-effective-than-chemotherapy

[659] https://futurism.com/a-new-cancer-treatment-could-be-more-effective-than-chemotherapy/

[660] Autophagy allows the degradation and recycling of cellular components and represents a modality to thrive in nutrient deprived conditions.

[661] https://www.eurekalert.org/pub_releases/2017-06/uotm-ssb062317.php

[662] https://www.eurekalert.org/pub_releases/2016-02/du-ndk020316.php

cystine."[663] By depriving the cancer cells of cystine, a form of cell death called necrosis had been triggered in mouse models of the disease. Cystine is responsible for maintaining high levels of antioxidants; so cystine starvation induced cancer cells death by oxidative stress.[664] Cystine starvation could be a new strategy to overcome chemotherapy resistance, killing cells through a different mechanism.

Targeting new pathways to trigger cell death

Trying to reveal a new pathway to trigger cell death in cancer cells that have traditionally been considered very resistant to cell death, a group of researchers discovered a new compound in algae, coibamide A, that cuts off cancer cells' ability to communicate with blood vessels and other cells – which triggers the diseased cell's death. Coibamide A was capable of killing many types of cancer cells and may be able to fight cancer through a mechanism not yet seen in existing drugs.[665]

Long-term perspectives

Identifying new cell death mechanisms and learning to activate and control multiple cell death pathways synergistically is an emerging strategy that heralds a significant leap in the effectiveness of cancer therapy. It simultaneously promises to mitigate or solve some of the toxicity and resistance issues that plague this field.

[663] http://www.eurekalert.org/pub_releases/2016-02/du-ndk020316.php
[664] http://www.eurekalert.org/pub_releases/2016-02/du-ndk020316.php
[665] Is ALGAE the key to beating cancer? Potent compound 'KILLS two most aggressive forms of the disease'

Printing & Materials

4.6 Group 6. Printing & Materials

4.6.1 2D Materials

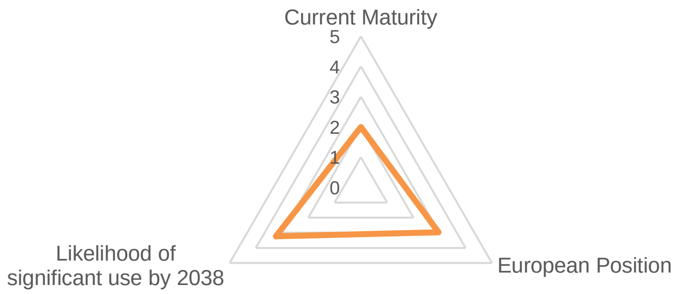

Figure 57: RIB Score of 2D Materials

Two-dimensional materials consist of atomically thin-layered materials. Since the first 2D material, graphene, was discovered in 2004, a large amount of research has been directed towards discovery, prediction and synthesis of other 2D materials (for example, transition metal dichalcogenides and Xenes have recently joined the family of 2D materials), due to their unusual characteristics. Stacking different combinations of 2D materials leads to new materials with novel properties. Current research focuses on the fundamental properties of such heterostructures, made of different layers of 2D materials, and their applications in photovoltaics, semiconductors, light harvesting devices and post-silicon electronics.

Recent progress directions

2D Semiconductors

Multiple stacked layers of 2D materials – known as heterostructures – create highly efficient optoelectronic devices with ultrafast electrical charge, which can be used in nano-circuits and are stronger than materials used in traditional circuits. Various heterostructures have been created using different 2D materials. For example, transition metal dichalcogenides (TMDs), atomically thin semiconductors containing a transition metal atom sandwiched between two chalcogen atoms offers a band gap, which differentiates it from graphene. This feature makes them promising candidates for semiconductor-based electronics and optoelectronics applications — even at room temperature".[666] Current research focuses on establishing optimal structure for the stacked layers of 2D materials for the fastest, most efficient transfer of electrical energy.[667]

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[666] https://www.nature.com/articles/nmat4854
[667] https://warwick.ac.uk/newsandevents/pressreleases/breakthrough_in_145wonder146/

2D Magnets

Scientists have created for the first time 2D magnets that are just one atom thick. They discovered an isolated 2D material with intrinsic magnetism that is highly robust. The revolutionary material is called chromium triiodide, or CrI3, and has "spins" of electrons which act like subatomic magnets that align in the same direction even without an external magnetic field. The 2D material even has new properties that have not been seen in multi-layered, 3D forms.[668]

Black phosphorus ink

Black phosphorus (BP) ink, a unique two-dimensional material similar to graphene, is compatible with conventional inkjet printing techniques. BP offers useful properties for electronic and optoelectronic devices, including a semiconductor band gap that can cover the visible and near-infrared region of the electromagnetic spectrum. "The functional ink, containing very small "flakes" of BP, allows printing, in highly uniform fashion on a wide variety of substrates including plastic, which remains stable for a prolonged period."[669]

Long-term perspectives

"The ability to understand and quantify how 2D material heterostructures work, and thus to create optimal semiconductor structures, paves the way for the development of highly efficient nano-circuitry, and smaller, flexible wearable gadgets. Solar power could also be revolutionised with heterostructures, as the atomically thin layers allow for strong absorption and efficient power conversion with a minimal amount of photovoltaic material."[670] Non-degradable ink printing compatible with conventional machines could enable high-volume manufacturing of next-generation laser and optoelectronic devices, and large arrays of 2D material-based light sensors.

"Computers that could solve the most mind-boggling scientific problems and unknown mysteries of deep space are one step closer after the discovery of minuscule 2D magnets. The invention announces an age of super slim computers that perform previously impossible experiments"[671], with potential applications in sensing and data storage.

[668] http://www.dailymail.co.uk/sciencetech/article-4583888/Scientists-create-world-s-2D-MAGNET.html
[669] https://phys.org/news/2017-08-breakthrough-ink-discovery-production-laser.html
[670] https://warwick.ac.uk/newsandevents/pressreleases/breakthrough_in_145wonder146
[671] https://futurism.com/scientists-have-finally-created-a-molecule-that-was-70-years-in-the-making

4.6.2 3D Printing of Food

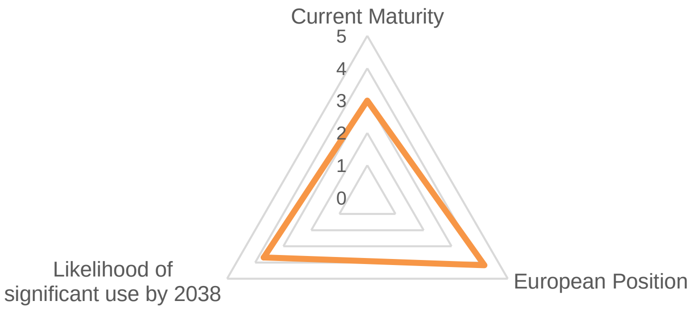

Figure 58: RIB Score of 3D Printing of Food

"Additive Manufacturing (AM) are the technologies that build 3D objects by adding layer-upon-layer of material, whether the material is plastic, metal, concrete, food or one day human tissue."[672] It is also called "3D printing". "Common to AM technologies is the use of a computer, 3D modelling software (Computer Aided Design or CAD), machine equipment and layering material. Once a CAD sketch is produced, the AM equipment reads in data from the CAD file and lays downs or adds successive layers (layer-upon-layer) of liquid, powder, sheet or other material to generate a 3D object."[673]

Many professional chefs are currently exploring the use of 3D printing for culinary purposes. While some efforts are being made to commercialize and make 3D printed edibles mainstream, for the moment it seems its true potential might lie either in gastronomic environments, where the professionals can play with and experiment with new 3D printed flavours and textures; or in medical ones, to help persons who have trouble eating.

Recent progress directions

Classic French onion soup with 3D printed twist

A well-known restaurant (Mélisse) has started serving an updated and reinvented French onion soup that features a tasty-looking 3D printed crouton. The crouton, which replaces the soup's traditional cheesy crouton topping, is 3D printed in a perforated cubic structure and is made out of an onion-flavoured powder. In developing the additively manufactured crouton, the cooks are aiming to use 3D printing technologies in the kitchen to offer their guests classic dishes with updated and innovative twists.[674] The 3D printed cubic croutons were also used as an edible vessel for a ball of onion petal-wrapped burrata, garnished with chive blossoms, chive, and a

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[672] http://additivemanufacturing.com/basics
[673] http://additivemanufacturing.com/basics
[674] http://www.3ders.org/articles/20170403-santa-monica-restaurant-melisse-reinvents-classic-french-onion-soup-with-3d-printed-twist.html

tempura onion sliver. When served, an oxtail broth is poured over the dish (in front of the customer) for extra effect.

The 3DP company is working with the Culinary Institute of America to explore the use of 3D printing for rethinking traditional artisan culinary methods (using a ChefJet Pro 3D food printer). It helped the winner of Top Chef season twelve to 3D print an intricate garnish for a Hawaiian-inspired dessert. It has even assisted a celebrity chef in making intricate and stunning wedding cakes.

3D food printing technology to help people with dysphagia

A Horizon 2020 project is developing new techniques of 3D food printing for people with chewing or swallowing difficulties. The background is that often people lose their appetite and are then in danger of malnutrition if they are forced to eat mashed meals every day. This concerns people in retirement homes as well as people at home. In the EU-funded project PERFORMANCE[675], attempts have been made to develop innovative food products - referred to as "smoothfood". Smoothfood tastes good and looks nice. Specific dietary requirements can be followed more easily and even additives can be used in a more appealing way. The idea is on its way to industrialization, and different menus are tested - from pizzas to burgers.

Long-term perspectives

More and more 3D printed food or ingredients are produced on time for direct use on the spot. Nearly all dishes can be imagined in a "printed" rather than cooked version. Even cake or cookies can be printed – without a bakery. The advantage is that missing ingredients do not need an additional shopping tour but can be printed out of a basic powder where and when needed; that is, fresh and in the amounts required. Furthermore, the quality and taste remain the same every time, there are no deviations.

[675] based on FP7, Project 312092, www.performance-fp7.eu; see also European Commission: Investing in European success, Horizon 2020. Research and Innovation to boost growth and jobs in Europe, Issue 2, 2015

4.6.3 3D Printing of Glass

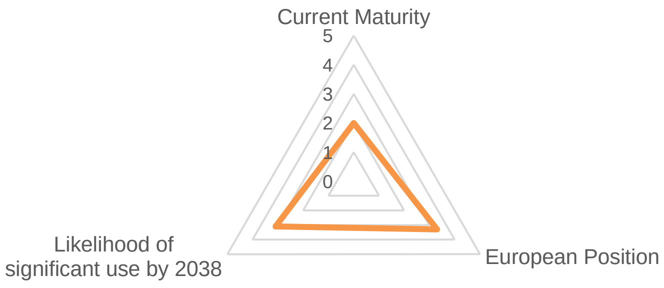

Figure 59: RIB Score of 3D Printing of Glass

Given the unique properties of glass, the prospect of manufacturing glass objects through rapid prototyping has always been very tempting. Recent advances in the 3D-printing of glass offer solutions for rapidly prototyping glass parts, while also holding various advantages over other types of more "traditional" 3D printing, such as those using powder materials. Because the technologies use molten glass, little post-processing would be needed once the print is complete.[676] However, because glass production still requires high-temperature ovens, it may take a while for the process to be available for the do-it-yourselfers.

Recent progress directions

Fused filament fabrication

Micron3DP and rivals at MIT have been exploring the fused filament fabrication (FFF) layering of molten glass. A layer thickness (100 microns) much finer than what was possible previously enables the printing of denser transparent structures. So far, objects are limited to sizes of up to 200 mm^3, not much taller, wider and longer than a typical pint glass. However, the companies above aim at a broad range of fields with their products, including security, architecture, and aerospace.[677] The additive manufacturing system is reportedly capable of printing in Soda-Lime and Borosilicate glass.

Stereolithography

In stereolithography, an ultraviolet laser is focused on a solution causing it to cure and harden at specific locations, thus building an object layer by layer. Creating customized structures from high-purity glasses is difficult due to the need for high temperatures and harsh chemicals. A novel technique overcomes this issue by using a free-flowing silica nano-composite called "liquid glass". Heat treatment produces optical-quality

[676] http://www.3ders.org/articles/20161209-micron3dp-introduces-high-res-glass-3d-printer-capable-of-100-micron-layer-thickness.html
[677] https://3dprintingindustry.com/news/micron3dp-mit-3d-printing-molten-glass-100702/

fused silica glass structures. These structures are smooth and transparent, with features as fine as a few tens of micrometres. The technique is advantageous for optical manufacturers, as it allows the refractive index of the glass to be controlled. This means glass with varying refractive indices can be created into a single flat optic instead of a complex-shaped optic.

By adding metal salt, coloured glasses can be created.[678]

Long-term perspectives

The ability to manipulate glass is bursting with potential, as glass is an essential high-performance material, because of its unparalleled optical transparency, excellent mechanical, chemical and thermal resistance, and thermal and electrical insulating properties. These outstanding features recommend its use in applications in biotechnology (microfluidic devices), optics, photonics, data transmission.

The advancements in 3D printing of glass pave the way for creating laboratory-grade equipment but also for bringing production in-house, so that technicians can get a more proximate finish. Artistic expression could also reach new bounds in experimentation with complex and geometric structures."[679]

4.6.4 3D Printing of Large Objects

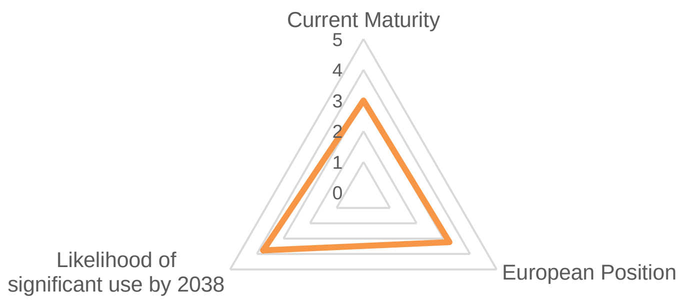

Figure 60: RIB Score of 3D Printing of Large Objects

Additive manufacturing (AM) or 3D printing[680] – i.e. the set of technologies that build 3D objects by adding layer-upon-layer of material[681] – is no longer limited to small objects. More and more large objects are fabricated by 3D printing directly (whole object), by gluing larger objects, or by inserting

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678 https://www.nanowerk.com/news2/gadget/newsid=46465.php; http://newatlas.com/glass-3d-printing/49157/; the process is published in Nature ("Three-dimensional printing of transparent fused silica glass") and also presented at the Hanover Fair.

679 https://3dprintingindustry.com/news/micron3dp-mit-3d-printing-molten-glass-100702/

680 The term AM encompasses many technologies including subsets like 3D Printing, Rapid Prototyping (RP), Direct Digital Manufacturing (DDM), layered manufacturing and additive fabrication.

681 http://additivemanufacturing.com/basics

rather large parts into an object. Different materials can be used, ranging from plastic to metal to, one day, even human tissue.

One of 3D printing technology's greatest advantages when it comes to product design, big or small, is the ability of manufacturers to control every single aspect of the object's physical form – the shape of the object can be optimized by a special software.[682] With new virtual reality techniques, the progress of a particular print job can be illustrated. For example, production plants will be able to use it to monitor their 3D printing work in real-time, remotely, from any location.[683]

Recent progress directions

Aerospace: Boeing and Siemens

With Boeing's 737 MAX having recently made its maiden flight, the reputation of 3D printing within the aerospace industry seems to be soaring as well. The test flight took place over 2 hours and 47 minutes, free of difficulties. The 737 MAX is powered by a pair of CFM International LEAP-1B engines, packed with futuristic parts such as nickel-alloy compressor blades grown from a single crystal, lightweight ceramic matrix composites (CMCs) – and 19 3D-printed fuel nozzles. According to the company, the 3D-printed fuel nozzles, made from a nickel cobalt alloy, could not have been made using any other manufacturing process. The GM-made nozzles are 25 % lighter than their predecessors, enable more intricate cooling pathways and support ligaments, reportedly resulting in a 5X increase in durability compared with conventionally manufactured alternatives. They are also a great deal simpler: the number of subparts decreased from 18 to 1.[684]

Besides airplane components, car parts can also be produced by 3D printing[685], e.g. to increase fuel efficiency while cutting noise and CO_2 emissions. Engineers from electronics manufacturer Siemens completed prototypes on a 3D-printing spider robot that could be used to build entire car bodies and airplane fuselages. Instead of relying on human workers for large-scale projects, companies could use the robots to cut costs and speed up production. The machines' big, longing eyes (actually, laser scanning the environment) more closely resemble WALL-E than actual spiders – a design consideration crucial in the development.[686] Robots work in tandem according to their specific programs. When one robot's battery is running low after about two hours, it will alert a nearby team member who will charge it back up. Right now, the only material the system can handle is a mixture of corn-starch and sugarcane known as poly lactic acid, one of two simple plastics that allow for rudimentary print jobs. The next phase will

[682] http://www.3ders.org/articles/20160211-shape-optimization-3d-printing-method-produces-unlikely-but-not-impossible-3d-printed-objects.html
[683] http://www.3ders.org/articles/20170407-eurecat-unveils-new-3d-printer-featuring-real-time-virtual-reality-monitoring.html
[684] http://www.3ders.org/articles/20160131-boeing-737-max-leap-1b-engines-with-3d-printed-fuel-nozzles-made-its-maiden-flight.html
[685] https://www.eurekalert.org/pub_releases/2017-01/uon-afc011917.php
[686] https://www.businessinsider.com/siemens-3d-printing-spiders-could-build-ships-and-planes-2016-4

focus on 3D-printing with materials "that will satisfy the industrial and scientific needs of Siemens".

Energy: 3D-printed turbine prototype

A prototype run-of-the-river turbine is being developed, capable of generating electricity with minimal environmental impact.[687] The water turbine system, called Volturnus, operates based on a horizontal design that generates energy while also deflecting river debris such as rocks, plants, or logs. The V-Pod turbines sit below the surface in flowing bodies of water, subtly and silently capturing enough energy to support as many as 40 households. Literally, within a day, purified water is available on spot for the first time; the same goes for electricity for cell phone towers and the Internet, computers, refrigerators and LED lighting.

Tyres

A China-based manufacturer of automotive tires has teamed up with the Beijing University of Chemical Technology to develop 3D-printed tires made from thermoplastic polyurethane (TPU) rather than rubber. The partners said they had successfully produced and tested a prototype of the innovative additively manufactured tire.[688]

Brick-laying 3D Printer Robot

"Within the construction field, Fastbrick Robotics has come up with a less traditional 3D printing material with their innovative brick-laying robot. The robot, called the Hadrian 105 robot, is capable of laying bricks at a much faster pace than human bricklayers and functions similarly to a large-scale robotic 3D printer."[689] "While the robot is large, it has been designed to be transported and function from the back of a truck, making it easy to bring on to construction sites. The fully-automated bricklaying 3D printer also works with an adhesive glue rather than traditional mortar to maximise the speed of the build and the strength and thermal efficiency of the finished structure, while at the same time minimising the impact of weather condition in the construction process."[690]

3D printed pedestrian bridge made of concrete

"In 2016, the city of Alcobendas in Spain "unveiled the first ever 3D printed pedestrian bridge made entirely of micro-refined concrete. Measuring 12 metres in length and 1.75 metres in width, the structure represents a milestone in civil engineering, an industry, which up until now has been

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[687] http://www.3ders.org/articles/20160317-verterra-energys-3d-printed-turbine-prototype-shows-promise-for-sustainable-hydropower.html
[688] http://www.3ders.org/articles/20170714-linglong-tire-successfully-tests-chinas-first-3d-printed-tpu-tire.html
[689] http://www.3ders.org/articles/20160728-this-brick-laying-3d-printer-robot-can-build-a-house-four-times-faster-than-a-human-bricklayer.html
[690] http://www.3ders.org/articles/20160728-this-brick-laying-3d-printer-robot-can-build-a-house-four-times-faster-than-a-human-bricklayer.html

reluctant to use additive manufacturing."[691] "Thanks to recycling raw materials during the manufacturing process, as well as the overall sustainability of 3D printing, the bridge has incurred virtually no economic cost to the city. The municipality reports that the amount of waste, resources, and energy typically needed to realize concrete structures has been vastly reduced. Other advantages to 3D printing concrete in large scale include the versatility and freedom of building structural elements without moulds, overall flexibility and adaptability to any shape, and an incredibly sturdy architectural design capable of withstanding great resistance."[692] It is hoped the bridge will open up more opportunities for using 3D printing in civil engineering.

Long-term perspectives

Not only small equipment but also large objects or the major components of large objects will be 3D printed in the near future. First applications in the engines of a Boeing 747 have proven feasibility. Should the engine prove itself a success in the long term, 3D printed engine components could soon become commonplace. The same for turbines in wind generation facilities.

Tyres and other large-scale objects from daily life can also be manufactured in an additive way – at the location where they are needed and with the functionality that is required.

Even complete buildings can be raised in a very fast way by a 3D printing robot using glue instead of mortar. Bridges can be built with 3D printing. Other possibilities are to split the work to many printers, robots or "spiders".

The large objects (and their functions) are optimized by a special design software that can adapt the material and functionality to the requirements of the environment. With virtual reality the prototypes can be "seen" and "tested" – this is much more than classical Rapid Prototyping.

[691]http://www.3ders.org/articles/20161214-spain-unveils-worlds-first-3d-printed-pedestrian-bridge-made-of-concrete.html
[692]http://www.3ders.org/articles/20161214-spain-unveils-worlds-first-3d-printed-pedestrian-bridge-made-of-concrete.html

4.6.5 4D Printing

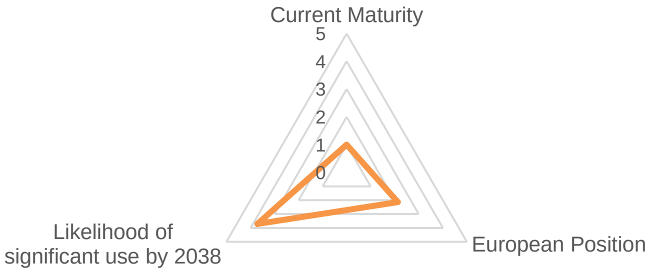

Figure 61: RIB Score of 4D Printing

4D printing is conventional 3D printing (the latter term is often used synonymously with "additive manufacturing"[693]) combined with the additional element of time and, sometimes, movement. 4D-printed objects can change shape or self-assemble over time if exposed to a stimulus – heat, light, water, magnetic field or other form of energy – that activates the process of change.

Researchers around the globe have been developing various "intelligent", programmable materials that can change their geometric configuration in a controllable way, in a reversible or irreversible manner. Among the best-known "smart materials" are hydrogels and shape memory polymers (SMP). More recently, "multi-material multi-method [m4] 3D printers" have been making products from a variety of materials including hydrogels, conductive inks, elastomers, and shape memory polymers. Four different printing technologies are used in different combinations: aerosol, inkjet, direct ink write, and fused deposition modelling.[694]

Recent progress directions

Exposure to heat

Researchers have created 3D printed objects that permanently transform with heat. The 4D printing process consists of 3D printing layers of shape memory polymers (SMPs), with each layer programmed to react differently when exposed to heat. SMPs are intelligent polymers programmed to "remember" their original shape and to shape-shift into a pre-determined

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[693] Additive Manufacturing (AM) describes the technologies that build 3D objects by adding layer-upon-layer of material, whether the material is plastic, metal, concrete or one day even human tissue. AM is often used synonymously to '3D printing'. Common to AM technologies is the use of a computer, 3D modelling software (Computer Aided Design or CAD), machine equipment and layering material. Once a CAD sketch is produced, the AM equipment reads in data from the CAD file and lays downs or adds successive layers of liquid, powder, sheet material or other, in a layer-upon-layer fashion to fabricate a 3D object.

[694] http://institute.swissre.com/research/risk_dialogue/magazine/3D_printing/4D_printing_Producing_programmable_materials.html

form when exposed to heat. Polymers change their form because of the thermomechanical properties of the resins they are made of.

In this process, "computational simulations are used to design composite components where the stiff material has a shape and size that prevents the release of the programmed internal stress from the soft material after 3D printing. At room temperature, the composite materials have one material that is soft but can be programmed to contain internal stress, while the other material is stiff. Upon heating, the stiff material softens and allows the soft material to release its stress; this results in a change – often dramatic – in the product shape."[695]

Recently, a ground-breaking advancement in materials research has been achieved by successfully developing the world's first-ever 4D printing for ceramics, which are mechanically robust and can have complex shapes. The breakthrough consists of a novel "ceramic ink" which combines polymers and ceramic nanoparticles. "The 3D-printed ceramic precursors printed with this ink are soft and can be stretched three times beyond their initial length. These flexible and stretchable ceramic precursors allow complex shapes, such as origami folding. With proper heat treatment, ceramics with complex shapes can be made."[696]

Water contact

Hydrogels are a precious material for 4D printing as they can swell by 150 % when activated by moisture. They are usually coupled with a rigid material that encodes the geometric information to generate transformations (fold, curl, twist, stretch, shrink, etc.). This combination comprises the information and the activation energy that allows going from one shape to another.

Mimicking the diversity of shape transformations that plant organs (e.g. leaves, flowers) undergo in reaction to environmental stimuli such as humidity or temperature, 4D-printed hydrogel composites have been developed which change shape when immersed in water. The hydrogel composite ink contains aligned cellulose fibrils which are programmed to contain precise, localized swelling. "The anisotropic nature of the cellulose fibrils gives rise to varied directional properties that can be predicted and controlled. Just like wood, which splits more easily along the grain than across it, when it is immersed in water the hydrogel-cellulose fibril ink undergoes differential swelling along and orthogonal to the printing path".[697]

Light as a stimuli

Research shows it's possible to program the self-folding of two-dimensional polymer sheets into 3D objects in a sequential way, using external light as an activating energy. Polymer sheets coated with printed ink "discriminately absorbs light on the basis of the wavelength of the light and the colour of

[695] http://www.3ders.org/articles/20170413-new-4d-printing-technique-allows-for-3d-prints-to-transform-permanently-when-exposed-to-heat.html
[696] https://www.sciencedaily.com/releases/2018/08/180818115803.htm
[697] https://news.harvard.edu/gazette/story/2016/01/4d-printed-structure-changes-shape-when-placed-in-water/

the ink that defines the hinge about which the sheet folds. The absorbed light progressively warms up the underlying polymer, which causes relief of strain to induce folding”. Such shape programming could have various uses, including reconfigurable electronics, actuators, sensors, implantable devices, smart packaging, and deployable structures.[698]

Long-term perspectives

The health industry would be strongly impacted by shape memory polymers: for example, drug devices meant to be inserted inside the body will be programmed to work upon the heat changes of the body, releasing the needed medicine when they notice body temperature changes. 4D printing could also be used for tissue engineering, self-assembling human-scale biomaterials, design of nanoparticles, and nanorobots for chemotherapy.[699]

In the energy industry, shape memory materials could be used in the future on solar panels, acting as sensors for detecting the sun and auto-rotating accordingly.

4D printing could prove useful in building smart infrastructure as well. Imagine “pipes of a plumbing system that would dynamically change their diameter in response to the flow rate and water demand”. Or, “bridges, shelters or any kind of installations, as they would build up themselves or repair themselves in case of weather damage.”[700]

4.6.6 Hydrogels

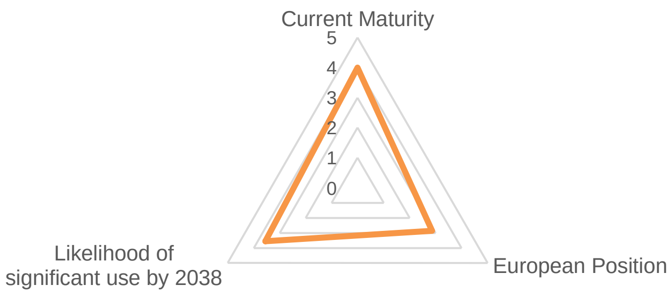

Figure 62: RIB Score of Hydrogels

Hydrogels are natural or synthetic polymeric networks capable of holding large amounts of water (over 90%). Owing to their water content, they exhibit “a degree of flexibility comparable to that of natural tissues”.[701] Hydrogels often serve as passive or active holders of molecular or cellular

[698] https://www.ncbi.nlm.nih.gov/pubmed/28275736
[699] https://hpmegatrends.com/4d-printing-and-a-world-of-smart-materials-ab91028cbd12
[700] https://www.sculpteo.com/blog/2017/10/25/4d-printing-a-technology-coming-from-the-future/
[701] https://books.google.hu/books?id=QdzTDgAAQBAJ&printsec=frontcover#v=onepage&q&f=false

species[702], which renders them capable of summing up "the dynamic signalling involved in biological processes, such as cell/tissue development".[703] Due to their biomimetism, hydrogels are among "the leading materials for biomedical applications such as drug delivery and stem cell therapy".[704,705]

In general, creating hydrogels requires chemical reactions and interactions among a set of precursor materials. These reactions take place via single or "multiple-step procedures involving the synthesis of polymer molecules having reactive groups and their cross-linking".[706] There are many mixes of methods to produce hydrogels.[707,708]

Recent progress directions

Regenerative medicine

Organ and tissue loss due to age, disease, damage, or congenital defects drives the progress of therapies that regenerate, repair or replace tissues (both structurally and functionally). Regenerative medicine, an interdisciplinary field that mixes engineering (e.g. tissue engineering) and life science relies on the human body's inborn healing response, which is stimulated to promote healing. Hydrogels can effectively replicate the natural, extracellular matrix that surrounds cells within the human body. This makes hydrogels useful as scaffolding for a variety of human tissues.[709]

In the development of hydrogels, natural polymers are more attractive than synthetic ones due to their functional properties, such as good hydrophilicity (better absorption of water), biodegradation and biocompatibility in the human body. As a result, hydrogels have also been used as tissue-like structures[710], such as load-bearing artificial ligaments and tendons[711], or for 3D printed organs.[712] The expandable polymeric matrix that creates hydrogels has shown a huge potential for the advanced engineering of

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702 https://www.biopharma-reporter.com/Article/2017/06/22/Cells-held-three-times-as-long-in-delayed-crosslinking-microgel-tech?utm_source=RSS_text_news&utm_medium=RSS_feed&utm_campaign=RSS_Text_News

703 https://www.eurekalert.org/pub_releases/2017-07/hkuo-pph070617.php

704 http://genengnews.com/gen-news-highlights/

705 https://www.dddmag.com/news/2017/06/micron-sized-hydrogel-cubes-show-highly-efficient-delivery-potent-anti-cancer-drug?__hstc=20249895.a6e3728a7ff198b6fb98388d566fddf1.1505833936472.1505962152824.1506015912310.4&__hssc=20249895.10.1506015912310&__hsfp=2029326761

706 https://www.sciencedirect.com/science/article/pii/S2090123213000969

707 http://feeds.feedblitz.com/~/236463122/0/gizmag~Stanfords-new-nontoxic-hydrogels-are-made-to-scale/

708 https://www.princeton.edu/news/2017/12/05/spaghetti-jumble-microfibers-and-water-comes-promising-new-material

709 http://www.iflscience.com/health-and-medicine/cotton-candy-machine-used-create-tiny-artificial-blood-vessels/

710 https://www.sciencedaily.com/releases/2016/04/160429105529.htm

711 http://www.impactlab.net/2017/03/03/fiber-reinforced-hydrogel-is-5-times-stronger-than-steel/

712 https://www.techradar.com/news/world-of-tech/lost-an-ear-this-3d-printer-will-make-you-a-new-one-1315047?src=rss&attr=all

elastic tissues, such as skin[713] and vasculature.[714] For example, researchers created thin channels made of hydrogels, which averaged in diameter around 35 micrometres, roughly the size of a natural capillary.[715]

Stem cells are the foundation for all tissues and organs and mediate disease evolution, development, and tissue repair processes. Their indefinite self-renewal and their ability to differentiate into other cell types makes them key to regenerative medicine. Many degenerative diseases result from changes of tissue stiffness, which can alter the behaviour of cells. A research group discovered an innovative and less costly approach of growing human stem cells. By means of hydrogels with a gradient that mimics the stiffness of human body tissues, researchers obtained positive outcomes for the growth of stem cells, with the goal of controlling tissue stiffness.[716]

Another groundbreaking way to grow stem cells was recently developed by inserting a butterfly gene into silkworms. The gene turns the silk into a material that can be used to make functional cell-stem growing hydrogels.[717] Inspired by the glue produced by a slug, the hydrogel can support the growth of stem cells without the risk of contamination from prions or viruses.

Additionally, the material demonstrated both high adhesion and strain dissipation, significantly greater than other medical adhesives and comparable to the body's own resilient cartilage.[718] This renders the material useful for wound healing. In fact, another research group fabricated a hydrogel dressing that provides moisture to a wound, can accelerate aspects of healing, and cool the wound down. To add anti-infective properties, they embedded into this dressing an antibacterial substance derived from the shells of crustaceans.[719]

Soft robots

Soft robotics represents a bioinspired evolution of traditional robotics. Soft robots are made from materials similar to those in living organisms, and one goal is to endow them with new movement capabilities, similar to those of invertebrates such as worms and octopi. The latter would permit adaptive and flexible behaviours in unpredictable environments. One driver of soft robotics research has been medical science, interested in the ability to deliver treatments to specific areas of the body or to carry out certain types of repairs or treatment without causing additional trauma.

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713 https://www.nanowerk.com/news2/biotech/newsid=45379.php

714 http://www.iflscience.com/health-and-medicine/cotton-candy-machine-used-create-tiny-artificial-blood-vessels/

715 http://www.iflscience.com/health-and-medicine/cotton-candy-machine-used-create-tiny-artificial-blood-vessels/

716 https://www.technology.org/2017/05/17/researchers-uncover-new-way-of-growing-stem-cells/

717 https://www.asianscientist.com/2017/06/in-the-lab/silkworm-butterfly-gene-silencing/

718 https://www.eurekalert.org/pub_releases/2017-07/wifb-sww072417.php

719 https://genengnews.com/gen-news-highlights/

The high water content of hydrogels makes them a suitable candidate for use in the human body[720], among others in the form of skin responsive to stimuli. "Layers of transparent hydrogel electrodes sandwiching an insulating elastomer sheet have been used to create an electroluminescent material that stretches to more than six times its original size while emitting light."[721] The crawling soft robot's layered panels make up the light-up skin (top layers) and the pneumatic actuators (bottom layers). The chambers alternately inflate and deflate, creating an undulating, "walking" motion.[722] Other soft robot "muscles" were created by using a hydrogel made of a synthesized protein, similar to that which makes up the jaw of a sea worm. This gives it structural stability and impressive mechanical performance.[723]

One of the challenges of cancer treatment has been to deliver drugs directly to the diseased site without impacting surrounding healthy tissue. Microbots made of biocompatible polymers and hydrogels have partly overcome this challenge. They were inspired by the shape of Trypanosoma brucei microbe and can be controlled using an electromagnetic field capable of altering their shape in response to the temperature of their surroundings.[724]

New robots have been created out of hollow, interlocking hydrogel cubes, arranged in such a way that when pumped full of water they curl up or stretch out. These fin-like devices flap back and forth like an articulated appendage that simulates a kicking action and a hand-shaped gripper. In their experiments, researchers found that their hydrogel robots could endure up to 1,000 cycles of repeated use without rupturing. These qualities, together with their soft hydrogel parts, make them suitable candidates for use in the human body's tissue and organs.[725]

Drug delivery

Drug delivery covers the technologies or systems used to bring a pharmaceutical complex in the body of humans or animals in order to achieve a therapeutic effect. Drug delivery is a matter of a drug's chemical construction, quantity and duration, but it may also involve medical devices, drug-device combination products, and even routes and type of drug administration (e.g. local or systemic).

Photo-responsive hydrogels are particularly interesting to material scientists working in the field of health "because light is regarded as an ideal tool to control molecules or cell behaviour with high spatiotemporal precision and little invasiveness".[726] So, in a recent research, entirely protein-based light-sensitive hydrogels were created in order to deliver useful proteins to treat diseases.[727] Other methods include the use of light-sensitive hydrogel coated

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[720] https://newatlas.com/mit-hydrogel-robot-fish/47683/

[721] http://news.cornell.edu/stories/2016/03/light-skin-stretches-boundaries-robotics

[722] http://www.futurity.org/glowing-robot-skin-1115352-2/

[723] https://www.nanowerk.com/nanotechnology-news/newsid=46544.php

[724] https://www.extremetech.com/extreme/232407-new-shapeshifting-medical-microbots-inspired-by-germs

[725] https://newatlas.com/mit-hydrogel-robot-fish/47683/

[726] https://www.eurekalert.org/pub_releases/2017-07/hkuo-pph070617.php

[727] https://www.eurekalert.org/pub_releases/2017-07/hkuo-pph070617.php

nanoparticles that convert near-infrared (NIR) into UV light. This induces the coating to release the protein/drug payload at the exact site.[728]

Many oncological treatments have substantial downsides, such as not mixing with water and as such having a limited solubility in blood; or lacking selectivity to cancer cells.[729] To tackle some of ordinary drugs' drawbacks, researchers developed hydrogel carrier micro-cubes embedded in an anti-cancer drug as a novel drug-delivery platform.[730]

A new way to simultaneously test and find the correct therapy for cancer was recently discovered. Researchers have developed a new 3D printable hydrogel that mimics or models a tumour microenvironment to test different anti-cancer drugs on it.[731]

Biothreat detection devices

Different contaminants (bacteria, fungi, drugs, etc.) found on surfaces and in soil, water or air represent a critical public health concern. Portable, compact, small and versatile devices that detect contaminants relatively rapidly may save time and lives. Detecting contaminated water can take days, putting humans and animals at serious risk. However, a newly developed E. coli detection system will identify "the bacteria right at the water source, before people start drinking the water. The device uses a porous hydrogel matrix that cages specific enzymatic substrates which release certain enzymes in E. coli cells."[732] When E. coli are present, the enzymes react and immediately turn red. When the water test is complete, a mobile app which has already been developed by the team can immediately deliver the results.[733]

A tree-shaped "living tattoo" – "a thin, transparent patch patterned with live bacteria cells"[734] – was created via 3D printing. The printer uses an ink which is a mix of from genetically engineered living cells and a hydrogel. "The branches of the patch are lined with cells sensitive to different chemical or molecular compounds. When the patch is placed on skin that was exposed to these compounds, corresponding regions of the tree light up in response. These cells can sense environmental chemicals and pollutants, as well as changes in pH and temperature".[735]

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[728] https://www.photonics.com/Article.aspx?AID=58246

[729] https://www.uab.edu/news/research/item/8453-micron-sized-hydrogel-cubes-show-highly-efficient-delivery-of-a-potent-anti-cancer-drug

[730] https://www.dddmag.com/news/2017/06/micron-sized-hydrogel-cubes-show-highly-efficient-delivery-potent-anti-cancer-drug?__hstc=20249895.a6e3728a7ff198b6fb98388d566fddf1.1505833936472.1505962152824.1506015912310.4&__hssc=20249895.10.1506015912310&__hsfp=2029326761

[731] https://www.eurekalert.org/pub_releases/2016-03/quot-ict032116.php

[732] http://news.yorku.ca/2016/05/17/york-u-invention-promises-rapid-detection-of-e-coli-in-water/

[733] https://www.nanowerk.com/nanotechnology-news/newsid=43425.php

[734] http://news.mit.edu/2017/engineers-3-d-print-living-tattoo-1205

[735] https://www.laboratoryequipment.com/news/2017/12/engineers-3-d-print-living-tattoo

Optogenetics

Optogenetics is a method that uses light to control molecular events in living cells or organisms. It is based on the use of genetically-programmed proteins that can change the behaviour of cells in the presence of light. Short pulses of light directed at targeted tissues can now be delivered by using needle-like fibres made from hydrogel. The needles are fully biocompatible and mimic the consistency of the brain.[736]

Long-term perspectives

Hydrogels hold great promise in the medical field. In the near future, hydrogels will provide the basis for first-aid kits enabling us to literally patch ourselves up. In more technologically sophisticated developments, curative soft robots will have access to the cells of living organisms, where they will perform surgeries at microscopic and submicroscopic level. 3D-printed hydrogels in the form of a patient's tumour will provide testing grounds for the correct therapy to target that particular tumour – a radical step towards personalized cancer treatment.

As interactions with robots will likely be more common, their capacity to manage our emotional behaviour and thus to form emotional connections with humans will be important. One way to enhance communication with robots is if the latter change their colour in response to our mood, if they detect an illness, or for other reasons. Stimuli-responsive hydrogels integrated in mobile phone screens will enable interactive displays to "sense environmental chemicals and pollutants, or changes in pH and temperature".[737] Results will be immediately available from a phone app.

4.6.7 Metamaterials

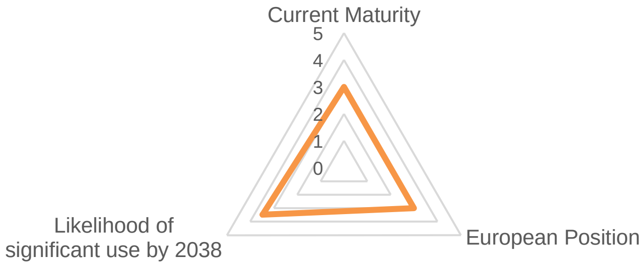

Figure 63: RIB Score of Metamaterials

Metamaterials are man-made assemblies composed of multiple individual nanoelements. These nanoelements are usually formed from conventional materials such as metals or plastics, but the materials are frequently organized in definite periodic patterns. Metamaterials exhibit qualities not

[736] https://www.eurekalert.org/pub_releases/2016-10/miot-rcs101716.php
[737] http://news.mit.edu/2017/engineers-3-d-print-living-tattoo-1205

found in nature, which result from both the properties of their component materials and from their geometrical arrangement.[738]

Recent progress directions

Cloaking devices

Cloaking devices are stealth technologies that can make objects become partly or entirely invisible to portions of the electromagnetic spectrum and sensors. In other words, cloaking devices are methods of making physical objects undetectable or 'invisible'.[739] Researchers have designed a new kind of metamaterial based on germanium antimony telluride – the kind of phase-change material found in CDs and DVDs – that can block or transmit specific wavelengths of light at the command of light pulses.[740] A 3D printable composite material filled with nanoparticles can make curved surfaces invisible to electromagnetic waves.[741] While not entirely new, this technology has been demonstrated to work at a greater range of frequencies than previously achieved.

A new idea for a cloaking technology has been introduced by scientists by creating an entire sheet of meta-metallic mesh that becomes invisible to certain electromagnetic signals coming from any direction around an antenna. Lab experiments with these materials showed that the invisibility worked at 10.4 gigahertz signal frequency commonly used in radio astronomy and satellite communications.[742] Researchers demonstrated that one can use metamaterials to screen devices "to the wavelength of sound at low frequencies – around 200 Hertz and below".[743] A new metamaterial-based skin was developed in order to become a radar invisibility cloak that will trap radio or microwaves so devices would not show up under a radar detector.[744]

Photovoltaic devices

A photovoltaic cell (solar cell) is an electronic device that harvests sunlight and turns it into electricity. A thermophotovoltaic cell has a heat energy component in addition to a light energy element. Australian researchers discovered new properties in a nanomaterial which unlocks new prospects for the fabrication of very effective thermophotovoltaic cells, which could gather heat in the dark and transform it into electricity. The team created a metamaterial from gold nanostructures and magnesium fluoride that

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[738] www.eurekalert.org/pub_releases/2016-02/kift-nms020216.php
[739] https://www.eurekalert.org/pub_releases/2017-07/uom-ncs071917.php
[740] https://www.eurekalert.org/pub_releases/2016-08/aiop-nmc072916.php
[741] http://www.3ders.org/articles/20160715-uk-scientists-pave-way-for-invisibility-cloak-with-3d-printed-nanoparticles-invisible-to-electromagnetic-waves.html
[742]http://feedproxy.google.com/~r/IeeeSpectrumFullText/~3/Aw2nmnIH-J8/metallic-mesh-becomes-invisible-to-antenna-signals
[743]http://feeds.feedblitz.com/~/139447980/0/gizmag~Acoustic-metasurface-design-completely-absorbs-low-frequency-sound/
[744]http://www.dailymail.co.uk/sciencetech/article-3480178/The-invisibility-cloak-SKIN-Material-shield-objects-radars-one-day-block-visible-light.html?ITO=1490&ns_mchannel=rss&ns_campaign=1490

radiates heat in precise directions and gives radiation in a specific spectral range.[745] Other researchers used a "thermal metamaterial" to control the emission of radiation at high temperatures.[746]

Medical imaging

Medical imaging designates various techniques that generate visual analyses of the human body in order to detect, screen, or treat medical illnesses. Magnetic resonance imaging (MRI) is an extensively used medical technique for checkup of inner organs which can offer information on structural and functional damage. MRI scans have a low signal-to-noise ratio and are time-consuming, however, with patients needing to remain still inside a MRI apparatus for periods as long as an hour. The result is personal discomfort and long waiting lists in hospitals. To confront this problem, a new metasurface-based technology for enhancing the local sensitivity of MRI scanners on humans[747] was tested for the first time. "The metasurface contains thin resonant strips arranged periodically. Positioned under a patient's head, it delivered much higher signals from the local brain region and reduced image acquisition time".[748]

Ultrasound imaging utilizes high-frequency sound waves to capture real-time images soft tissues and internal organs. Scientists found a "simple and cheap way of creating finely shaped sound waves using acoustic metamaterials."[749] They "assembled a metamaterial layer out of small bricks that each coil up space. The space-coiling bricks act to slow down the sound meaning that external sound waves can be transformed into any required sound field".[750]

Morphic materials

Morphic materials can be considered new classes of materials reconfigurable (in terms of shape and properties) for different applications. With a combination of design and computational modelling[751], researchers were able to create a number of different arrangements, as well as a blueprint for quickly and accurately building metamaterials for a range of purposes.[752] A team of researchers found a way to "model" a metamaterial in a way that its surface can change between hard and soft.[753] Now, a group of scientists has created a metamaterial that can be programmed to change its shape, volume and stiffness.[754]

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[745] https://www.nanowerk.com/nanotechnology-news/newsid=43152.php
[746] https://www.sciencedaily.com/releases/2016/09/160915174938.htm
[747] https://www.azooptics.com/News.aspx?newsID=23361
[748] http://www.nanotech-now.com/news
[749] http://www.sussex.ac.uk/broadcast/read/39354
[750] https://www.eurekalert.org/pub_releases/2017-02/uos-ssi022317.php
[751] https://www.nanowerk.com/spotlight/spotid=45701.php
[752] http://www.3ders.org/articles/20170123-3d-printing-helps-harvard-scientists-develop-multifunctional-and-reconfigurable-metamaterials.html
[753] https://phys.org/news/2017-01-metamaterial-hard-softand.html
[754] https://technabob.com/blog/2016/03/17/transformable-metamaterial/

Long-term perspectives

In the more immediate future, metamaterials will make their way into the manufacturing of improved satellite antennas – especially much lighter ones –, sensors, and photovoltaic cells. If prices come down, light antennas could one day connect individuals directly to the satellites and allow them to bypass wired local internet infrastructures.[755] Cheap and powerful radars, on the other hand, could be fitted to aerial vehicles such as drones, simplifying detection and thus traffic control. Thermophotovoltaic cells, which can harvest energy from infrared radiation and do not need direct sunlight, could complement or even replace solar cells as an important source of renewable energy.

Portable invisibility cloaks for moving objects in the visible spectrum will remain a dream for a long while. However, there are hopes that the high configurability of metamaterials will allow for the creation damage-resistant materials. For example, bicycle tires made from metamaterials could self-adjust to ride more easily on soft surfaces such as sand or, respectively, on very hard surfaces. Clothes manufactured with metamaterials would sense possible damage and adjust the surface of the fabric in order to protect the wearer.

4.6.8 Self-healing Materials

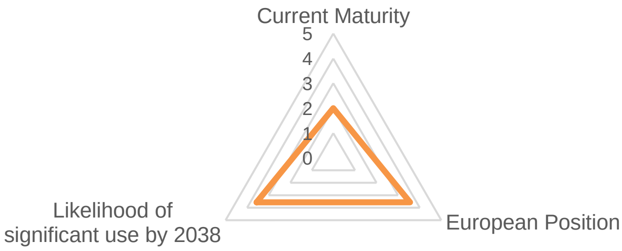

Figure 64: RIB Score of Self-healing materials

Self-healing is the capability of materials to diagnose and to fully or partially "heal" (recover/repair) internal damages all by themselves. For a material to be "autonomously self-healing", it is essential that the healing takes place without human involvement. Typically, self-healing materials detect degradation by initiating a repair/heal mechanism that reacts to micro-damage. Generally, these materials are artificially created and may be considered "smart structures", as they adjust to numerous environmental conditions according to their integrated "sensing" abilities.[756] This technology could be applied to almost any material and any domain, in "situations where repair or replacement is challenging, such as offshore

[755] https://www.ft.com/content/c6864c76-de7d-11e7-a0d4-0944c5f49e46
[756] http://www.3ders.org/articles/20170713-self-healing-3d-printing-gel-means-your-broken-phone-screen-could-soon-fix-itself.html

wind turbines, or even ‘impossible’, such as aircraft and satellites during flight.”[757]

Recent progress directions

Civil engineering

Civil engineering is a branch of engineering that deals with the preparation, design, and maintenance of building structures (roads, railroads, bridges, dams, pipelines, power plants, sewage, etc.). In many of these structures, if a crack moves through the material it needs to be immediately stopped, before fatal accidents happen. However, cracks are very hard to discover. This is where self-healing materials can be used. A self-healing gel that “can change in response to various outside stimuli and then autonomously repair”[758], returning to its original state, has been tested. It works by emitting a colour-coded response to various external stimuli and subsequently returns to its previous condition and colour.[759] Integrated into various structures, such polymer gels could also report on their state after self-repairing.[760]

With an average life span of 30-40 years, “the cement around geothermal production wells ultimately cracks over time resulting in vulnerability to leakage, reduced strength, and corrosion.”[761] However, repairs can cost millions of dollars and need a lot of time. To reduce these costs, a research team discovered that “by mixing in 5 to 20 percent polymers with typical cement before it is poured and cured, the cement can repair itself in a few days when cracks occur”.[762] This self-healing cement can also self-heal continuously: “it can repair itself many times and maintain the rheological and mechanical properties necessary for geothermal wells”.[763]

Roads too are exposed to a lot of mechanical and thermal stress, as well as environmental effects, leading to potholes. A patented method repairs stress-induced cracks in the asphalt to prevent potholes from forming in the first place, potentially doubling the lifespan of roads.[764] Mixing magnetic nanoparticles into the bitumen during the preparation of asphalt and then slightly heating this material with a small magnetic field causes the bitumen to melt and leak into cracks, allowing the asphalt to ‘self-heal’.

Protective clothing

Protective clothing is worn by individuals for occupational safety, health, and recreational activities. Other purposes include reducing exposure to various hazards such as physical, electrical, heat, chemicals, biohazards,

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[757] https://www.birmingham.ac.uk/news/latest/2016/09/self-healing-composites.aspx
[758] http://news.mit.edu/2016/promise-of-fluorescent-polymer-gels-0701
[759] http://energy.mit.edu/research/novel-metallic-gels-fluoresce
[760]http://www.laboratoryequipment.com/news/2016/07/color-changing-materials-used-detect-structural-failure-energy-related-equipment
[761] https://phys.org/news/2017-02-pressure-problem-high-strength-self-healing.html
[762] https://phys.org/news/2017-02-pressure-problem-high-strength-self-healing.html
[763] https://phys.org/news/2017-02-pressure-problem-high-strength-self-healing.html
[764]http://www.businessinsider.com/researchers-developing-asphalt-repair-cracks-itself-technology-science-infrastructre-2017-8

and airborne particulate matter. But current coatings can get damaged. Coatings with self-healing properties enable garments made of everything from wool to silk to effectively "heal" rips and tears when exposed to water.[765] By further adding enzymes into the clothing fibres, it could even neutralize chemicals. If chemicals come into contact with a coated garment, the enzymes break them down before they reach the skin.[766]

Energy storage devices

Following the increasingly widespread use of energy storage devices, a team developed a 3D-printable magnetic ink using micro-particles of neodymium and carbon black, a material with electrochemical properties often used to make batteries. One such item was damaged nine times in the same place and cut in four separate parts – the ink could repair itself while still maintaining most of its conductivity.[767]

Usually, the deterioration of lithium ion batteries, the type most commonly used nowadays, can lead to complications such as flammable, toxic, or corrosive gases, or liquid leaks. To ensure the safety of a damaged battery, a team has developed a new family of lithium ion batteries with self-healing abilities that can overcome such accidents. "Even after completely breaking apart, the battery grew back together without significant impact on its electrochemical properties".[768]

There has been no shortage of materials that harvest power from the human body. From generators that produce electricity from the friction or movement of the wearer to the use of the body itself, scientists have been exploring how our everyday existence can lend power to the electronics we depend on. A flexible thermoelectric generator is not only capable of producing electricity from body heat, but it is also able to self-heal. The use of liquid metal to connect the low-resistance thermoelectric elements increased the power output, while also making the device self-healing, since the liquid metal can reconnect when a connection is broken.[769]

Soft Robotics

In contrast to conventional robots built from stiff materials, soft robots are more flexible and adaptable to complex tasks. They reduce the risk of injury to self, humans, and surroundings, which enables their use in fields such as medicine and manufacturing.[770] Unfortunately, this also makes them more susceptible to damage. To solve this problem, a team of researchers developed a way to create soft machines that can heal themselves if injured. They made a gripper, a robotic hand and an artificial muscle from

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[765] http://perfscience.com/content/2144650-biodegradable-liquid-material-inspired-squid-ring-teeth-helps-fabric-self-heal

[766] http://www.impactlab.net/2016/08/13/scientists-create-self-healing-fabrics-that-also-protect-from-harmful-chemicals/

[767] http://www.3ders.org/articles/20161108-ucsd-engineers-develop-self-healing-magnetic-ink-for-3d-printed-batteries-circuits-and-sensors.html

[768] https://www.asianscientist.com/2016/10/tech/healing-lithium-ion-battery/

[769] https://www.treehugger.com/gadgets/flexible-device-harvests-body-heat-power-wearable-electronics.html

[770] http://www.futurity.org/stretchy-polymer-1142362-2/

jelly-like rubbery polymers. After the robot is injured, its strands reorganize and lock together when applying heat.[771]

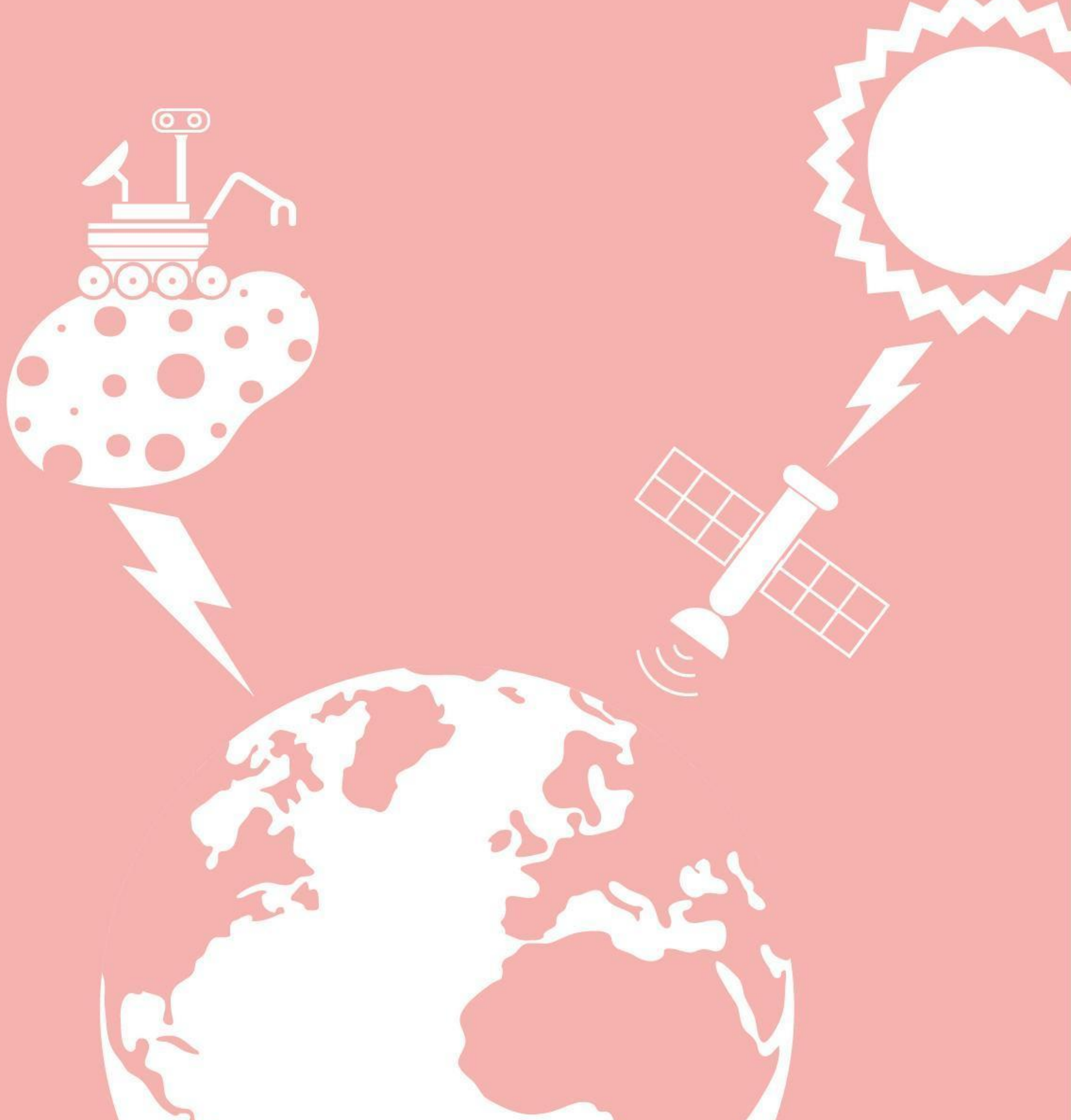
Long-term perspectives

At various points in the future, you will be able to repair your ripped jeans just by adding water. And when dropped, your smartwatch, laptop or cell phone will self-heal the cracks in its display. These devices' batteries will also last longer, among others due to their self-healing properties.

In the future, robots will be sent routinely to perform tasks in unpredictable terrains, where they will interact with objects of unknown geometry. Some fields of medicine, mostly neurosurgery, will benefit from the flexibility and compatibility of soft robots to enable operations in areas hard to reach by humans.

[771] https://www.engadget.com/2017/08/17/soft-robot-self-healing-polymers/

Breaking Resource Boundaries



4.7 Group 7. Breaking Ressource Boundaries

4.7.1 Bioplastic

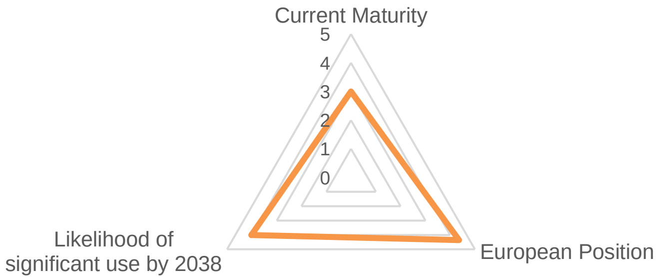


Figure 65: RIB Score of Bioplastic

Bioplastics are plastics that use as a source of carbon renewable natural feedstock and fossil fuel in different proportions. These may include corn, rice, potatoes, palm fibre, tapioca, wheat fibres, wood cellulose and bagasse. Depending on their chemical composition and percentage of biobased ingredients, bioplastics may or may not be biodegradable. Bioplastics are used in different industries like food and beverage packaging, health care, textiles, agricultural, automotive or electronics. The main advantage of bioplastics is the fact that they leave a smaller energy footprint and they produce less pollution.[772,773]

Recent progress directions

The PolyBioSkin EU-funded project that comprises of 12 partners promises the development of biopolymers for skin-contact applications, for the sanitary, personal care, cosmetics and biomedical products industry. Skin-contact products are mainly fabricated from fossil-based polymers that are non-recyclable and non-biodegradable, thus being an environmental threat. The project proposes to develop three products that will contain 90% renewable materials and have a small environmental footprint. They are working on a biodegradable diaper, a biodegradable and bioactive facial beauty mask, and a nanostructured biocompatible non-woven tissue.[774]

Researchers at the University of Seville and the University of Huelva, have developed bioplastic by using soya protein. This bioplastic is biodegradable and environmentally friendly, and can absorb 40 times its own weight in water. They modified the molecular structure of soy, thus altering the absorption properties, and made it retain three times more water than it would normally do. By injecting a solid concentrate of proteins into a mold,

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[772] https://www.creativemechanisms.com/blog/everything-you-need-to-know-about-bioplastics
[773] http://www.sustainableplastics.net/about
[774] https://www.european-bioplastics.org/polybioskin-develops-biopolymers-for-high-demand-skin-contact-applications/

they created test tubes, with application in horticulture. They want to use them as soil dispensers for agricultural nutrients.[775]

A team of researchers led by Xinlong Wang developed electronic components made out of degradable bioplastic. The developed electronics were made out of a corn-starch-derived bioplastic called polylactic acid (PLA). By blending metal-organic framework nanoparticles with this bioplastic, they succeeded in developing a material with the right mechanical, electrical and flame retardant properties for use in electronics.[776]

Scientists at Wyss Institute for Biologically Inspired Engineering developed a method for wound repair using Shrilk, an already existing biocompatible chitosan bioplastic that they created. Chitosan is an approved material for clinical use that has antimicrobial properties. They managed to combine chitosan with the enzyme transglutaminase in order to make chitosan bond with living tissue. Thus they developed different kinds of chitosan materials like sheets for would patching, a spray for sealing puncture wounds or covering large areas of burns, and a foam that can seal the cavities of large wounds. They also considered using this method to bond inorganic materials like biomedical implants or microfluidic devices to different tissues.[777]

The Technical Research Centre of Finland developed a method of using methane-rich biogas to produce raw materials for bioplastic. The biogas produced by farms is fed into a gas fermentor where methanotrophic bacteria circulate through the pipes. The bacteria grow using methane as a source of carbon and energy. The methanotrofic bacteria contain polyhydroxybutyrate plastic (PHB), which can be used as a raw material to produce bioplastic. The PHB is then separated from proteins from the dried cell mass of the methanotrophic bacteria inside the biogas fermentor.[778]

Long-term perspectives

The plastic industry is focusing on developing new ways of producing bioplastic by using natural feedstock found in nature or as by-products from other industries or processes. Bioplastic is on high-demand in many diverse areas and researchers find new applications for this material. Everybody is looking for a way to reduce the environmental footprint that plastics leave.

[775] https://phys.org/news/2017-06-bioplastic-derived-soya-protein-absorb.html
[776] https://www.acs.org/content/acs/en/pressroom/presspacs/2017/acs-presspac-april-19-2017/degradable-electronic-components-from-corn-starch.html
[777] https://wyss.harvard.edu/patching-a-gap-in-wound-care/
[778] https://www.sciencedaily.com/releases/2016/11/161117082452.htm

4.7.2 Carbon Capture and Sequestration

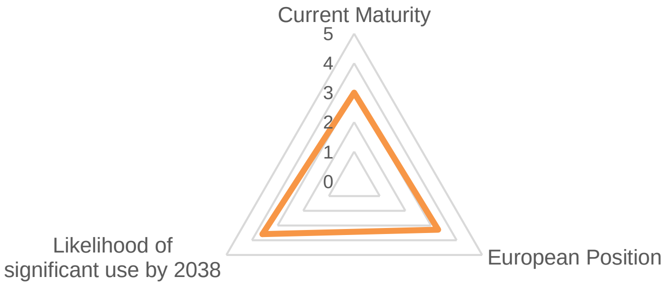

Figure 66: RIB Score of Carbon capture and sequestration

Carbon is a vital element at the basis of our life on Earth. Yet carbon dioxide produced by human activities is one of the main greenhouse gases (GHG) responsible for climate change. Managing carbon dioxide (CO_2) is one of the greatest social, economic and political challenges of our time. To avoid a loss of carbon to the atmosphere, it is captured for storage and further processing at the source of a high CO_2 output, such as smoke stacks in various industries and carbon-based power plants. Direct air capture technologies remove carbon from ambient air anywhere in the environment. Carbon dioxide is separated out of air or flue gas with absorption, adsorption, or membrane gas separation technologies. Captured CO_2 or extracted carbon could be stored minerally, as it reacts exothermically with metal oxides. In other cases, it is transported in pipelines for usage somewhere else, e.g. for injection into older fields to extract oil.

Recent progress directions

Exploring new storage solutions

Carbon can be either stored (CCS) or used (CCU). CCS systems, as currently designed, typically consist of three stages: (1) removal of CO_2 via controlled chemical reactions from a mix of other gases (industrial or naturally occurring, see CO_2 splitting); the resulting CO_2 is then liquefied by compression and (2) transported through pipes or by special vehicles to (3) a storage site. Scientists at the Trent University in Canada have found a rapid way of producing magnesite. This mineral takes CO_2 from the atmosphere for permanently storage.

New uses for CO_2

Carbon capture and utilization (CCU) may mitigate some of the problems and costs raised by storage, though not the cost of the capture itself. New emissions-free or zero-emissions fossil fuel power plants are being build, such as US energy start-up Net Power in Texas.[779] Scientist are looking for turning carbon into construction materials, e.g. by creating solid carbonates through mineral carbonation.[780] Scientists at Rice University have found a way to make the asphalt-based sorbents better at capturing carbon dioxide from gas wells.[781]

Long-term perspectives

Combining direct air capture with carbon storage may fulfil a dual function: as a carbon dioxide removal technology, and as a form of climate engineering if deployed at large scale. New uses for CO_2 – Carbon capture and utilization (CCU) mitigate some of the problems and costs raised by the storage, though not the cost of the capture itself. Once costs and incentives for climate change mitigation rise even higher, carbon capture technologies may become attractive for dealing with emissions from diffuse sources such as automobiles and aircraft. At the same time, critics argue that these technologies are very expensive, carry some risks and that the actual effects are far from clear.[782]

4.7.3 Desalination

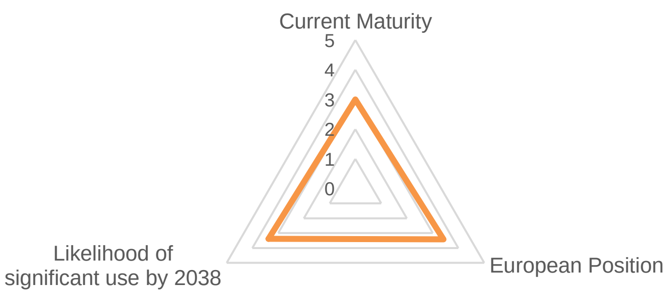

Figure 67: RIB Score of Desalination

Desalination is the procedure by which various salts are removed from water. This goal is traditionally achieved through distillation, electrolysis, or filtration. These techniques are costly and energy-intensive, since they

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[779] https://www.theguardian.com/environment/2017/jan/03/indian-firm-carbon-capture-breakthrough-carbonclean
[780] https://futurism.com/revolutionary-carbon-capture-method-makes-building-materials-out-of-emissions
[781] https://www.nanowerk.com/nanotechnology-news/newsid=44535.php
[782] http://www.climatechangenews.com/2012/10/02/carbon-capture-and-storage-time-to-bury-the-myth/ accessed 19/09/2018

currently imply either splitting water, or bringing it to boiling point (by burning fossil fuels or concentrated solar power) and condensing it, or filtration via harsh chemicals to clean fouled membranes.

New laboratory developments have shown progress in achieving desalination by filtering water through new artificial materials that use various forms of graphene – a one-atom thick layer of equally spaced carbon atoms – or in other ways. They usually entail considerably lower energy requirements and offer greater useful flow throughput.

Recent progress directions

Nanofiltration

Membranes which perform microfiltration can trap comparatively larger particles, such as sand, silt, or clays, and organisms such as algae and some species of bacteria. Nanofiltration membranes are an improvement, in that they can retain much smaller particles. They can remove "most organic molecules, nearly all viruses, most of the natural organic matter and a range of salts. Nanofiltration membranes also remove divalent ions, which make water hard, rendering them a popular and eco-friendly option to soften hard water."[783]

Graphene oxide membranes[784], "whose pore size can be precisely controlled, can sieve common salts out of water and make it safe to drink".[785] They also "filter out small nanoparticles, organic molecules, and even large salts".[786] "The atomic scale tunability[787] of the pore size also opens a new opportunity to fabricate membranes with on-demand filtration, capable of filtering out ions according to their sizes".[788]

Since filter clogging is a major issue in designing viable membranes, self-cleaning[789] nanotube[790] membranes can be of vital importance in this area. They may solve "the unwanted build-up of organic and inorganic deposits on a membrane's surface that reduces its ability to filter impurities".[791] Graphene carbon nanotubes are "tiny cylindrical tubes made of tightly bonded carbon atoms, measuring just one atom thick. … These can clean themselves when a low-voltage electric shock is run through them, resulting in the immediate restoration of the membranes' flux."[792]

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[783] https://www.nanowerk.com/nanotechnology-news/newsid=46394.php
[784] https://www.nanowerk.com/nanotechnology-news/newsid=47826.php
[785] https://www.sciencedirect.com/science/article/pii/S0958211817301143
[786] https://www.nature.com/nnano/volumes/12
[787] https://www.nanowerk.com/nanotechnology-news/newsid=46295.php
[788] https://www.sciencedirect.com/science/article/pii/S0958211817301143
[789] https://www.nanowerk.com/nanotechnology-news/newsid=46394.php
[790] https://www.tun.com/blog/northeastern-university-remove-salt-seawater-nanotubes/
[791] http://www.scienceandtechnologyresearchnews.com/self-cleaning-membranes-sustainable-desalination/
[792] https://www.nanowerk.com/nanotechnology-news/newsid=46394.php

Graphene coating[793] is a simple spray-on technology which could enhance current membranes for "clean water solutions, as well as protein separation, wastewater treatment and pharmaceutical and food industry applications… Current work attempts to overcome the scalability issues and provide an inexpensive, high quality membrane at manufacturing scale."[794]

Nano-scale slit[795] membranes are created by making extremely small openings in a material, rather than building it. This solution focuses on desalination through size exclusion and it represents a crucial step to forming high-flux water desalination.

New distillation solutions

Direct solar desalination[796] is a form of membrane distillation which uses "engineered nanoparticles that harvest as much as 80 percent of sunlight to generate steam. By adding low-cost, commercially available nanoparticles to a porous membrane, researchers have essentially turned the membrane itself into a one-sided heating element that heats the water by itself to drive membrane distillation."[797] Depending on the quantity of water necessary at any one time, a modular system could be built, with solar panels added according to needs. Electrode-based distillation[798] employs new forms of battery technology - electrodes that use only a fraction of the energy to attract salts and minerals out of the water for the desalination of low-salinity brackish inland water from industrial and commercial sources. This technology could remove not just sodium ions, but also the magnesium, calcium, and potassium usually present in wastewater.

Long-term perspectives

The new developments in precision filtration technology could have massive impacts in the global economy, on ecosystems and thus on a smaller or broader societal level, in the developed world as well as in emerging markets.

These technologies will bring costs down by increasing the energy efficiency of industrial filtration of wastewater, rendering industrial actors more willing to lower the ecological impacts of their enterprises. They will also make the technology accessible to emerging markets, which may not have "the financial infrastructure to fund large plants without compromising on the yield of fresh water".[799]

Areas that are affected by droughts can more cheaply desalinate ocean waters or locally filter inland sources. Turning seawater into drinking water will have a social and health impact for populations with scarce access to

[793] https://www.nanowerk.com/nanotechnology-news/newsid=47899.php
[794] https://www.mri.psu.edu/mri/news/toward-smart-graphene-membrane-desalinate-water
[795] https://www.azonano.com/news.aspx?newsID=35893
[796] https://www.rdmag.com/news/2017/06/creating-freshwater-salt-water-using-only-solar-energy
[797] http://news.rice.edu/2017/06/19/freshwater-from-salt-water-using-only-solar-energy-2/
[798] http://www.editiontruth.com/battery-technology-saltwater-desalination-process/
[799] http://www.manchester.ac.uk/discover/news/graphene-sieve-turns-seawater-into-drinking-water/

clean water, or in areas threatened by sea level rise potentially affecting clean water sources.

4.7.4 Geoengineering and Climate Engineering

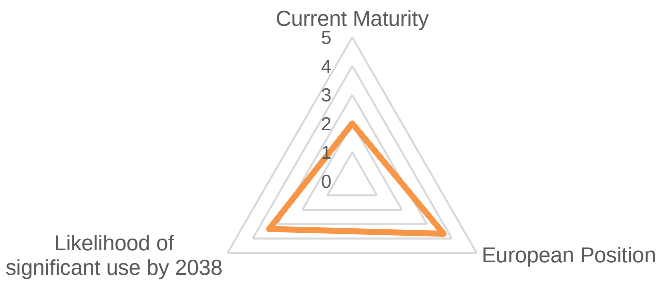

Figure 68: RIB Score of Geoengineering and climate engineering

Geoengineering and climate engineering often go together. Geoengineering is concerned with changing full landscapes – such artificial lakes, the Three Gorges Dam project in China – or the climate. Additional examples are changing riverbeds or using mountains for artificial islands; one famous case of the latter is the Kansai International Airport in Japan. Geoengineering has become more daring as far as size is concerned over the last years.[800]

Climate engineering serves as an umbrella concept covering chiefly two types of endeavours: greenhouse gas removal and the management of solar radiation. Stakeholders hold very diverging views on the desirability, security and feasibility of geo-engineering.

Recently, various types of actors have debated the prospects of geo- and climate- engineering solutions for tackling climate issues. One concern is "how their development might complement or weaken efforts at mitigation (reducing greenhouse gas emissions) and adaptation (buttressing societal capacities to endure climatic changes)."[801]

Recent progress directions

Geoengineering: changing landscapes

An example of landscape change in China is the Tree Gorges Dam: this hydroelectric dam on the Yangtze River in China feeds one of the largest power stations in the world. The 34 generators' output is equivalent to that produced by burning 25 million tons of crude oil or 50 million tons of coal.

[800] Geoengineering was one of the important issues in the Japanese Foresight, see NISTEP (2015): The 10th Science and Technology Foresight, Report no. 164, Tokyo, http://data.nistep.go.jp/dspace/bitstream/11035/3079/2537/NISTEP-NR164-SummaryE.pdf

[801] https://ce-conference.org/what-climate-engineering, accessed 17/9/2018.

The dam generated 98.8 TWh in 2014.[802] Conversely, the project has interfered with some of China's most beautiful natural areas.

The dam made of concrete and steel is 7,661 feet long and almost 600 feet high. Some 510,000 tons of steel went into erecting it. The reservoir has an area of 405 square miles. Among the dam's purposes is that of preventing the floods that traditionally affected some areas of China, as well as allowing massive ocean freighters to reach deep into the land. Ongoing environmental concerns[803] have been voiced in connection with the Three Gorges Dam. According to some reports, the number of individuals relocated exceeded 1.2 million, while biodiversity is being threatened.[804]

An example close to climate engineering is the geoengineering of arctic glaciers. In order to delay the loss of ice sheets that contributes to sea-level rise approaches like blocking warm water from the glaciers, pinning ice shelves through artificial islands and removing the layer of water that acts as a lubricant below the glacier are discussed.[805]

Climate Engineering: Greenhouse gas removal

Carbon dioxide removal is the most typical form of greenhouse gas removal - but not the only one. The idea is to combat global warming by clearing the atmosphere of greenhouse gas. The main technique is mechanical in nature. Carbon Dioxide Removal (CDR) additionally involves solutions that also remove greenhouse gases, such as methane.[806] Both are part of climate engineering approaches.

Climate Engineering: Solar radiation management

Solar radiation management aims to offset the effects of greenhouse gases by causing the Earth to absorb less solar radiation.[807] One approach to that goal is stratospheric injection. Stratospheric injection works by "spraying particles high above the Earth could help reflect more heat back into space, offsetting rising temperatures. It would mimic a natural phenomenon that occurs when large volcanic eruptions blast sulphur dioxide into the atmosphere, which nudges down global temperatures in the months that follow." One small experiment involved launching high-altitude balloons to spray materials such as sulphur dioxide, alumina, or calcium carbonate, in small quantities, into the stratosphere. Sensors then gauge these particles' reflectivity and how much dispersion is achieved, as well as their interactions with other compounds.[808] An older idea are space sunshades or shields.[809]

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[802] https://en.wikipedia.org/wiki/Three_Gorges_Dam, accessed 17/9/2018.
[803] https://www.scientificamerican.com/article/chinas-three-gorges-dam-disaster/, accessed 17/9/2018.
[804] http://primaryfacts.com/2754/10-three-gorges-dam-facts/ accessed 17/9/2018.
[805] https://www.nature.com/articles/d41586-018-03036-4, accessed 18/9/2018.
[806] http://www.geoengineeringmonitor.org/cat/technologies/carbon-dioxide-demoval/, accessed 17/9/2018
[807] https://en.wikipedia.org/wiki/Climate_engineering, accessed 17/9/2018.
[808] https://www.technologyreview.com/s/608312/this-scientist-is-taking-the-next-step-in-geoengineering/, accessed 17/9/2018
[809] https://en.wikipedia.org/wiki/Space_sunshade, accessed 17/9/2018.

Long-Term Perspectives

More countries and regions in the world are considering geoengineering even though it is contested. Some regard it as necessary and argue that growing pressure from climate change makes it necessary, safe and accepted. Counter arguments point to the risk of large-scale, unexpected and uncontrollable impacts. Others argue that geoengineering is unnecessary if innovations at a smaller scale find solutions. In some countries, geoengineering creates new infrastructures, which may herald progress in the way of living or the improvement of national economies (as with the Grand Ethiopian Renaissance Dam). On the other hand, such projects often lead to geopolitical conflicts.

Therefore, for both geoengineering and climate engineering, the perspectives appear hazardous to many and the controversy is on-going, as contemplation of geoengineering does little to diminish the need to address the root causes of climate change. In the future, governance and regulation of geoengineering and climate engineering is needed on a global level, which raises many policy questions far beyond research and innovation policy.[810]

4.7.5 Hyperloop

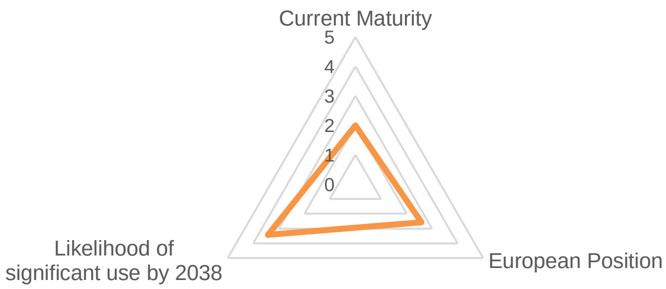

Figure 69: RIB Score of Hyperloop

The Hyperloop is a transportation system currently in development. It will use pressurized pods for passengers and it can also carry cargo in its vessel. Pods are accelerated progressively by an electric linear motor through a tunnel or tube from which the air has been removed (low-pressure environment). "The pod then quickly lifts above the track using magnetic levitation, gliding at airline speeds due to ultra-low levels of aerodynamic drag."[811]

[810] some are discussed here: https://en.wikipedia.org/wiki/Climate_engineering#Ineffectiveness, accessed 17/9/2018.
[811] https://arstechnica.com/cars/2018/03/is-it-time-to-take-the-hyperloop-seriously/

Recent progress directions

First successful test of subsystems

The US company developing the hyperloop system (Hyperloop One) achieved its first full-systems test in Nevada.[812] The test was not of a deployment-ready system; it involved sending a levitating test sled 315-foot (96 m) and transit pod, made from aluminium and carbon fibre along a section of tubing rather than a pod capable of carrying freight or passengers. Nevertheless, the vacuum, propulsion, magnetic levitation, guidance and braking systems were all integrated and tested together for the first time, and the tube used, 11 ft. (3.3 m) in diameter, was full-size. The sled reached a speed of 70 mph (112.6 km/h) in 5.3 seconds, accelerating at 2 g, propelled by 100 ft (30.5 m) of linear motor mounted inside the tube. This is a long way from the target speed that Hyperloop One has set for the system (700 mph or 1126 km/h), but is seen as a first key step.

Section of Hyperloop Track finalized in the Netherlands

A Dutch company has built a section of hyperloop track in the first stage of a bid to connect two cities in the next four years.[813] After completing low-speed tests on the new track, they plan to build a facility that will allow it to test systems at high speed. This facility will be used to explore aspects of the technology involved in cornering and the changing of lanes within the vacuum tube at top speed. If the program is successful, construction of a route between two cities will get underway.

Further tests under way at several sites

A start-up that plans to cut travel time from Seattle to Portland to just 15 minutes was a finalist in the Hyperloop One Global Challenge back in April 2017.[814] Pacific Hyperloop is hard at work in turning their plans into reality. Further routes are planned in several other sites in the US, in Europe as well as in Dubai. Hyperloop One hopes to build its first full-scale system and get it operational, most likely outside the US, by 2021.

Long-term perspectives

Hyperloop aims to help solve mass transportation and infrastructure challenges around the world. It is fast, innovative, silent and sustainable and so very interesting for the transportation needs of the future. The system could help relieve some of the pressures facing big cities today, enabling people to commute from outside metropolitan areas with short transit times. Implementing Hyperloop would not only alleviate traffic on highways for others, but also create a consistent and reliable commuting experience that would not be affected by factors like car accidents or crazy

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[812] https://www.theengineer.co.uk/hyperloop-one-reveals-first-successful-full-systems-test/
[813] https://www.theengineer.co.uk/dutch-team-builds-europes-first-hyperloop-track/
[814] https://futurism.com/this-hyperloop-could-one-day-transport-you-175-miles-in-just-15-minutes/

weather. Ultimately, proponents aim to create a world "where distance no longer matters" and where "you will have the freedom to live and work wherever you want to."

4.7.6 Plastic-Eating Bugs

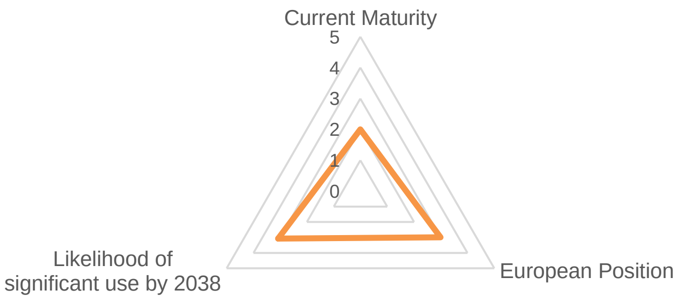

Figure 70: RIB Score of Plastic-Eating Bugs

PET (polyethylene terephthalate) is both one of the most commonly manufactured products around the globe – and non-biodegradable. As these plastics accumulate in landfills, water, and elsewhere around us, they have emerged as a serious environmental concern. Since turning PET (back) into oils has proven to be a tricky process, scientists have begun to look for bugs that could metabolize or digest the materials, turning them into biodegradable products. There have been recent signs of success, although the road to industrial plastic disposal processes remains long at this point.

Recent progress directions

Plastic-devouring bacteria

Japanese researchers have discovered a new type of bacterium that can metabolize plastic. Ideonella sakaiensis, which scientists collected from discarded PETs, breaks down the plastic by using only two enzymes.[815] Indeed, plastics seem to be its only food source. The hope is that either the bacteria or, more promisingly, the enzymes could be used to create new ways of disposing of plastics.[816]

Further up the food chain: plastic-colonizing fungi

Micro-organisms more complex than simple bacteria seem to have evolved the ability to feed on plastics as well. The mycelium of a species of fungus called Aspergillus tubingensis is able to colonize polyester polyurethane and

[815] http://science.sciencemag.org/content/351/6278/1196
[816] https://www.newscientist.com/article/2080279-bacteria-found-to-eat-pet-plastics-could-help-do-the-recycling

degrade it in the process. After spending two months with a sheet of polyester polyurethane in a lab, the fungus completely destroyed it.[817]

Micro-to-macro: plastic-munching worms

Additional hopes that plastic waste could be reduced to biodegradable waste were prompted by a recent study which showed that mealworms could be "natural trash-disposers". The bugs were force-fed on a diet of Styrofoam and other types of polystyrene, breaking them down and excreting the remains into – potentially crop-feeding – biodegradable droppings.[818]

In a similar development, a species of caterpillar was accidentally discovered to be able to eat polyethylene. The larvae of the wax moth Galleria mellonella can devour polyethylene at a rate of two milligrams per worm per day. Although this may not amount to much, the enzymes which the organism uses to consume plastics could ideally be turned into some kind of industrial plastics-disposal process.[819] This being said, more research is needed to prove that the caterpillars process the polyethylene rather than simply break the material down through "mechanical milling" and excrete it chemically unchanged.[820]

Long-term perspectives

Dreams of a world where plastic waste is easily dealt with, and perhaps even turned into natural fertilizers to feed the soil, have been rekindled by the recent discovery of plastic-eating bugs. If the enzymes used by bacteria, fungi or the microbes in the guts of worms can be leveraged to create industrial processes of plastic disposal, the mountains of plastic bottles and packages in landfills might become sights of a bygone era.

Still, there might be a dark side to this new world. Plastic is sterile, and therefore ideal for packaging food and for widespread use in many other products – which explains its ubiquity in the first place. If micro-organisms are evolving to colonize it, some of the plastics' desirable properties might become things of a bygone era as well.[821]

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817 http://www.iflscience.com/plants-and-animals/plasticeating-fungus-found-at-a-landfill-site-in-pakistan

818 http://www.iflscience.com/environment/plastic-eating-mealworms-could-help-reduce-landfill-waste

819 https://www.theguardian.com/commentisfree/2017/apr/25/plastic-eating-bugs-wax-moth-caterpillars-bee; https://www.scientificamerican.com/article/plastic-eating-worms-could-inspire-waste-degrading-tools

820 https://phys.org/news/2017-09-german-scientists-plastic-eating-caterpillars.html

821 http://www.iflscience.com/plants-and-animals/plasticeating-fungus-found-at-a-landfill-site-in-pakistan

4.7.7 Splitting Carbon Dioxide

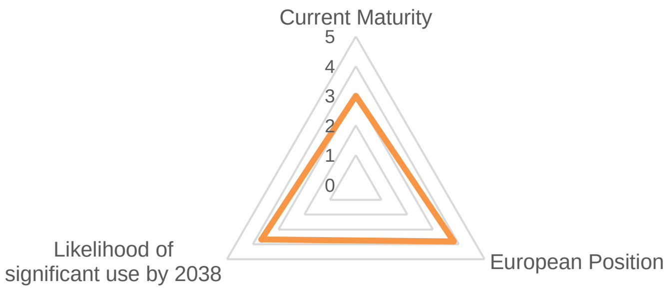

Figure 71: RIB Score of Splitting carbon dioxide

Carbon dioxide is a waste product gas – a greenhouse gas amassing in the atmosphere and directly contributing to global climate changes. Different methods for carbon capture and storage are currently being used to reduce the levels of CO_2 in the atmosphere, and thus its effects. Instead of storing, direct use of CO_2 by splitting is intended as well as splitting the CO_2 from the storage locations. Researchers are currently focussing on a new method for reducing CO_2 by splitting the gas into carbon and oxygen, or by using CO_2 as a feedstock for producing synthetic fuels.[822]

Recent progress directions

Low-cost carbon dioxide splitting

Researchers at Ecole Polytechnique Fédérale de Lausanne, developed the first carbon dioxide splitting technique that uses earth-abundant materials and is low-cost. Their catalyst process uses copper-oxide nanowires covered with an atomic layer of tin oxide. The electro-catalysis system that integrates this catalyst has a CO_2 splitting efficiency of 13.4 %. The system is linked to a triple-junction solar cell with a Faradic efficiency of 90 %. This kind of system can be used to convert solar energy and store it and, at the same time, decrease levels of CO_2.[823] Carbon dioxide splitting is thus largely connected to carbon capture and storage (see above).

By using a solar reactor-powered thermochemical process, scientists at the Swiss Federal Institute of Technology, have successfully split carbon dioxide into carbon monoxide and oxygen. They used a 4 kW solar reactor containing cerium oxide or ceria, with a two-step cyclical process. During the initial step, the ceria is heated to 1500°C in reduced pressure atmosphere, to produce oxygen. During the second step, the reduced ceria is re-oxidised by CO_2, in order to generate carbon monoxide. Their system

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[822] https://www.scientificamerican.com/article/splitting-carbon-dioxide/; https://www.theguardian.com/environment/2008/sep/05/carboncapturestorage.carbonemissions 1

[823] https://phys.org/news/2017-06-low-cost-carbon-dioxide.html

has an efficiency of 83 % molar conversion from CO_2 to CO, with a solar-to-fuel energy efficiency of 5.25 %.[824]

Researchers at the North Carolina State University have enhanced their carbon dioxide splitting into carbon monoxide, achieving a 98 % conversion efficiency. In order to achieve this, they developed a nanocomposite made of strontium ferrite dispersed in a chemically inert matrix of calcium oxide or manganese oxide.[825] This material is able to capture one oxygen atom from the CO_2 gas, resulting in CO. The captured oxygen is further combined with methane in order to produce syngas by using solar energy.[826]

Scientists at the Ulsan National Institute of Science and Technology developed a new technology of making biofuel using carbon dioxide. They achieved this by directly converting CO_2 into liquid fuels, after it reacts with hydrogen, prior generated by solar water splitting. The existing catalysts only convert CO_2 and H_2 to methane or methanol. The team at UNIST created a delafossite-based catalyst that is capable of converting CO_2 into liquid hydrocarbon-based fuels like diesel fuel. The new catalyst is made of copper and steal, and it allows the creation of longer carbon chains, thus making the production of diesel in one single step, possible. The fuel obtained through this method can be used by vehicles with diesel engines.[827]

Long-term perspectives

Scientists are looking for ways of splitting and converting carbon dioxide into fuels. Specifically, they are trying to create new, cheap, catalyst materials capable of high-specificity and high-conversion rates that can be applied in industrial-scale systems. At the same time, they are combining this technology with renewable energy devices that will enable them to reduce the levels of CO_2 in the atmosphere and, concomitantly, to store solar energy directly into liquid fuels.

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[824] https://www.chemistryworld.com/news/solar-reactor-splits-carbon-dioxide-into-fuel/2500528.article
[825] https://news.ncsu.edu/2017/08/water-co2-splitting-2017/
[826] https://news.ncsu.edu/2017/08/water-co2-splitting-2017/
[827] https://www.eurekalert.org/pub_releases/2016-11/unio-urt111816.php

4.7.8 Technologies for Disaster Preparedness

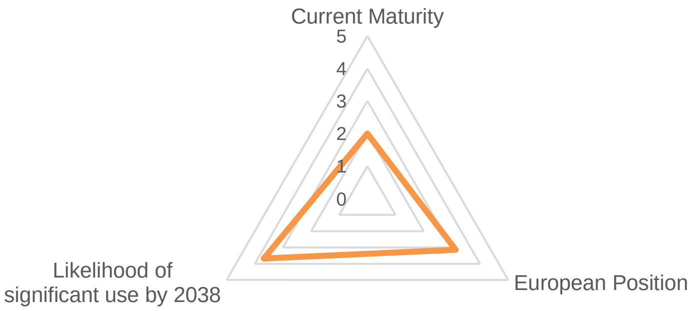

Figure 72: RIB Score of Technologies for disaster preparedness

As the number of natural disasters is expected to increase and the risk of flooding for many coastal cities has risen significantly, it is becoming imperative to find ways to adapt to increasingly frequent and devastating environmental crises. Futures studies, in Asia in particular, focus on technologies for predicting natural hazards. Earthquake prediction, prevention in case of earthquakes, tsunamis, volcano activities and heavy rain are very high on the agenda in Asian Foresight processes.[828] Also, emergency systems, rescue robots, complete rescue systems, and information systems for citizens (during and after a disaster) are in development for these cases. Prevention with scenarios on the one hand, and technology development on the other hand is in the forefront, but there are also efforts to limit the negative effects of a disaster with technologies, e.g. rescue robots.

Recent progress directions

Environmental Monitoring

Environmental monitoring is one key aspect of disaster preparedness. Beneath approaches like e.g. animal monitoring, technical monitoring for earthquake and volcano activity observation needs sensors. One option is to integrate sensors into the existing submarine telecommunication cable network (smart-cables). Cable relay stations can be outfitted with a number of monitoring devices, including seismographs, pressure gauges, and accelerometers, giving scientists access to critical data used in monitoring global climate change as well as the early detection of earthquakes and tsunamis. International efforts are under way to establish such a submarine early warning system.[829]

[828] Especially in the Japanese Foresight, they ranked very high in importance, see NISTEP (2015): The 10th Science and Technology Foresight, Report no. 164, Tokyo, http://data.nistep.go.jp/dspace/bitstream/11035/3079/2537/NISTEP-NR164-SummaryE.pdf, but also in Korea, KISTEP (2017): Delphi Survey, Seoul. In Europe, it was an issue in OBSRERVE, see Warnke, Ph. et al. (2016): OBSERVE. Deliverable 1.2 Horizon Scanning Report.
[829] https://en.unesco.org/courier/2017-october-december/harnessing-submarine-cables-save-lives, accessed 18/09/2018

Robots & AI emergency response

Robotics and AI systems can theoretically support fast and effective responses to emergency situations. It is also expected that they may be of help it the area is too dangerous for human beings (e.g. in case of a nuclear accident or under water). They can reach hazardous places that humans cannot reach and they can collect information. They can reach victims and provide them with fluids and medication until human help reaches the location. Rescue robots thus need to be smart and dynamic not to become obstacles for the rescue team. As the environment is often unstructured, unknown and dynamic, robots are tele-operated or act independently.[830] Many robots and intelligent systems are developed for these purposes, for example they are part of the Japanese robot strategy.[831] Some are embedded in larger technical systems, others are practical drones.[832]

A particular challenge is the coordination of different types of robots on land, air and underwater and the operation of robots in complex urban environments.[833] In an emergency, it is important to act fast.[834] In Europe, systems are trained via competitions[835] but emergency management and coordination for civilian purposes still need improvement, whereas some institutions, e.g. ESA, already professionalised it.[836]

Long-term perspectives

The key aspect of disaster preparedness is societal resilience i.e. the "ability of a community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of essential basic structures and functions." (IMPROVER definition). This may well entail adopting a different configuration in the face of a changing environment rather than repairing the prior state of the system. Technologies can only make a minor contribution to societal resilience, as it rests mainly on the capacity of the social fabric. It seems that the capability to deal with uncertainty and complexity is becoming an important capacity of the 21st century not only for societies, but also for organisations and individuals. In this sense, preparing for any kind of emergency does also mean being prepared for any kind of new complex situation of the future.

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830 http://www.rroij.com/open-access/rescue-robota-study.pdf; accessed 20/9/2018
831 http://www.meti.go.jp/english/press/2015/pdf/0123_01b.pdf, accessed 20/9/2018.
832 https://robohub.org/robots-to-the-rescue/, accessed 20/9/2018.
833 https://sciroc.eu/ accessed 19/09/2018
834 https://www.techemergence.com/search-and-rescue-robots-current-applications/, http://www.rroij.com/open-access/rescue-robota-study.pdf; both accessed 20/9/2018
835 https://eu-robotics.net/robotics_league/erl-emergency/about/ accessed 18/09/2018
836 http://esa.act.gov.au/emergency-management/emergency-coordination/ accessed 20/09/2018

4.7.9 Underwater Living

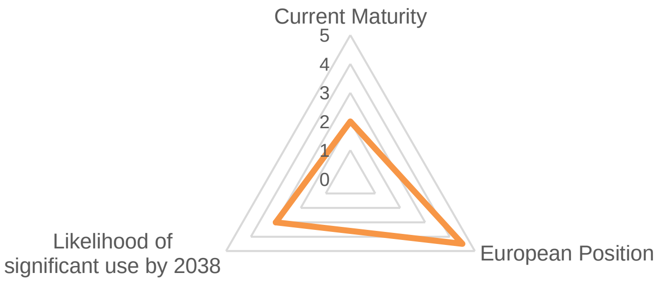

Figure 73: RIB Score of Underwater living

The idea of human beings living below the water surface is often brought up as a potentially important part of the future of humanity, perhaps as an alternative to an Earth surface made inhabitable by overpopulation or catastrophe.[837] Numerous underwater habitats have been designed, built, and used around the world since the early 1960s.[838] Before human beings are able to live under water, the first step may be underwater gardens as theme parks[839] or for harvesting under water[840] by growing plants beyond sea food. It is even expected that these underwater activities might help the oceans.[841]

Recent progress directions

Aquanaut technologies for living under water

The main habitable actual underwater facilities include[842]:

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[837] This issue was rated as important in the Japanese Foresight, NISTEP (2015): The 10th Science and Technology Foresight, Report no. 164, Tokyo, http://data.nistep.go.jp/dspace/bitstream/11035/3079/2537/NISTEP-NR164-SummaryE.pdf; and scanned in OBSERVE, Warnke, Ph. et al. (2016): OBSERVE. Deliverable 1.2 Horizon Scanning Report.

[838] https://en.wikipedia.org/wiki/Underwater_habitat, accessed 18/09/2018

[839] https://www.underwatergardens.com/, accessed 20/9/2018

[840] rated as an important issue in OBSERVE, Warnke, Ph. et al. (2016): OBSERVE. Deliverable 1.2 Horizon Scanning Report; and NISTEP (2015): The 10th Science and Technology Foresight, Report no. 164, Tokyo, http://data.nistep.go.jp/dspace/bitstream/11035/3079/2537/NISTEP-NR164-SummaryE.pdf. as examples see https://curiosity.com/topics/are-underwater-gardens-the-key-to-feeding-the-world-and-combatting-climate-change-curiosity/, https://www.fastcompany.com/3048234/there-are-secret-underwater-gardens-off-the-coast-of-italy-where-diver-farmers-are-growing-v, https://www.fastcompany.com/3048234/there-are-secret-underwater-gardens-off-the-coast-of-italy-where-diver-farmers-are-growing-v, http://www.nemosgarden.com/; https://www.weforum.org/agenda/2017/11/why-underwater-gardening-could-save-our-oceans, accessed 20/9/2018

[841] https://www.weforum.org/agenda/2017/11/why-underwater-gardening-could-save-our-oceans, accessed 20/9/2018

[842] http://listverse.com/2014/01/23/10-underwater-facilities-you-could-actually-live-in/, accessed 18/09/2018

- SeaOrbiter (the marine research vessel of the future, is the epitome of innovation, exploration and inspiration serving the Ocean, Space and Blue Society)[843];
- Phil Pauley's Sub-Biosphere (self-sufficient Sub-Biosphere 2 can house up to 100 People)[844];
- the Conshelf project[845];
- Jules' Undersea Lodge[846];
- Sealab[847];
- Aquarius Undersea Laboratory[848];
- the Atlantica Expeditions (first undersea colony)[849];
- U.S. Submarine structures (H2OME[850], Poseidon Undersea Resort in Fiji, the Ocean Activity Center OAC).

Undersea habitats have been investigated for a variety of purposes, among others for the training of astronauts and aquanauts or for research into marine ecosystems. Matters of interest included physiological processes or breathing gases under pressure.[851] NASA trains astronauts in an undersea habitat, to simulate living and working in the International Space Station. Meanwhile, developers are planning submerged hotels in locations including the Maldives[852], Dubai, Singapore and Norway[853] mainly with a view towards tourism.[854]

Entering a sustainable underwater future

Training to live in an undersea habitat (much as in space) requires being very sustainable, including a circular use of resources. This has to be combined with many different technologies for pressure regulation, oxygen circulation and nutrition providing as well as transport[855] in and to the

[843] http://www.seaorbiter.com/, accessed 18/09/2018
[844] https://inhabitat.com/futuristic-sub-biosphere-2-provides-self-sufficient-home-for-100-people-under-the-sea/, accessed 18/09/2018
[845] https://www.cousteau.org/english/precontinent-i--ii-et-iii.php, accessed 18/09/2018
[846] http://www.jul.com/AboutUs.html, accessed 18/09/2018
[847] https://www.scottcarpenter.com/sealab.htm, accessed 18/09/2018
[848] https://aquarius.fiu.edu/dive-and-train/facilities-and-assets/aquarius-undersea-laboratory/index.html, accessed 18/09/2018
[849] http://underseacolony.com/prime/mainhub_revA.html, accessed 18/09/2018
[850] http://www.ussubstructures.com/index.html, accessed 18/09/2018
[851] https://en.wikipedia.org/wiki/Underwater_habitat, accessed 18/09/2018
[852] http://www.mariefranceasia.com/travel/now-or-never/travel-news/the-maldives-is-opening-the-worlds-first-underwater-hotel-this-november-309793.html#item=1, accessed 18/09/2018
[853] http://www.bbc.com/future/story/20140411-i-have-lived-underwater, accessed 18/09/2018
[854] https://www.businessinsider.com/underwater-travel-innovations-2015-6?IR=T, accessed 18/09/2018
[855] like amphibious submarines, see https://en.wikipedia.org/wiki/Amphibious_assault_submarine. Until now, submarines are used for transport in specific cases, e.g. for drugs, but less for passengers, but the ideas are discussed: https://www.quora.com/Why-arent-submarines-and-ships-used-for-transportation

habitat.[856] Underwater gardens and farms growing a large variety of food (beyond seafood) are on the way.[857]

The outlook for living under water is very long-term. Until now, this is economically unreasonable[858] even though submarines for tourists exist[859] and are used on private basis. With a growing population, more and more scientists think about the option of living in and using underwater spaces, as a first step for specialists exploiting underwater resources or researchers who have an interest to live close to their research object, later for ordinary people.

Long-term perspectives

New knowledge from living in space and new underwater projects will improve the prospects of living below the surface. But for large-scale habitats like cities or villages, there seems to be a long way to go. The start is seen for trained specialist, for example those people who exploit resources, harvest in underwater gardens, need to be at the location or for researchers. As housing space on land is scarce, coastal areas are more and more detected for living. The first undersea habitats are rather expected to be located close to the coast providing a living for more and more people, and making use of the space when sea levels rise because of climate change.

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[856] http://www.ipsnews.net/2018/05/united-arab-emirates-entering-sustainable-future/?utm_source=rss&utm_medium=rss&utm_campaign=united-arab-emirates-entering-sustainable-future

[857] https://www.weforum.org/agenda/2017/11/why-underwater-gardening-could-save-our-oceans, https://curiosity.com/topics/are-underwater-gardens-the-key-to-feeding-the-world-and-combatting-climate-change-curiosity/, https://www.fastcompany.com/3048234/there-are-secret-underwater-gardens-off-the-coast-of-italy-where-diver-farmers-are-growing-v, https://www.fastcompany.com/3048234/there-are-secret-underwater-gardens-off-the-coast-of-italy-where-diver-farmers-are-growing-v, accessed 20/9/2018

[858] https://www.quora.com/Why-arent-submarines-and-ships-used-for-transportation

[859] https://www.uboatworx.com/journey; https://www.businessinsider.com/underwater-travel-innovations-2015-6?IR=T

4.7.10 Wastewater Nutrient Recovery

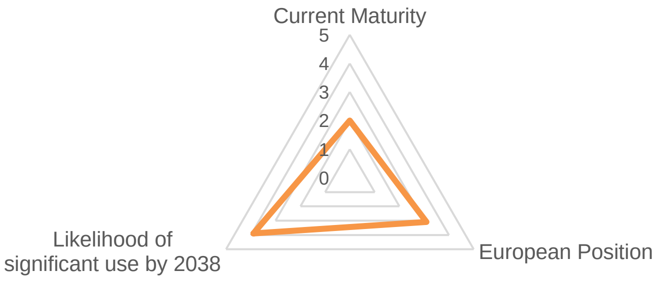

Figure 74: RIB Score of Wastewater nutrient recovery

Nutrient recovery is the practice of recovering nutrients such as nitrogen and phosphorus from used water streams that would otherwise be discarded and converting them into an environmental friendly fertilizer used for ecological and agricultural purposes. Nutrient recovery is one of the highlighted developments in wastewater treatment. Biological technologies, advanced reuse and recycling techniques and green-based practices "have led to various economic, environmental and societal benefits that can help reduce costs, conserve energy, sustain the environment, and improve customer service."[860] A special case is Biological phosphate removal (BPR).[861]

Recent progress directions

New wastewater treatment

The wastewater industry has put effort into saving or re-using resources. Nutrient recovery is the practice of "recovering nutrients such as nitrogen and phosphorus from used water streams that would otherwise be discarded and converting them into an environmental friendly fertilizer used for ecological and agricultural purposes". Such a solution has multiple advantages: removing the nutrients cleans the sewage, while also providing feedstock.[862]

BPR, biological phosphate removal, represents a special case of nutrient recovery from wastewater. It allows the recycling of 90 % of the phosphorus in wastewater.

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[860] https://www.waterworld.com/articles/print/volume-31/issue-2/features/nutrient-recovery-technology-transforms-world-s-largest-wastewater-treatment-plant.html

[861] The issue was rated as important in the Korean Foresight, KISTEP (2017): Delphi Survey, Seoul; and a Frost & Sullivan (2017): Top 50 Emerging Technologies: Growth Opportunities of Strategic Imperative' is the leading research offering of the TechVision group, the global emerging technology, innovation, and convergence, a market study used for trend analysis; it was a Delphi statement in BOHEMIA, see European Commission/ European Union (2017): New Horizons: Data from a Delphi Survey in Support of European Union Future Policies in Research and Innovation; Report KI-06-17-345-EN-N; doi:10.2777/654172

[862] http://www.waterworld.com/articles/print/volume-31/issue-2/features/nutrient-recovery-technology-transforms-world-s-largest-wastewater-treatment-plant.html

Long-term perspectives

There are attempts to develop more technologies that recover the different resources from wastewater, but most developments will be improved in an incremental way. The general principle is clear, though: the scarcer the resource, the larger the investment in recovery. The amount of nutrients that can be gained from wastewater altogether may firstly be high for feedstock, followed by very scarce resources and those that can be filtered out in larger masses. To make use of wastewater as a source on a large scale will be the real breakthrough.

4.7.11 Asteroid Mining

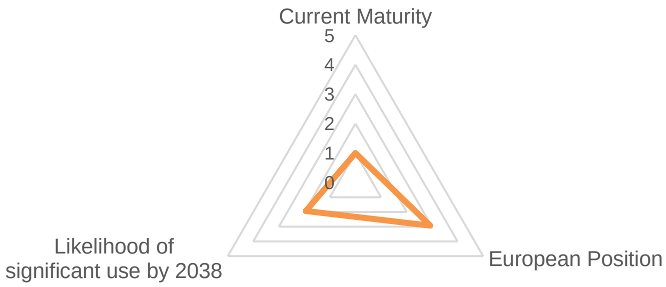

Figure 75: RIB Score of Asteroid Mining

Asteroid mining refers to harvesting raw materials from asteroids and other small celestial bodies, primarily near-Earth objects (NEOs), a category that also includes comets. The list of minerals that could, in principle, be exploited is quite large. Some would be worth transporting back to earth – gold, iridium, silver, osmium, palladium, platinum, rhenium, rhodium, ruthenium, or tungsten. Others could be used for in-space construction – iron, cobalt, manganese, molybdenum, nickel, aluminium, or titanium. The long-term challenges of such an enterprise include building the mining installations on NEOs and shipping the raw materials back to Earth.[863]

Recent progress directions

Asteroid detection

To mine an asteroid, the latter has first to be detected. Over the past two decades, space agencies have taken much better stock of near-earth asteroids. Though their total number is probably in the millions (including very small bodies), some 18,000 objects have been tracked and their orbits have been accurately charted.[864]

[863] https://en.wikipedia.org/wiki/Asteroid_mining
[864] https://www.space.com/41260-near-earth-asteroid-detection-video-nasa.html

Asteroid exploration

After detecting asteroids, their surface has to be explored. A number of recent developments have enhanced the ability to detect the raw materials available below the NEOs' surface. Thus, a California company intends to demonstrate a small, low-cost spacecraft for asteroid exploration by 2020 already. The plan is to equip the craft with instruments collecting data about asteroids' composition and 'dig-ability'. Other companies in the US and elsewhere are pursuing similar projects, and some countries have started offering incentives to these ends.[865]

While NASA plans a rendezvous with an asteroid for the end of 2018, Japan's Aerospace Exploration Agency has already landed two rovers on the surface of Ryugu, a 1-km large satellite, in 2018. A film of the surface has already been broadcast back to Earth and the first samples are scheduled to arrive at the end of this year.[866]

A solution that does not involve touchdown is to explore asteroids via satellites. The UK's first asteroid mining mission will launch a satellite by the end of 2020. The APS1 uses spectral scanning to determine if the asteroid is a 'viable candidates' for mining.[867]

In the meantime, India is looking closer to home: it plans to launch an exploration for nuclear material on the south side of the moon.[868]

Capturing minerals

A more risky-sounding idea is to deflect celestial bodies towards the earth "so our atmosphere can act as a giant catching mitt for resource-rich space rocks." The idea builds on aerobraking, the drag created by Earth's atmosphere, to slow down the asteroids and put them on an orbit close to the Earth, where they could be mined more easily.[869]

Long-term perspectives

As the Earth's mineral resources deplete, asteroids will provide a cache of essential materials that will not be available or will be increasingly harder to mine on our planet. According to the latest Goldman Sachs report, asteroid mining could be a trillion-dollar business.[870]

[865] https://www.theguardian.com/science/2018/jun/09/asteroid-mining-space-prospectors-precious-resources-fuelling-future-among-stars
[866] https://edition.cnn.com/2018/09/28/asia/japan-hayabusa-rovers-first-video-intl/index.html
[867] https://www.bbc.com/news/uk-scotland-scotland-business-45006938
[868] http://www.mining.com/web/quest-find-trillion-dollar-nuclear-fuel-moon/
[869] https://www.sciencemag.org/news/2018/08/asteroid-miners-could-use-earth-s-atmosphere-catch-space-rocks
[870] https://www.businessinsider.de/goldman-sachs-space-mining-asteroid-platinum-2017-4?r=UK&IR=T

Energy

4.8 Group 8. Energy

4.8.1 Bioluminescence

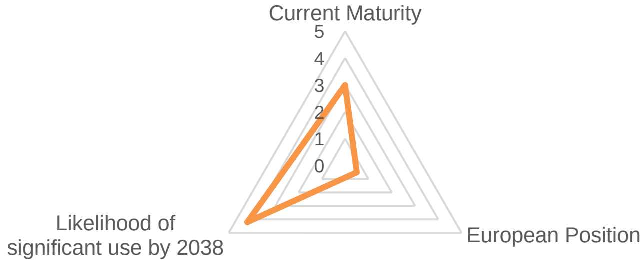

Figure 76: RIB Score of Bioluminescence

Bioluminescence is the natural ability of an organism to produce light. It is produced by a chemical reaction within the organism. Bioluminescence needs a molecule named luciferin and oxygen. When they react together, light is produced. There are different types of luciferin. Some organisms form a molecule of luciferin and oxygen called a photoprotein that is waiting to be triggered. Bioluminescence is found in some insects, fungi, bacteria and marine animals.[871] Researchers are currently trying to transfer bioluminescence and apply it in biology and medicine and in light production.

Recent progress directions

Glowing plants

A group of researchers at IMT want to create glowing plants that can replace electrical devices. They functionalized nanoparticles with luciferin, luciferase and co-enzyme A substances that make the fireflies glow, and inserted them into plants like watercress, arugula, kale, and spinach. They used 10 nm silica nanoparticles to carry luciferase and larger PLGA and chitosan nanoparticles to carry luciferin and co-enzyme A. The nanoparticles are inserted into the plant, where the silica nanoparticles enter the leaf’s cells, while the bigger nanoparticles remain in the extracellular space. They developed 10 cm watercress seedlings that could glow for 3.5 hours. The intensity of the light needs to be a thousand times more powerful in order to be enough to read by. Researchers want to optimize this process to make the plants glow brighter and to increase the duration of the light.[872]

Visualization of gene expression

A group of scientists from Vanderbilt University Institute of Imaging Science and Mass Spectrometry Research Center developed a new way of imaging invasive Staphylococcus aureus infection by combining magnetic resonance

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[871] http://oceanexplorer.noaa.gov/facts/bioluminescence.html
[872] http://news.mit.edu/2017/engineers-create-nanobionic-plants-that-glow-1213

imaging (MRI), mass spectroscopy and bioluminescence imaging (BLI). While MRI and mass spectroscopy reveal physical anatomy changes and specific molecules, respectively, bioluminescence imaging reveals in vivo changes in the gene expression of the bacteria. They can make use of BLI by utilizing a modified S. aureus strand that has bioluminescence. By using this method, they were able to identify which genes are expressed in different environments the S. aureus tries to colonize. Their research can be used for vaccine and therapeutic development.[873]

Brain imaging

A team of Japanese researchers led by Atsushi Miyawaki created AkaBLI, a bioengineered bioluminescence system that allows the imaging of cells in the brain and track the brain-cell activity. They used a synthetic luciferin molecule called AkaLumine-HCl that can penetrate the blood-brain barrier. They mutated the natural luciferase and obtained Akaluc protein, which is compatible with AkaLumine-HCL. Together these two molecules compose the AkaBLI system. This bioluminescent complex is 1000 times more potent than the natural luciferin-luciferase molecules. This method was used to track deep-brain neurons in mice and monkeys in order to better understand neural circuitry.[874]

Biosensors

Scientist at the University of Oxford genetically engineered bacteria that glow when exposed to certain proteins. They engineered Rhizobia bacteria so that it would become a biosensor that will let them know what certain molecules and where these molecules are produced by the root of a plant. They inoculated the modified Rhizobia bacteria in the pea plant. The bacteria were modified to glow when nitrogenase enzyme was present. Using this method, they can better study the importance of difference root secretions.[875]

Cancer detection

An international group of researchers used engineered mice to study metastases in cutaneous melanoma. They linked the expression of the vascular endothelial growth factor receptor 3 gene, expressed by expanding lymph vessel cells, with the production of luciferase, which makes lymph vessel cells bioluminescent. They used this method to understand the importance of the lymphatic vessels and to observe metastasis and if after their surgical removal, a recurrence was taking place.[876]

Long-term perspectives

Researchers are trying to transfer bioluminescence to different organisms like bacteria, plants, or mammals, in order to better understand different

[873] https://news.vanderbilt.edu/2018/03/15/imaging-unprecedented-views-staph-infection/
[874] https://www.sciencedaily.com/releases/2018/02/180222145018.htm
[875] https://www.the-scientist.com/?articles.view/articleNo/49494/title/Image-of-the-Day--Root-Rave-/
[876] https://www.the-scientist.com/?articles.view/articleNo/49759/title/Transgenic-Mouse-Illuminates-Melanoma-Metastasis/

physiological processes that could not be studied by now and to develop new imaging and research techniques. At the same time, they are working on developing new light sources that could decrease the current load on worldwide energy consumption.

4.8.2 Energy Harvesting

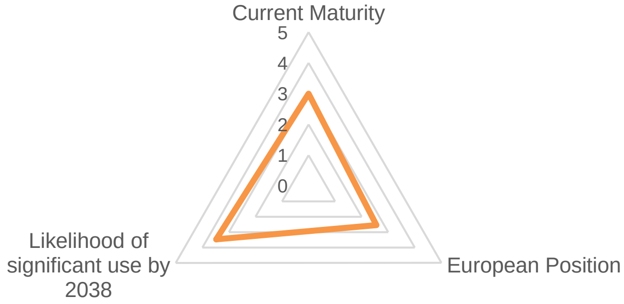

Figure 77: RIB Score of Energy Harvesting

Energy harvesting (terms such as "power harvesting", "energy scavenging", or "ambient power" are used synonymously) refers to the conversion, into practical quantities of electricity, of energy which is easily available in the environment, though typically in small quantities. Such small energy sources generate significantly less power than larger devices, such as solar panels or thermoelectric devices applied to large sources of heat. Nonetheless, "the energy captured is adequate for most wireless applications, remote sensing, body implants, RFID, wearables and other applications at the lower segments of the power spectrum." When the energy thus obtained is too low to power a device, it can extend its battery.[877]

The technologies which aim at capturing ambient energy sources include "mechanical devices designed to extract energy from vibrations and deformations; thermal devices aimed at pulling energy from temperature variations; radiant energy devices that capture energy from light, radio waves and other forms of radiation; and electrochemical devices that tap biochemical reactions".[878]

Recent progress directions

Biological motion

Many recent announcements in this field pertain to muscle motion. Scientists have created devices such as: an ultrathin flexible sheet that generates electricity from day to day human motion[879]; clothing that

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[877] https://www.allaboutcircuits.com/technical-articles/how-why-of-energy-harvesting-for-low-power-applications/
[878] https://news.vanderbilt.edu/2017/07/21/device-harvests-electricity-human-motion/
[879] https://news.vanderbilt.edu/2017/07/21/device-harvests-electricity-human-motion/

produces energy as we walk[880]; yarns that generate electricity when they are stretched or twisted[881]; "a light-weight device inspired by Chinese and Japanese paper-cutting arts" that captures and stores energy from body movements[882]; flooring which converts footsteps into electricity[883]; a system to harvest energy from simple motions like scrolling on your smartphone or touching your wearable watch.[884]

One low-cost device generates energy via mere gestures. It uses a Ferroelectret Nanogenerator (FENG) "that can operate an LCD touch screen, a bank of 20 LED lights and a flexible keyboard, all with a simple touching or press motion and without the aid of a battery".[885] Also, researchers have demonstrated the feasibility of harvesting biomechanical energy from the heart of a living animal and using it for radio data transmission.[886]

Bodily substances (and fluids)

Tapping into the chemical potential of living bodies, scientists have developed a very small biological computer powered by "the substance that provides energy to all the cells in our bodies, Adenosine triphosphate (ATP)."[887]

More practically, scientists at the U.S. Army Research Laboratory developed a nano-galvanic aluminium-based powder which, combined with water, produces a chemical reaction that outputs hydrogen, which in turn can be used to power fuel cells. This synthesized material spontaneously splits water into hydrogen. The researchers calculated that one kilogram of aluminium powder can produce 220 kilowatts. During tests, they also observed that when using urine as a water source, the chemical reaction occurred two times faster than with water. They hypothesized that this happens because of the electrolytes and the acidity of urine. The research team is now working on optimizing the process in order to offer future soldiers a renewable and lightweight energy source.[888]

A group of four teenage girls figured out a practical way of turning a litre of urine into six hours of electricity using a power generator that is commonly used in African houses. The process starts by putting the urine into an electrolytic cell, thus separating the hydrogen. The latter is then purified and enters a gas cylinder, where it is further pushed into a recipient that contains liquid borax to remove the moisture. Finally, the hydrogen enters the power generator where it is used as an affordable, renewable and

[880] http://www.euronews.com/2017/01/23/energy-generating-jackets-could-be-ready-to-wear-before-2023
[881] https://www.tasnimnews.com/en/news/2017/08/25/1501520/energy-harvesting-yarns-generate-electricity
[882] https://www.rdmag.com/news/2017/04/art-paper-cutting-inspires-self-charging-paper-device
[883] https://www.eurekalert.org/pub_releases/2016-10/uow-mos102016.php
[884] https://www.firstpost.com/tech/news-analysis/researchers-working-on-harvesting-energy-from-scrolling-to-help-charge-your-smartphone-3694599.html
[885] https://www.firstpost.com/tech/news-analysis/nano-energy-may-soon-help-us-harvest-energy-from-human-motion-to-charge-electronic-devices-3693985.html
[886] https://www.nanowerk.com/nanotechnology_articles/newsid=47306.php
[887] https://www.eurekalert.org/pub_releases/2016-02/mu-blb022616.php
[888] https://www.eurekalert.org/pub_releases/2017-09/uarl-asd091217.php

carbon-neutral fuel. Due to the explosion risk in using hydrogen as a fuel source, as a safety measure all the valves of the device are one-way.[889]

Other sources: wind, heat, radio signals

Using a combination of solar cells and fibre-based triboelectric (i.e. static electricity generated through rubbing) nanogenerators, scientists have developed a "hybrid-power textile" that generates electricity from both sunshine and flapping in the wind.[890] Another team has built a thermo-magneto-electric generator, a new type of thermal energy harvester designed to operate efficiently at everyday (low) temperature gradients.[891]

For sensor-based devices (e.g. smoke alarms, pollution sensors), low-power security camera or wearables, a commercial solution has been already announced: a system that harvests energy from radio frequency (RF) signals and turns it into usable, "perpetual" (albeit very low) power.[892]

Long-term perspectives

Efficient energy harvesting techniques promise a variety of systems requiring minimum or no maintenance and powered by readily available matter in our immediate environment. This promises: virtually unlimited functioning for wireless sensor networks used in pollution, weather, fire, corrosion, structural and health monitoring; prolonged life for smartphone batteries; self-powered medical implants; battery-free wearables; colour-changing smart clothes; install-and-forget home automation or IoT devices – and many other similar small but common gadgets whose combined power consumption is actually very large.

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889 http://russelsmithgroup.com/innovation-lives-here/four-african-girls-create-generator-uses-urine-fuel/

890 http://www.dailymail.co.uk/sciencetech/article-3790028/Charging-phone-soon-breeze-New-fabric-harvests-energy-wind-sun-create-electricity.html?ITO=1490&ns_mchannel=rss&ns_campaign=1490

891 https://www.technology.org/2017/03/06/powered-by-magnets-energy-harvester-converts-wasted-heat-into-electricity/

892 http://www.impactlab.net/2016/04/04/want-to-generate-power-out-of-thin-air-freevolt-may-have-the-answer/

4.8.3 Harvesting Methane Hydrate

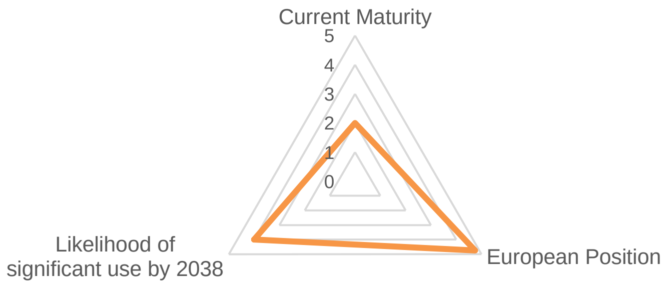

Figure 78: RIB Score of Harvesting Methane Hydrate

Methane hydrate is an "ice" that only occurs naturally in subsurface deposits where temperature and pressure conditions are favourable for its formation.[893] Methane hydrate deposits within national territorial waters represent a promising source of energy for the future, especially for countries that depend on imports of gas, coal and oil for a large share of their energy needs. However, the necessary technology for industrial exploitation of the hydrates is not yet available. Following successful test wells on land, initial research projects are now being carried out in the ocean, particularly in South-East Asia. Accordingly, the Japanese and the Korean Foresight have harvesting methane hydrate on the future agenda.[894]

In addition to abundant minerals, there are large amounts of methane hydrate beneath the sea floor. Some countries hope to become independent of energy imports by exploiting marine gas hydrate deposits near their own coasts. The technology for production, however, is not yet available. Furthermore, the risks to climate stability and hazards to marine habitats associated with extraction of the methane hydrates must first be clarified.[895]

Recent progress directions

Methane Hydrate Gas extraction from an ice-like substance in China

Being more an aspiration than a real technology for a long time, there are new developments: China has for the first time extracted gas from an ice-like substance under the South China Sea considered key to future global energy supply.[896] "It looks like ice crystals but if you zoom in to a molecular level, you see that the methane molecules are caged in by the water

[893] https://geology.com/articles/methane-hydrates/, accessed 20/9/2018
[894] KISTEP (2017): Delphi Survey, Seoul, and NISTEP (2015): The 10th Science and Technology Foresight, Report no. 164, Tokyo, http://data.nistep.go.jp/dspace/bitstream/11035/3079/2537/NISTEP-NR164-SummaryE.pdf.
[895] https://worldoceanreview.com/en/wor-3/methane-hydrate/ accessed 20/9/2018
[896] http://www.bbc.com/news/world-asia-china-39971667; https://www.geomar.de/news/article/methanhydrat-das-brennende-eis/; https://www.welt.de/wissenschaft/article164875577/Brennendes-Eis-soll-die-Energie-der-Menschheit-revolutionieren.html

molecules," Associate Professor Praveen Linga from the Department of Chemical and Biomolecular Engineering at the National University of Singapore told the BBC.[897]

Officially known as methane clathrates or hydrates, they are formed at very low temperatures and under high pressure. They can be found in sediments under the ocean floor as well as underneath permafrost on land. Despite the low temperature, these hydrates are flammable. If you hold a lighter to them, the gas encapsulated in the ice will catch fire. Hence, they are also known as "fire ice" or "flammable ice". By lowering the pressure or raising the temperature, the hydrates break down into water and methane. One cubic metre of the compound releases about 160 cubic metres of gas, making it a highly energy-intensive fuel.

Energy from methane hydrate gas on a large scale

Since it has been known that a gigantic supply of methane hydrates is stored in the oceans, methane hydrate is more than a scientific object. It is in the focus of governments and energy companies for exploiting on a large scale. Methane is a much sought-after energy source. Current estimates suggest that the amount of fossil fuel potentially available from methane hydrates far exceeds that from crude oil, coal and classically produced natural gas. However, the figures vary because there are different models for calculating the methane hydrate volumes. Figures between 100 and 530,000 gigatons of carbon can be found. By way of comparison, the remaining reserves of fossil fuels, crude oil and coal, are estimated at around 5,000 gigatons. However, only a very small proportion of gas hydrates could actually be used as a source of energy, as many deposits are inaccessible or technically impracticable for extraction. A sense of proportion is also required here so that no unwanted side effects such as tsunamis or the release of methane are caused during degradation.[898]

Long-term perspectives

Today, we are just beginning to understand the complex systems linked to marine gas hydrate deposits. If it is exploited it may become a "game changer".[899] The majority of the gas hydrate deposits are located far below the sea surface and can only be reached by drilling platforms and deep-sea drilling vessels. The deeper you go, the greater the technical effort.[900] The expectations of being able to harvest methane hydrate are very high - because the amount of energy that can be harvested might be very high and you do not have to drill that deep. But the risks are also high: until now, there is no technology available for full-scale harvesting of this energy because methane is unstable. As methane is flammable and when exploiting it, methane escapes into the air via leakages causing more greenhouse effect, which makes it a risky technology[901] with many potential impacts (positive and negative). Among the negative (side) impacts single large

[897] http://www.bbc.com/news/world-asia-china-39971667
[898] https://www.geomar.de/news/article/methanhydrat-das-brennende-eis/, accessed 20/9/2018
[899] https://geology.com/articles/methane-hydrates/ accessed 20/9/2018
[900] https://www.geomar.de/news/article/methanhydrat-das-brennende-eis/, accessed 20/9/2018
[901] https://science.howstuffworks.com/environmental/green-tech/energy-production/frozen-fuel4.htm, accessed 20/9/2018

fires, an increased introduction of the climate effective gas methane, harm to coasts or even eroding of coasts are expected.

There is a famous novel on this topic in Germany warning and illustrating what kind of global effects might occur if such kind of technology is in full application[902] and even more if methane hydrate is exploited in large amounts.

4.8.4 Hydrogen Fuel

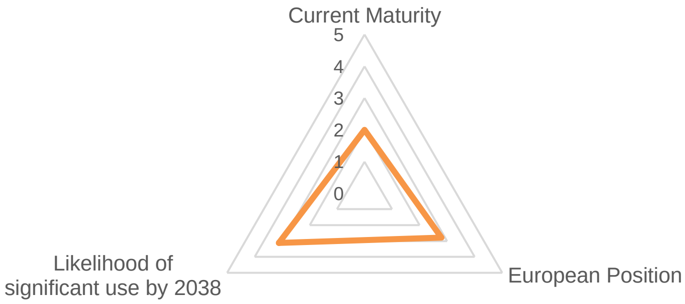

Figure 79: RIB Score of Hydrogen fuel

The gravimetric energy density of hydrogen is about three times that of fossil fuels, rendering it excellent for combustion engines, as the hydrogen burns highly exothermically in the atmospheric air, releasing water, hydrogen peroxide and small amounts of nitrogen oxides. An alternative way to exploit hydrogen as a fuel is in the hydrogen fuel cell (a type of electrochemical cell), where the hydrogen reacts with the oxygen creating a flow of electrons that can be collected as electric current in an external circuit. Only the water results as a by-product. Thus, hydrogen fuel cells represent an alternative energy source to carbon-based fuels, with no environmental impacts. Hydrogen fuel cells are very attractive for vehicle propulsion, and most big car companies are trying to adapt to this new technological solution. The production, storage and transportation of the hydrogen, as well as its usage as a fuel, are important steps in the exploitation of this alternative source of energy.

However, while abundant, in a pure state hydrogen is limited and needs a substantial amount of energy and expensive materials to be produced at industrial scale. Research efforts are therefore being invested for the development of clean, safe, efficient and cost-effective technological solutions for the production, storage, transportation and exploitation of the hydrogen.

[902] Schätzing, F. (2005): Der Schwarm (The Swarm).

Recent progress directions

Production

Researchers discovered that the microalgae produce hydrogen continuously by photosynthesis and succeeded to increase the hydrogen production by effective mechanisms of oxygen removal.[903]

Belgian scientists have created a photoelectrochemical cell that, in the presence of sunlight, generates hydrogen gas and purifies the air at the same time.[904]

A stable high-strength aluminium alloy has been developed on whose surface water bubbles are produced that result in hydrogen gas. The effect could be used to produce hydrogen on demand, without using catalysts or high temperatures and avoiding the problems related to hydrogen production, storage and transportation.[905]

An international research team produced hydrogen from water using photosensitive protein inserted in titanium dioxide photocatalysts. The hydrogen is released when the photocatalyst is dissolved in water and mixed with platinum under sunlight. The team observed a very high hydrogen production under white light.[906]

Another team "has shown that hydrocarbon wax rapidly releases large amounts of hydrogen when activated with catalysts and microwaves".[907]

Finally, a gas separation membrane reactor has been developed for clean, cheap production of compressed hydrogen from methane.[908]

Storage

Researchers at the Berkeley Lab embedded magnesium nanocrystals with graphene sheets. The latter shield the nanocrystals from oxygen, moisture and contaminants, while letting hydrogen molecules pass through. "These graphene-encapsulated magnesium crystals act as "sponges" for hydrogen, offering a very compact and safe way to take in and store it."[909]

Hydrogen-powered vehicles

Riversimple, a British company, announced the manufacturing of the aerodynamic car Rasa that weighs only 580 kilograms and is hydrogen-powered with zero emissions. The braking system converts mechanical energy into electricity, which is stored in fast charging super-capacitors. The

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[903] http://www.technology.org/2016/10/09/harnessing-algae-creation-clean-energy/

[904] http://www.dailymail.co.uk/sciencetech/article-4488336/New-device-generates-POWER-polluted-air.html

[905] https://futurism.com/hydrogen-fuel-could-become-a-viable-energy-alternative-thanks-to-this-aluminum-alloy

[906] https://futurism.com/scientists-produced-hydrogen-fuel-with-nothing-but-light-and-fats

[907] https://www.eurekalert.org/pub_releases/2016-10/uoo-sns102016.php

[908] https://www.eurasiareview.com/10122017-producing-hydrogen-from-methane-in-cleaner-cheaper-way

[909] http://www.eurekalert.org/pub_releases/2016-03/dbnl-nfc031116.php

stored electric energy is used by the engine to accelerate when necessary.[910]

Long-term perspectives

Hydrogen is the most abundant element. A hydrogen-based economy promises industries and households powered by this pollution-free fuel rather than the fossil variety. Furthermore, the fuel would be generated from renewables through sources that are local or even domestic. In this world, transportation would be virtually clean - as well as cheap.

4.8.5 Marine and Tidal Power Technologies

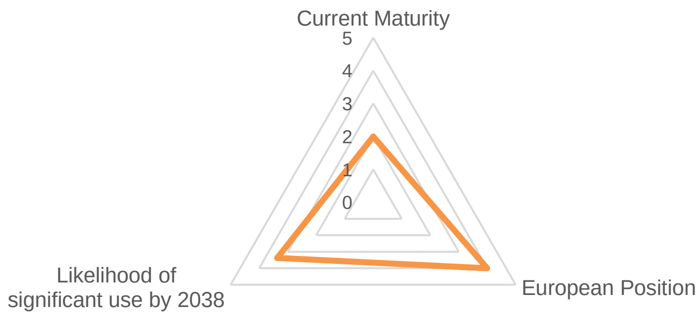

Figure 80: RIB Score of Marine and tidal power technologies

The oceans of the earth offer vast amounts of renewable energy. Technologies to harness the power of the seas are at an early stage of development still. Even the most advanced of them, tidal current and ocean wave, face considerable barriers.[911] In different Foresight surveys, the exploitation of marine energy is very high on the agenda because harvesting energy may be possible on a large scale.[912]

Recent progress directions

New technologies for tidal and wave energy harvesting

Tidal and wave energy represent the two most advanced types of ocean energy technologies. The EU's goal is to install 100 GW of combined wave and tidal capacity by 2050. "In order to achieve these targets, the sector needs to overcome a series of challenges and barriers with regards to technology readiness, financing and market establishment, administrative and environmental issues and the availability of grid connections especially

910 https://www.theregister.co.uk/2016/02/18/brit_hydrogen_powered_car
911 https://renewablenw.org/node/wave-tidal-energy-technology; http://creativecommons.org/licenses/by-nc-nd/4.0/
912 http://www.oecd.org/sti/oecd-science-technology-and-innovation-outlook-25186167.htm; p. 43; NISTEP (2015): The 10th Science and Technology Foresight, Report no. 164, Tokyo, http://data.nistep.go.jp/dspace/bitstream/11035/3079/2537/NISTEP-NR164-SummaryE.pdf

in remote areas."[913] Currently, these barriers are hindering the sector's progress; its ability to attract inwards investments and to engage with the supply chain to unlock cost-reduction mechanisms.[914]

Most past attempts had different success and tried to exploit energy directly from waves, tides, marine currents, thermal gradients, and differences in salinity. Wave-energy extraction still seems to be the most promising way because they are more constant and more predictable than wind or sunlight.[915]

In order to avoid large-scale investments, new small-scale technologies are proposed. One is to fix a system of buoys (or 'floaters') and generators to existing marine structures. This is possible with breakwaters, jetties and parts of disused wartime ports, which are all out of the way of most underwater creatures and not as vulnerable to storms, etc. because they are more flexible (e.g. by uplifting).[916] SRI Internationally also tested a so-called artificial muscle to generate power from the motion of a buoy riding up and down the waves.[917] Fully functional buoy systems are intended to be installed at Chinese coasts.[918] Generally, the buoys are placed in water depths of 100 to 200 feet, before the waves start to break and dissipate their energy, at about one to three miles offshore. Thus, the wave parks cannot or can only partly be seen from the beach.[919]

At Oregon State University, novel direct-drive generators were tested, where the buoy's velocity and force is directly coupled to the generator without the use of hydraulic fluid or air. They are more simple and the generators respond directly to ocean movement by employing magnetic fields for contactless mechanical energy transmission and power electronics for efficient electrical energy extraction.[920] Other options are new piezoelectric technologies to support better energy exploitation.[921]

Long-term Perspectives

Several "policy initiatives and mechanisms have been put in place to ensure that ocean energy technologies could become cost-competitive in the short term, in order to exploit the benefits that these technologies could provide

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913 https://renewablenw.org/node/wave-tidal-energy-technology; http://creativecommons.org/licenses/by-nc-nd/4.0/

914 Scruggs, J and Jacob, P.: Harvesting Ocean Wave Energy, in: Science 27 Feb 2009, Vol. 323, 5918, pp. 1176-1178. DOI: 10.1126/science.1168245

915 https://www.asme.org/engineering-topics/articles/renewable-energy/harvesting-the-power-of-the-ocean

916 https://www.wired.co.uk/article/eco-wave-power-ocean-energy-harvesting-renewable, see also https://www.technologyreview.com/s/408557/harvesting-power-from-the-ocean/

917 https://www.technologyreview.com/s/408557/harvesting-power-from-the-ocean/

918 https://www.wired.co.uk/article/eco-wave-power-ocean-energy-harvesting-renewable

919 https://www.asme.org/engineering-topics/articles/renewable-energy/harvesting-the-power-of-the-ocean

920 https://www.asme.org/engineering-topics/articles/renewable-energy/harvesting-the-power-of-the-ocean; https://www.technologyreview.com/s/408557/harvesting-power-from-the-ocean/

921 Nguyen, V.; Wu, N.; Wang, Q. (2017): A review on energy harvesting from ocean waves by piezoelectric technology, DOI: · 10.1515/jmmm-2016-0161

to the EU."[922] New hydroelectricity technologies are seen as trend technologies in the UK and Russia.[923] In Japan, other marine resources from the sea are in the forefront. For harvesting large amounts of energy, wave energy exploitation with wave parks seems to be the most promising approach. Using buoys and other more flexible technologies is a promising option for small-scale investments, testing and avoiding vulnerabilities. In the long run, the amount of energy harvested may also increase because of new generator technologies.[924]

4.8.6 Microbial Fuel Cells

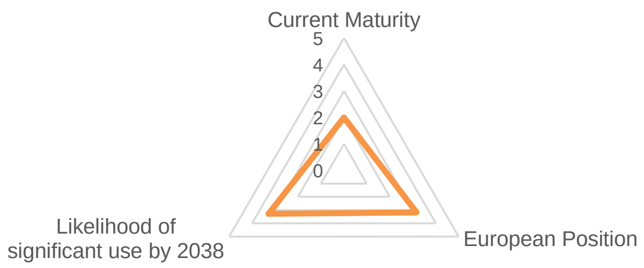

Figure 81: RIB Score of Microbial fuel cells

The microbial fuel cell (MFC) is a bio-electrochemical system that mediates the transfer of electrons from bacteria to the anode of the cell. Just like any standard fuel cell, the MFCs consist of anode and cathode chambers separated by a proton exchange membrane (PEM).[925] The bacteria grow and proliferate, forming a dense cell aggregate (a biofilm) which that adheres to the MFC's anode.[926] The role of the expensive transition metal catalyst is taken by the bacteria that act at the anode as active biocatalyst by oxidization of the organic substrates and produce carbon dioxide, protons and electrons. The protons are conducted to the cathode chamber through the PEM and the electrons flow through an external circuit from anode to cathode, generating electricity.

Bacteria are everywhere, in air, soil, plants, algae, animals and in-house dust, but also in the municipal, manufacturing and agricultural waste. Thus, the waste can be converted by MFCs into clean energy. Because of the low efficiency and the high costs of the component materials, microbial fuel cell technology is currently still in the development stage.

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922 https://renewablenw.org/node/wave-tidal-energy-technology

923 This was a big issue in some Foresight studies, e.g. http://www.oecd.org/sti/oecd-science-technology-and-innovation-outlook-25186167.htm; NISTEP (2015): The 10th Science and Technology Foresight, Report no. 164, Tokyo, http://data.nistep.go.jp/dspace/bitstream/11035/3079/2537/NISTEP-NR164-SummaryE.pdf; KISTEP (2017): Delphi Survey, Seoul; https://issek.hse.ru/en/news/204251974.html

924 Nguyen, V.; Wu, N.; Wang, Q. (2017): A review on energy harvesting from ocean waves by piezoelectric technology, DOI: · 10.1515/jmmm-2016-0161

925 https://www.sciencedirect.com/science/article/pii/S1110016815001635

926 https://biodesign.asu.edu/news/waste-watts-improving-microbial-fuel-cells

Recent progress directions

New catalysts

A low-cost cathode catalyst was developed based on carbon cloth with a nitrogen-doped aerogel made of glucose and an egg white protein, which replaced the precious platinum.[927] The miniaturization of the cell achieved by reducing the anode-to-cathode distance increased the surface area-to-volume ratio, offering an improvement of the fuel cell's efficiency.

Researchers in the United States developed, through atomic-scale control of nanoscale materials, new jagged nanowire catalysts, which are very active and "dramatically reduce the amount of precious metal used as catalysts in fuel cells and thus lower their cost".[928] Moreover, the wires have a high surface area and extraordinary surface activity, which increases the fuel cell's performance.[929]

Paper – cheap material for electrodes

A team of researchers at the University of Rochester have developed an electrode using a common and cheap material, paper, which replaces the metals (which rapidly corrodes) or the carbon felt (which is prone to clogging). The paper is lined with a mixture of mineral oil and graphite (carbon paste). "The carbon paste-paper electrode is not only cost-effective and easy to prepare; it also outperforms the carbon felt. The specific bacterium used, Shewanella oneidensis MR-1, consumes the toxic heavy metal ions in the wastewater and ejects electrons. The electrode is created as a layered sandwich of paper, carbon paste, a conducting polymer and a film of the bacteria."[930,931]

Another team of researchers has developed "a new high-performance, paper-based battery powered by saliva which can be used in extreme conditions where normal batteries do not function".[932] The battery is created by "inactive, freeze-dried cells which generate power within minutes of adding saliva".[933] Compared to typical power storage and generation technologies, this device is suitable for extreme environments or situations, as it only needs a readily available biological fluid.

Wearable energy devices

British researchers developed a foot-pumped urine-powered wearable MFC and used it to power a wireless transmitter. "MFCs embedded within a pair

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927 http://www.electronicsweekly.com/news/research-news/low-cost-fuel-cell-dines-on-urine-2016-04

928 http://newsroom.ucla.edu/releases/changing-fuel-cell-catalyst-shape-would-dramatically-increase-efficiency-lower-cost

929 http://www.technology.org/2016/11/19/changing-fuel-cell-catalyst-shape-dramatically-increase-efficiency-lower-cost

930 https://www.eurekalert.org/pub_releases/2017-02/uor-bab020617.php

931 http://www.rochester.edu/newscenter/building-a-better-microbial-fuel-cell-using-paper/

932 https://www.binghamton.edu/news/story/709/new-battery-is-activated-by-your-spit

933 http://indianexpress.com/article/technology/science/now-paper-based-battery-powered-by-your-saliva-4790606

of socks were supplied with fresh urine, circulated as the human operator was walking".[934] The pump consisted of a trivial fish circulatory system and it was driven by the body movements specific to walking, which pushed the urine on the MFCs. "Soft tubes, placed under the heels, ensured frequent fluid push-pull by walking. The wearable MFC system successfully ran a wireless transmission board, which was able to send a message every two minutes to the PC-controlled receiver module".[935,936]

Urine-into-electricity

Scientists at the University of the West of England created a microbial fuel cell whose anode and a cathode are colonized by bacteria that catalyse the decomposition of organic materials in urine. The process can generate sufficient energy to power light bulbs or LED tubes. They designed a prototype placed at a urinal at Glastonbury festival, where it was used by a thousand users per day. The prototype included 432 microbial fuel cells which generated 300mW. Future plans involve testing the urinals in some regions in Africa, in refugee camps, schools and public toilets that lack lighting.[937]

Long-term perspectives

The big advantage of MFC over other fuel cell technologies is that it could reduce environmental damage by simultaneously treating waste and producing clean energy. The technology "still faces practical barriers, the low power and current density, due to the high internal resistance, the turbulence in each compartment, the membrane resistance in the proton transportation process and the low efficiency of the cathode reaction".[938] Massive research efforts are necessary to make the MFCs more efficient, stable and cheaper before it is widely adopted.

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[934] https://info.uwe.ac.uk/news/uwenews/news.aspx?id=3246
[935] http://www.laboratoryequipment.com/news/2015/12/wearable-energy-generator-uses-urine-power-wireless-transmitter
[936] http://www.swinnovation.co.uk/tag/research/
[937] https://phys.org/news/2016-07-urinal-electricity-urine.html
[938] https://www.sciencedirect.com/science/article/pii/S1110016815000484

4.8.7 Molten Salt Reactors

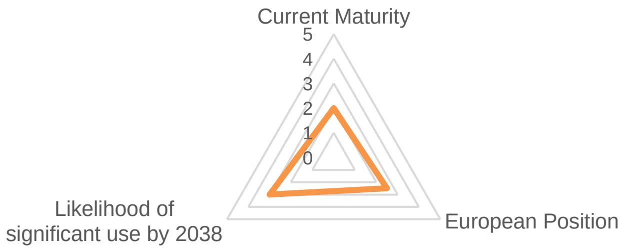

Figure 82: RIB Score of Molten Salt Reactors

A molten salt reactor (MSR) is a nuclear reactor which uses a molten salt mixture in the form of a very hot chloride or fluoride. Since it is liquid, the molten salt can serve both as the fuel producing the heat and as the coolant which carries the heat to electrical generators. In principle, this makes the MSR design simpler and safer than the conventional nuclear reactors featuring solid fuels and water coolants.

Although the concept of molten salt reactors was researched and developed in the 1950s and 1960s in the USA, it was largely abandoned by the 1970s in favour of competing nuclear technologies. Since early 2000s, there has been renewed interest and investment in MSR technology – and, particularly, in the Liquid Fluoride Thorium Design, which uses thorium and uranium dissolved in a fluoride salt.

The proponents of molten salt reactors describe them as inherently safe, sustainable and efficient. Unlike conventional reactors, where the melting of solid fuel rods could result in uncontrolled fission with catastrophic effects, MSRs cannot melt, since they are molten by design. (In addition, the fuel salt is not reactive with air or water.) MSR advocates claim these reactors do not have a long-term radioactive waste problem, although it's not yet clear what form the nuclear waste will take in this case. Moreover, studies have suggested that thorium-based MSR technology could enable the thermal burning of radioactive waste and thus alleviate the nuclear storage problem.

Despite its advantages, which still need to be proven practically, the MSR technology also poses a number of challenges, such as designing containment vessels which resist corrosion.

Recent progress directions

In the summer of 2017, Dutch researchers at the Nuclear Research and Consultancy Group (NRG) have begun tests on the safety of thorium molten salt reactors, in what has been billed as the first experiment of its kind for the first time in over 40 years.[939] The suite of tests is run under the SALIENT

[939] https://www.nextbigfuture.com/2017/08/nuclear-thorium-molten-salt-experiments-started-in-europe.html

moniker, which stands for SALt Irradiation ExprimeNT. Initially, the NRG team is testing several reactor setups on a small scale. The first experiment involves a waste-burning molten-salt fast reactor with a lithiumflouride/thoriumfloride material mixture. Its goal is to determine if the noble metals which form during the uranium fission reactions enable the cleaning of the salt. Subsequent experiments will focus on different material mixtures, further testing the ability of containment materials to resist chemical corrosion when interacting with salt. Corrosion resistance is a critical property, as the materials must be able to resist chemical corrosion and intense radiation.

In November 2017, the Canadian Nuclear Safety Commission (CNSC) notified Terrestrial Energy Inc., a Canadian advanced nuclear reactor company, that it successfully completed the first phase of the CNSC's pre-licensing vendor design review for its new Integral Molten Salt Reactor (IMSR) nuclear power plant design.[940] In March 2018, Terrestrial Energy signed a fuel testing contract with the European Commission's Joint Research Centre in Karlsruhe, Germany. And, in April 2018, Terrestrial signed an agreement with Energy Northwest to build and operate an IMSR at a site at the Idaho National Laboratory in south eastern Idaho.[941] While these announcements could be regarded as just the initial steps in a long R&D and regulatory process, they allow Terrestrial to advance its IMSR technology, through collaborative efforts, beyond the initial conceptual design. The Canadian company hopes to make its technology commercially available in the 2020s.

In December 2017, China announced that it will spend 22 billion yuan (3.3 bn USD) to build two prototype molten salt nuclear reactors at Wuwei in Gansu province.[942] The reactors, designed as testbeds for MSR technology developed in China since 2011, are planned to be ready for testing in 2020. The building of the Gansu reactors fits within a highly ambitious roadmap which targets commercial deployment of thorium-breeding molten-salt reactors in 2030s.[943] Using thorium as the main fuel makes economic sense for China, as it has some of the world's largest reserves of this chemical element.

A couple of other countries, including India and Indonesia, are also engaged in preliminary work on molten-salt reactors.

Long-term Perspectives

In the quest for clean and efficient energy, molten salt reactors face competition from a number of emerging technologies, such as renewables or fusion reactors.

[940] http://www.world-nuclear-news.org/NN-Integrated-Molten-Salt-Reactor-passes-pre-licensing-milestone-0911177.html
[941] http://www.world-nuclear-news.org/NN-Companies-team-up-to-site-IMSR-in-Idaho-3103187.html
[942] https://www.nextbigfuture.com/2017/12/china-spending-us3-3-billion-on-molten-salt-nuclear-reactors-for-faster-aircraft-carriers-and-in-flying-drones.html
[943] http://www.world-nuclear.org/information-library/current-and-future-generation/molten-salt-reactors.aspx

4.8.8 Smart Windows

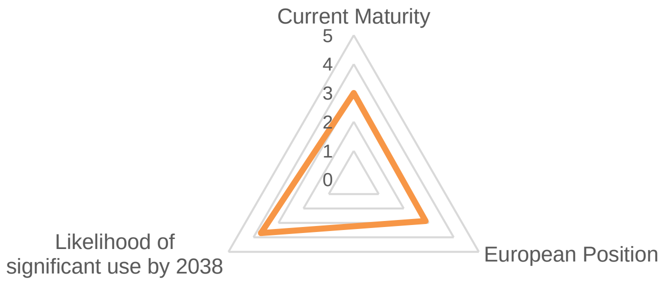

Figure 83: RIB Score of Smart windows

Smart windows can harness solar power and turn it into electric power, and, with the help of other technologies incorporated between the glass sheets or covering the glass itself, regulating the building's need for heat or air conditioning.

These windows use smart glass for which "light transmission properties are altered when voltage, light or heat is applied. Generally, the glass changes from translucent to transparent, changing from blocking some (or all) wavelengths of light to letting light pass through."[944]

Recent progress directions

Electrochromic materials

"Electrochromic materials[945], which change colour and transparency in response to an applied voltage, can be used to help windows switch from transparent to opaque, potentially saving energy by blocking sunlight on hot days and thus reducing air-conditioning costs."[946] As electrochromic materials have a slow response time, leading to very gradual changes in level of opacity, researchers use "sponge-like materials called metal-organic frameworks (MOFs), which can conduct both electrons and ions at very high speeds"[947], thus increasing the response time.

"The new material is made by combining two chemical compounds, an organic material and a metal salt. Once mixed, these self-assemble into a thin film of the switchable material. No extra power is needed until the switch is flipped to turn the material back to its former state, whether clear or opaque. This contrasts with many existing electrochromic materials that require a continuous voltage input. In addition to smart windows, the material could also be used for low-power displays whose properties are somewhat similar to electronic ink (used in devices such as the Kindle and

944 https://en.wikipedia.org/wiki/Smart_glass
945 http://www.nanowerk.com/nanotechnology-news/newsid=44216.php
946 http://news.mit.edu/2016/self-shading-windows-0811
947 http://news.mit.edu/2016/self-shading-windows-0811

based on MIT-developed technology), but based on a completely different approach."[948]

Nanomaterial coating

A smart window coating[949], also aimed at controlling the light going through glass, could be far easier and cheaper to apply than traditional methods. A plastic film with a unique nanostructure doubles the efficiency of the darkening process. It can be made at low temperatures, and can switch between clear and tinted modes more quickly, using less power, than the traditional high-temperature process. In testing, the team created a flexible coating that can be lightened or darkened with a small electric charge of about 4 volts. The transmission of heat through the glass can be controlled by applying that coating to glass.

Liquid crystal sandwich

For privacy and light control on demand via one's windows, "researchers created a new smart window by sandwiching a polymer matrix containing microdroplets of liquid crystal materials and an amorphous silicon layer - the type often used in solar cells - between two glass panes. When the window is "off," the liquid crystals scatter light, making the glass opaque. The silicon layer absorbs the light and provides the low power needed to align the crystals so light can pass through and make the window transparent when the latter is turned "on" by the user. The extra energy that doesn't go toward operating the window is harvested and could be redirected to power other devices, such as lights, TVs or smartphones."[950]

Exploiting near-UV

By absorption of near-ultraviolet light, solar cells lead the new windows completely self-powered. "The smart window controls the transmission of visible light and infrared heat into the building, while the new type of solar cell uses near-UV light to power the system.

Because near-UV light is invisible to the human eye, researchers set out to harness it for the electrical energy needed to activate the tinting technology. Using near-UV light to power these windows means that the solar cells can be transparent and occupy the same footprint as the window without competing for the same spectral range or imposing aesthetic and design constraints."[951] The organic semiconductors -- contorted hexabenzocoronene (cHBC) derivatives -- used for the solar cells were chosen because "their chemical structure can be modified to absorb a narrow range of wavelengths -- in this case, near-UV light. To construct the solar cell, semiconductor molecules are deposited as thin films on glass with the same production methods used by organic light-emitting diode (OLED)

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[948] http://news.mit.edu/2016/self-shading-windows-0811

[949] http://www.techradar.com/us/news/world-of-tech/smart-windows-a-step-closer-to-arriving-in-your-home-1326940?src=rss&attr=all

[950] https://phys.org/news/2016-11-solar-smart-window-privacy-demand.html

[951] https://engineering.princeton.edu/news/2017/06/30/self-powered-system-makes-smart-windows-smarter

manufacturers. When the solar cell is operational, sunlight excites the cHBC semiconductors to produce electricity. At the same time, the researchers constructed a smart window consisting of electrochromic polymers, which control the tint, and can be operated solely using power produced by the solar cell. When near-UV light from the sun generates an electrical charge in the solar cell, the charge triggers a reaction in the electrochromic window, causing it to change from clear to dark blue. When darkened, the window can block more than 80 percent of light."[952]

Nanocrystals

"A thin coating of nanocrystals embedded in glass can dynamically modify sunlight as it passes through a window. Unlike existing technologies, this coating provides selective control over visible light and heat-producing near-infrared (NIR) light. Thus, windows can maximise both energy savings and occupant comfort in a wide range of climates."[953]

Long-term perspectives

Although costs still keep smart windows from being widely adopted for the existing buildings, large office buildings and other large-scale constructions with glass facades can get to use the power harnessed from the sun. This will ease the energy bills of the buildings and the carbon footprint of the businesses.

As soon as mass production starts, smart windows will be essential to "smart home" design. For the moment, most of the breakthroughs described are at the prototype level, waiting to be scaled up.

4.8.9 Thermoelectric Paint

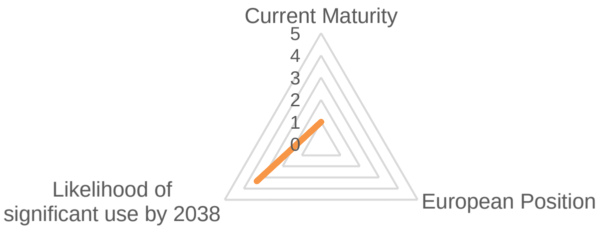

Figure 84: RIB Score of Thermoelectric paint (please note that data on the European position are not available)

Thermoelectricity works by converting temperature differences to electric voltage – and the other way around. To achieve this effect, however, thermoelectric materials have to be applied to the objects that act as heat

[952] https://engineering.princeton.edu/news/2017/06/30/self-powered-system-makes-smart-windows-smarter
[953] https://foresight.org/nanocrystal-in-glass-composite-controlled-by-voltage/

source. Since the traditional solution uses solid-state devices for this purpose, it has typically been reserved for objects with flat surfaces.

As many heat-giving objects do not have large plane exteriors, however, the traditional thermoelectric designs would be inefficient in these cases. So far, one solution has been flexible thermoelectric materials. These generate additional design/efficiency constraints, although they have shown promise in products such as wearables.[954] The ideal material would be amenable for all types of surface – that is, it would be liquid and sticky.

Recent progress directions

Photovoltaic paint

A liquid, paint-like thermoelectric material that can be moulded to cover non-flat surfaces has been recently announced by a team of Korean materials scientists. They have developed photovoltaic paints that can be used to make "paint-on solar cells" with an average output of 4 mW/cm^2. While the level of output is not in itself ground-breaking,[955] the fact that the material can cover large surfaces of any shape makes it a potential efficiency champion.

The paint contains thermoelectric particles of bismuth telluride (Bi2Te3) and Sb2Te3 (antimony telluride). Telluride is commonly used in conventional thermoelectric devices. The researchers also added molecular sintering aids which, on heating, cause the thermoelectric particles to coalesce, increasing their density in the paint. This brings about greater energy conversion efficiency.[956]

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954 https://newatlas.com/wearable-thermoelectric-generator/31617/
955 https://phys.org/news/2016-11-thermoelectric-enables-walls-electricity.html
956 http://www.cleantechconcepts.com/2016/12/thermoelectric-paint-recovers-electricity-from-waste-heat

Long-term perspectives

Thermoelectric paint can turn any heat source into a generator of electricity. It can also shield interior spaces from external heat, such as that of the sun, reducing the need for additional cooling. Easy application on any surface raises that hope that common objects that such as buildings or vehicles would be covered one day in electricity-generating paint. This would save vast amounts of the energy that is today wasted as heat.

4.8.10 Water Splitting

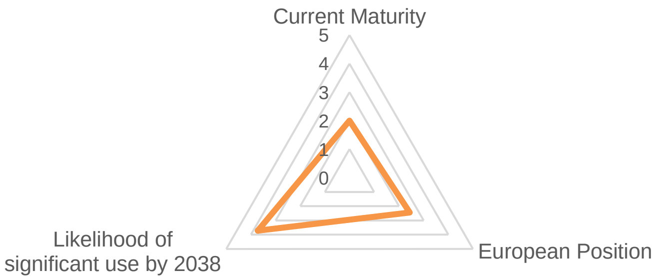

Figure 85: RIB Score of Water Splitting

Water splitting refers to a chemical reaction in which water is separated into hydrogen and oxygen. This conversion process is potentially important for clean energy: it can open the way to widespread use of hydrogen, which is both a zero-emission fuel and can be efficiently stored on a large scale. Currently, there are many diverse methods of achieving water splitting. However, they are highly complex, rather inefficient, and/or very expensive to implement.

Research in this area focuses on improving technologies to make water splitting easier and more affordable to implement. This would improve access to renewable energy. Additionally, research aims to expand the uses of the chemical reaction.

Recent Progress directions

New Catalysts

Electrocatalytic water splitting technology relies on rare metal (e.g. platinum, ruthenium) oxide catalysts, limiting large-scale applications due to their cost/scarcity.[957] Researchers have developed other new catalysts to solve this problem. Corroded stainless steel plates proved, for example, suitable as an efficient, low cost, stable electrode.[958]

[957] http://www.nanowerk.com/spotlight/spotid=45103.php
[958] http://www.asianscientist.com/2016/07/tech/rusty-steel-electrode-electrocatalyst-water-splitting/

Researchers also reported using molybdenum sulfoselenide particles on a three-dimensional, porous nickel diselenide foam to increase catalytic activity. The foam, made with commercially available nickel foam, significantly improved catalytic performance as it exposed more edge sites, where catalytic activity is higher than on flat surfaces.[959]

NiCoP, a rarely explored ternary compound, achieves stable catalytic performance toward both hydrogen evolution reaction (HER) and oxygen evolution reaction (OER). Its performance is superior to that reported for metal phosphides and metal chalcogenides, ranking among the most active water splitting electrocatalysts reported so far.[960]

Another catalyst that has been developed by chemists is based on ultrathin slices of porous metal-organic complex materials coated onto a foam electrode, using abundant, non-precious metals like nickel, iron and copper.[961] A different approach involves an effective, low-cost, and durable catalyst that is an electrolytic film made of three layers: graphene, nickel, and a metallic compound of iron, manganese and phosphorus.[962]

Laser-induced graphene (LIG), appropriately prepared, also proved to be an efficient catalyst, using just a quarter of the platinum in commercial catalysts.[963]

Fertilizers

Water splitting technology has been paired with the bacteria Ralstonia eutropha in a bionic leaf. When exposed to sunlight, it mimics a natural leaf by splitting water into hydrogen and oxygen. It then consumes hydrogen and takes carbon dioxide out of the air to make liquid fuel and fertilizers. The technology can be used in soil for crops, particularly since the biomass and liquid fuel generated are substantially higher compared to those from natural photosynthesis. In tests, radish crops grown on such soil weighted 150 percent more than the controls.[964]

Long-term perspectives

Widespread, cheap water splitting technology could significantly change the way we look at energy production and consumption. It may wholly change the dynamics of renewable energy. Being able to easily produce hydrogen using an effective, cost-efficient process based on water and electricity from solar panels or wind turbines would significantly reduce humankind's carbon footprint. Furthermore, as hydrogen would be stored on a substantial scale, water splitting would solve the present problem of excess renewable energy, significantly increasing the efficiency of the technologies already in place.

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[959] https://www.eurekalert.org/pub_releases/2016-10/uoh-rdm100316.php
[960] http://www.nanowerk.com/spotlight/spotid=45103.php
[961] https://www.technology.org/2017/06/07/new-ultrathin-material-for-splitting-water-could-make-hydrogen-production-cheaper/
[962] https://edgylabs.com/a-new-catalyst-works-twice-as-hard-toward-clean-energy
[963] https://www.azonano.com/news.aspx?newsID=35742
[964] https://www.nanowerk.com/news2/biotech/newsid=46292.php

4.8.11 Airborne Wind Turbine

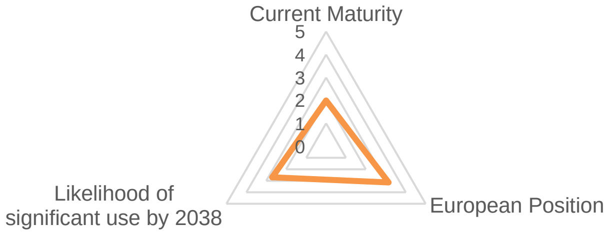

Figure 86: RIB Score of Airborne Wind Turbine

In the race for achieving cleaner (non-fossil, non-nuclear) and cheaper energy that can keep up with the consumption rate of today's society, capitalizing on endless resources such as wind currents seems the way to go. However, harnessing wind power is not a new idea and airborne wind turbines function on the same principle as normal wind turbines. In brief, a propeller that is moved by wind is connected to a rotor which in turn spins producing electric energy. The novelty lies in harnessing Airborne Wind Energy (AWE), that is high-altitude wind power[965], alleviating thus the problem of variation and consistency in patterns and speed of wind currents. Airborne wind energy systems (AWES) are generally much smaller and use less material than conventional, ground-based turbines - and they could (theoretically) be moved around easily and deployed to remote areas, such as isolated settlements or places struck by natural disasters. Economically, the hope is that AWES could eventually produce clean energy at less cost than conventional systems.

Recent progress directions

Ground-Generator Airborne Energy Systems[966]

This type of technical solution consists of three parts: a ground station, a flexible tether and an aircraft. A ground station acts as fixing, energy generator and control point for the aircraft while transforming the kinetic power received through the rope from the airborne flying object. Energy is obtained in a two-phase process, in which the traction force exhibited by the aircraft on the flexible tether activates an electric winch that is connected to an electric generator. The recovery phase is the second part of this process in which a small part of the electric energy produced is consumed on bringing the aircraft to the ground, thus resetting it for the next production phase. Variations to the model include moving ground systems[967,968,969], different types of tethers and many types of flying aircrafts from simple kites to miniature aircraft and drones.

[965] https://www.sciencedirect.com/science/article/pii/S1364032115007005
[966] https://www.sciencedirect.com/science/article/pii/S1364032115007005
[967] https://cleantechnica.com/2017/04/11/e-invests-innovative-drone-based-airborne-wind-energy/
[968] http://www.kitegen.com/en/products/stem/

Although AWES prototypes have largely been confined to research papers, labs and niche ventures, prompting some analysts to wonder if the technology has a (commercial) future, a couple of new investments and trials have recently been announced. Twingtec, a Swiss company which develops a GG-AWES system called Twing (short for "thethered wing") announced a pilot project at a Canadian mining site for 2018, to be followed by a second phase involving the development of a 100kW plant.[970] In 2017, the major E.ON energy company invested in the Dutch company Ampyx Power, with the goal of advancing and testing its 2MW AWES.[971] That follows E.ON's 2016 investment in a competing player: Scotland-based airborne wind energy startup, Kite Power Systems.

Flying-Generator Airborne Wind Systems[972]

Although this type of technical solution has largely the same main components as the GG-AWES there are some differences in functionality that confer greater productivity performances. The on-ground station acts as a collection point for the electric energy that is being produced in the flying aircraft, while securing it to the ground. The production can be easily enlarged using multiple turbines mounted on different types of flying aircrafts.

In December 2016, Makani Power - a wind power tech company which joined X, the so-called moonshot factory within Alphabet (the parent company of Google), in 2013 - managed to produce power for the first time using its M600 kite concept.[973] M600 is a carbon fibre aircraft featuring a 26m wingspan and 8 rotors. Each rotor spins and drives a magnet motor, which generates electricity on board, which is then transferred back to ground via a 0.5-kilometer-long flexible tether.[974] M600 has a rated power of 600 kW, which could power about 300 homes. Although there has been speculation about Alphabet's commitment to the Makani technology[975], further M600 tests are planned in Hawaii during 2018.[976]

Long-term Progress

As of 2018, no functional AWES is up and running outside experimental setups. It is much more costly to produce airborne wind energy, compared to traditional wind generationy. Even if ongoing and future trials are successful, it will probably take half a decade or longer until the first functional systems will be commercialized.

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969 http://www.kitenergy.net/technology-2/prototype/

970 https://www.swissinfo.ch/eng/sci-tech/drone-technology_swiss-startup-flies-a-kite-to-produce-wind-power/43350880

971 https://cleantechnica.com/2017/04/11/e-invests-innovative-drone-based-airborne-wind-energy/

972 https://www.sciencedirect.com/science/article/pii/S1364032115007005

973 https://renewablesnow.com/news/google-x-produces-1st-power-with-600-kw-kite-569167/

974 https://x.company/makani/technology/

975 https://www.bloomberg.com/news/articles/2017-08-04/alphabet-s-green-energy-ambitions-hit-turbulence

976 https://www.greentechmedia.com/articles/read/alphabet-remains-committed-to-makani-wind

Considering the energy market as a whole, airborne wind turbines compete not only with conventional wind turbines - but also with a host of power generation alternatives, even when considering just the growing sector of renewables. If airborne wind turbines do finally take off (literally and economically), they could conceivably provide a cheap source of clean energy and render the existing wind farms obsolete - but AWES will at best be just a (sizeable) piece within the energy mix of the future.

4.8.12 Aluminium-based Energy

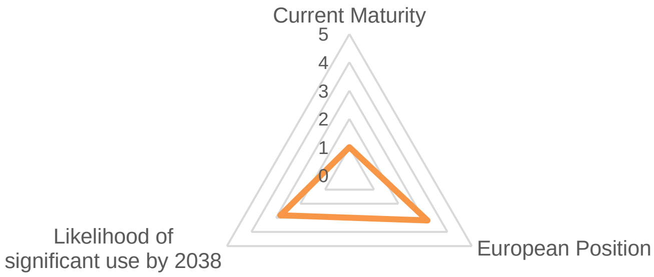

Figure 87: RIB Score of Aluminium-based energy

The use of aluminium for the generation and storage of electricity is currently researched as a complement and possibly an alternative to existing technologies. "Aluminium is the most abundant metal in the planet's crust."[977] It is also light and ductile. Gradually switching energy industries from much rarer and more expensive materials, such as lithium, towards aluminium would have obvious advantages, especially in the production of storage systems like rechargeable batteries. Beside its important role in building light-weight structures, in the future aluminium could be also used for the development of new and more efficient photovoltaic cells[978] or thermal systems.[979]

Lithium-ion batteries are currently the best performing electrical energy storage systems. Given the trend of electrification in many branches of the global economy, from wearables to transportation, the demand for high-performance batteries is on the rise. Lithium is scarce and lithium-ion batteries are heavy and sometimes become unstable, catch fire or explode.[980],[981] In addition to being light-weight and cheaper, aluminium batteries would also have the advantage of higher energy densities. Lithium

977 https://www.thebalance.com/metal-profile-aluminum-2340124
978 http://www.cuet.ac.bd/icmere/files2017f/ICMERE2017-PI-384.pdf
979 https://www.sciencedirect.com/science/article/pii/S0038092X17306886
980 http://www.newsweek.com/iphone-battery-mysterious-explosion-causes-apple-store-evacuation-776529
981 https://www.forbes.com/sites/christinenegroni/2017/12/01/dreamliners-beleaguered-lithium-ion-battery-creates-problem-on-united-flight-to-paris/#7f9ae64c8513

ions are monovalent, whereas aluminium ions are trivalent, i.e. their charge is triple that of lithium.[982]

There are still significant problems with the experimental aluminium batteries which have been developed so far. For example, cathodes tend to disintegrate, life cycle (how many times the battery can be recharged) is short, and the discharge voltage is lower than expected.[983] Such problems will have to be overcome if a commercially viable aluminium battery is to be developed.

Recent progress directions

Aluminium-ion batteries

Since aluminium-ion batteries seem the most promising avenue of research, there have been efforts to develop better performing cathode materials and electrolytes. Materials such as titanium oxide and vanadium pentoxide have been experimented with for cathodes[984], and some results are positive.[985] Batteries with ionic liquid electrolytes and graphite cathodes are also being tested[986], as is graphene as cathode material.[987] Nanomaterials, such as carbon nanotubes are yet another possible solution to the cathode problem, though for the moment it is also in its early experimental stages.[988] Beside organic ionic solutions used as electrolytes (at room temperatures), recently there have been experiments with inorganic molten salts at high temperatures (sodium chloroaluminate at 120°C).[989] In principle, such systems could deliver extremely long life cycles, suitable for storing large amounts of energy (e.g. for balancing grids).

Aluminium-air batteries

Research continues on aluminium-air batteries, too. In their case, the hardest problem is that the aluminium anode is consumed by its reaction with oxygen from the air and has to be replaced. In other words, the system cannot be recharged. Various alloys, such as those of aluminium with transition metal elements, are being tested in the hope that they would reduce corrosion.[990]

Long-term perspectives

There is substantial pressure to find an alternative to lithium-ion batteries, and aluminium batteries are strong candidates in this competition. Scientific progress is likely to continue on understanding the electrochemical properties of aluminium interacting with various compounds. The development of aluminium-ion batteries with comparable or better

[982] http://pubs.rsc.org/-/content/articlehtml/2017/se/c7se00050b
[983] https://www.nature.com/articles/nature14340
[984] http://pubs.rsc.org/-/content/articlehtml/2017/se/c7se00050b
[985] https://onlinelibrary.wiley.com/doi/full/10.1002/aenm.201602093
[986] https://www.nature.com/articles/ncomms14283
[987] https://onlinelibrary.wiley.com/doi/abs/10.1002/anie.201802595
[988] https://onlinelibrary.wiley.com/doi/full/10.1002/asia.201700570
[989] http://pubs.rsc.org/-/content/articlelanding/2017/ta/c6ta09829k/unauth#!divAbstract
[990] https://www.sciencedirect.com/science/article/pii/S246802571730081X

performance than lithium systems depends on such progress. An engineering breakthrough may follow, but it may necessitate prior investment and commitment from state and corporate actors. The same goes for other applications of aluminium in the energy economy.

For example, to develop aluminium-air batteries for electrical vehicles, it may first be necessary to develop a network of rapid battery replacement stations, and facilities to recycle used anodes. Similar arrangements have already been proposed to mitigate the long time required to charge lithium-ion batteries in cars, so this is less a scientific challenge and more of a political and financial one.

4.8.13 Artificial Photosynthesis

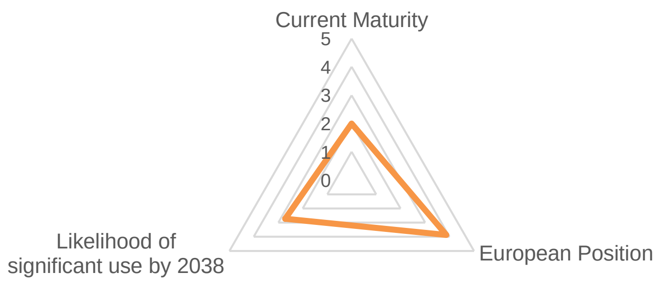

Figure 88: RIB Score of Artificial Photosynthesis

Artificial photosynthesis is "a chemical process that mimics the natural process of photosynthesis by converting sunlight, water and carbon dioxide into carbohydrates and oxygen".[991,992] In the context of ever increasing fuel consumption and levels of CO_2, this field of research focuses on a "one-two punch" solution inspired by nature: artificial photosynthesis that both reduces CO_2 levels and also generates power.

[991] https://en.wikipedia.org/wiki/Artificial_photosynthesis
[992] https://www.sciencedirect.com/topics/chemistry/artificial-photosynthesis

Recent progress directions

Drug production

Devices called artificial leaves passively convert light into power. Although these devices are not necessarily new, recent developments for the first time enabled artificial leaves to power chemical reactions usable in the production of drugs or fuels. This has been possible by turning to Luminescent Solar Concentrators (LSCs) to mimic the light-capturing molecules in natural leaves.[993] This opens up the future possibility of creating solar-powered factories that can produce drugs or other useful chemicals even in remote locations.

Fuel processing

Researchers developed an artificial leaf which consists of two silicon triple-junction photovoltaic cells to harvest light and achieved a breakthrough by introducing the tungsten diselenide and ionic liquid co-catalyst system on the cathode side and cobalt oxide in potassium phosphate electrolyte on the anode side. The leaf produces a synthetic gas which can either be burnt directly as fuel, or processed into diesel or other hydrocarbon fuels. Typically, the cells in solar panels convert radiation (light) into electricity. An artificial leaf is different, since it "essentially does the work of plants, converting atmospheric carbon dioxide into fuel, solving two crucial problems at once. A solar farm of such "artificial leaves" could remove significant amounts of carbon from the atmosphere and produce energy-dense fuel efficiently".[994]

A different approach to producing fuel from solar energy involved an engineered supramolecule that uses a photocatalyst – that is, a substance that stimulates chemical reactions when exposed to light. The structure of the photocatalyst comprises metal nuclei made of ruthenium ions, which capture light, coupled to one rhodium catalytic centre.[995]

Efficiently harvesting renewable energy

Scientists engineered bacteria to add nanocrystals on the surface of their cell surface. Thus, miniature solar panels can be built, which are more efficient than plants in converting light to energy. These cyborg bacteria, with 80 % efficiency, can outperform plants at photosynthesis, making them potentially essential in renewable solar fuels.[996]

Air purification

A procedure which causes a chemical reaction in a type of synthetic material – metal-organic frameworks (MOF) – was also identified. Such reactions use

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993 http://feeds.feedblitz.com/~/247481602/0/gizmag~Artificial-leaf-could-make-a-medicinal-minifactory/

994 http://www.eurekalert.org/pub_releases/2016-07/uoia-bsc072216.php

995 http://www.dailymail.co.uk/sciencetech/article-4578888/Researchers-create-artificial-photosynthesis-system.html?ITO=1490&ns_mchannel=rss&ns_campaign=1490

996 https://www.theverge.com/2017/8/22/16183036/cyborg-bacteria-solar-panels-artificial-photosynthesis-biofuel

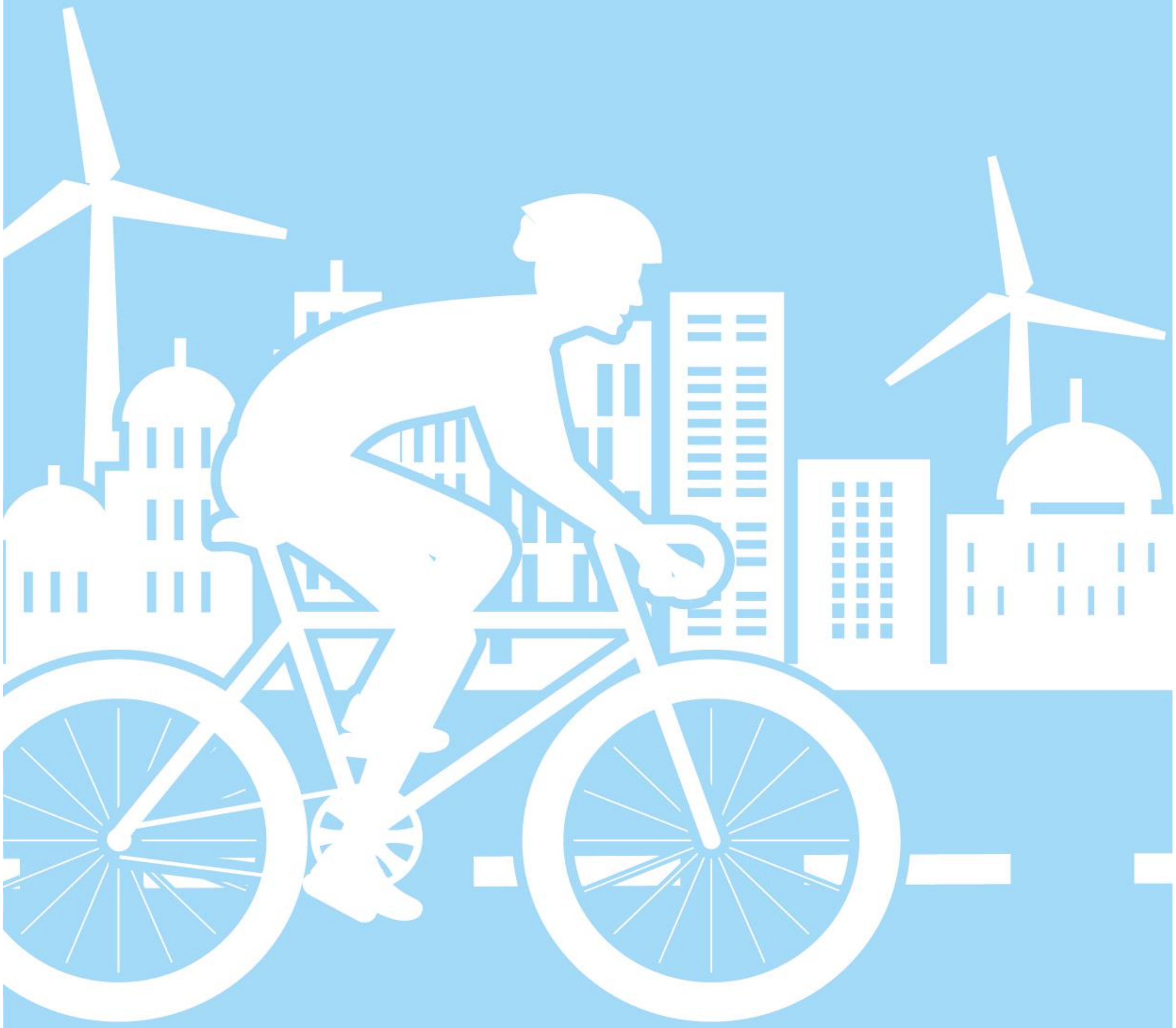
carbon dioxide to generate organic materials which are benign. This system can absorb specific wave lengths of light, "using titanium, a common nontoxic metal, and adding organic molecules that act as light-harvesting antennae. The chemical reaction transformed the CO_2 in two reduced forms of carbon, formate and formamides (two kinds of solar fuel), while cleaning the air in the process".[997]

Long-term perspectives

Large farms of artificial leaves could stop global warming in its tracks by significantly reducing the carbon footprint of humankind even more efficiently than natural leaves could on their own. Moreover, if systems based on artificial photosynthesis reach a point where costs are sufficiently low, they could drastically decrease the usage of and demand for their alternative, fossil fuels. Not only would these systems be a solution to the scarcity problem which now generates price increases; they would also render fuels would be available to anyone, i.e. not only to countries that have privileged access to natural resources. This may relax one of the major causes of global conflict.

[997] http://feeds.nanowerk.com/~/298766896/0/nanowerk/agwb~Scientist-invents-way-to-trigger-artificial-photosynthesis-to-clean-air.php

Social Breakthroughs



5 Radical Social Innovation Breakthroughs (RSBs)

This chapter describes a number of emerging societal practices that have been recorded in the literature as social innovations likely to be widely adopted in of 2038. We consider these to be "Radical Social Innovation Breakthroughs" in that they are relatively new and potentially disruptive. At the same time, they are practiced in society, and are thus considerably more "mature" than the technological RIBs, which makes them not directly comparable. Being social practices, their diffusion does not necessarily take place through markets. However, as social and policy experimentation becomes increasingly relevant to achieving the objectives of EU Research and Innovation policy, we find that these social practices may become involved in facilitating or in impeding such policy objectives.

5.1 Collaborative Innovation Spaces

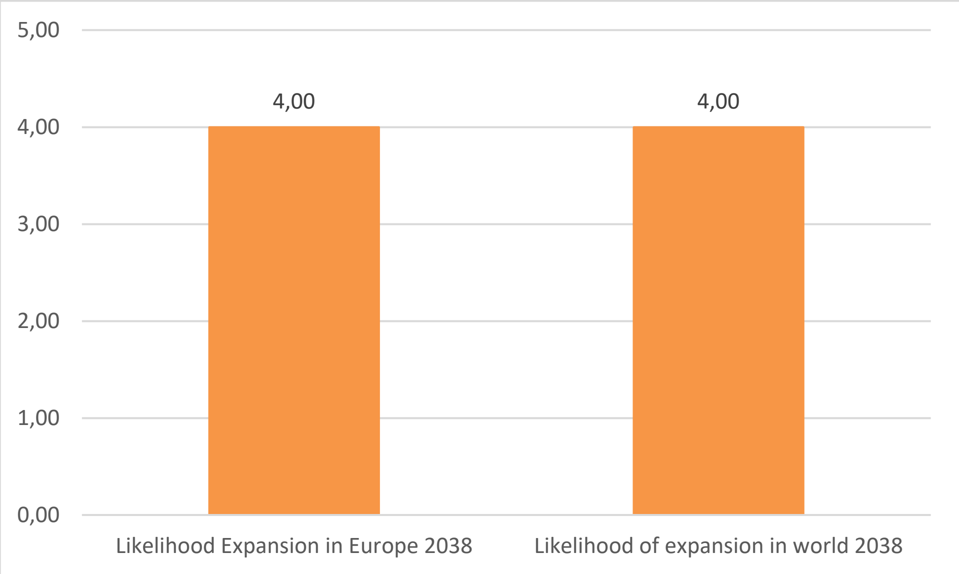


Figure 89: Likelihood of expansion of Collaborative innovation spaces by 2038

There is a rise in new forms of associations for passing on knowledge and innovating, usually under the form of a hub of skilled people gathering around them others from a community or a community of interest. Called makerspaces, hackerspaces or innovation labs, these settings act as communal workshops, where people can share ideas and tools. Collaborative innovation spaces can pop up anywhere, including schools, libraries, and community centres. Different locations offer different resources, ranging from 3D printers to synthetic biology kits.

Recent progress directions

Makerspaces on the rise

During the last ten years, makerspaces have exploded in popularity all over the globe. User-reported numbers show nearly 1,400 active spaces, 14 times as many as in 2006.[998] Makerspaces see themselves as representing

[998] https://www.popsci.com/rise-makerspace-by-numbers, accessed 10/8/2018.

the democratization of design, engineering, fabrication, and education.[999] Behind this is a vision of a society where people are enabled to develop their individual capacities to express themselves but at the same time, local communities are strengthened. Some expect a "prosuming" society where consumers actively participate in the production of personalised products and services - a development that may go along with a stronger distribution of manufacturing sites.

This boom takes specific turns in different cultures. For example, in Tokyo, the maker culture has intersected with the rise in 3D printing options and digital fabrication services in the city. It also connects with the Japanese concept of *monozukuri* ("making things") that runs deep through its craft and artistic traditions.[1000] In the US, especially libraries are reinforcing their role as community centres by transforming into makerspaces. In 2015, more than 135 million adult makers are counted, more than half of the total adult population in America. The White House even held its own inaugural Maker Faire in 2014, inspiring former President Obama to declare an official National Week of Making the following year.[1001]

5.2 Gamification

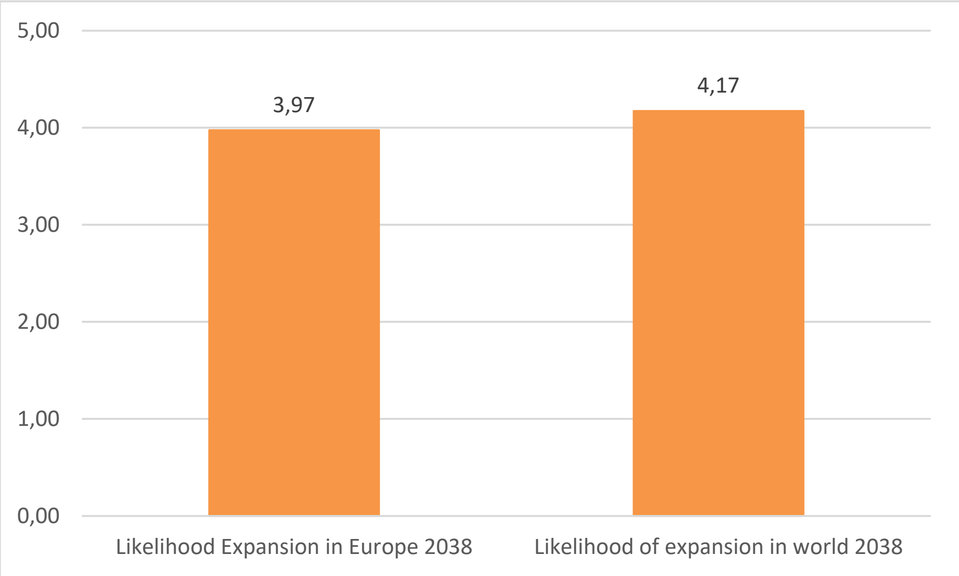


Figure 90: Likelihood of expansion of Gamification by 2038

Gamification is the application of game-design elements and game principles in non-game contexts to improve user engagement, organizational productivity, flow, learning, crowdsourcing, employee recruitment and evaluation, ease of use, usefulness of systems, physical exercise, traffic violations, voter apathy, and more. In a time, in which young people are more and more playing virtual games and are therefore used to being trained this way, gamification makes use of the new conditions needing less attention time for one issue.

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[999] https://spaces.makerspace.com, accessed 10/8/2018.
[1000] http://www.japantrends.com/maker-culture-spaces-fab-labs-hackerspaces-tokyo/, accessed 10/8/2018.
[1001] http://oedb.org/ilibrarian/a-librarians-guide-to-makerspaces/, accessed 10/8/2018.

Recent progress directions

Companies are engaging in gaming

More and more companies have launched gamification projects.[1002] Serious and learning games are applied in companies and they are more and more investing in gaming for learning. Online learning is also partly directed towards game-based learning, e.g. the Khan Academy tries this concept. Gaming is also a way to:

- Recruit and retain the best talent from the gamer generation and beyond
- Train employees and drive excellence with noncash incentives
- Cut through the market noise and ignite consumer sales growth
- Generate unprecedented customer loyalty without breaking the bank[1003]

Even in the financial sector, gaming is used. Synchrony Sling is a program that focuses on financing education for associates, managers, and owners. The primary objective serves a variety of partners whose associates had limited digital access or time to learn how they could help. By creating a web-based app that runs on smartphones, computers, and tablets, Synchrony Sling is readily available and teaches the basics of offering finance. As gamification grows from an emerging trend and into normality, companies like Synchrony Financial will continue to pioneer the landscape.[1004]

Data Generation combined with Participation via Gaming

Data generation is more and more embedded in games or performed in a "game-like" environment. The purpose is incentivizing permanent data generation. This makes the participation of many different actors possible and can even be used in Citizen Science surroundings. Ways for gamification are described are described in the example of CitizenCyberlab.[1005] In other examples, real scientific projects are performed directly or are supported.[1006] The most prominent games are the game

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[1002] Since the beginning of the gamification industry in 2010, over 350 companies have launched major gamification projects. http://www.huffingtonpost.com/gabe-zichermann/gamification_b_2516376.html, https://elearningindustry.com/science-benefits-gamification-elearning, checked 10/8/2018.

[1003] cited from Zicherman, G.; Linder, J. (2013): The Gamification Revolution: How Leaders Leverage Game Mechanics to Crush the Competition, USA.

[1004] http://www.dealerscope.com/partner/gamification-make-financing-fun, checked 10/08/2018.

[1005] Citizencyberlab: http://citizencyberlab.eu/research/gamification/; Morris, B. J. et al. (2013): Gaming science: the "Gamification" of scientific thinking. In: frontiers in psychology, https://doi.org/10.3389/fpsyg.2013.00607; http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3766824/pdf/fpsyg-04-00607.pdf; http://yukaichou.com/gamification-examples/top-10-gamification-examples-human-race/; http://www.spiegel.de/netzwelt/games/gamification-wie-spiele-das-leben-leichter-machen-a-844328.html, all checked 10/08/2018.

[1006] http://www.scientistlive.com/content/20362; http://centerforgamescience.org/blog/portfolio/foldit; http://www.pcworld.com/article/2047564/gamification-using-play-to-motivate-employees-and-engage-customers.html, http://www.forbes.com/sites/gartnergroup/2013/01/21/the-gamification-

"Foldit" for protein folding and the aim of finding cures, e.g. for AIDS, or the support of citizens to monitor whole galaxies in "Galaxy Zoo". Even charitable donations are using gaming (example CrowdRise).[1007]

Gaming for Physical Education and Health

A specific alliance to use games for health already exists[1008] in the USA. Game companies support and profit from the national efforts to animate for physical education[1009], a wave that started with the WII Fit games and is underlined by the use of smart watches, bracelets or mobile phones to monitor health data. The physical activity rate for adults and children has decreased dramatically (for children between 9–15 by 60 %) worsening the trend towards obesity, diabetes or other diseases already in young age. For this generation, clips like Zamzee that track children's activities when they run around are designed – and gets kids motivated to exercise more: they can upload their activity data onto a website and see how many points they receive and whether they have accomplished challenges or if they earned badges. Zamzee has concrete data[1010] demonstrating that the activity rate of children increased (by about 60 %).

Others provide games to sustain or improve the general health condition[1011] of human beings or to supervise or improve specific illnesses.[1012] The puzzle game "Foldit" (see above) was able to achieve a breakthrough in AIDS research that scientists could not solve alone or the RPG Diary Game Pain Squad helps patients to combat cancer by providing both purpose and data.[1013]

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of-business/#269060df5d57; Citizencyberlab: http://citizencyberlab.eu/research/gamification; Monitoring galaxies: https://www.galaxyzoo.org; http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3766824/pdf/fpsyg-04-00607.pdf; http://yukaichou.com/gamification-examples/top-10-gamification-examples-human-race; https://elearningindustry.com/science-benefits-gamification-elearning, all checked 10/8/2018.

[1007] People create their pages and profiles, and they can accumulate points and match up against others on a leaderboard based on how much they can fundraise, see http://yukaichou.com/gamification-examples/top-10-gamification-examples-human-race; checked 10/8/2018.

[1008] https://gamesforhealth.org, accessed 10/10/2017.

[1009] like the WII Fit 'games'

[1010] reported on http://yukaichou.com/gamification-examples/top-10-gamification-examples-human-race; checked 10/8/2018.

[1011] e.g. SuperBetter, a site to help people accomplish their goals by building physical, intellectual, emotional, and social resilience.

[1012] e.g. http://www.re-mission2.org/

[1013] http://yukaichou.com/gamification-examples/top-10-gamification-examples-human-race/

5.3 Access/ Commons-Based Economy

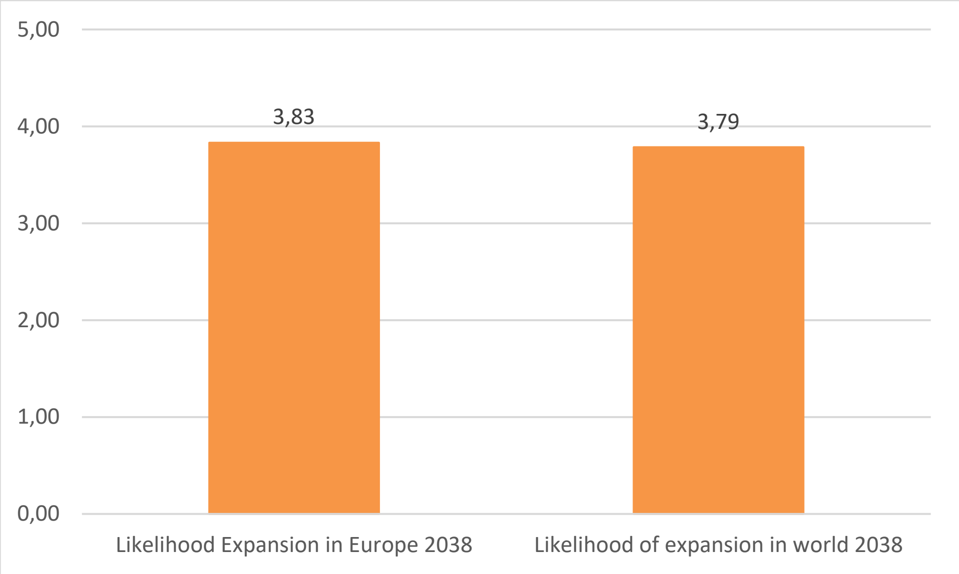

Figure 91: Likelihood of expansion of Access/Commons-based Economy by 2038

The terms "access economy", "sharing economy" or "platform capitalism" are used to describe new forms of organising access to good and services that are increasingly emerging. These phenomena are driven by a set of simultaneous developments; the rise of the internet and especially the mobile access to it have radically reduced the costs for collaboration. The increasing use of online social networks has substantially fostered the readiness to share information and digital goods. The digitalization of more and more goods such as music and books extends the range of sharing possibilities. Consumer needs at least in rich economies are expected to further shift towards experience rather than ownership. And finally, economic and environmental crises and the rise of poverty have encouraged people to share the use of scarce resources. Across the diverse practices detailed below, it is argued that an access based economy may generate an increasing share of value for both economy and society which would transform this emerging practice into a future global value network. The key question however is over the governance of these value generation patterns.

Recent progress directions

Online Sharing

In the anthropological sense, sharing is "the act and process of distributing what is ours to others for their use and/or the act and process of receiving or taking something from others for our use"[1014] in an act of "nonreciprocal pro-social behaviour".[1015] It often serves to extending the circle of people

[1014] Belk, R. (2007): Why not share rather than own? In: Annals of the American Academy of Political and Social Science, 611, p. 127.
[1015] Benkler, Y. (2004): Sharing Nicely. In: The Yale Law Journal, 114, pp. 273-358.

who can enjoy the benefits of the shared resource".[1016] The internet-has enabled new types of such true sharing practices like.[1017]

- Intentional online sharing of ephemera (opinions, expertise, photos, videos) as part of a group of others doing the same thing and thereby creating and recreating a community, e.g. Tripadvisor
- Online facilitated offline sharing, i.e. borrowing and lending without any fees involved such as non-profit tool libraries and freecycling[1018]
- Non-commercial peer to peer online sharing such as Kickstarter
- Non-profit online-facilitated hospitality such as CouchSurfing.

Rise of the Commons

Commons are resources shared by a restricted group of people following shared rules like for example a lake that is jointly managed by a community of villagers. Nobel Price winning economist Elinor Ostrom has shown that under certain condition this type of stewardship generates better results for governing goods that are used up by consumption (rival goods) than private or public ownership.[1019] Online mediation has enabled new kinds of commons like sharing of cars and tools.

Commons Based Peer Production

"Commons based peer production" is the "large scale collaboration of individuals [...] who cooperate effectively to provide information, knowledge or cultural goods without relying on either market pricing or managerial hierarchies to coordinate their common enterprise".[1020] Examples are Wikipedia, Linux or Tripadvisor and sites where people share recipes or designs. It is argued that this form of value creation, which coordinates diverse motivations, is especially suitable for addressing complex societal problems.

Access-Based Business Models

Through an access-based business model, goods and services are traded based on access rather than ownership. This can be organized by the company that owns the resources (e.g. ZipCar), or through a platform that is merely connecting owners/ service providers and users as in the case of Airbnb.[1021] One consequence of the rise of this type of business model is that thanks to companies such as NetJets, GetMyBoat and ThirdHome.com, the merely rich can upgrade to the lifestyles of the ultra-wealthy by getting

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[1016] Widlock, Th. (2004): Sharing by Default: Outline of an Anthropology of Virtue. In: Anthropological Theory, 4 (1), pp. 61.

[1017] cited according to Belk, R. (2014): Sharing versus Pseudo-Sharing in Web 2.0. In: Anthropologist, 18 (1), pp. 7-23.

[1018] http://www.casi2020.eu/casipedia/cases/freecycle-leuven, accessed 08/08/2018.

[1019] Ostrom, E. (1990): Governing the commons: The evolution of institutions for collective action. Cambridge: Cambridge University Press.

[1020] Benkler, Y.; Nissenbaum, H. (2006): Commons-based Peer Production and Virtue. In: The Journal of Political Philosophy 14 (4) p. 394.

[1021] Schor, J. (2014): Debating the Sharing Economy, Great Transition Initiative, https://www.greattransition.org/publication/debating-the-sharing-economy, accessed 08/08/2018.

access to luxury items such as private planes, luxury yachts, and interior-designed, exclusive homes.[1022]

5.4 Read/Write Culture: diversifying information gatekeepers

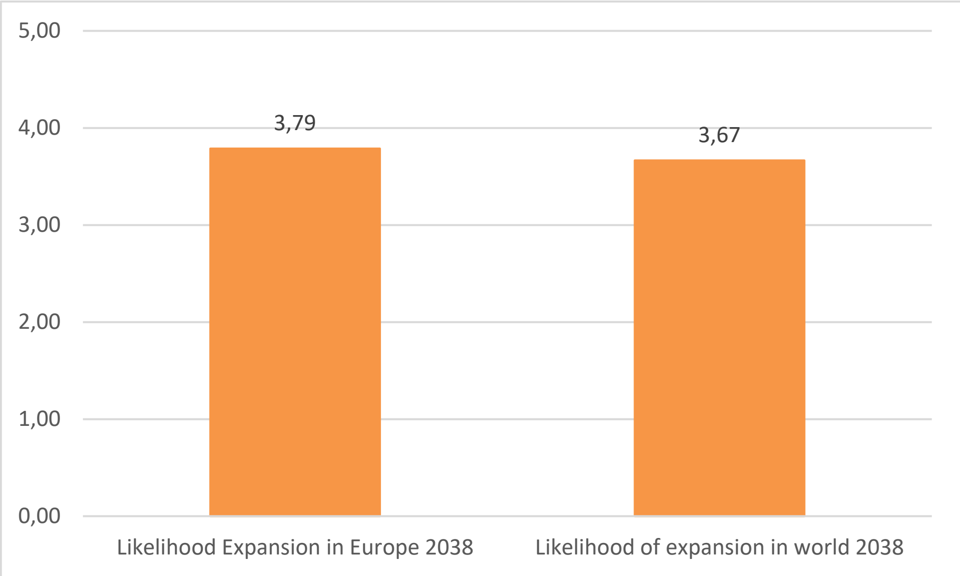

Figure 92: Likelihood of expansion of Read/Write Culture diversifying information gatekeepers by 2038

Through "social media", people become "active audiences"[1023] with the ability to not only share, but also generate, manipulate and transform digital content.[1024] Examples are the rise of vloggers (video bloggers), movie fan editing, and personal live streaming. Philosopher Lawrence Lessing has called this "read/write culture"[1025], as opposed to a "read only culture" where information or product is provided to passive consumers by a "professional" source. The transition has taken place in a relatively short time with consequences not yet fully understood.

Recent progress directions

Breakdown of established gatekeepers

Established gatekeepers such as newspapers and broadcasters are rapidly losing control of the information circuit. Instead, it is now very often the online world taking control of breaking news. Increasingly, the public discourse is characterised by contradictory information, 'the truth' is more and more contested, trust in information is eroding.

[1022] http://www.economist.com/news/business-and-finance/21710767-thanks-companies-such-netjets-getmyboat-and-thirdhomecom-merely-rich-can-upgrade, accessed 08/08/2018.
[1023] Warnke, Ph. et al. (2016): OBSERVE. Deliverable 1.2 Horizon Scanning Report, „Active Audiences", p. 8.
[1024] https://www.mediaite.com/online/the-rise-of-culture-2-0, checked 10/08/2018.
[1025] Lawrence Lessing (2009): Remix: Making Art and Commerce Thrive in the Hybrid Economy.

Ownership disruption

In the internet, stories are endlessly copied, altered, remixed, recycled and recombined, in ever-new creative ways. At the same time a fight over intellectual property is going on between software developers, record labels, and publishers on the one side, and programmers, authors, artists, and file sharers on the other. The music industry was heavily disrupted other industries like media, entertainment and education are changing rapidly.

5.5 Reinventing Education

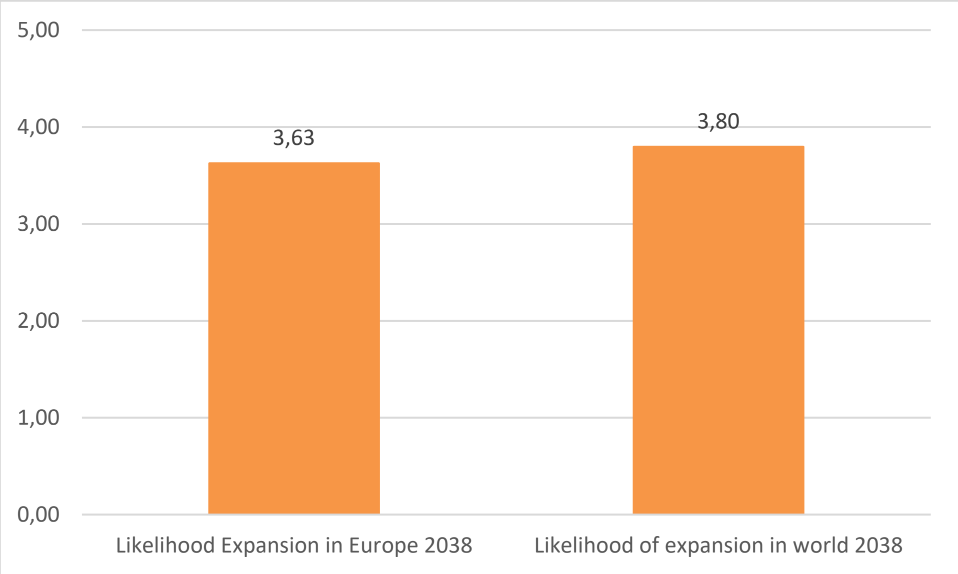

Figure 93: Likelihood of expansion of Reinventing Education by 2038

Education during the whole lifetime (including secondary education adding new forms of education later in life, life-long learning concepts) sees a huge diversification of education providers, Apps and of training partnerships. The structures, in which new knowledge is acquired, change on the institutional level. New knowledge providers are present in the scene. The second major change can be seen in the interdisciplinary way of teaching. More and more MOOCS are available offering a diverse range of courses and certificates. Formal education provision is complemented by new entrepreneurial ventures.[1026] The questions how to name new degrees, the meaning and value of certificates and to keep the quality of education high remain.

Recent progress directions

Increase in number of new education providers

The number of actors offering new platforms and methods for training and learning has grown exponentially (supply side, new institutions); it is no longer limited to formal education establishments. Over 800 universities already offer lectures on app stores, making it possible to learn anything, anytime and anywhere on a smartphone or tablet. Digital technologies are a

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[1026] EPSC (2017) http://ec.europa.eu/epsc/sites/epsc/files/epsc_-_10_trends_transforming_education_as_we_know_it.pdf, checked 10/08/2018.

catalyst for personalising learning and making it an increasingly active and flexible learning experience. Peer-to-peer platforms enable people from very diverse parts of society and the world, to engage and learn from each other.[1027]

Increase in diversity of actors in and forms of education

The growing diversity of actors engaging in education opens up numerous new opportunities for people to train and retrain at different moments in their lives (all ages, new demand). New education solutions can also help to reach out to individuals, who would otherwise be excluded. New forms of partnerships between school actors as well as between public and private actors are rejuvenating curricula, experimenting with new intersections between disciplines, and are already having an impact on employability.[1028]

An example of a qualitatively new tech entrepreneur in Europe is a coding school. In France, École 4215 is a free, teacher-less, self-organized university set up by a tech entrepreneur - mainly for secondary education. It is schooling thousands of programmers through project-based learning and peer-to-peer learning. Entry is totally merit-based as students are selected through a one-month, elimination-based test that they must endure to get a place at the school, and the curriculum is "gamified". Almost 80% of students have a job before they finish the course, and 100 % are employed by the end of it.[1029]

Going digital: Corporate training for a job or a promotion

More and more technology and software companies are creating platforms for practical trainings. Individuals or companies can use them to acquire valuable new digital and other skills, providing certification that is globally recognised. The German multinational software company SAP has set up trainings through Enterprise MOOCs (Massive Open Online Courses) offering flexible and interactive courses on topics from procurement to how to collect, process and analyse data. Its learning hub provides education content to support self-paced e-learning, as well as access to a community of learners through expert-led live online sessions and collaborative social learning rooms. The added value of these practical trainings is that they offer certification programmes by area of focus and skills levels that are globally recognised by all SAP partner companies and customers.[1030]

[1027] http://ec.europa.eu/epsc/sites/epsc/files/epsc_-_10_trends_transforming_education_as_we_know_it.pdf, checked 10/08/2018.
[1028] http://ec.europa.eu/epsc/sites/epsc/files/epsc_-_10_trends_transforming_education_as_we_know_it.pdf, checked 10/08/2018.
[1029] http://ec.europa.eu/epsc/sites/epsc/files/epsc_-_10_trends_transforming_education_as_we_know_it.pdf, checked 10/08/2018.
[1030] http://ec.europa.eu/epsc/sites/epsc/files/epsc_-_10_trends_transforming_education_as_we_know_it.pdf, checked 10/08/2018.

5.6 Body 2.0 and the Quantified Self

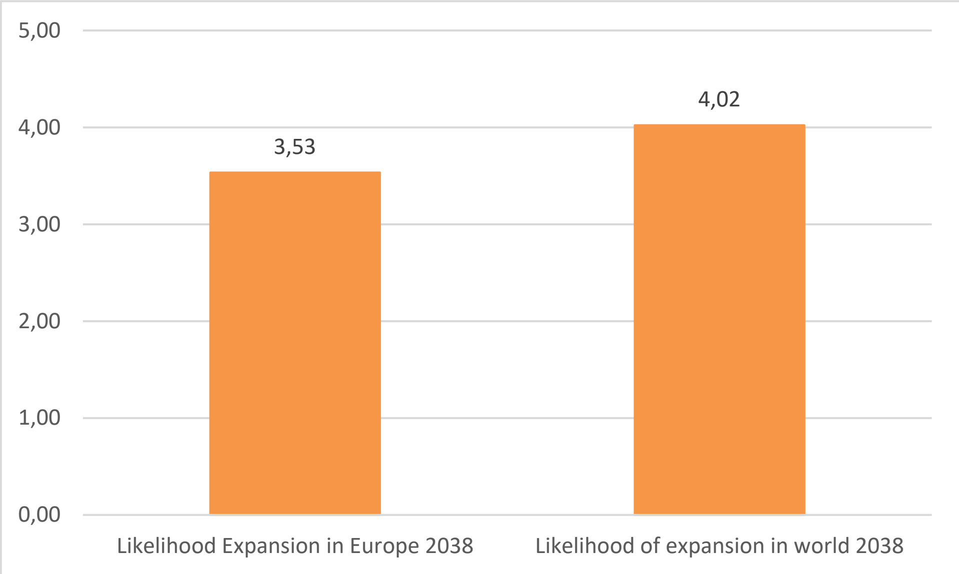

Figure 94: Likelihood of expansion of Body 2.0 and the Quantified Self by 2038

The Quantified Self movement encourages users to better understand themselves by collecting data on every aspect of their daily life[1031]: from food consumption, air quality, blood oxygen levels, arousal, to bowel movements and so on. The slogan of the movement is "self knowledge through numbers".[1032] The Quantified Self movement is also known as "lifelogging".

Body 2.0 and Quantified Self both mean the permanent monitoring of the human body and the almost medical monitoring of one's bodily functions, via wearables, Smartphone Apps or separate sensors. The new technical possibilities are combined with an increased concern over the body as "the temple" where the mind resides.

Recent progress directions

Tools for tracking common devices

The number of tools to monitor body and functions is increasing continuously and more and more people wear bracelets, watches and other devices which can deliver the data to an online tool, often in real-time so that the information are permanently published. Some tools were only developed for medical purposes, others are dedicated to the sports or wellness area.

Companies already created many different systems, a guide lists 505 tools[1033] (in the year 2017). Some examples of devices and systems beyond

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[1031] see also Zweck et al. (2017): Social changes 2030. Volume 1 of results from the search phase of BMBF Foresight Cycle II, Düsseldorf.

[1032] http://quantifiedself.com, accessed 08/08/2018.

[1033] http://quantifiedself.com/guide, accessed 08/08/2018.

apps and bracelets that are used on a personal level are: Cardionet[1034], Bodymedia, Toumaz or Raisin, which measures when and if a patient takes medication, and how various bodily vital signs, such as heart rate, respond to the medication, a system currently in clinical trial.[1035]

The Quantified Self movement encourages users to better understand themselves by collecting data on every aspect of their daily life: from food consumption, air quality, blood oxygen levels, arousal, to bowel movements and so on. Then apps, such as Instant, compile all the data into a personalised dashboard. People have the ability to scrutinise the data, recognise trends, and potentially alter their behaviour. This form of lifelogging is not seen to pose any serious threat, mainly because it is voluntary[1036] and more and more people participate in this "game" or are willing to accept a "human enhancement".[1037]

Body 2.0 – monitoring at the workplace

Some companies already monitor their employees by asking employees to wear a device that tracks their activity. The monitoring is constant, 24/7. The "socio-metric badges" monitor employees' health, mental state, location, workplace conversations, sleeping patterns and so on.[1038] This is very helpful when it is important to stay awake (e.g. when monitoring facilities at night) or when attention is needed. It is also helpful to notice if somebody is disposed to an unhealthy environment. Even production processes can be adapted to the health or condition of the individual worker or learning processes started (because of the feedback). The aim is to create 'augmented human beings' and altogether happier employees. Until now, many people are already monitoring and collecting this type of data but on a personal level. It is different when your work or your workplace starts logging your behaviour. Companies claim the use of this kind of "socio-metric badges" is only encouraged and thus similar to lifelogging. This seems fine but the data could be used for different reasons later.

Monitoring and self-tracking as a social must-have

Already, for many people, the continuous monitoring of the body is normal or even a duty[1039] – a must-have. They cannot imagine, anymore, living without a body monitoring. Self-tracking is included in the new normal. It is not normal to refuse it. For many of the tracking functions, new technologies are still necessary (e.g. permanent measuring of bodily fluids). "Years from now people will look back and find it unbelievable that heart attacks, strokes, hormone imbalances, sugar levels, and hundreds of other

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[1034] List and descriptions from https://singularityhub.com/2009/03/20/body-20-continuous-monitoring-of-the-human-body/#sm.000v772oy14k4eiwx0e16hsvihu5z, accessed 10/08/2018.
[1035] http://littleatoms.com/work-wear-trackable-device, accessed 10/08/2018.
[1036] http://littleatoms.com/work-wear-trackable-device, accessed 10/08/2018.
[1037] European Parliament; Science and Technology Options Assessment (STOA) (2009): Human Enhancement Study. (IP/A/STOA/FWC/2005-28/SC35, 41 & 45) IPOL/A/STOA/2007-13; PE 417.483; Brussels.
[1038] http://littleatoms.com/work-wear-trackable-device, accessed 10/08/2018.
[1039] https://singularityhub.com/2009/03/20/body-20-continuous-monitoring-of-the-human-body/#sm.000v772oy14k4eiwx0e16hsvihu5z, accessed 10/08/2018; citation included there.

bodily vital signs and malfunctions were not being continuously anticipated and monitored by medical implants." Many communities in the quantified-self movement confirm that this kind of monitoring is a must-have.[1040] Self-tracking guides, tools for analysis or platforms for exchange of knowledge are already provided for several years[1041], most of them are found in the area of health.[1042.]

Seeing the advantages, some communities wonder why body monitoring is not already more successful and widespread. Technical problems still exist, e.g. most of the body monitoring we like to do requires direct access to the blood stream and other bodily fluids. One technique is to prick the skin periodically to extract and analyse blood, yet this only works for periodic monitoring. It does not provide continuous access to bodily fluids. For this, sensors implanted permanently into the blood stream are needed, but the difficulty is that moisture, enzymes, and the immune system quickly wreak havoc on mechanical devices and destroy them. There are additional risks by implants for life threatening infections, a problem that is not solved, yet. These challenges are certainly within means to overcome, and progress is being made all over the world - pushed by platforms, communities, and companies. The medical monitoring, device, and implant potential is large, with a myriad of active companies and research projects.

[1040] see e.g. www.quantifiedself.com; www.qsdeutschland.de; www.meetup.com, all accessed 10/08/2018.

[1041] see e.g. Swan, M. (2009): Emerging Patient-Driven Health Care Models: An Examination of Health Social Networks, Consumer Personalized Medicine and Quantified-Self-Tracking. In: International Journal of Environmental Research Public Health 6 (2), S. 492-525, http://www.mdpi.com/1660-4601/6/2/492, accessed 10/08/2018.

[1042] e.g. https://www.myfitnesspal.com/; https://daytum.com/; https://www.chartmyself.com/ or https://www.anytimefitness.com/apps/ just to mention a few of them.

5.7 Car-free City

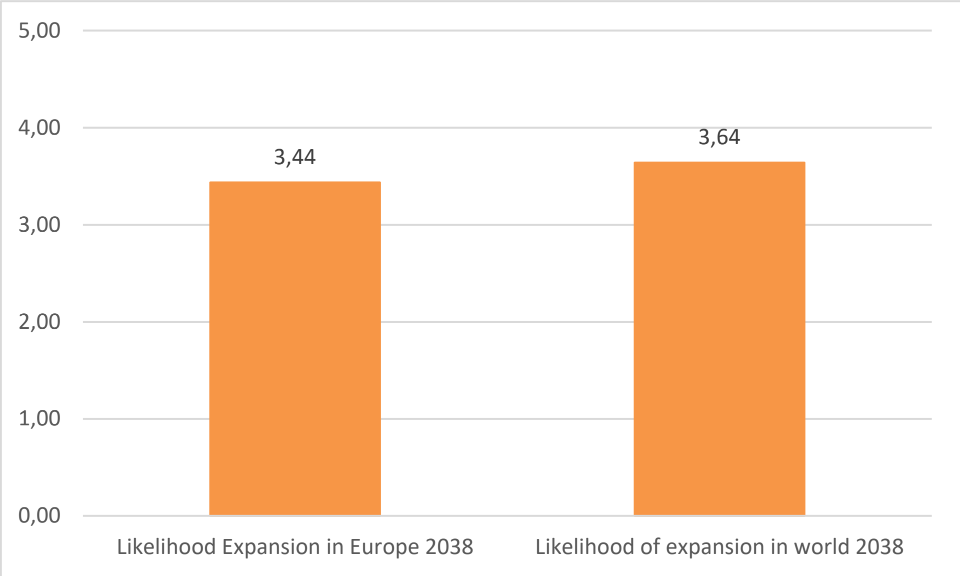

Figure 95: Likelihood of Car-free City by 2038

A car-free city relies primarily on public transport, walking, or cycling for transport within the urban area. Car-free cities greatly reduce petroleum dependency, air pollution, greenhouse gas emissions, automobile crashes, noise pollution, and traffic congestion. The innovation is to transform highly car-dependent cities or construct new car-free cities from scratch.

Recent progress directions

Banning cars from cities

At least seven major cities with a high car dependency are starting to go car free. A growing number of cities is starting to get rid of cars in certain neighbourhoods.[1043] Examples are Chengdu, Copenhagen, Hamburg, Helsinki, Madrid[1044], Milan and Paris.[1045] They have different concepts from partly banning cars to "green networks".[1046] In the case of Milan, the city is even paying commuters to leave their car parked at home and take the train instead. When smog levels spiked in Paris, the city banned, three days in a row, cars with alternatively odd or even-numbered plates.[1047] Pollution dropped as much as 30% in some areas, and now the city plans to start permanently discouraging cars. In the city centre, people who do not live in

[1043] https://www.fastcompany.com/3040634/7-cities-that-are-starting-to-go-car-free; https://www.businessinsider.com/cities-going-car-free-ban-2017-8?IR=T#madrids-planned-ban-is-even-more-extensive-2, accessed 10/8/2018.
[1044] http://indianexpress.com/article/india/car-free-madrid-connaught-place-all-following-global-trend-to-make-streets-more-pedestrian-friendly, accessed 10/8/2018.
[1045] https://www.independent.co.uk/news/world/europe/paris-car-ban-anne-hidalgo-air-pollution-a7115791.html, accessed 7/9/2018
[1046] Hamburg is implementing a "grünes Netz" with the long-term intention to ban cars completely from the city centre, see http://www.bbc.com/future/story/20140204-can-a-city-really-go-car-free, accessed 10/8/2018.
[1047] https://www.theguardian.com/environment/2017/jan/29/paris-fight-against-smog-world-pollutionwatch, 29-1-2017, accessed 7/9/2018.

local neighbourhoods will not be able to drive in on weekends, and that rule could soon roll out to the whole week. In 2001, 40% of Parisians did not own a car; now that number is 60%.[1048]

The changes are happening fastest in European capitals that were designed hundreds or thousands of years before cars were ever built. In sprawling U.S. suburbs that were designed for driving, the path to eliminating cars is obviously more challenging.

Countries and cities even create new laws to accelerate the trend. In Singapore, it started with car-free Sundays, now a new Active Mobility Bill passed the Parliament.[1049] It foresees punitive measures for errant riders and it legitimises the use of bicycles and personal mobility devices or PMDs – the term specifies devices like e-scooters, hoverboards and unicycles as a mode of transport. Bicycles and PMDs are now officially allowed to go on footpaths, the usual cycling paths and shared paths. E-bikes have been consigned to the roads, cycling paths and shared paths. Riders face stiff fines or even jail terms if they do not comply.[1050]

Other countries are less drastic, e.g. in Germany, a ban on diesel cars is discussed for specific cities or streets, in which the limits of nitrogen oxide in the air are exceeded.[1051] In Norway, diesel vehicles are banned from municipal roads as a measure to end acute, high air pollution for a certain time (i.e. from 6:00 a.m. until 10:00 p.m.) and completely from 2025.[1052] If the ban is violated, drivers will be fined 1,500 kroner ($176). Emergency vehicles, taxis and transport for disabled people are among some of the vehicles exempt from the ban. The list of cities with diesel ban is getting longer.[1053]

New cities without the necessity of a car

Building new cities from scratch based on walking distances for any important location combined with public transport can be an option for European regions, too. Examples from Asia are: A new satellite city planned in Southwest China could serve as a model for a modern suburb. Instead of a layout that makes it necessary to drive, the city is designed in a way that *any location* in the city can be reached by 15 minutes on foot from any point of departure. Motorized vehicles are only allowed on half of the road area. The connection to Chengdu, the closest large city, is with public transport. Most of the expected 80,000 people living there will be able to

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1048 https://www.fastcompany.com/3040634/7-cities-that-are-starting-to-go-car-free, accessed 10/8/2018

1049 http://www.straitstimes.com/singapore/transport/full-impact-of-car-lite-drive-in-10-to-15-years, accessed 10/8/2018.

1050 http://www.straitstimes.com/singapore/transport/full-impact-of-car-lite-drive-in-10-to-15-years, accessed 10/8/2018.

1051 Tagesschau, 28/11/2017; the first street is in Hamburg, https://www.ndr.de/nachrichten/hamburg/Diesel-Fahrverbot-Fragen-und-Antworten,fahrverbote120.html, accessed 10/8/2018.

1052 https://www.welt.de/wirtschaft/article162353921/So-arbeitet-Norwegen-an-einer-besseren-Welt-fuer-die-Nachkommen.html, all accessed 10/8/2018.

1053 https://en.wikipedia.org/wiki/List_of_countries_banning_fossil_fuel_vehicles, accessed 10/8/2018 walk to work in local neighbourhoods. The project was originally supposed to be completed in 2020, but suffers some delay.[1054]

South Korea is building a $35 billion city designed to eliminate the need for cars[1055] in the International Business District (IBD) of Songdo, South Korea. The inhabitants may go to work without driving a car. In the mixed-use urban plan, retail, office space, parks, medical facilities, and schools are all close to housing. Most non-residential buildings are in walking distance from everything else. Apartment buildings and businesses were built with a distance of 12 minutes to the next bus or subway stops. Fifteen miles of bike lanes connect the district and a larger 90-mile network in Songdo City. The project started in 2002 and is expected to be completed by 2020, when the district will span 100 million square feet.

5.8 New Journalist Networks

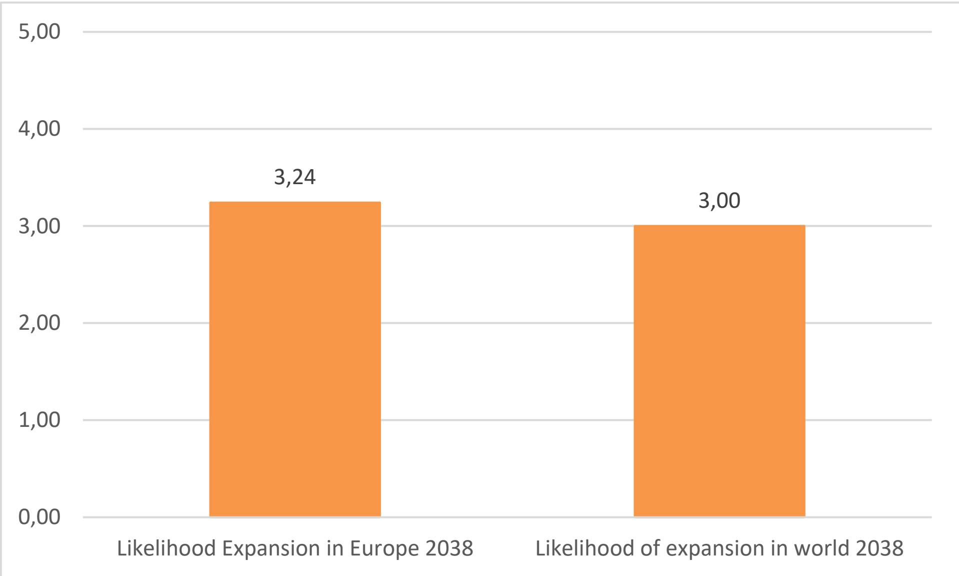

Figure 96: Likelihood of expansion of New Journalist Networks by 2038

Journalists work together on specific targets to reveal news and find evidence for big or small but global stories. They co-operate globally - with newspaper journalists or freelancers. The networks are established based on interest, news factor and story. This saves resources (especially time, but also money) and allows new ways of spreading news and finding evidence.

[1054] https://www.fastcompany.com/3040634/7-cities-that-are-starting-to-go-car-free; https://www.businessinsider.com/cities-going-car-free-ban-2017-8?IR=T#madrids-planned-ban-is-even-more-extensive-2, all accessed 10/8/2018.

[1055] https://www.weforum.org/agenda/2017/11/south-korea-is-building-a-35-billion-city-designed-to-eliminate-the-need-for-cars, accessed 10/8/2018.

Recent progress directions

Large-scale investigative journalism network

The largest investigation until now were the 'Panama Papers'. Journalists from all around the world worked on revealing a scandal called 'Panama Papers', in which fictional companies in offshore islands and especially in Panama were established to save taxpaying in the home country. The Panama Papers are 11.5 million leaked documents that detail financial and attorney-client information for more than 214,488 offshore entities. Journalists from 107 media organizations in 80 countries analysed documents detailing the operations of the law firm. After more than a year of analysis, the first news stories were published on April 3, 2016, along with 150 of the documents themselves. All journalists in the network went public at the same time. The project represents an important milestone in the use of software tools by journalists and their mobile collaboration.[1056] The Consortium of Investigative Journalists trying to find the resources for large-scale investigations is the most prominent example[1057], other consortia revealed the Cum-Cum and Cum-Ex scandals starting in Germany[1058].

5.9 Local Food Circles

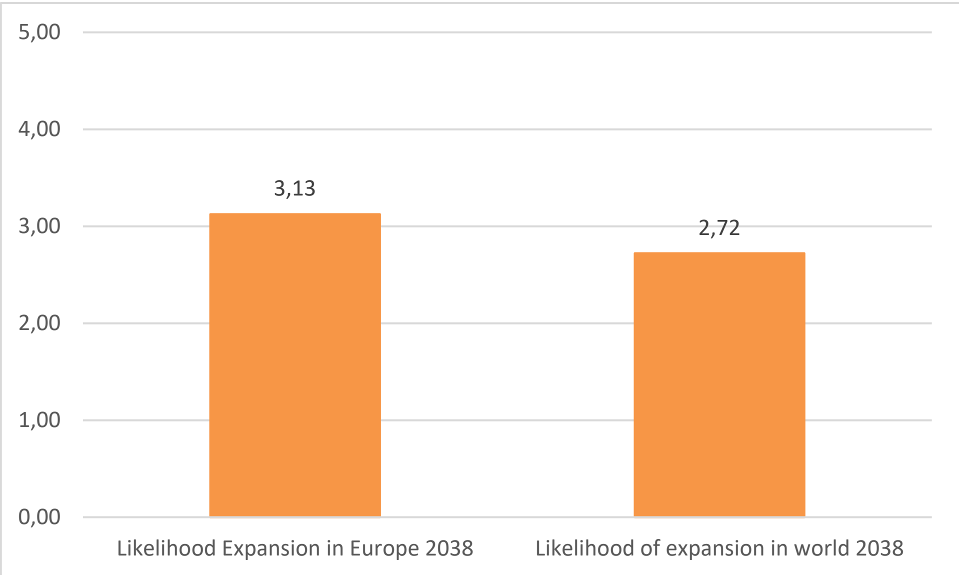

Figure 97: Likelihood of expansion of Local Food Circles by 2038

As formulated by the Food Circles Network "A Food Circle is a new way of conceiving of and organizing our agricultural and food systems. It links the many people involved in food production together in interdependent, holistic ways. ... Practically, a Food Circle is concerned with promoting the consumption of safe, regionally grown food that will encourage sustainable

[1056] https://www.theguardian.com/news/2016/apr/03/what-you-need-to-know-about-the-panama-papers, https://www.icij.org/investigations/panama-papers/, all checked 7/9/2018.
[1057] https://www.icij.org/investigations/panama-papers/, checked 7/9/2018.
[1058] https://www.sueddeutsche.de/thema/Cum-Ex; https://www.zeit.de/video/2017-06/5461015755001/kurz-erklaert-wie-der-cum-ex-steuerskandal-abgelaufen-ist; https://www.tagesschau.de/multimedia/bilder/cum-ex-deals102.html, checked 8/11/2018.

agriculture and help to maintain farmers, who will sustain rural areas. While the concept sounds simple, it means that we must radically change the way we participate in the act of growing and consuming food."[1059] In countries around the world a number of social innovations are emerging around this vision of localised chains of food production and consumption.

Recent progress directions

Localised Food Systems

The global industrialised food system has brought about many concerns with respect to food safety, food security, health, and social and ecological sustainability. At the same time, the rapid growth of organic food has also led to some criticism. Recently, more radical alternative food concepts are fast emerging. These initiatives are emphasizing embedded localized systems such as e.g. the slow food movement or "localvores". Advocates for these movements are against any industrialization of the food chain, its production, and distribution. They focus on the reduction of food mileage, carbon footprint and non-industrialization of the food chain, and therefore strongly support local food networks. In the US and Europe, community-supported agriculture (CSA) programs are thriving where food consumers connect with the famers directly and buy products at farmers markets.[1060]

Indoor Gardening

The interest in growing of food indoors seems to be rising fast. Indoor gardening involves combinations of high-tech developments and new social practices. A recent example is "Herbert" a hydroponic LED-powered indoor growing system, which grows the plants in a water-based solution (water plus nutrients) instead of soil[1061], allowing for a smaller grow unit (plants need less space for growing medium) as well as more control over nutrient delivery, while also using 90 % less water than soil-based systems. This indoor unit makes it possible to grow fruits and vegetables all year round. The system received enthusiastic support in a Kickstarter crowdfunding campaign in 2017. Also IKEA's innovation lab has designed a "live" piece of furniture that works as a spherical garden for growing plants and vegetables indoors.[1062]

Community Gardening

Community gardening is a movement, which aims to connect food producers and food consumers in the same geographic region, in order to develop more self-reliant and resilient food networks; improve local economies; or to have an impact on the health, environment, community,

[1059] http://www.foodcircles.missouri.edu/index.htm checked 13/9/2018
[1060] http://www.casi2020.eu/casipedia/cases/eco-partnership-community-in-herencsny/; http://www.casi2020.eu/casipedia/cases/social-innovation-in-outright-purchases, checked 10/08/2018.
[1061] https://www.treehugger.com/gadgets/meet-herbert-vertical-hydroponic-wall-garden.html, checked 10/08/2018.
[1062] http://www.businessinsider.de/ikeas-space10-designed-a-vertical-farm-for-the-home-2017-9?r=US&IR=T; checked 10/08/2018.

or society of a particular place. Community gardens are set up on unused soil (abandoned areas, construction areas that are currently not used). The CASI Social innovation repository reports a number of cases in Europe.[1063] Many initiatives target in particular urban communities. Other initiatives target especially children and contributions to combat climate change.

Permaculture

Permaculture (permanent agriculture) was defined by its founder, the Australian scientist Bill Mollison, in 1978 as "the conscious design and maintenance of agriculturally productive ecosystems which have the diversity, stability, and resilience of natural ecosystems. It is the harmonious integration of landscape and people providing their food, energy, shelter, and other material and nonmaterial needs in a sustainable way."[1064] Today, it has come to mean an integrated, ethical approach to designing healthy, productive, sustainable, planet-friendly systems where humankind works with nature rather than against it.[1065] Permaculture revisits "old ways" in agriculture – rotating cultures, complementary crops and not ploughing the soil in order not to lose its moist. Proponents argue that a return to these practices would replenish the depleted soils. They stress that small scale is not necessarily a bad thing and point to plenty of evidence to show that small-scale food production, including gardening, actually yields more food than large scale. "It may produce less per person employed and certainly produces less financial return, but on average, it does produce more food per hectare."[1066] The global Permaculture network is reporting a fast growing list of Permaculture projects from all-over the globe (current number 2516).[1067]

[1063] http://www.casi2020.eu/casipedia/cases/community-gardens/; http://www.casi2020.eu/casipedia/cases/bioszentandrs-ecological-farming/; http://www.casi2020.eu/casipedia/cases/gaan-we-samen-wortels-plukken/; http://www.casi2020.eu/casipedia/cases/kokoza-more-green-in-cities/; http://www.casi2020.eu/casipedia/cases/farmama/, all checked 10/08/2018.
[1064] http://synergypermaculture.ca/home/what-is-permaculture; http://www.irishtimes.com/life-and-style/homes-and-property/gardens/permaculture-ethical-gardening-for-a-better-future-1.2923368, both checked 10/08/2018.
[1065] http://www.irishtimes.com/life-and-style/homes-and-property/gardens/permaculture-ethical-gardening-for-a-better-future-1.2923368, checked 10/08/2018.
[1066] http://www.thelandmagazine.org.uk/sites/default/files/Permaculture%20Back%20to%20Basics.pdf, checked 10/08/2018.
[1067] https://permacultureglobal.org/projects checked 13/9/2018

5.10 Owning and Sharing Health Data

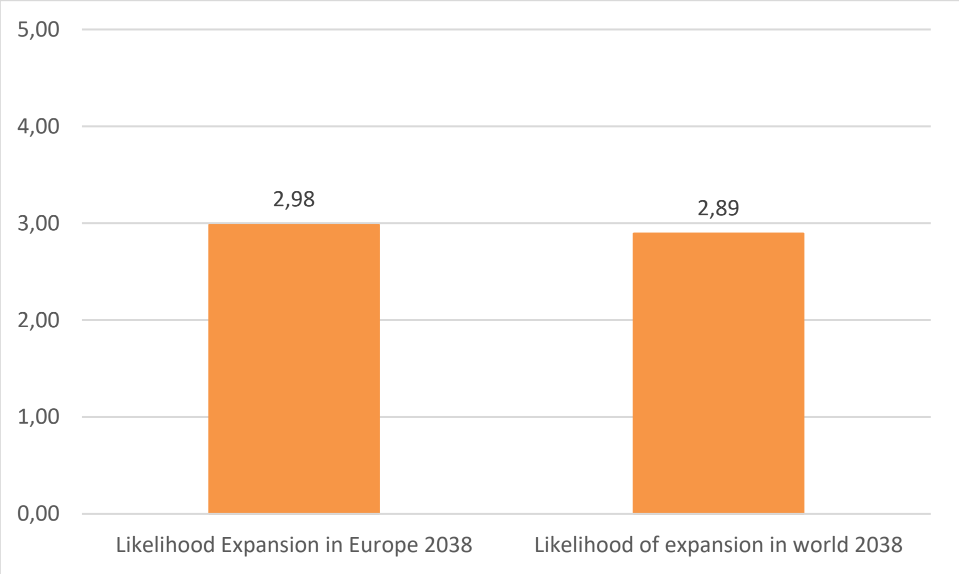

Figure 98: Likelihood of expansion of Owning and Sharing Health Data by 2038

Personal health data are becoming more and more valuable. There are movements to create spaces, in which the persons who are the subjects of the data know that their data are safe and can be used, e.g. for research, and in which individuals benefit directly from providing their data. This is a counter-initiative against companies exploiting personal health data generated in different situations, intentionally and unintentionally.

Large databases are already hosted by different institutions, companies, organisations with data on different aggregation scales (single individual data, aggregated data, study data, etc.). In Switzerland, there are new models of data ownership organized in Co-ops (cooperatives[1068] for health data basis – Genossenschaften Gesundheitsdatenbanken). Individual persons (data owners) themselves decide who they allow to make money with their data or who is given access to use them in research. This is managed and annotated in the database directly, people are asked in cases they did not give their previous permission.

Recent progress directions

Safe health information management for personal health data

Managing and storing health information plays a large role when individuals provide their data. A new idea and concern for many is that every individual decides about own data, but allows a certain usage. The particular interests from the nation state and companies are kept out and safety and privacy are in the focus. Co-ops in the hand of citizens are forms of organisations to handle the data.

[1068] A Coop is an 'autonomous association of persons united voluntarily to meet their common economic, social, and cultural needs and aspirations through a jointly-owned and democratically-controlled enterprise'. (International Cooperative Alliance)

An example for allowing this is the Swiss Coop Healthbank that started in 2013[1069] as a "global people-owned platform for managing health and medical data in one secure database" according to Swiss standards. Healthbank is directed towards patients and their health information. It can store everything from blood results to the DNA profile. If a pharmaceutical company wants to do research with the data, it has to pay and the data givers share the amount of money (like an eBay for health data). By the end of 2017, 500 profiles were in the database. A data deal with the pharma industry does not exist yet. The bank of the Coop is developing a digital medication plan with a risk capital of 3 million Euro. The money is given by private persons and a company.

Personal health data exploitation for research - safe but without making profit

The second possibility is providing personal health data for research purposes without making any profit. The example Midata is also from Switzerland, started in 2013, but is concentrated on research.[1070] It is citizen-owned, not for profit and open source. In Midata, scientists are able to "park" health data from citizens in the database (if they have the permission of the individual to do so). Different projects can be hosted in this way. There is no payment for the citizens in order not to give incentives for data trading. In 2017, the data of weight and general status of health as well as the movement profiles of 70 corpulent patients are available in the database. Currently, the data of multiple sclerosis are added. Further Coops are planned in the UK, Netherlands and Germany.

Sharing scientific health data for money

A third option is speeding up research by sharing scientific health data on a clear profit-basis. An example is (according to the Nesta Social Innovation Database) PatientsLikeMe[1071], which is an "online platform and support network for people to share their patient data to help speed up the pace of research and understand better ways of caring and coping." The site has gathered a community of 250,000 patients and carers, pooling information, both data and anecdotal, "in order to understand their day-to-day lives in a broader, communal context".

PatientsLikeMe makes money by sharing health data, which is unusual for social innovations. Guided by a strict privacy policy and set values, the aim is to "champion the needs of their community, through the data they provide, to non-profit healthcare developers and providers who need to improve their services, and for whom the data is a valuable insight".[1072]

[1069] https://www.healthbank.coop/, accessed 10/8/2018.
[1070] https://www.midata.coop/, accessed 10/8/2018.
[1071] https://www.nesta.org.uk/news/everyday-social-innovations/patientslikeme, accessed 10/8/2018.
[1072] https://www.nesta.org.uk/news/everyday-social-innovations/patientslikeme, accessed 10/8/2018.

5.11 Alternative Currencies

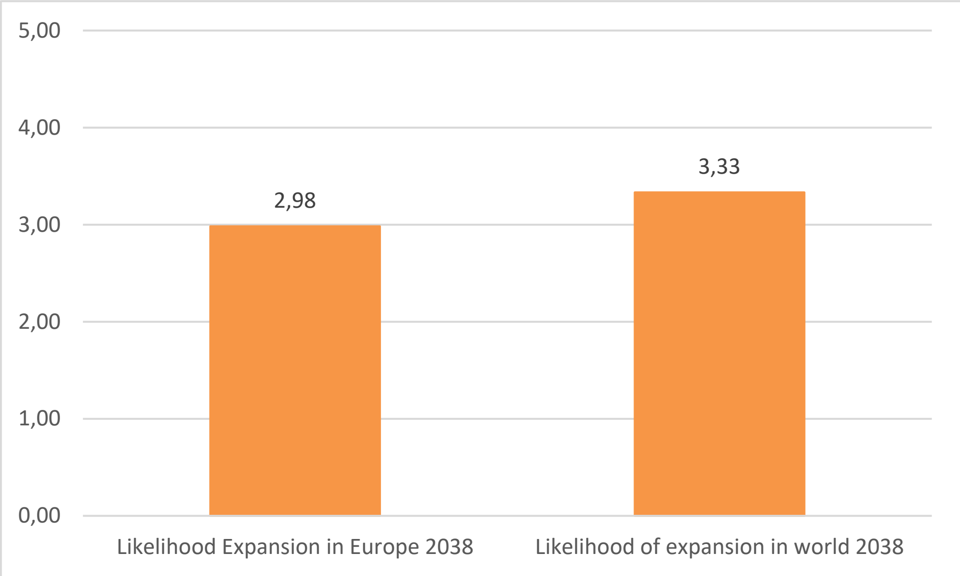

Figure 99: Likelihood of expansion of Alternative currencies by 2038

Alternative currencies can be digital (often called "crypto-currencies") or non-digital. Some even use time as a currency. In economics, a time-based currency is an alternative currency or exchange system where the unit of account/value is the person-hour or some other time unit.[1073]

As especially the use of credit cards and cryptocurrencies is increasing, more and more cashless transactions to pay for services or products of any kind are on the rise around the world. Some even expect a cashless society, in which financial transactions are conducted through the transfer of information (usually an electronic representation of money) between the transacting parties without money in the form of physical banknotes or coins. The calculation of the transaction can take place in crypto-currencies.

Recent progress directions

Crypto-currencies traded world-wide

Crypto-currencies are on the rise, with bitcoin being the most famous one developed by Satoshi Nakamoto in 2009. But there are many more crypto-currencies, the list gets longer[1074] to many more than the 50 currencies of the year 2017. Especially North Asia has been a fertile ground for crypto-currencies.[1075] In Japan, there is room for experimenting with crypto-currencies - the government regulators know the dangers and defined parameters, e.g. in a 'virtual-currency act' declaring that they are assets and can be used for payments.[1076] Crypto-currencies gained momentum

[1073] https://en.wikipedia.org/wiki/Time-based_currency

[1074] Even the Wikipedia list (https://en.wikipedia.org/wiki/List_of_cryptocurrencies) names already 50 currencies, most of them still active. The more detailed list of https://coinmarketcap.com/all/views/all/ names 1523 (as of 27/2/2018).

[1075] Digital Currencies: The crypto sun sets in the East. In: The Economist, Jan. 20, 2018, p. 69.

[1076] Digital Currencies: The crypto sun sets in the East. In: The Economist, Jan. 20, 2018, p. 69.

when there was a bitcoin bubble in autumn 2017 with unknown heights in the value of one bitcoin. Bitcoin has increased more than 1,500 percent to near $16,200 over 12 months. It decreased about 18 percent from its all-time high above $19,800 hit in mid-December 2017.[1077]

As there were ups and downs in the use and value of crypto-currencies, governments noticed the volatility of the virtual money. It evokes different reactions, for example China was alarmed and banned domestic exchanges. A criticism is also that bitcoin mining needs a lot of energy, so that the order in China was for "local authorities to choke off the power supply to bitcoin miners, computer networks that create new coins through massively energy-intensive calculations."[1078] On the other hand, the Chinese government admires the technology and wants to reap the benefits - prodding its big financial firms to experiment with blockchain (the system of distributed ledgers popularised by bitcoin).

Non-digital currencies gaining in variety

Not only digital but also non-digital currencies exist. They are not related to a National Bank and used in regional or worldwide contexts and show an increasing variety: Examples are[1079]: Beenz, e-gold, Rand (not connected to South African Rand) and Ven. These kinds of currencies are not linked to a nation-state. Especially regional and local currencies usable only in a geographically limited area gain attention as complementary currencies. The Complementary Currency Resource Center worldwide database lists about complementary currencies.[1080] Examples from different European regions are the Chiemgauer[1081], Brics, Langenegger Talente, Rheintaler, Urstromtaler, Bristol Pound, Exeter Pound, OSEL, Ekhi, Ecoroma, Venti[1082], or when Germans can pay on local market places with their former currency Deutsche Mark.[1083] The purposes for using these currencies can be very different, for example as economic, policy and social instruments designed to address issues or problems that remain unfulfilled with conventional currencies.[1084]

Time banks also manage a non-digital currency: time. Time is measured in minutes or hours, so that one hour equals one service credit value assumed that everyone's contributions are rated equally. The principle in these systems is that one person volunteers to work for an hour for another person and can redeem an hour of service from another volunteer. Time banks, sometimes called "time trade", are an invention of former times[1085]

1077 https://www.cnbc.com/2018/01/05/five-predictions-for-digital-currencies-in-2018.html, accessed 08/08/2018

1078 Digital Currencies: The crypto sun sets in the East. In: The Economist, Jan. 20, 2018, p. 69.

1079 https://en.wikipedia.org/wiki/List_of_digital_currencies, accessed 08/08/2018

1080 www.complementarycurrency.org, accessed 18/9/2018.

1081 http://community-currency.info/en/glossary/regional-currency/ accessed 18/9/2018.

1082 A starting list can be seen here: https://en.wikipedia.org/wiki/Local_currency, accessed 18/9/2018.

1083 Some of these activities were arranged to get the Deutsche Mark from the market as many Germans still stored it - but there are also events where it is circulated at special occasions even though it is no official currency, anymore.

1084 http://community-currency.info/en/glossary/complementary-currency/, accessed 18/9/2018.

1085 http://community-currency.info/en/glossary/complementary-currency/, accessed 18/9/2018.

but come back and grow with new management on digital (global) platforms (e.g. TIMEREPUBLIK[1086]). The idea of time banks, in which participants could earn time credits which they could save and spend any time during their lives was realized in Japan already in 1973 by Teruko Mizushima.[1087] Current units used are for example TimeDollars or nims (1 nim = 1 minute of life). Links to Universal Basic Income calculations exist.[1088]

A "local exchange trading system" (also "local employment and trading system", "Tauschring") is a locally initiated, democratically organised, not-for-profit community enterprise that provides a community information service.[1089] Normally, it records transactions of members exchanging goods and services directly or by using locally created currency. Often, currency is avoided, which can be solved by using single services or time as currency, so that one hour of service 1 (e.g. cut hair) is paid by one hour of service 2 (e.g. dishwashing).

Giving up cash

More and more products and services are paid digitally, even children pay with debit cards.[1090] In Europe and some other countries, this lead to the discussion to give up cash. Some coins and banknotes are already taken out of the currency cycle and in some countries, there are policies for giving up cash. Singapore for example plans to "catch up" on becoming a cashless society[1091] and making payments easier. A peer-to-peer funds transfer service was launched to enable users to pay and receive money with their mobile numbers and their Singapore identification number, regardless of their home bank.[1092]

In Europe, Sweden is the most advanced country on the way to a cashless society. Digital payments via card or apps are so widely accepted that many Swedes no longer carry cash. Already 80% of all transactions in Sweden are made by cards, only 1% of the value of all payments were made using coins or notes in 2017, compared to around 7% across the EU and in the US.[1093] Sweden's authorities are worried. A special parliamentary committee is looking into the potential dangers of the rapid transformation and what it could mean for the payment infrastructure and for people without access to the digital economy. The central bank is even looking into making a digital version of the krona.[1094]

1086 https://www.focus.it/ambiente/ecologia/time-republik-e-la-banca-del-tempo-mondiale, accessed 18/9/2018.

1087 http://intersections.anu.edu.au/issue17/miller.htm, accessed 18/9/2018.

1088 https://en.wikipedia.org/wiki/Time-based_currency, accessed 18/9/2018.

1089 https://en.wikipedia.org/wiki/Local_exchange_trading_system, accessed 18/9/2018.

1090 https://sweden.se/business/cashless-society, accessed 08/08/2018.

1091 http://www.zdnet.com/article/singapore-outlines-plan-to-catch-up-on-becoming-cashless-society, accessed 08/08/2018.

1092 http://www.zdnet.com/article/singapore-outlines-plan-to-catch-up-on-becoming-cashless-society, accessed 08/08/2018.

1093 http://www.bbc.com/news/business-41095004, accessed 08/08/2018.

1094 https://www.bloomberg.com/news/articles/2018-02-19/sweden-s-march-toward-a-cashless-society, accessed 08/08/2018.

5.12 Basic Income

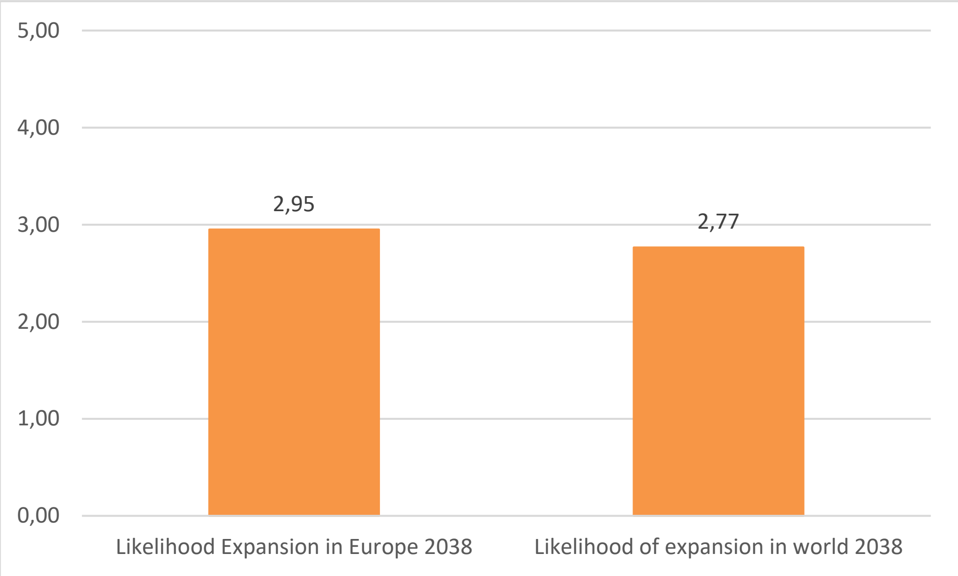

Figure 100: Likelihood of expansion of Basic Income by 2038

Guaranteed minimum income (GMI) or "basic income" is a system of social welfare provision that guarantees all citizens or families to have an income sufficient to live on.[1095] There are different possibilities: unconditional basic income (UBI, when citizenship is the only requirement for receiving it) or conditional income, which is provided if people meet certain conditions or fulfil certain duties. Basic income means the provision of identical payments from a government to all of its citizens. While most modern countries have some form of GMI provided under certain conditions, a general, unconditional basic income paid to all citizens is rare. With such a basic income, people can dedicate their (already paid) time to work in areas like science, healthcare, education, etc.

The concept is increasingly being discussed[1096] as a countermeasure to rising inequality, for replacing the practices in current social welfare payments, and a means to reach SDGs 1 (end poverty) and 10 (reduced inequality). There are many discussions about basic income as an answer to the expected job losses due to AI-based automation extending also to highly skilled occupations.[1097]

Countries like Finland or Canada[1098] tested unconditionally basic income at the national level. Kenya may follow. Some activities were regionally limited.[1099] Basic Income experiments[1100] on the national level were already

[1095] https://en.wikipedia.org/wiki/Guaranteed_minimum_income, accessed 8/8/2018.

[1096] https://basicincome.org/basic-income/history/, accessed 18/9/2018

[1097] e.g. OECD Policy Brief Basic Income as a policy option can add it up. Policy Brief on the Future of Work. Paris 2017, the discussion started with Rifkin, J. (1995): The End of Work: The Decline of the Global Labor Force and the Dawn of the Post-Market Era, Putnam Publishing Group, US.

[1098] https://basicincome.org/news/2017/07/canada-mowat-centre-report-shows-impact-basic-income-social-entrepreneurship/, accessed 7/9/2018; Report with first results see Crawford Urban, M. and Yip, C. (2017): Basic Impact: Examining the Potential Impact of a Basic Income on Social Entrepreneurs, Mowat Centre.

[1099] For a short overview, see https://en.wikipedia.org/wiki/Basic_income_around_the_world, accessed 18/9/2018.

performed in the Netherlands, in Denmark and are planned in Ireland and India ("poverty reduction by cash").[1101] This is a disruption to the major paradigm of economic drivers of nation states that are focused on gainful employment and social policies to enable participation in employment. Political unrest and/ or political apathy among the most vulnerable populations create the conditions for a renewed social pact or improved social policies.[1102] A basic income is supposed to be an incentive, an addition and to give motivation and freedom to people.[1103]

Recent progress directions

Unconditional Minimum Basic Income

The forms of unconditional basic income differ. Experiments test different forms on the national level, for specific citizen groups or within certain organisations. As the number of experiments planned increased, here are some examples: In Finland's experiment citizens are provided with a basic income, regardless of employment. The two-year pilot scheme will provide 2,000 unemployed Finnish citizens, aged between 25 and 58, with a monthly basic income of 560 euros ($581.48) that will replace their other social benefits. These citizens will continue to receive the basic income even if they find work.[1104] Earnings do not reduce the sum. This is different from now: The current system can potentially discourage the unemployed to find work as their earnings reduce the benefits they may receive.

In Kenya, 6,000 people are given an unconditional income through an experiment run by GiveDirectly, a charity organisation. People are able to use the money for whatever they want, e.g. food, clothing, shelter, gambling, alcohol — anything — all in an effort to reduce poverty. All around East Africa, GiveDirectly wires people money and monitors how they fare later in life. The experiment in some of the selected villages ran smoothly with the experience of "giving hope to the individuals"[1105], but there was also scepticism. Instead of accepting the cash transfers with open arms, many Kenyans have recently been saying "No, thank you." GiveDirectly's investigations have shown that people who refuse the cash are sceptical because they cannot believe it[1106], and "... as a result, many

[1100] For further examples, see https://en.wikipedia.org/wiki/Basic_income_around_the_world, accessed 18/9/2018.
[1101] http://indianexpress.com/article/opinion/columns/no-proof-required-financing-basic-income-for-the-bottom-50-per-cent-4462648, accessed 08/08/2018.
[1102] https://www.theatlantic.com/business/archive/2017/01/economism-and-the-minimum-wage/513155, accessed 08/08/2018.
[1103] https://basicincome.org/news/2017/06/karl-widerquist-universal-basic-income-good-deal-people-like-capitalism/ accessed 7/9/2018)
[1104] https://www.cnbc.com/2017/01/03/finland-experiments-universal-basic-income.html or http://mashable.com/2015/12/06/finland-basic-income-800-euros/#D4_fIDynIEqZ, accessed 08/08/2018.
[1105] https://www.businessinsider.de/kenya-village-disproving-biggest-myth-about-basic-income-2017-12?r=UK&IR=T, accessed 7/9/2018.
[1106] http://www.businessinsider.de/givedirectly-basic-income-experiment-unexpected-trouble-2016-9?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+typepad%2Falleyins

people have created their own narratives to explain the cash, including rumours that the money is associated with cults or devil worship."[1107]

National Referendum on unconditional basic income

Switzerland was the first country to hold a national referendum on an unconditional basic income.[1108] Swiss voters rejected by a wide margin a proposal to introduce a guaranteed basic income for everyone living in the wealthy country – after an uneasy debate about the future of work at a time of increasing automation. Opponents, including the government, said it would cost too much and weaken the economy. Other countries may follow with an own referendum.

5.13 Life Caching

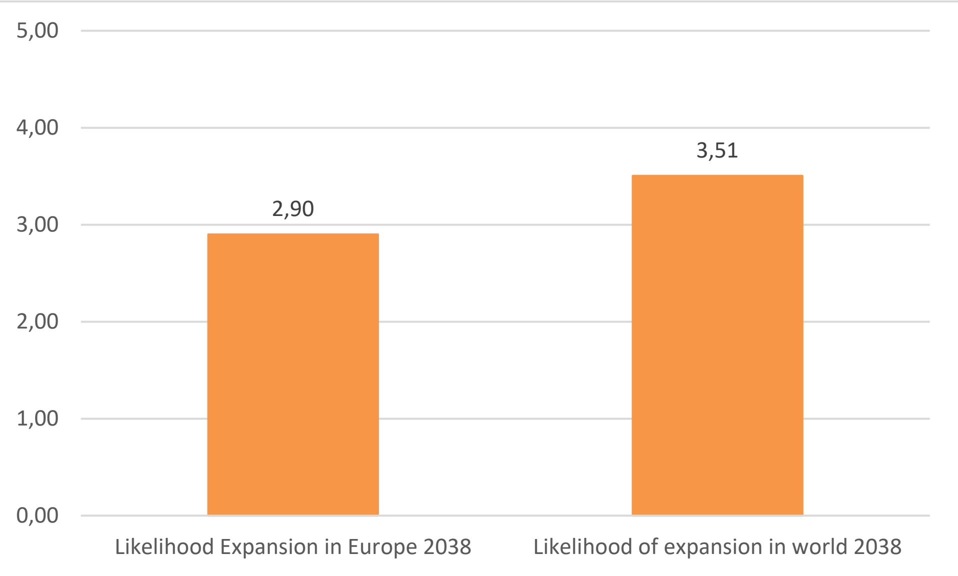

Figure 101: Likelihood of expansion of Life Caching by 2038

Life Caching means collecting, storing and displaying one's entire life for private use, or for friends, family, even the entire world to peruse. Millions of people are digitally indexing their thoughts, rants, pictures, video clips; most of them with new means online, disclosing the virtual caches of their daily lives, exciting or boring. The purpose of life caching is mainly keeping the memory. There is a link to lifelogging (self-tracking), in which individuals record and even quantify all their activities with activity trackers, cameras, etc.

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ider%2Fsilicon_alley_insider+%28Silicon+Alley+Insider%29&r=US&IR=T, accessed 08/08/2018.

[1107] http://www.businessinsider.de/givedirectly-basic-income-experiment-unexpected-trouble-2016-9?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+typepad%2Falleyinsider%2Fsilicon_alley_insider+%28Silicon+Alley+Insider%29&r=US&IR=T, checked on 08/08/2018.

[1108] https://www.newyorker.com/business/currency/the-swiss-vote-on-guaranteed-income-is-about-rich-peoples-problems or https://www.cnbc.com/2016/06/05/swiss-expected-to-overwhelmingly-reject-free-money-plan.html, accessed 08/08/2018.

Recent progress directions

Live caching as a growing industry

“Life caching” is a major trend (and a US $2.5 billion industry) where people effectively download (or upload) everything from emails and text messages to photographs, video clips, words and spoken words[1109] to store their own life. With this, they want to be unforgotten. The trend owes much to bloggers[1110]: since writing and publishing one's diary has become easy, millions of people take part and index their thoughts, rants, etc. The industry only functions online and induces people to reveal more than they want.

Scrapbooking increases

Scrapbooking is a trend that already holds for some years although it is suspected that this might have more to do with nostalgia and relaxation than with immortality and memory. In scrapbooks, everything from a person's daily life, e.g. photos, postcards, maps, tickets and nice pictures are inserted. Do-it-yourself and stationary shops make a huge market out of it, as many people are fixated with preserving their own memory.[1111] Scrapbooks are physical, not digital books.

[1109] http://www.nowandnext.com/top-trends/society-culture, accessed 10/08/2018.
[1110] www.blogger.com, accessed 10/08/2018.
[1111] http://www.nowandnext.com/top-trends/society-culture, accessed 10/08/2018.

6 Analysis of the Radical Innovation Breakthroughs

6.1 Social Innovation Breakthroughs (RSBs)

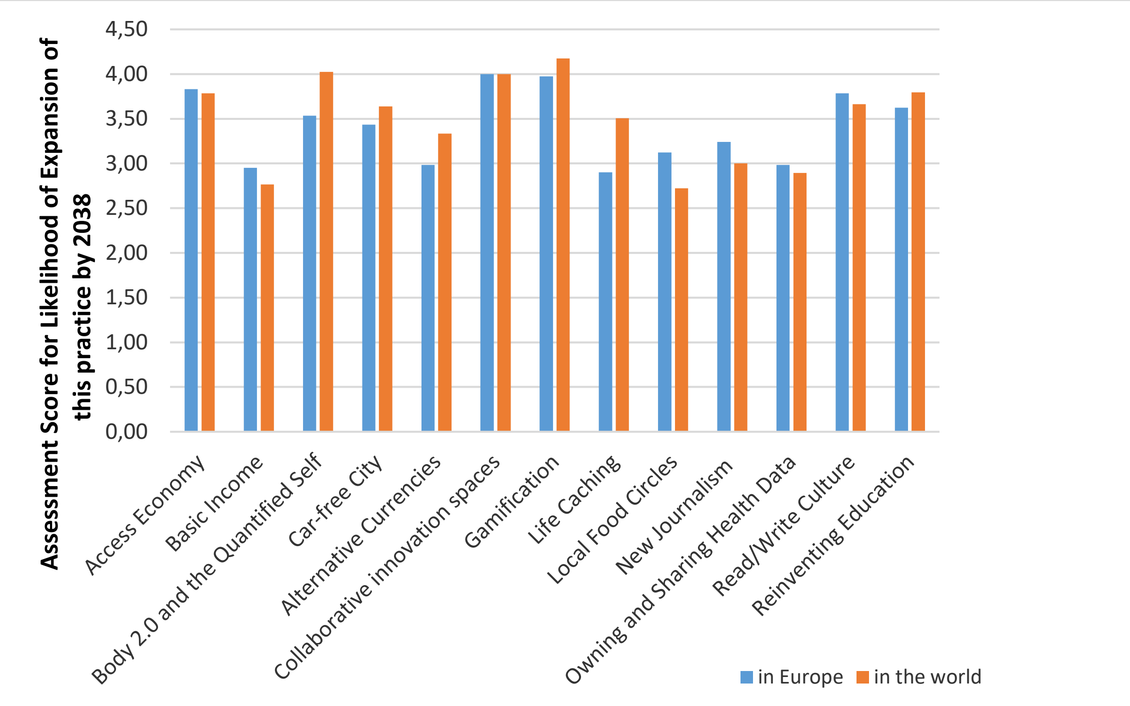

Figure 102: Likelihood of expansion of the social innovation breakthroughs

As indicated in Figure 102, for most of the thirteen social innovation breakthroughs, the likelihood of their expansion was assessed to be about equal for Europe and the rest of the world. There are however four notable exceptions: For "life caching", "alternative currencies" and "body 2.0", the uptake in other parts of the world is seen as more likely than the one in Europe, whereas the expansion expectation of "local food circles" is higher for Europe than for other regions. Looking at the overall figures for likelihood of expansion, the two most likely ones are "gamification" and "collaborative learning spaces" followed by "access economy" and "body 2.0". The most unlikely one is "basic income" with "local food circles" and "owning and sharing health data" scoring only slightly higher. As already discussed in the introduction, these social practices are of a different nature from the technological RIBs. As social innovations are local by nature and are reported and monitored much less systematically than science and technology developments, the ones with the potential to disrupt global value creation patterns will be few and are mostly already far advanced. Nevertheless we can see these potential shifts as a context for the emerging technologies and will come back to their possible interplay with technology RIBs in the overarching analysis.

6.2 Technology Innovation Breakthroughs (RIBs)

In this section, we discuss the ranking of the RIBs along the three criteria captured by our indicators. We start with the likelihood of significant use in 2038 and then add insights emerging from our assessments of the

European position and maturity. Table 2 below gives a result overview of the indicators for all the technological RIBs. All scores for the indicators were classified into five size classes using a metric scale. The table gives the resulting size class for each indicator and each technology RIBs. The size classes can be translated into qualitative labels ranging from 1 = very low to 5 = very high. #**NV means "no value**". For the European position, size class 5 means a very good position and 1 indicates a very poor position.

Table 2: Assessment of RIB technologies (ordered according to total likelihood of significant use in 2038)

RIB Name	Likelihood of significant use by 2038	European Position	Current Maturity
Speech Recognition	5	4	3
Neuromorphic chip	5	4	1
Nano-LEDs	5	4	4
Lab-On-A-Chip	5	5	2
Flexible electronics	5	4	2
Gene editing	5	4	2
Exoskeleton	5	4	2
Swarm Intelligence	5	4	3
Blockchain	5	4	2
Biodegradable sensors	5	4	2
Hyperspectral imaging	5	4	2
Chatbots	5	5	3
Automated indoor farming	5	2	3
Bioluminescence	5	1	3
Augmented reality	5	4	3
Driverless	5	4	3
Gene Therapy	5	3	3
Warfare drones	5	3	2
Bioplastic	5	5	3
Computational Creativity	5	4	3
Harvesting Methane Hydrate	5	5	2
Emotion recognition	4	4	2
Touchless gesture recognition	4	4	3
Precision farming	4	4	2
Regenerative medicine	4	4	3
Genomic vaccines	4	3	2
Wastewater nutrient recovery	4	4	2
Computing memory	4	3	3
Nanowires	4	3	4

Quantum Cryptography	4	5	2
Molecular recognition	4	4	2
Artificial Intelligence	4	4	2
3D Printing of Large Objects	4	4	3
Water Splitting	4	3	2
Drug delivery	4	4	3
4D Printing	4	3	1
Smart windows	4	3	3
3D Printing of Food	4	5	3
Technologies for disaster preparedness (prevention and reduction of damages)	4	4	2
Splitting carbon dioxide	4	4	3
Carbon capture and sequestration	4	4	3
Quantum Computers	4	4	2
Self-healing materials	4	4	2
Hydrogels	4	3	4
Microbiome	4	4	2
Brain Machine Interface (BMI)	4	4	2
Optoelectronics	4	3	3
Carbon Nanotubes	4	3	4
Soft robot	4	4	3
Metamaterials	4	3	3
Energy Harvesting	4	3	3
Brain Function Mapping	4	4	2
Smart Tattoos	4	4	2
Hyperloop	4	3	2
Holograms	4	4	4
Epigenetic change technologies	4	4	3
Desalination	4	4	3
Marine and tidal power technologies	4	5	2
Graphene Transistors	4	3	3
Thermoelectric paint	4	#NV	1
Geoengineering: changing landscapes	4	4	2
Bioprinting	4	3	2
Antibiotic Susceptibility Testing	4	4	2
Reprogrammed human cells	4	3	2
Microbial fuel cells	4	4	2
High-precision clock	4	4	2
Bionics (medicine)	4	3	3
Neuroscience of Creativity and Imagination	4	4	1
2D Materials	4	3	2
Targeting cell death pathways	4	3	3

Humanoids	4	4	2
Hydrogen fuel	4	3	2
3D Printing of Glass	4	4	2
Plastic Eating Bugs	4	3	2
Molten Salt Reactor	4	4	2
Underwater living	4	3	2
Control of gene expression	4	5	2
Bioelectronics	3	4	2
Aluminium-based energy	3	4	1
Artificial Photosynthesis	3	4	2
Spintronics	3	4	1
Airborne wind turbine	3	4	2
Artificial synapse/ brain	3	3	2
Flying car	3	3	2
Plant communication	3	4	1
Bioinformatics	3	3	3
Asteroid Mining	2	3	1

Looking at the list of technology RIBs ranked by **likelihood of significant use** in table 3 we can see that "speech recognition" is leading the list as the most likely RIB to reach widespread uptake by 2038, closely followed by "neuromorphic chip" and "nano-LEDs". In total, 21 technology RIBs are within size class 5, the group with the highest likelihood (marked blue). At the bottom of the table we find ten technology RIBs with only medium likelihood (marked orange). There are no RIBs with low or even very low likelihood.

The assessment of the **European position** in terms of technology RIBs rests on two sources, the RIBRI expert consultation and the analysis of the patents and publications for each RIB.[1112] We have focused our analysis on two pillars of leadership in RTI, namely applied research (Compendex Publications) and transfer into applicable products as indicated by transnational patents. Figure 103 gives an overview of the distribution of the resulting scores for "European position" for the set of technology RIBs. It shows that Europe excels in eight technology RIBs and holds a good position in 49 technology RIBs. Table 4 lists the ten RIBs with the best European position.

[1112] For a detailed description of the methodology for this indicator, cf. Part II, section 1.8

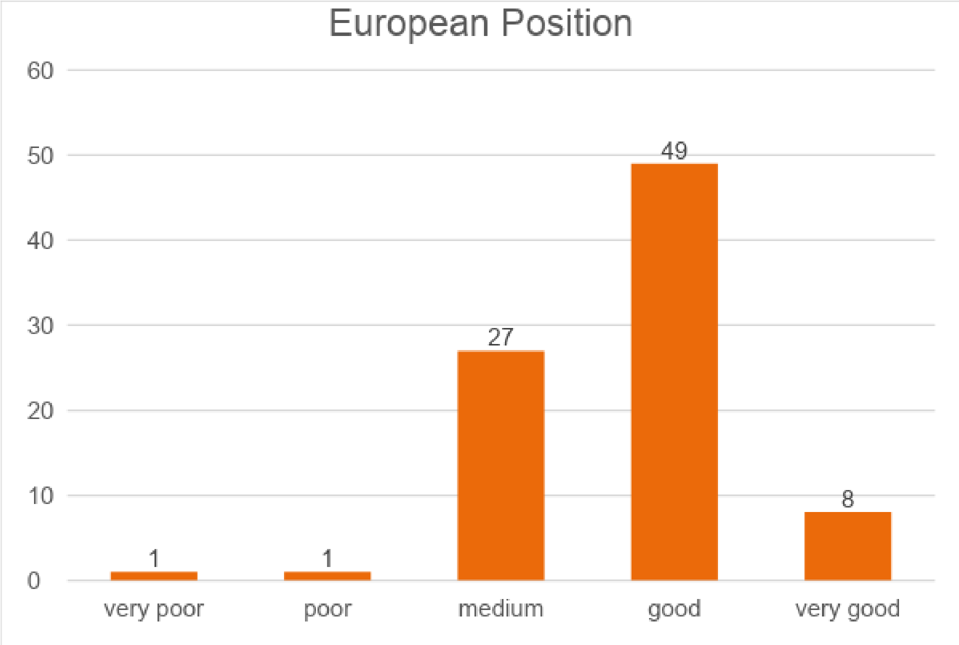

Figure 103: Distribution of EU position in RIBs

Table 3: Ten RIB technologies with the highest European position (in order of descending exact values for EU position)

RIBs	EU Position	Likelihood	Maturity
Harvesting Methane Hydrate	5	5	2
Underwater living	5	4	2
Bioplastic	5	5	3
3D printing of food	5	4	3
Lab-On-A-Chip	5	5	2
Chatbots	5	5	3
Quantum cryptography	5	4	2
Marine and tidal power technologies	5	4	2
Driverless	4	5	3
Blockchain	4	5	2

Figure 104 provides more detail on the nature of the European position. Europe leads in 18 RIBs in transnational patents and ranks second with another 59 technology RIBs. The EU leads both in patents and publications in 10 RIBs: Underwater living, bioplastics, 3D printing of food, lab-on-a-chip, marine and tidal power technologies, driverless, blockchain, artificial photosynthesis, humanoids, and spintronics. There are only two cases (quantum cryptography and technologies for disaster preparedness) where Europe leads in patents but not in publications; in both cases China leads in terms of publications. Table 4 lists the ten RIBs with the lowest scores in regards to the European position.

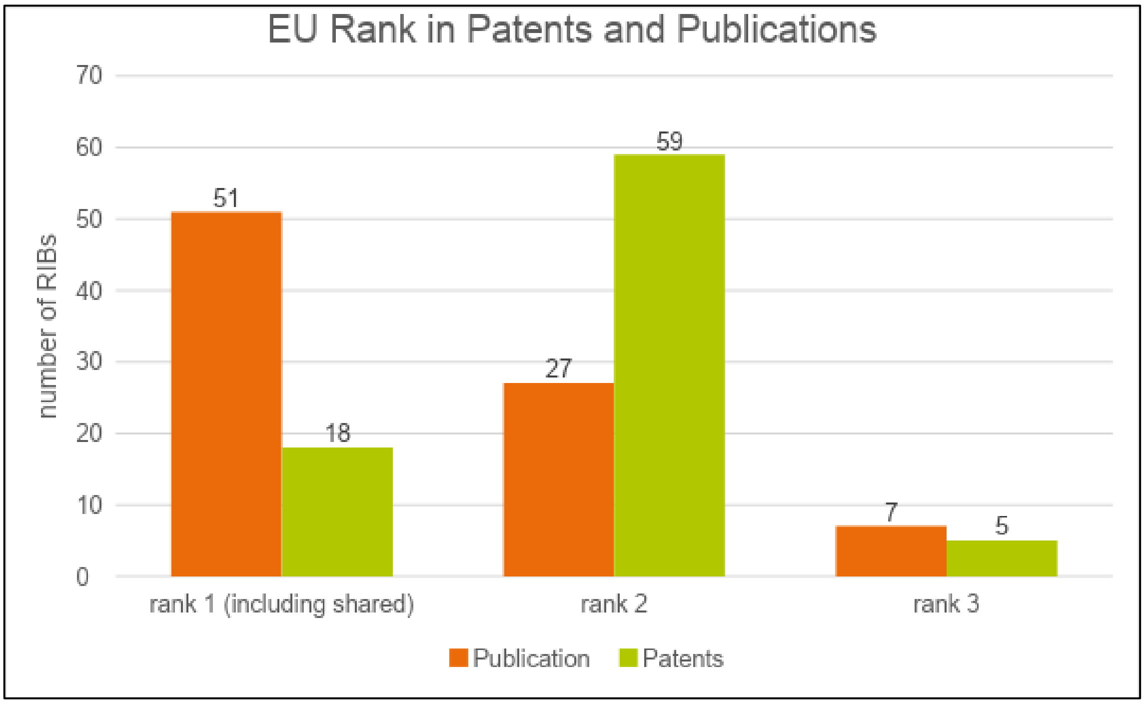

Figure 104: EU rank in RIBs patents and publications[1113]

Table 4: Ten RIB technologies with lowest European position (from lowest level upwards)

RIBs	EU Position	Likelihood of significant use in 2038	Maturity
Bioluminescence	1 (very low)	5	3
Automated indoor farming	2 (low)	5	3
4D Printing	3 (medium)	4	1
Water Splitting	3	4	2
Bioinformatics	3	3	3
Computing memory	3	4	3
Molten Salt Reactors	3	4	2
Graphene Transistors	3	4	3
Energy Harvesting	3	4	3
Hyperloop	3	4	2

In Bioluminescence Europe is especially weak in publications, ranked behind China, the US, Japan and Korea. In "automated indoor farming" the EU position is low. Here Japan is leading the field followed by the US. Nine of these ten technology RIBs, where Europe apparently performs relatively poorly, are very likely or likely to be in the market by 2038, competing with European innovations. Figure 105 and Figure 106 detail the shares of patents and publications for these nine "critical" RIBs. They indicate that in these cases Europe lags behind in both patents and applied publications.

[1113] Includes cases where this rank is shared with another country

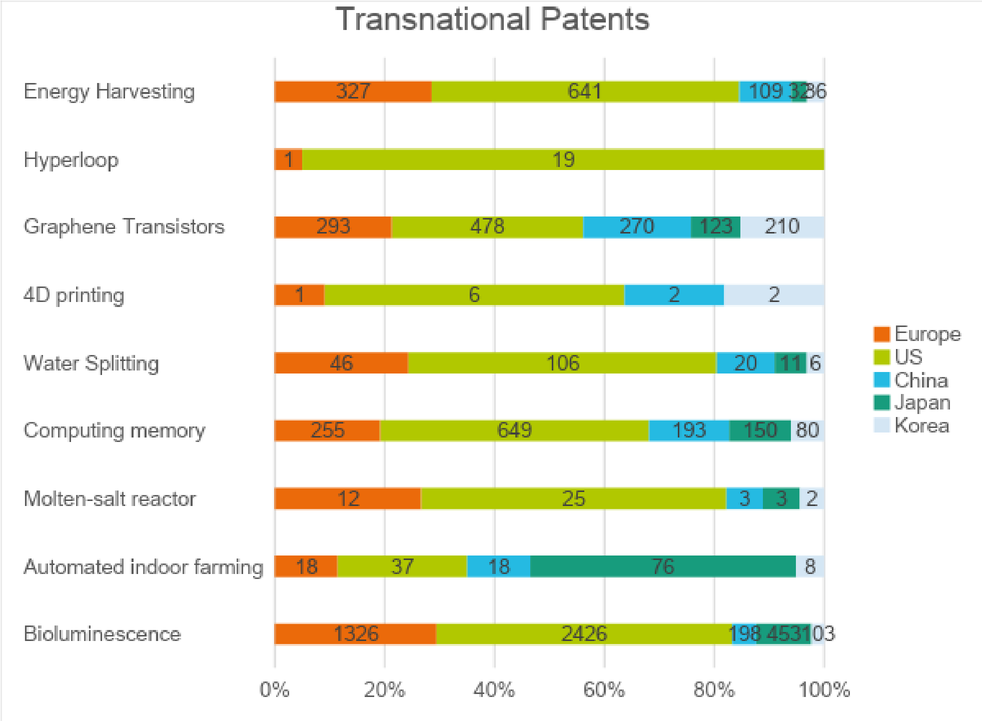

Figure 105: Transnational patents for the nine technology RIBs with the lowest European position but high or very high likelihood to be in the market by 2038

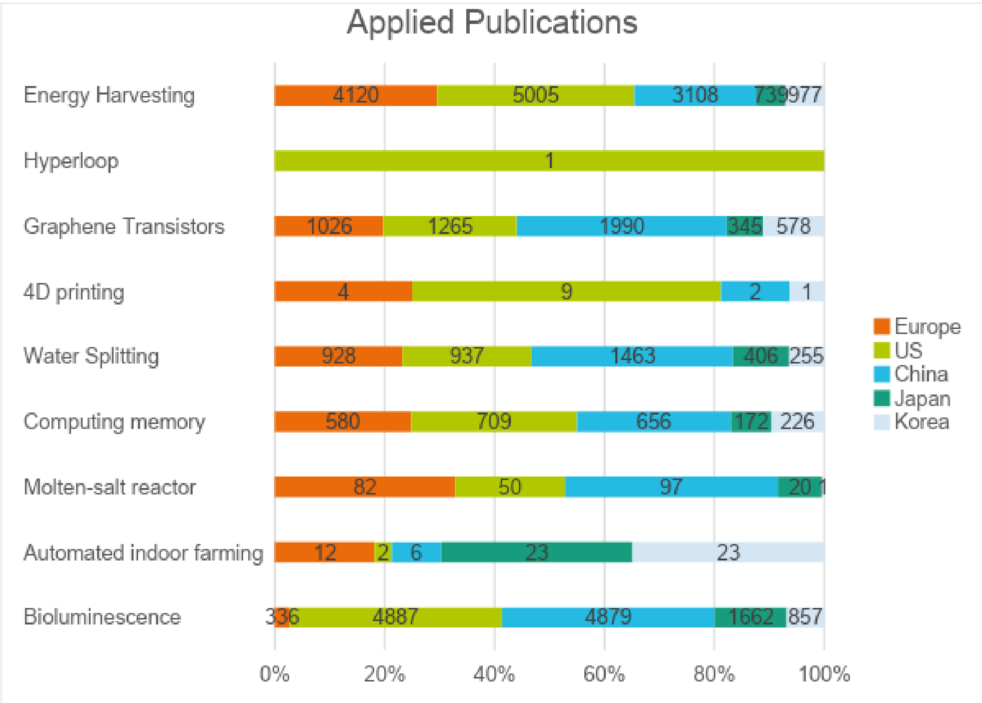

Figure 106: Applied publications for the nine technology RIBs with the lowest European position but high or very high likelihood to be in the market by 2038

Figure 107 visualises the scores for likelihood of significant use by 2038, vis-a-vis the scores for the European position for all RIBs. The red frame marks the segment with very high likelihood of significant use by 2038, but a less than excellent European position. Figure 108 focuses on this segment.

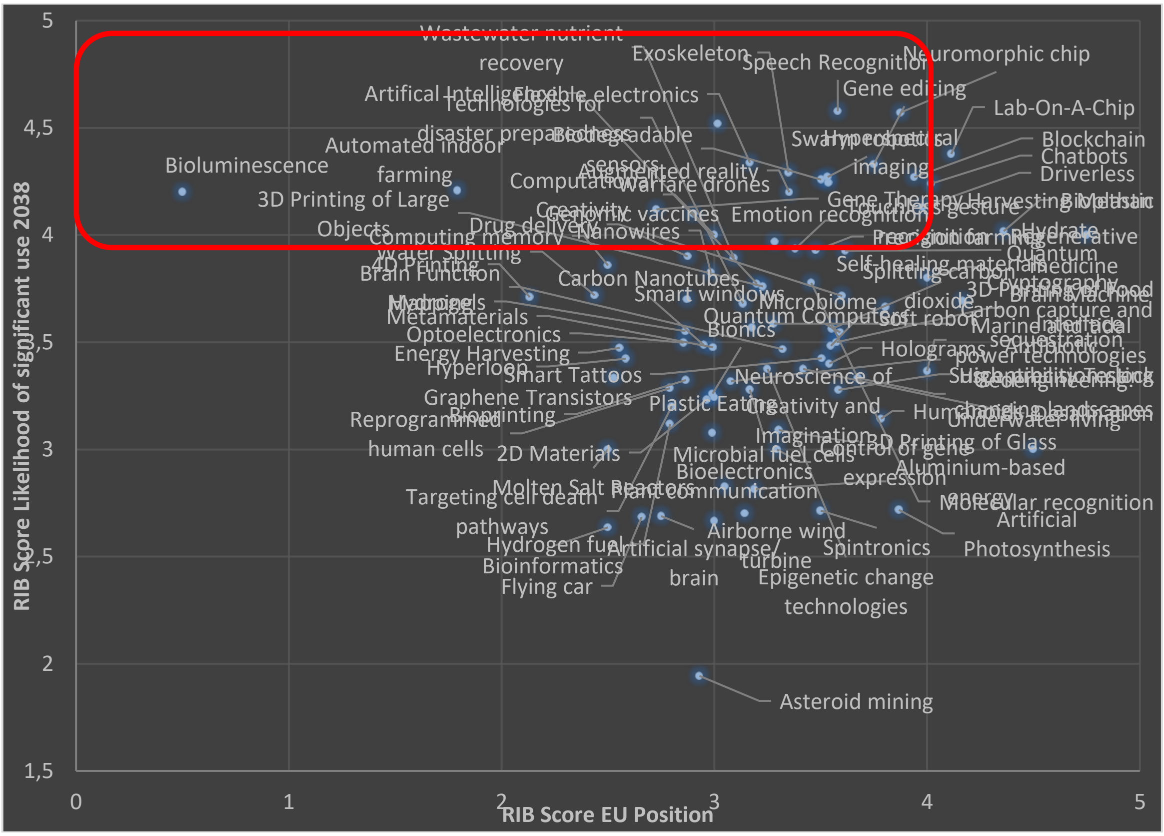

Figure 107: RIB score likelihood of significant use vs. European position

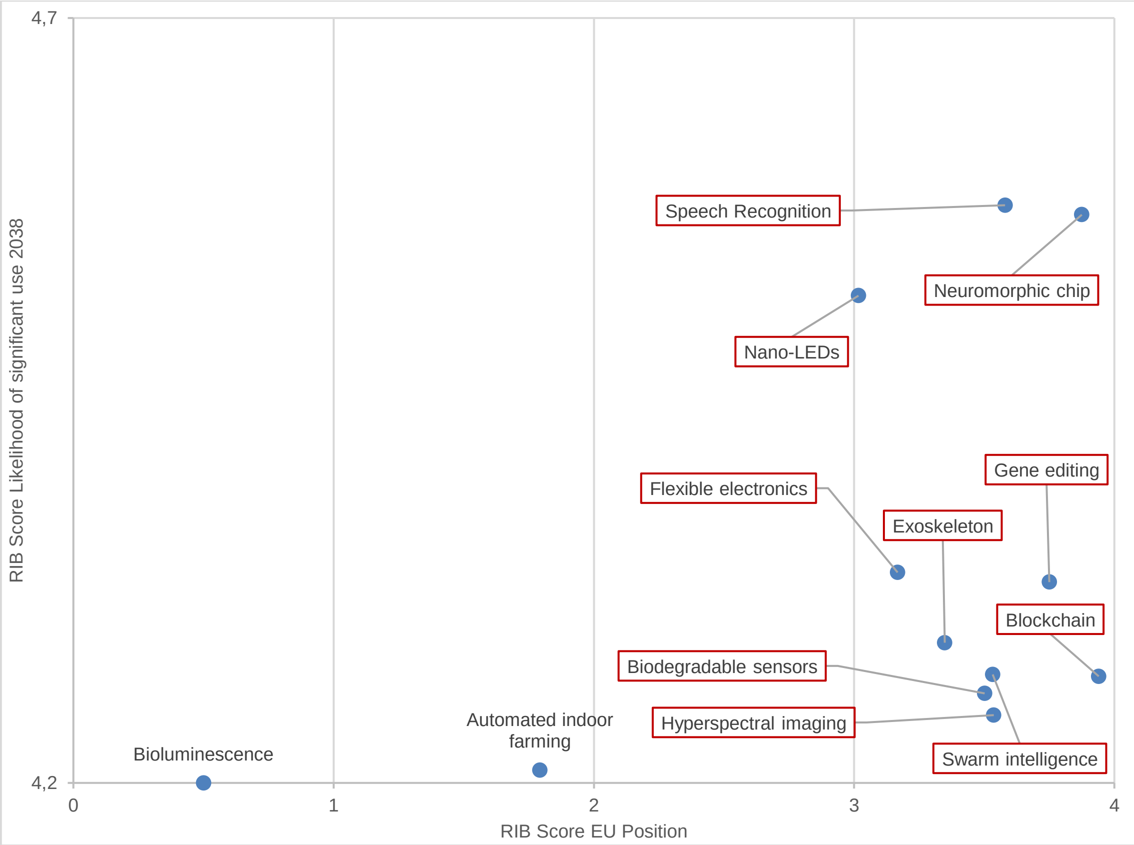

Figure 108: EU position vs. likelihood (selection likelihood >= 3.5)

Figure 108 reveals that Europe’s position stands out as low in bioluminescence and automated indoor farming. In addition, Europe is well positioned, but does not excel in ten highlighted RIBs shown as high in likelihood of significant use by 2038. Figure 109 and Figure 110 present applied publications and transnational patents respectively for these technologies[1114]. It is interesting to note that for all of them Europe leads in publications except for flexible electronics (lead US) and nano-LED (lead China). For the patents, the situation is reversed. Europe ranks second in all cases except for the blockchain RIB where it holds a narrow lead.

[1114] Neuromorphic chip is not presented because, due to its low maturity, the patent situation is not conclusive.

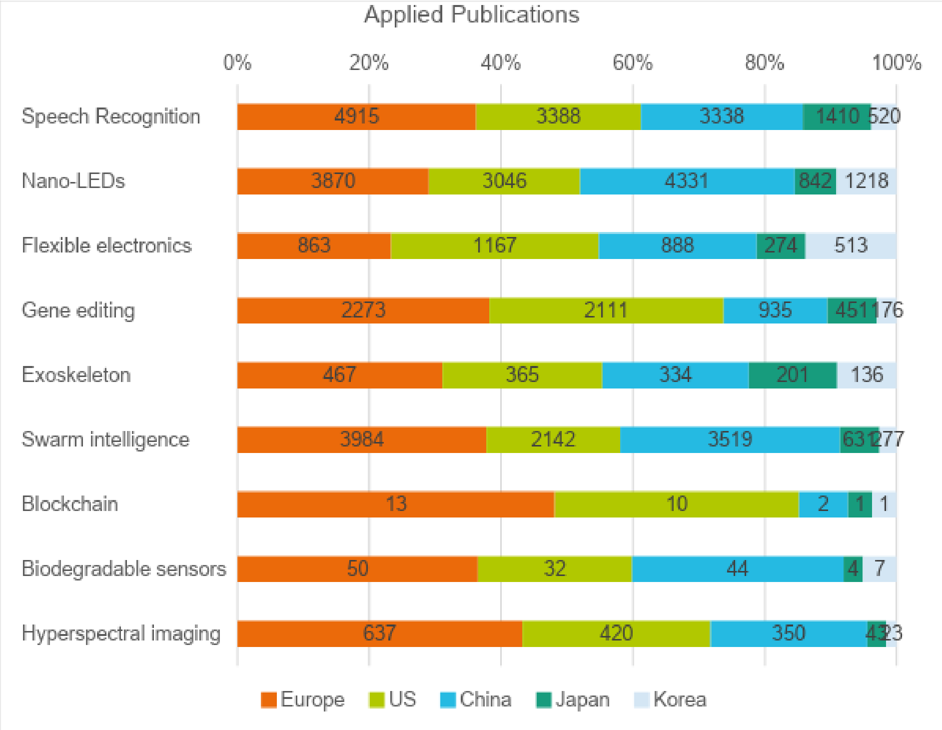

Figure 109: Applied publications for nine technologies with very high likelihood; EU position not excellent (from top to bottom descending likelihood)

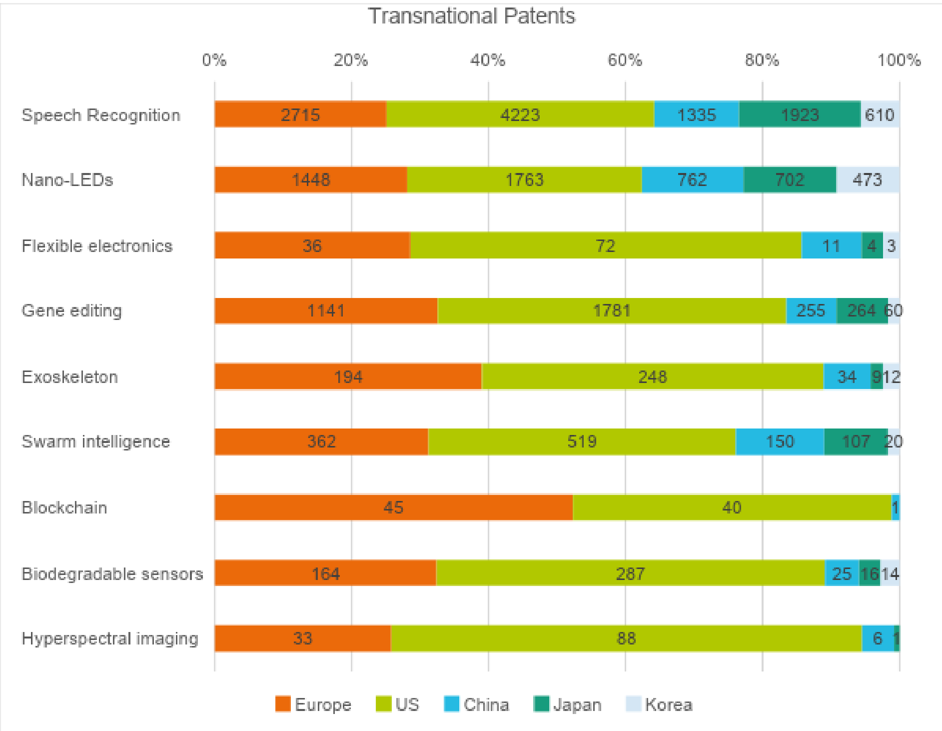

Figure 110: Transnational patents for nine technologies with very high likelihood; EU position not excellent (from top to bottom descending likelihood)

The **current maturity** of RIBs was assessed through an analysis of the patents and publications within the RIB areas (c.f. Final Report, Part II, section1.7). Very low maturity characterises RIBs with hardly any patents and few publications, such as "4D printing", which has 11 transnational patents and 16 publications. For some of the earliest RIBs such as “plant communication” or “asteroid mining” only publications but no transnational patents were identified. On the other end of the spectrum are mostly RIBs with a high number of patents such as e.g. carbon nanotubes with ca. 40,000 patents in total, out of which around 9600 transnational ones. Next to the total level of patents and publications, we also took into account the growth dynamics of patents. For technologies with a high level of patents already, but still fast rising publications, we assumed that they receive new impulses from science and are therefore not fully mature yet. Examples for this situation are gene editing, targeting death cell pathways, and speech recognition, which has one of the steepest increases in patents in the last decades, with a strong increase since 2013. As a second corrective input, we used the assessment given by the writers of the briefs who are experts in the respective area. Using this kind of qualitative reasoning, we classified the RIBs maturity on a scale from 1 to 5, with 1 indicating very low maturity i.e. proof of concept or even first speculations, and 5 very high maturity for a technology already applied in first products. Looking at the resulting distribution of the maturity presented in Figure 110 we can see that only five RIBs are rated as mature, and the large majority of RIBs is still in their infant phase.

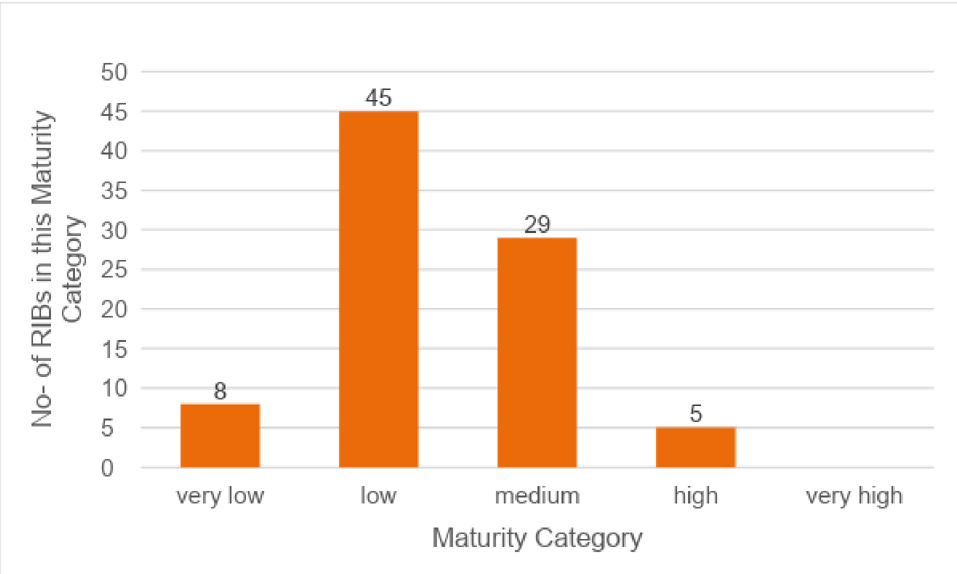

Figure 111: Distribution of RIB technologies scores in terms of current maturity

The eight technology RIBs that are assessed as highly immature are listed in table 6. These very early emerging technologies are particularly interesting from a foresight point of view. Among them the three RIBs “aluminium-based energy”, “plant communication” and “spintronics” could be seen as the most speculative, as the confidence of their development and subsequent score of likelihood of significant use by 2038 is only medium.

Table 5: Technology RIBs with very low maturity (please note that for thermoelectric paint no data for European position are available)

RIB Name	Likelihood of significant use by 2038	European Position x	Current Maturity
Neuromorphic chip	5	4	1
4D Printing	4	3	1
Thermoelectric paint	4	#NV	1
Neuroscience of Creativity and Imagination	4	4	1
Aluminium-based energy	3	4	1
Spintronics	3	4	1
Plant communication	3	4	1
Asteroid mining	2	3	1

Table 6 lists RIBs that are relatively immature today but expected by many to reach significant use by 2038. In this "high dynamics group" there are a number of technologies that are situated at the interface of life sciences on the one hand and automation and robotics on the other, such as "precision farming", "gene editing" and "biodegradable sensors". This assessment may indicate that these technologies may develop very fast and jointly form a wave of technologies emerging within the next two decades, and possibly also new socio-technical paradigms. Another interpretation could be that in these domains expectations are high but based on feeble ground, implying that the RIBs are in the middle of a technology hype cycle. In both cases, it may be worthwhile to have a closer look at these technologies either to avoid a bubble with inflated hopes and weak investments or to prepare for the steep rise which may be turbulent and involve unexpected interactions between the technology lines. This includes the need for societal dialogue and ethical reflection on responsible pathways for exploring these developments, as is obvious in some cases such as warfare drones and gene editing. This may be especially relevant for those RIBs that may impact many domains of economic and societal activity such as "artificial intelligence", "emotion recognition" and "blockchain".

Table 6: RIBs with very low or low maturity today and high or very high likelihood of significant use in 2038 (please note that for thermoelectric paint no data for European position are available)

RIB Name	Likelihood of significant use by 2038	European Position	Current Maturity
Neuromorphic chip	5	4	1
Lab-On-A-Chip	5	5	2
Flexible electronics	5	4	2
Gene editing	5	4	2
Exoskeleton	5	4	2

RIB Name	Likelihood of significant use by 2038	European Position	Current Maturity
Blockchain	5	4	2
Biodegradable sensors	5	4	2
Hyperspectral imaging	5	4	2
Warfare drones	5	3	2
Harvesting Methane Hydrate	5	5	2
Emotion recognition	4	4	2
Precision farming	4	4	2
Genomic vaccines	4	3	2
Wastewater nutrient recovery	4	4	2
Quantum Cryptography	4	5	2
Molecular recognition	4	4	2
Artificial Intelligence	4	4	2
Water Splitting	4	3	2
4D Printing	4	3	1
Technologies for disaster preparedness	4	4	2
Quantum Computers	4	4	2
Self-healing materials	4	4	2
Microbiome	4	4	2
Brain Machine Interface (BMI)	4	4	2
Brain Function Mapping	4	4	2
Smart Tattoos	4	4	2
Hyperloop	4	3	2
Marine and tidal power technologies	4	5	2
Thermoelectric paint	4	#NV	1
Geoengineering: changing landscapes	4	4	2
Bioprinting	4	3	2
Antibiotic Susceptibility Testing	4	4	2
Reprogrammed human cells	4	3	2
Microbial fuel cells	4	4	2
High-precision clock	4	4	2
Neuroscience of Creativity and Imagination	4	4	1
2D Materials	4	3	2
Targeting cell death pathways	4	3	3
Humanoids	4	4	2
Hydrogen fuel	4	3	2
3D Printing of Glass	4	4	2
Plastic Eating	4	3	2
Molten Salt Reactor	4	4	2
Underwater living	4	3	2

RIB Name	Likelihood of significant use by 2038	European Position	Current Maturity
Control of gene expression	4	5	2

Table 8 lists RIBs seen as mature and having a high likelihood to be used significantly in 2038. In three of these technologies the European position is only medium. Figure 112 provides the patent situation and Figure 113 the distribution of applied publications. It is interesting to note that except for hydrogels China leads the publications.

Table 7: RIBs with high maturity and high likelihood (in descending order of likelihood)

RIB Name	Likelihood of significant use by 2038	EU Position	Current Maturity
Nano-LEDs	5	4	4
Nanowires	4	3	4
Hydrogels	4	3	4
Carbon Nanotubes	4	3	4
Holograms	4	4	4

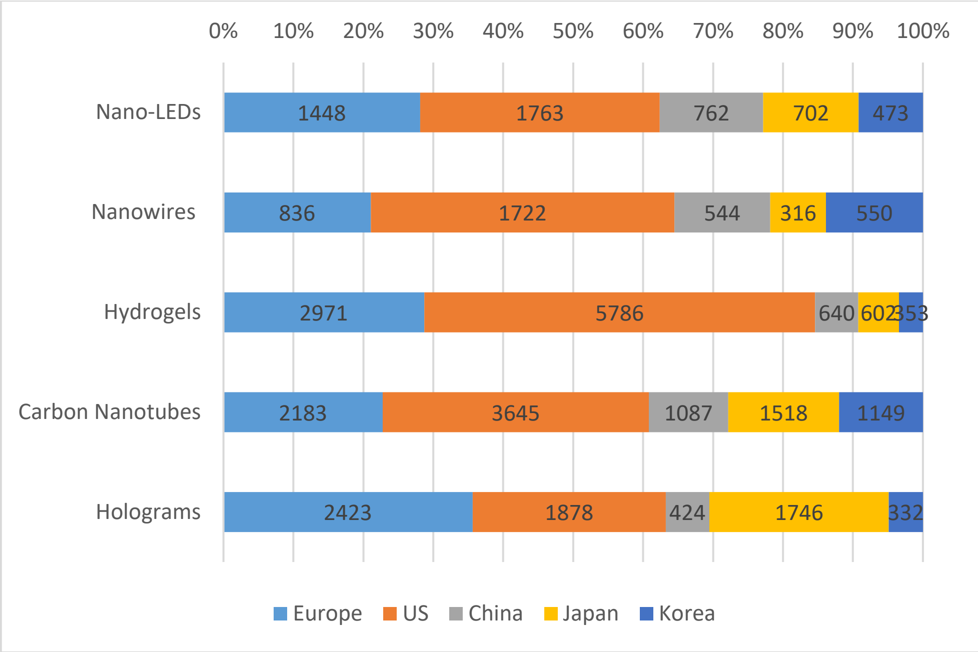

Figure 112: Transnational patents for the five RIBs with high maturity and high likelihood

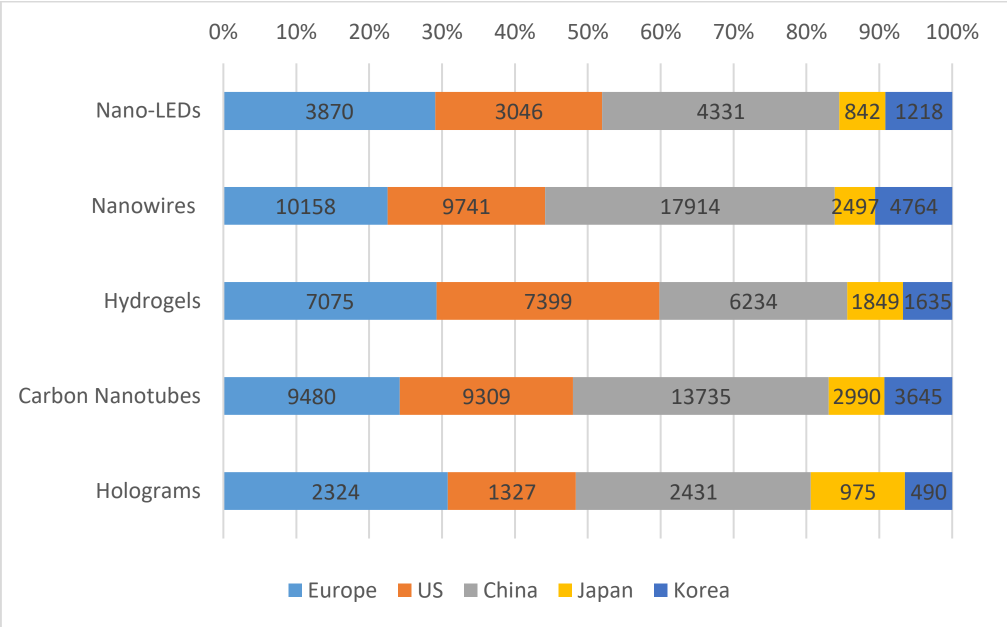

Figure 113: Applied publications in the five RIBs with high maturity and high likelihood

7 The Global Value Networks

In this chapter, we present the 22 Global value networks that we developed as a complementary framework for interpreting the RIBs.

A Global Value Network (GVNs) is a network of actors connected by relationships that create value. Those relationships can be based on material or immaterial exchange and include both competitive and cooperative relationships. A GVN displays stability over time, which gives the network a regime-like character – exercising regulatory influence over the behaviour of actors. A Global Value Network is thus a concept similar to that of a techno-economic paradigm.[1115]

The important defining feature of a GVN is its special global value promise. A value promise is associated with some global demand, which could be a need that all humans share, for example good health promoting services or better possibilities to move from one place to another place, or a collective need associated for example with the survival of the human species. Collective needs are associated with the aspirations and values of the European Union and the UN Sustainable Development Goals.

We believe that both types of needs will reconfigure the markets and the value creation processes of the future. In addition, while there are often contradictions between shared individual needs and collective needs, we believe that by 2038, the arbitration of such contradictions will involve global functions performed in networks such as those described in this chapter.

7.1 Planning and infrastructure for liveable human settlements

Background

Urbanisation is a megatrend. It is forecasted that over the next 20 years, the population of the world's cities will increase by more than the population of China and India combined. Cities will be more and more the origins of global problems and the spaces that inspire and create innovative solutions. Urban and territorial planning increasingly become a global need around which a number of networks converges. Already, across the globe networks of cities emerge and local political authorities begin to exercise local policies over and beyond national norms in matters that relate to environment, security, economy, education, innovation and quality of life.

Key aspects of the GVN regime of 2038:

At the core of this GVN are the liveable, inclusive, safe and green urban spaces. The function of the global network is much broader than the coordination of local politics, and includes important aspects of governance related technologies, infrastructures and regulations (including "smart",

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[1115] Carlota Perez; Technological revolutions and techno-economic paradigms, Cambridge Journal of Economics, Volume 34, Issue 1, 1 January 2010, Pages 185–202, https://doi.org/10.1093/cje/bep051 “healthy”, “resilient”, “green” and “sustainable” cities) as well as urban-rural interactions and relationships. All these together increase the quality of life of urban dwellers and enable increasingly sustainable, densely inhabited areas that are platforms for growing and evolving innovation, culture and economic competitiveness as well as for preserving historical and cultural heritage.

Cities are encountering complex threats, such as large-scale land degradation, which require completely new strategies. City authorities cooperate globally in experimenting and pioneering innovative solutions in many fields, such as energy and carbon efficiency, air quality and integrated transport. Transparent planning processes, including Public/Private cooperation, fulfil their promises and further increase public trust. Bottom-up and co-designing activities as well as local cooperative knowledge production are increasingly important. New solutions are designed and implemented in a thoroughly contemplated manner.[1116]

City centres are now zones of services and social activities allowing just bicycles and small electric cars. Despite the convenience of online shopping, accessibility and attractiveness of city centres support thriving local stores and services. Cycle-friendly planning follows examples from i.e. Copenhagen, Utrecht and Amsterdam. Overall, cities enable active lifestyles and provide “urban health advantage”[1117] with their infrastructures, planning design and availability of new technologies. Open public spaces provide important environments for interaction and further support the sense of local communities, which are challenged by phenomena such as hyper-mobility and over-tourism.

“Urban” is no longer considered on its own, but it is seen as interconnected to the surrounding region. The strict distinction between cities and non-cities disappear; urban areas are ruralised and vice versa. Territorial planning increases the liveability of non-urban areas as well as sustainable urban-rural connections. Importantly, the challenges require cooperation beyond city borders. For example, without active measures, the megacities of Africa generate severe problems and risks for Africa as well as Europe. Using the lessons learned in Europe, sustainable cities are also co-created with international collaboration in regions where the pace of urbanisation is fast, like in Africa and Asia.

[1116] For example, stronger monitoring of city dwellers increases safety, but without careful planning it can become be counteractive to liveability, as surveillance and big data governance are contradictory to some citizens’ values and ethics.

[1117] Sustainia (2014) Sustainia Guide to Co-Creating Health. https://issuu.com/sustainia/docs/sustainia_health_sector_guide

7.2 Sustainable energy solutions

Background

Under pressure from climate change and with a large number of new energy solutions, energy ceases to be a geostrategic asset. Trade in energy solutions flourishes and individual customer choice expands worldwide. Energy policies become economic policies. The global demand for energy continues to increase, especially in Africa, due to growth in population, urbanisation and per capita income levels. An energy mix of affordable low-carbon energy sources largely replaces fossil fuels. Politicians, citizens and companies actively promote climate change mitigation and a more efficient energy production and distribution.

Key aspects of the GVN 2038:

Energy is affordable, safe, environmentally friendly and, partly due to the falling costs of renewable energy technologies, accessible for all the people in the world. Energy has been a complex and "hot" issue with grand geo-political challenges related to it. Yet, facing the impacts of climate change, many countries now cooperate in providing and transporting sustainable energy. International regulations and agreements between interlinked countries enable a more efficient and sustainable energy system globally.

The new sustainable energy system is built on an energy mix consisting of various sources including solar power, wind power, geothermal heat, hydropower, biomass, waste burning and safe nuclear power. The energy system integrates novel key element solutions in e.g. supply, transport, ICT-supported infrastructure, smart grid, storage solutions, and business models. The new solutions enable highly efficient production, transmission and net "use" of energy. Converting ambient energy into electrical energy ("energy harvesting") is widely applied. The radical improvement in battery, hydrogen and fuel cell based storage solutions has been a paramount factor for the development of low-carbon electricity supply and sustainable trade in energy. By enduring stable energy supplies and large-scale facilities, the novel solutions for storage have made the mining and burning coal unattractive in those countries, which were sceptical about the transformation towards renewable energy sources. The high share of low-carbon energy sources has been further enabled by the decrease of prices in solar energy.[1118]

Smart grids allow the integration of small-scale energy production into the network, and promote equal access to sufficient energy. Small-scale, diverse and decentralised solutions together with local autonomy contribute to the resilience of the energy system. Information about different energy choices and their impacts is easily available to all.

[1118] On average 5% yearly price reduction for solar energy during the period 2018-2038.

7.3 Carbon retention for climate change mitigation

Background

In order to meet climate goals, carbon storage must become wealth and carbon emissions must become leakage. The value of storage and the cost of leakage are based on the concentration of carbon in the atmosphere. A global value network associated with creating and managing "carbon sinks" is built on the strength of a global political agreement for the governance of carbon in the atmosphere with fiscal powers, and on the potential of clean tech and carbon emissions monitoring and management technologies. The fiscal powers are used to shift economic incentives to avoid deforestation, retain carbon dioxide in oceans and recapture waste carbon resulting from human activities.

Key aspects of the GVN regime of 2038:

At the core of this GVN is carbon storage that mitigates climate change. Both compliance and voluntary carbon offset markets have grown substantially, and they are important tools in carbon reduction commitment. Careful management of carbon markets is crucial. The management of carbon stocks in the atmosphere is a massive complex task with huge economic consequences. Mitigating climate change with carbon retention has required effective global governance.

In the late 2010’s, the existing European forests were already near in reaching saturation point as carbon sinks. Sustaining and strengthening the sink capability of European forests required new approaches and strategies. With global agreements, destruction of tropical rainforests has ceased and there are efforts to grow more forests. The effective monitoring of forests and carbon emissions involves the development and deployment of new sensors. Special efforts focus on low-input farming, soil fertility management, nutrition disorders and sustainable non-food crops. Farm-based carbon credits bring economic benefit for environmentally minded farmers. Production of bioenergy uses biomass residue only.

Next to political commitment, technological development enables implementation of carbon capture as well as considerable cuts in carbon emissions. New effective carbon capture and utilisation (CCU) technologies and infrastructure emerge to complement and give momentum to carbon capture and storage (CCS) solutions. Furthermore, the effective use of biology and genetic engineering has increased the carbon capture of various kinds of plants. In order to ensure holistically green and sustainable processes, the novel technological solutions for carbon capture and storage are designed in ways that minimise unintended negative side effects for the environment.

7.4 Sustainable use of water systems and resources

Background

A territorial governance of water that ensures sustainability of clean water supplies and sufficiency of water resources emerges under the pressure from climate change and environmental degradation. The threat of a severe conflict resulting from shrinking water resources has brought about a GVN, where global, national and regional public and private actors rise to ensure adequate water supply for all. Helped by energy abundance, water ceases to be a geostrategic resource. It becomes an abundant, non-rival and common inheritance of humanity, ensured with transboundary water management and global treaty on water.

Key aspects of the GVN regime of 2038:

In general, this GVN concerns the use of water that promotes economic value, security and avoids pollution, depleted fisheries, and loss of coastal habitats. This has required commonly agreed geopolitical paths to solve the geostrategic implications of water scarcity and to challenge the former paradigm of established rights on water. Together with global warming, water scarcity is acknowledged as a threat that can generate conflicts. Thus, notions of responsibility for management of water resources – especially at country-level – needed to change.

Primarily, safe and good quality water is available for everyone in the world. New efficient desalination and purification processes and greatly improved water use efficiency for industrial as well as individual actors reduce the pressure on fresh water resources. Open access systems guarantee the availability of technologies for all. Various actors on regional, national and international levels collaborate to secure sufficient amount of water through a combination of easy access to technologies that monitor water condition and use, through water purification and recycling, and through collective governance of water related geo-engineering. Importantly, the global water governance has a regional layer. Shared water resources are managed in cooperation by neighbouring countries.

Undesirable changes in water systems, caused by climate change, are addressed with collaborative geo-engineering efforts by scientists, companies and private actors. The plastic and chemical release into the oceans and water systems from European and global coastal areas has ceased. Ocean pollution and acidification have incentivised global action. New water-harvesting solutions provide self-supplies of water for agriculture or drinking in areas that suffer from low rainfall. Simultaneously these technologies serve another important purpose, as they help mitigating floods.

Oceans provide with nutrition and well-being. As anticipated in the Manifesto of Bioeconomy[1119], European marine and coastal areas are

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1119 https://www.researchgate.net/publication/316751201_Targeting_sustainable_bioeconomy_A_new_development_strategy_for_Southern_European_countries_The_Manifesto_of_the_European_Mezzogiorno sustainably managed environments of localised, hybrid solutions. As an example, about half of all fish consumed in Europe is now produced by sustainable aquaculture, and there is a system of global governance for fishing. Alternative nutrition sources, such as seaweed, support responsible consumption of food from the oceans.

7.5 Sustainable use of materials

Background

Under pressure from waste pollution and the overexploitation of mineral resources, a GVN emerges based on the principles of sustainable circular economy, which take prime position in the practice and teaching of engineering, design and industrial organisation. Next to strong incentives by multilevel decision and policymaking, the key driving actors – the demanding customers and innovative companies who provide accessible, easy to use solutions – have changed the scene. Municipal authorities charge the costs of environmental remediation, pushing for material efficiency, reuse and recycling.

Key aspects of the GVN regime of 2038:

At the core of this GVN are the material cycles with negative environmental footprint. An important factor is the finding of affordable novel solutions and materials suitable for the sustainable cycle of material use, such as e.g. biodegradable materials. Raw materials are developed and selected for use according to their end-of-life possibilities in mind. Overall, the principles of circular economy, adapted widely throughout different sectors of production, have increased the overall value captured from resources. Production is less dependent on primary materials and due to the smart use material, the need for virgin material input is extremely low.

Towards the end of 2010's it was realised that the recycling solutions did not offer sufficient results. For example, some materials became toxic when recycled too many times. Europe, having strongly been leaning towards circular economy, invested in novel, more effective recycling and recovery technologies and infrastructure. Consequently, Europe is now a global pioneer exporting the recycling technologies. Most material, critical raw materials included, and waste in general is recycled or re-used into valuable inputs with new effective recycling solutions that consider the different recycling strategies required for i.e. minerals and metals. The identification of different materials and sorting waste is automated, accurate and efficient. All plastic is now reusable and recyclable. Leakage of plastic debris and micro plastics in water and the environment is prevented. Advanced bio refineries, supported with long-term policy instruments, use valuable ingredients effectively and produce food, materials, energy and chemicals. Biomass is processed sustainably and used efficiently. Importantly, local conditions concerning sustainable material have been standardised and the differences in regulations and standards concerning circular economy do not vary as substantial from city to city or from country to country anymore.

Social innovations and campaigns have raised circular economy awareness. Overconsumption is avoided, and so is planned obsolescence that wastes resources and energy. Sharing economy and collaborative consumption flourish and give attractive alternatives to private ownership. More and more products are designed and manufactured to be adaptable to changing requirements, durable and easy to repair if necessary. New design approaches, such as biomimicry, enable more sustainable products. The transition towards circularity provides traditional industries with innovation opportunities.

7.6 Smart transport

Background

Driven by the human need for mobility, trade and the environmental impact of transport a new GVN emerges that goes beyond the existing networks of manufacturers of means of transport, transport companies and insurance markets. New entrants include new power sources, new control and governance systems, increasingly active public authorities and active citizens. Efficient, automated and multimodal transportation systems unite people and goods with their destinations.

Key aspects of the GVN regime of 2038:

In this GVN, various actors on local, regional, national and international levels collaborate to enable convenient and safe passenger travel as well as smart logistic chains for the transportation of goods and raw materials with minimum environmental footprint. The strong cooperation on traffic management on regional, national and international levels, together with integrated data from individual vehicles, infrastructure and road networks guarantee a well-matched, safe, smart, efficient and traceable global multimodal transportation system.

Joint logistic systems with automated loading, unloading and distribution are located outside of the city centres and connected first-/last-mile solutions are used for urban freight delivery. This guarantees a systematic and more cost-effective transportation of goods, yet most traffic is removed from densely populated areas.

City centres and urban areas are planned in a way that supports non-motorised transport modes, such as walking and cycling. Inter-city transport models like Hyperloop bring down the environmental impact of transport substantially. Public and private sectors provide service-like mobility solutions for passengers through collaborative platforms. Individualised and on-demand services, together with reliable and affordable public transport, have reduced the attractiveness of and the need for privately owned cars. Robotic and autonomous electric vehicles support passenger transportation. With effective optimisation and planning, automated, autonomous and easy-to-use modes of passenger transportation do not increase congestion problems. Importantly, the trust issues and responsibility in case of accidents with autonomous vehicles have required careful designing. Furthermore, the well-functioning automated transportation with high level of connectivity has required cooperation between different car companies in order to address the questions related to standardisation, protocols and automated information as well as the vulnerability to cyber-attacks and viruses.

7.7 Individualised manufacturing close to the customer

Background

Scanning and printing in 3D enables local production of goods and equipment and facilitates servicing. Manufacturing and associated value chains become reconfigured. In the new GVN, different kinds of companies, suppliers and individuals produce goods, equipment and material locally, on demand, for specialised needs of individuals and other companies. Users benefit from the tailored products and systems as well as rewarding co-creation experience. Engineering and design knowledge and competence become widely available, supported by public libraries of printable designs for all kinds of goods, machines, materials and components. Intellectual property, health, safety and security are protected with regulation.

Key aspects of the GVN regime of 2038:

This global value network concerns the availability of efficiently produced fully personalised products with flexible inroads for user interventions and add-on services. A significant proportion of manufacturing is decentralised and carried out by consumers or local businesses. Importantly, prosumer models enable new ways of collaboration. The foundation of this GVN are the various forms of additive manufacturing and 3D imaging that promote customisation.

Robotisation brings flexibility to production lines. With artificial intelligence, robots can produce small series or individualised products locally and on demand, which increases cost-effectiveness. Fast prototyping enables experimentation and flexible testing. This has radical effects for example in healthcare sector, where 3D printing enables precisely tailored prosthetics and organ transplants. Concerning the materials, several technological challenges have been overcome, including the use of 3D printing with different materials, combinations of printing materials, material density/composition scanning and the consistent high printing quality, making 3D printing very competitive.

Personalised production is not efficient in the same way than mass-production, and sustainability issues have required new approaches within the new paradigm. For example, cheap transport and efficient logistics have been planned to favour centralised mass scale production. Yet, overall, the novel modes of manufacturing promote the principles of a circular economy, as the production of spare parts at the location where they are needed makes repairing easy.

7.8 Remote interaction with people and machines

Background

Being able to interact with other people from a distance as if they were physically present and to control things, machinery and processes has been a guiding ideal for communications technology experts, providers and politicians inhabiting Ministries of Telecommunications. This ideal continues to drive the development of interfaces between people, between machines, between infrastructures or between people, machines and infrastructures. As interfaces improve, the multiplicity of distant modes of interaction becomes a core feature of socio-technical networks that become more and more independent of place and enable individuals to reach the whole world.

Key aspects of the GVN regime of 2038:

This GVN enables people to routinely perform tasks and provide services without being at the same location as the utilised devices or tools. For example, experts collaborate to share and co-create knowledge in domain-specific online and virtual communities of practice that extend throughout the world. Reliable communication allows multiplication of skills. In addition, intelligent machines control other machines and human beings from a distance, using human language if required. As tasks are taken on by autonomous systems, human capacity is released for more meaningful and creative efforts.

Augmented reality and virtual reality together with Artificial Intelligence provide accessible communication environments. The experiences of distant presence are almost identical to those of physical presence, enabling the positive impacts, such as trust, credibility, meaningfulness and innovation, of face-to-face meetings. Specific diagnosis tools and visual communication programmes support the network.

Telepresence promotes and benefits from globalisation. Telepresence-based models increase work outputs and reduce unwanted or unnecessary travel. People are able to choose their place to live more freely and stay there for longer times, if they wish. Savings in commuting time have become interesting also for the employers, as they are acknowledged to increase the wellbeing of employees. Yet, many people still prefer to be near people instead of telepresence.

7.9 Sustainable housing

Background

As population rises across the planet, good housing is a growing need. The construction industry is one the drivers of economic growth across the globe, one of the biggest consumers of mineral resources and one of the most important sources of greenhouse gas emissions in the atmosphere. The environmental impact of housing and our increasing knowledge of the relationships between housing, health and economic productivity drive the emerging global value network. Despite empty property, many large cities have the problem that owning a house is not affordable and even renting is very expensive.

Key aspects of the GVN regime of 2038:

Primarily, this GVN is about buildings with negative environmental footprint that are tailored to the needs of users and promote dignified living.

Built environments support community building as well as the health and well-being of the occupants. Housing and spaces are designed to promote a sense of community, facilitate interaction and enable social networks. Changing housing needs, caused by i.e. demographic aging, are considered in planning processes and supported with innovative modular and multifunctional housing solutions. Sharing economy models decrease housing and living costs and provide social benefits and meaningful interaction.

The environmental impact of housing is low and the land use is efficient. Overall, the ecological functionality of buildings is high. For example, by turning the outer walls and roofs into solar panels, space can be used efficiently for energy generation. Energy-efficiency is planned beyond a focus on single buildings. The renewal of existing housing stock has been an important question for Europe. Due to regulations, old constructions and apartment buildings have been widely retrofitted and renovated to meet the energy efficiency standards. By doing so, many old houses have been saved from destruction. In general, the principles of circular economy are followed in construction processes, and smart, sustainable and innovative material (i.e. polymer) or material substitutions are utilised.

In the built environment, digital and physical worlds are now interrelated throughout the entire lifecycle. Digital information, artificial intelligence, 3D printing and robots are efficiently used in the planning, assembling, building and maintenance of buildings. With robotisation, many tasks in casting, moulding, painting, transferring materials, installation and finishing are automated. Increasing digitalisation and Internet of Things enable sustainable solutions, and they are designed in a way that addresses the unwanted issues such as spy programs and viruses. Structures and spaces are functionalised. For example, many structures are self-healing, they intrinsically detect their maintenance needs and utilise information technology as well as living materials. Many of the formerly passive materials and infrastructure (walls, streets, furniture, street signs) are interactive or functional (reducing noise, for example).

7.10 Valid information and knowledge co-creation

Background

As information circulates freely and online communities of practice flourish, knowledge co-creation is practiced by anyone interested in doing so. Citizens, scientists, science funders and policy makers across the world cooperate to establish open data available to anyone, and structures that provide evidence-based public advice for decision-making. Artificial intelligence algorithms continuously scan sources of evidence and advice, and customise information to the decision needs of their users.

Key aspects of the GVN regime of 2038:

Availability and co-creation of valid information and knowledge are the basis for individual and societal decision-making in this GVN. Overall, the availability of valid and updated information in a relevant form improves the skills and knowhow of European citizens making them interested in science and a scientific way of thinking, which further helps solving wicked problems such as climate change.

Up to date and relevant information stemming from various certified sources is easily available for citizens. Accordingly, the production and distribution of fake information is avoided and traced systematically. Algorithms support dialogue instead of creating "filter bubbles", which separate information that is contradictory to or may challenge the person's viewpoint. Public, independent broadcasting and free media are the main sources of information. Agile, critical and personalised media sources support the public broadcasting system. Invalid information and fake news are rapidly identified and excluded from discussions. Importantly, media freedom, diversity and pluralism are protected as pivotal factors of freedom of expression. Equal opportunities for data and media literacy are actively advanced.

Artificial Intelligence supports the transparency of the political and economic decision-making across the EU and many other parts of the world. As a challenge, AI is not yet completely able to explain how it makes its choices, which still implies the risk of manipulation and the misuse of AI against the general European targets. Furthermore, it should be noted that evidence alone is not enough for smart decisions. Co-creational activities as well as participatory research and science support decision-making that meets the citizen demands. The quality of information produced by citizens and independent researchers is inspected by trustworthy scientific institutions. Science is open – with few exceptions – and the communication of scientific results is instant and clear. Furthermore, the transfer of scientific knowledge between countries is open. Similarly to the press, critical scientists enjoy freedom of speech and are not oppressed by those in power.

7.11 Self-directed individualised learning

Background

Education is the driver of change and socio-economic dynamics. The global market for education services has been growing, increasingly so due to digitalisation. Globally competitive elite schools and universities continue to be associated with aspirations for success and upward socio-economic mobility. Open data, expert advice systems, simulators, online training communities and flexible career structures complement the learning experiences provided by formal education systems, making knowledge and skills available to those seeking to acquire them. All this gives individuals the possibility to decide what and how to learn.

Key aspects of the GVN regime of 2038:

This GVN has emerged around the creation and support of personalised learning trajectories. Overall, teaching is organised in a way that supports the talents and needs of each individual. It is calibrated and partly customised according to each pupil's capacities. Emphasis on lifelong learning approaches enables training, personal development and education for people throughout their lives, for meaning and competitiveness. National strategies and policies support and inform the reformation and recalibration of education systems that meet the needs of societies, working lives and the world of the future. Although quality assurance and certification of the learning trajectories are considered essential, it is done in a manner that acknowledges the individualisation of education instead of rigid standardisation.

The range of services offered by schools and universities has increased considerably, from global MOOCs to highly selective intensive targeted short courses, and from courses associated with professional accreditation to curiosity-driven education that supports social integration. Despite their long traditions and professional independence, traditional public monopolies in the education sector introduce the technological or social innovations. Importantly, in many EU countries, the roles of teachers are now highly valued and they are no more under-paid. In order to answer the paradigm of individualisation, personal mentoring is increasingly prevalent as a high-end service.

An important learning method is problem solving in groups or in shared projects. Many publicly funded schools and universities in the EU and elsewhere in the world have replaced the conventional disciplinary teaching methods with a problem-solving-based pedagogy and curricula. Besides basic instrumental skills (e.g. reading and mathematics), the focus of childhood education is on social capacities. Furthermore, the emphasis in learning shifts from information accumulation to posing new questions and creativity. Individual progress is tested with problem-solving situations simulated by Artificial Intelligence and digital technologies. Artificial intelligence can correct performance and provide enough motivational stimulation for learning. Artificial intelligence and simulators can certify the achieved skills.

7.12 Pro-active health and self-care approaches

Background

Health becomes an ever more important value in people's lives. The majority of people have developed an active role in healthcare with the support of a network of healthcare professionals and specialists. The primary goal of all actors in this network is to avoid, detect and cure (dangerous) illnesses. There is a growth in the provision of knowledge, infrastructures and services for activities, which improve and maintain physical and mental health on all sides. Key elements are patient empowerment and responsibility, prevention and pro-action as well as continuous monitoring of symptoms and behavioural advice, supported by responsible and liable professional medical and care companies and providers.

Key aspects of the GVN regime of 2038:

This GVN promotes health with fast and early diagnosis with fast (self) help, immediate treatments, availability of knowledge and capabilities for healthy lives. At the core of the network are preventive and pro-active approaches, which are based on continuous, active and automated self-monitoring by the patient. Treatment is conducted in an active interplay of a trustworthy health specialist or machine expert and the patient. Different specialists are included in the network if needed. Healthcare is holistic and preventive, focusing on behaviour, diet, profession and lifestyle of the individual. Personal genetic information and peer information from persons with similar symptoms are used for diagnosis and treatment. Experts motivate citizens for an active, healthy way of life.

Avoiding and delaying the onset of dementia through active and healthy lifestyles is mainstream culture. The obesity trend in the EU and other world regions is inverted. However, there has been little success in curing Alzheimer disease. An equal access to health promoting lifestyles narrows the health divide. Special support and exemptions are given to groups of people with lost physical or mental capabilities.

Next to medical professionals, artificial intelligence is paramount in self-care. AI systems give decision-support on the activities during treatments to the patient. Each average household has devices for constant monitoring and the first symptoms are detected early. Digitalised health data is designed with careful focus on privacy, data protection and standardisation. Without reliable existing knowledge, expert recommendations or AI, self-care may result in wrong decisions, non-scientific of inefficient cures, incorrect diagnoses or and excessive use of medicine (overdoses or the thinking that more helps more) for purposes that could be cured with pro-active health promotion. Big data and continuous monitoring have also paved the way for customised medicine. New technologies, such as robotic legs, medication dispensers, artificial eyes, housekeeping robots and distant assistants help those with permanently lowered functional capability. Related to this, ethical disputes have emerged around more extreme practices of "human enhancement".

Many insurance systems require participation in the continuous controlled health monitoring activities focusing on early identification or prevention of symptoms. Monitoring devices, tools and technologies are affordable, accessible and easy to use. This puts further pressure on citizens to choose long-term health benefits and adapt prevention-based system over unhealthy lifestyle (fast food, no sports, etc.). Notably, self-care strategies are not suitable for all, and they may leave behind people without required capabilities, will or economic resources. Minors cannot be subject to self-care.

7.13 User data markets

Background

Data is to this century what oil was to the last one: a driver of growth and change.[1120] Especially data arising from the use of digital platforms, services and devices in the internet of things are of tremendous value as the basis for the development of artificial intelligence algorithms. A new value network emerges around data as a "new asset class" with open data markets replacing the data silos of today. Such a data economy may well include individuals who are trading with the data arising from their web activities like with any other asset, as well as intermediate actors who take part in trading activities. This may multiply possibilities for exploitation of data flows through public and private players. A steady flow of fresh data from individual users is highly valued as the key precondition for successfully training artificial intelligence algorithms and for developing advanced private and public services.

Key aspects of the GVN regime of 2038:

The new GVN regime revolves around privacy respecting, user controlled and advanced utilisation of data flow from use of web platforms and internet of things, which is used for optimisation of public and private services. There are various practices and regulations related to data ownership, data model contracts, privacy, secure data flows, and transparency of data utilisation. Online firms are no longer exchanging data for free-services, but pay consumers for the use of their data, which becomes an economic asset to the company. Mechanisms for data pricing and accounting are in place. Public and private data brokers have emerged to enable data negotiations.

Consumers can opt for different degrees of sharing for different types of data, e.g. more strict strategies with their health data than with their consumption information. Furthermore, consumers are empowered to become data entrepreneurs and they are well informed on different contracts and regulations and how to work with them. Overall, rules are now user friendly and transparent. Technological solutions underpin and support these sharing models. Diverse types of unstructured data flows are integrated by AI algorithms in a sophisticated and meaningful way. Furthermore, these solutions increase the trust of consumers in data brokers and users and decrease the possibilities to misuse of the data for purposes not expected by consumers (criminal use, manipulation, advertising).

As a result, relevant data, integrated form various sources, are no longer stuck in a silo with the platform where they were generated but instead, they are distributed through the data market to where they are needed. Especially public sector actors can use data to inform their policies and design tailored public services. Europe has formed a data union with high standards of controlled use of web platform user data as well as a high degree of data harmonisation. Change has required creation and

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[1120] https://www.economist.com/news/briefing/21721634-how-it-shaping-up-data-giving-rise-new-economy implementation of new regulation. This has become a competitive advantage for Europe and challenged former monopolies.

7.14 Peer to peer based consumption decisions

Background

In this GVN, networks of people around the world advising each other are the dominant factor in democratised consumption and purchasing decisions for products and services. Competing and complementary digital platforms provide access to detailed product information provided in a transparent manner. At the same time, retailers have bridged digital and physical shopping experiences so that virtual shopping now involves a range of personalised high quality interaction to support the consumption decision making.

Key aspects of the GVN regime of 2038:

Reliable and transparent support for consumption, purchasing and transaction decisions is the core feature of the new regime, as well as the personalised, high quality, digital shopping experience in the selection of goods and services. During the past 20 years, social media have come to play a key role in the selection decisions of products and services. Former Business to Business to Consumer (B2B2C) networks have transformed into Consumer to Business to Consumer (C2B2C) configurations.

Customer trust is generated through reliable and transparent peer review, rating and reputation systems. Easily comparable evaluation of and information on different products and services are easily available. Peer evaluation is now the most believed source of information. Due to the increased importance of reputational capital, user feedback is a valuable status symbol for product and service providers. As user feedback becomes important capital, it also becomes more and more prone to falsification. Preventing or filtering fake customer feedback is a key feature for a well-functioning and reliable peer review system. Prosumption and do-it-yourself ethics emerge, as consumers actively take part in the design and production processes. Generating customer trust is fundamental for prosumption, as the broader spectrum of makers means larger diversity of product or service quality.

As people like to go to look at the concrete product in order to be sure about its suitability, trade, search and selection of goods in online and virtual stores resemble traditional, physical shopping experiences. For example, one can use a virtual mirror to look at clothes and the goods can be picked up from virtual shelves. Immersive digital services resemble over-the-counter service experience. The customer servant, human or a machine, assists the buyer interactively. If the service requires measuring or fitting, the user is provided with a technology, which gathers the required information for the service provider. The virtual store can be located in homes or at the corner shop, which is equipped with, for example, a larger display and measurement devices. The ordered goods are delivered to a robotic distribution automat typically at walking distance.

7.15 Sustainable food for all

Background

With the rising global population, food availability is an important need and an important challenge. Sustainable food system is fundamental in solving many of the global issues, such as mass migration or the double burden of famine of obesity. The spreading of different lifestyles across the planet and the associated food intake, together with the development of sustainable and healthy food habits and associated public health advice shape the Global Value Network. In this, public and private actors around the world address and reconcile multiple goals, including security and quality of food supply for a growing world population, environmental protection, employment creation and empowerment of communities.

Key aspects of the GVN regime of 2038:

The new regime concerns high quality, healthy and sustainable food for the needs and tastes of all people. Equal access to sustainable food for everyone is a complex issue that has required strong international political will, as well as a mix of sustainable food production, food literacy, lifestyle, retail and food service industry. Sustainable agriculture, supported with AI and ICT solutions, provides the main foundation for the food supply system. The increase in human population, the fight against climate change, progressive soil erosion and claims for healthy diets for everyone spurred significant changes. Emphasis is on less intensive and antibiotic-free farming, regenerative agriculture and eco-system support as well as required investments, adjustments to policies and steady efforts to reduce food waste.

Although efficient large-scale production with global logistics and established agri-food business incumbents dominate the markets, the role of local food production has become increasingly important. A focus is on local and regional food production catering to the growing diversity of tastes in all regions. To support this, urban farming, aquaponics, gardening, and customised agriculture in cities are emerging practices. Digital platforms provide new marketplaces to match supply and demand. In addition, a diversified range of alternative food production and supply chains has emerged. These started as niche applications for inner city specialised markets. As food prices rose and technology matured, they became a visible part of the food supply chain.

The exact nutritional content of products is available and people are able to measure the direct physiological impacts of their individual nutrition on their personal health. Matching food with the genetic information of the eater is a starting point for individualised food production. As a result, diet-related chronic diseases have decreased. Overall, there has been a substantial reduction of meat consumption and a radical increase in land-grown and non-animal protein sources. A wider selection of alternative proteins together with health, lifestyle and sustainability reasons have caused the overturn from meat heavy regime. Flexitarianism, veganism and vegetarianism are trending diets. During the recent years, prejudices towards new production methods of food, such as genetic modifications, have decreased.

7.16 Virtual citizen interaction for entertainment, art and culture

Background

Online platforms provide intense educational, entertainment and social experiences, so much so that individuals find meaningful relationships in communities across the planet, accessing arts and cultural experiences that transcend their national or regional identities. Online networks support the new emerge of hyperlocal communities.

Key aspects of the GVN regime of 2038:

The new regime is about vastly accessible entertainment, art, culture, education and social interaction, responding to a situation where people spend an increasing amount of their leisure time engaged in online games, simulated worlds and worlds where computer games and the physical world connect. This GVN further promotes social wellbeing, as digitalised communities and online communication support the self-expression and freedom of speech. Online communities harbour an immense diversity and inclusion, and they offer meaning and connectivity to users. Social information networks provide easy ways to contact other people and help with coping with foreign places and cultures. Hobbies and cultural activities lead to the emergence and strengthening of professional contacts as well as learning skills that are important in work.

Cyborgs and robots track and recognise motions and gestures of the user and are able to use his or her national language. Free of charge translators assist in real-time translation. Overall, the experience of virtual reality is unhampered and resembles a face-to-face meeting. Technology expands experiences not only concerning spatiality, but also in temporal aspects. For example, interactive virtual and augmented reality environments are also used to reconstruct historical settings or to simulate completely new worlds. Movies are interactive in a similar way as games and they are partly based on real-time crowdsourcing.

The successful design of virtual environments has required the addressing of several challenges. For example, the decrease in cyberbullying, cyber harassment and manipulation as well as questionable or fake information and security issues requires co-design processes and cooperation across fields. Additionally, if people are too immersed to virtual worlds, they are not able to function in the world without information technology. Well-designed virtual citizen interaction lessens isolation and disconnection instead. Otherwise, the potential for manipulation grows if people numb themselves with entertainment and distance themselves from physical communities and societal experiences.

7.17 Enabling mechanisms for self-organising communities

Background

Internet-mediated self-organising communities move beyond hobbyist contributions of leisure time to become global value networks that take on major aspects of the economy, as distributed ledger technologies, such as blockchain, enable peer-to-peer transactions and operating models to replace complex contracting structures, previously internalised in large corporations or in communities of purpose (e.g. Linux).

Key aspects of the GVN regime of 2038:

This GVN is simply about easy and direct transactions between peers at no cost and in real-time. At the core of it are platforms that enable trustful and complex transactions and that are inherently resistant to data modification at a later point in time. These platforms are widely available to those wishing to collaborate in value creation activities including social and public goods. A large part of the financial transactions between citizens or citizens and companies is conducted through such platforms without any mediating financial institution. Some transaction systems have a sectoral scope (for example, in health, agriculture or legal services) and are tied to major global actors – corporations as well as non-commercial players. Other systems are community-based, or only available in a small group. Complementary regulatory enabling mechanisms for protected open exchange are in place, and lessen the "grey area" between legal and illegal, as well as the possibility to use the platforms for organised crime.

Platform based peer-to-peer networks have become a major factor in global value creation systems across sectors. For many people contributing to these networks has become the dominant mode of work. In general, the platforms provide environments for collaborative value creation including complex contracting mechanisms that protect the rights of all contributors. Furthermore, the platforms promote traceability and transparency and by doing so, they create new relationships and in that way build trust within local communities. Many of the platforms are places of communication and learning. They all co-exist, compete and learn from one another. One asset for the social interaction has been the improvement in capturing and interpreting emotional response, which helps to understand feelings and behaviour related to transactions. Concerning technological solutions, the radical development in the availability of abundant energy enables the blockchain-like tools with high-energy consumption.

7.18 Sustainable tourism

Background

Tourism belongs to the world's and Europe's largest and fastest growing industries, supported by the growth of transport industries, the diffusion of lifestyles, growth of cultural empathy and proximity brought by the globalisation of information. At the same time, tourism challenges local communities, depletes local assets and subverts local ways of life. For many regions in Europe, tourism is the main source of income. In the new GVN, tourism industries work together with stakeholders and local communities. All sectors relevant for tourism are included in the cooperation.

Key aspects of the GVN regime of 2038:

Tourism has remained one of the leading job creating sectors and a substantial employer in Europe and worldwide. The new regime of tourism is one of sustainability, with lasting benefits for both visitors and hosting regions. The undesirable impacts of rapid tourism growth are now managed through cooperation of governments, business and stakeholders. The concern for sustainability is addressed with strategic planning efforts and is integrated in activities by all actors. The dynamics of tourism concern economic and geopolitical fluctuations as well as possible safety problems.

Tourism policies and practices are more and more community-driven. Local governments develop their distinct strategies that are suitable for different types of locations. Well-planned policies help to avoid the unwanted aftermath of socially unsustainable tourism, for example, radically increasing housing prices and uncontrolled gentrification. This further feeds positive attitudes of locals towards tourists. Sharing economy offers a model for sustainable and social interaction. When local people temporarily share with tourists what they own or what they do, natural resources are saved and social contacts built between local people and tourists. In order to function well, sharing economy models have been remodelled and are now holistically regulated in a way that does not harm local communities with i.e. rising housing costs. Globally, sustainable tourism has enhanced mutual recognition of diverse cultures. Historical sites and cultural heritage in general are preserved and conserved.

It has been long acknowledged that tourism contributes substantially to greenhouse emissions and climate change. Cheap and affordable transportation and prevailing lifestyles that admire frequent travelling encourage fast and invasive tourism. In some cases, stricter visitor limitations have been required. The situation has been addressed with many efficient means. Particular focus is drawn into new low-season opportunities in order to enable steadier inflow of visitors throughout the year and reduce the unwanted impacts of seasonality. Furthermore, virtual reality partly replaces the need of physical experience and excessive rapid tourism. Sustainability is also the new regime within tourism as an industry. Exploitative profit-driven business models have given way to alternative economic logics to establish diverse value for touristic destinations.

7.19 Security network against military and criminal attacks

Background

Safety and security are important human needs. Global, European and national safety and security levels are deeply intertwined, and at all levels internal and external security are interdependent and inseparable. As technologies make people more potent, the need for stronger security arrangements permeates more aspects of life. The emerging GVN covers and includes actors from the most essential livelihoods, social safety nets, order management, logistics, national defence and various property security, product safety, environmental damage prevention, risk mapping and even insurance policies.

Key aspects of the GVN regime of 2038:

This GVN is as much about security against all kinds of risks concerning the welfare of nations and people as it is about security as a business. The competitive nature of security arrangements is a major challenge as communities and nations have traditionally competed for developing the most potent weapons to guarantee their own security. Global security is seen as a complex issue that requires holistic, multidisciplinary cooperation across all sectors. Special focus is given to preventing threats and reasons for conflicts and wars. Strategies and security measures are planned resiliently according to the evaluation.

Security threats are now handled effectively through international cooperation and with means of AI, quantum cryptography and signal listening of information networks. The traditional means of digital security, e.g. pin codes and passwords, become rapidly inefficient because of AI and quantum computing. Quantum cryptography is among possible solutions for the challenge. One security focus is in complex communication systems and electric grids. Connectivity makes infrastructures vulnerable to attacks. The damage caused with e.g. remotely controlled devices or a virus is maximal without large economical or casualty loss for the attacker. Notably, new technologies have a dual role, as they create both security and risks.

Security by design models are considered and applied from the beginning of planning processes in order to ensure a precautionary and holistic approach to security issues. As new bioweapons are difficult to perceive, the regulation of substances and the control of research laboratories is an increasingly important element in prevention of chemical and biological weapons. Overall, many illegal activities that threaten countries and cities worldwide relate to events that are difficult to identify or anticipate, for example terrorist attacks that carried out by local cells or individuals from distributed networks. Tools of foresight and cyber security games are used for anticipating possible risk situations related to security. Advanced and intelligent technologies assist in monitoring the illegal activities at the external borders of the EU and countries all over the world.

Security is not executed merely by authorities, as citizens engage in 'do-it-yourself networks' of surveillance, which strengthens communities and feeling of security. The interest of the people is understood as an integral part of (national) security and as a fundamental part of societal resilience.

7.20 Human and social security

Background

A Global Value Network emerges based on a holistic understanding of people-centred, globally interlinked and preventive security, adapted to varying contexts of various different livelihoods. At the core of this GVN is the provision of sufficient support against any harmful conditions that may lead to injuries, sickness, poverty, unemployment or death. It is about the protection of the security, dignity and material and physical needs of ordinary individuals in their everyday life. The approach is as much about building resilience as it is about reducing vulnerabilities. When needed, the consequences of the threats are mitigated efficiently. In this GVN, states and national stakeholders, communities, global networks of partnerships, NGOs, business sector and insurance companies cooperate to build objective and subjective security.

Key aspects of the GVN regime of 2038:

Security and freedom from all kinds of threats concerning the welfare or the dignity of the citizens is the foundation of the new GVN regime. It is characterised by a holistic understanding of a multiplicity of possible threats and risks stemming from issues related to health, economy, environment, communities and nutrition as well as personal and political topics. National, regional and local contexts are equally needed in order to understand multifaceted contexts related to all dimensions of human security. This calls for dialogue, as the conceptions of preferred measures for security may be contradictory depending on the actors.

As many threats to human security do not respect state boundaries, they require efficient and integrated international cooperation. Overall, inequality and poverty are considered as main challenges to be addressed. The promotion of democratic principles and participation is a key element that enables trust between individuals, communities and political institutions. In addition, providing minimum living standards and universal basic education everywhere is an acknowledged priority. Minimum health services as public goods and life-saving drugs are available for all people in the world. Anticipating threats, preventing disasters and preparing for catastrophes are important functions of this GVN, which is crucial for resilient communities and societies.

7.21 Decent and meaningful life for elderly people

Background

As people live longer, the differences between the generations and the communication and interest gaps increase drastically (we have four generations alive). At the same time, we see a rise in non-communicable diseases and disabilities, which prevent people from functioning in private and from participating in community activities (because of age, lifestyle and other reasons). This GVN is as much about providing support, care, entertainment and mutual exchange platforms, as it is about enabling people to be physically and mentally stronger, faster, and more resilient, and to live longer fulfilling lives.

Key aspects of the GVN regime of 2038:

The emerging GVN connects people to be able to overcome physical and mental impairments, and improve their daily performance. At the core of it are the new capabilities for people who have lost their functional health as well as elderly remaining active in social activities and seeing a meaning in their life. Importantly, a specific age-based definition of "old age" is no more suitable. The majority of people of 65-95 years still have energy and are active. Work-related, voluntary and social activities together with lifelong learning possibilities create meaning for the aged and a valuable resource for the society. The aging are encouraged to stay in work as long as they are able and willing. Age management approaches, executed cooperatively by organisational management, health services and workers, help to maintain work ability of ageing workforce. Next to structural flexibility to delay retirement and the will to work from the employee’s side, the employer’s mind-set have become favourable for working longer and elderly people are seen as an important asset in workplaces.

For a truly sustainable aging Europe and world, affordable and accessible innovations are needed. Novel service concepts and social innovations enable the societal participation of senior citizens. Co-created solutions in various areas, such as housing, transportation and urban planning, match the need of older citizens and increase social inclusion.[1121] Active intergenerational environments provide human contacts and enhance active and meaningful living of physically and socially old people. Age-friendly smart technologies and intelligent machines provide security in homes. For example, social media, AI-based solutions and social robots can support the daily life people maintaining a high standard of quality of life.

Improved medical solutions result in longer and better lives. Better-functioning assistive devices increase safety and independence. Furthermore, many new treatments and cures are possible. Yet, substantial progress in understanding the nature of and, accordingly, finding a cure for neurodegenerative diseases such as dementia are still awaited. Overall, there is a great demand for elderly health care services and "caregivers" with skills beyond classic physical caregiving: care for people with mental problems, coaches, advisors for daily problems and administrative issues, entertainment, cleaning, etc. Due to the greater demands, the working conditions in the sector have substantially improved and qualified caregivers are available.

7.22 Global Capacity for Social Innovation

Background

Social innovators develop and implement novel practices that address their own or their communities’ needs. Policy makers and researchers

[1121] https://www.healthcarebusinessinternational.com/hbi-2017-the-future-of-elderly-care-in-europe/

increasingly recognise that social innovations generate substantial social and economic value for societies. If social innovators connect globally and exchange on practices and solutions a global value network may emerge around a global social innovation capacity.

Key aspects of the GVN regime of 2038:

A global social fabric with substantial capacity to experiment social innovations is the core element of solutions for social needs in this global value network. Around the globe, social entrepreneurs and innovators are important contributors for solutions to different social needs such as poverty, aging and immigration. As described in the Sustainable Development Goal 17, they engage into a continuous mutual learning dialogue to advance practices and processes through cooperation and global partnership.[1122] Social innovation has emerged partly as an answer to the threat of the "jobless society" posed by automation. It provides a meaningful and rewarding line of activities for people. The visibility gained from addressing the challenge made the mobilisation of the social innovation solutions rapid and helped to gain sufficient funding and broad partnership support for social innovation network.

The rise of social innovation capacity changes the social fabric within and across communities: New relationships are formed. Trust, connectedness and cohesion rise, social capital and cooperation multiply. Attachment to societal and political institutions grows. Social innovation and the dialogue around the actors are supported by advanced technological solutions that allow seamless exchange of ideas, tools and concepts, and underpin new modes of governance (YouTube 2.0). Furthermore, teaching relevant skills for social innovation has become an important part of education.

There is often a tension between global and local in social innovation. The local context is crucial for successful social innovation, and once actors start to operate on global level they often lose touch with people. Thus, it is not easy to exchange experience related to social innovation, as it is difficult to trace context. Examples of glocal social innovations, such as transition towns, fair trade and local currency have set the example for operating functionally between local and global contexts. Organised responses to disaster are realised locally but global exchange of experience is very important for the development and dissemination of social innovation. Nevertheless, supporting social innovation requires acknowledging and fostering complexity without trying to control it. This is yet challenging for policy makers and many other actors to accept. An economic model such as basic income may be needed to make social innovation a sustainable social practice in the long-run.

[1122] http://www.undp.org/content/undp/en/home/sustainable-development-goals/goal-17-partnerships-for-the-goals.html

7.23 Space as a global commons

Background

As a vast resource of materials, as a location for infrastructures, an energy source, a place for depositing waste, a source of valuable knowledge and as a harsh environment for testing technological performance, space offers a new opportunity for the entire humanity. It is an opportunity to overcome the social, economic and environmental disasters of the past and to develop a new culture of global commons, where peaceful exploration and exploitation are regulated by global space governance mechanisms. The GVN of dreamers, explorers and engineers is organised around key actors in the governance of space.

Key aspects of the GVN regime of 2038:

In general, this GVN is about valuable economic resources gained beyond our planet's borders to complement planetary sources. Outer space offers prospects for multiple purposes that have the potential to transform the telluric limits. Plans considering space – as spaceflight soon becomes affordable and frequent – address new commercial opportunities for mining scarce minerals, producing affordable solar energy and developing health research and medicine.

Exploring space requires active international and supranational cooperation of public and private actors. The economic and technological challenges have been conquered with multinational partnerships led by international space agencies. Contradictory goals and aspirations between different nations as well as between private and public investments. For example, private actors may not share the idea of space as global commons. Similarly, military research makes the use of space as a strategic option easier, but their objectives may differ from other actors. An international and institutional framework together with regulation to control the use of space resources enable to approach space as a global common.

Space serves as a test-bed for technologies and material innovations that will be required in a large scale in the near future when the space exploration becomes more common. The decreased cost of developing the required technological solutions for space exploration has enabled successfully accomplished manned mission to Mars, which sets an example for safe long-term space travel. Space tourism is emerging for recreational and leisure purposes. Outer space is utilised for safe disposal of hazardous material such as radioactive waste. In addition, space is also a resource of affordable and abundant energy. The production has been enabled by a combination of photovoltaic panels and microwave transmission technologies.[1123] Military research plays an important role in using the space as a strategic option.

[1123] https://futurism.com/is-space-based-solar-power-the-answer-to-our-energy-problem-on-earth/

8 Drawing things together – relationship between RIBs and GVNs

Following the approach of the Finnish Radical Technology Inquirer (RTI) we assessed the linkage between the RIBs and the GVNs. As the GVNs in turn impact economic activities and our ability to address the UN Sustainable Development Goals (SDGs) we saw this relationship as a means to estimate the social and economic impact of the RIBs (details see 8.6). Figure 114 illustrates this reasoning.

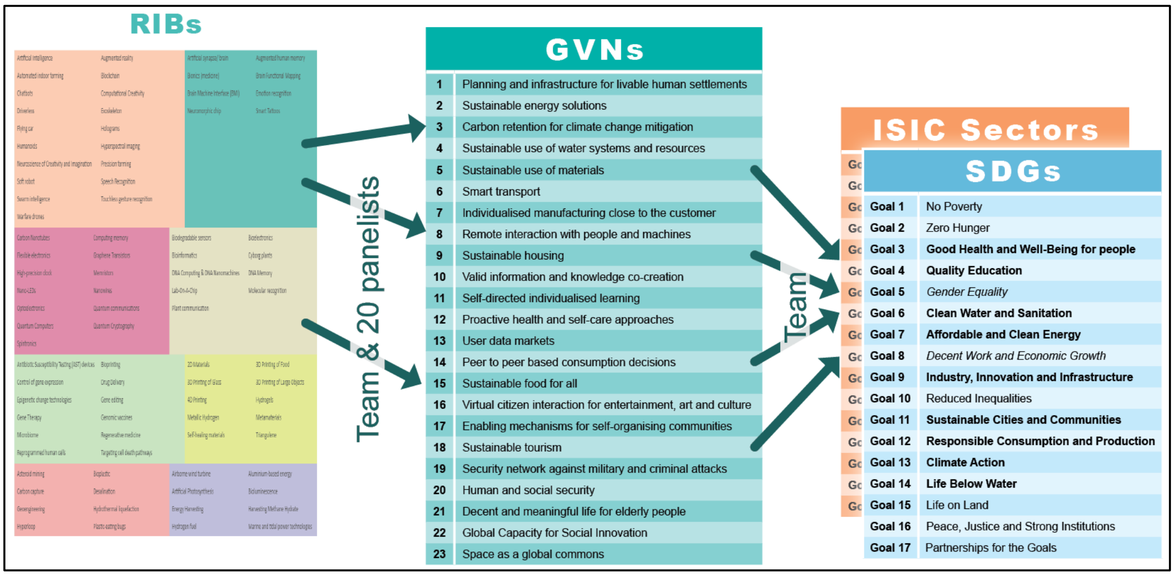

Figure 114: The approach of RIB assessment

Even though we abandoned the idea of deriving exact impact indicators from this framework for a number of reasons discussed in the methodology section, we would like to highlight three insights from this exercise that seem valuable for drawing overall conclusions for Europe and the world.

1. Set of highly transversal RIBs

There is a set of fifteen RIBs listed in table 9 that significantly influence more than 2/3 of the GVNs. Most of these RIBs are technologies involved in digitalisation and automation of value creation activities. Among them, AI stands out with the highest total GVN relationship score, but also as the only one significantly influencing all 23 GVNs. This result reflects the widespread expectation that digitalisation and automation will have a substantial impact on the majority of future value creation activities. Seven of these especially transversal technology RIBs have been assigned a very high likelihood of significant use in 2038 (highlighted in the table). Another observation is that several of these RIBs, and in particular emotion recognition, seem to be rather immature today. It seems that the impact of these RIBs may be spread across sectors, including some unexpected ones beyond the obvious ICT based value networks. As an example AI and Augmented Reality are both expected to impact aspects of GVNs 9. Sustainable housing, 12. Proactive health and self-care approaches, 21. Decent and meaningful life for elderly people, and 22. Global Capacity for Social Innovation. Together this may indicate a high level of uncertainty for the next decades, as a set of technologies that are yet not fully understood may significantly shape the way value is created in many fields.

At the same time, it is striking that none of the very important health related RIBs is on this list, even though healthy humans definitely seem a key enabler for all sorts of value creating activities. This may reflect a cognitive bias in the way we tend to think about future techno-economic paradigm and the role of humans within them.

Table 8: RIBs with significant impact on more than 15 GVNs (ordered according to total likelihood of significant use in 2038[1124])

RIB Name	Likelihood of significant use by 2038	European Position	Current Maturity
Speech Recognition	5	4	3
Flexible electronics	5	3	2
Blockchain	5	4	2
Biodegradable sensors	5	4	2
Chatbots	5	5	2
Augmented reality	5	4	3
Computational Creativity	5	4	3
Emotion recognition	4	4	1
Artificial Intelligence	4	4	2
Brain Machine Interface (BMI)	4	4	2
Energy Harvesting	4	3	3
Holograms	4	4	4
Humanoids	4	4	3
Bioelectronics	3	4	2
Flying car	3	3	2

2. GVNs not equally affected by RIBs

When looking at the overall relationship between technology RIBs and GVNs, it emerges that not all GVNs are equally impacted by the set of RIBs. As illustrated by Figure 115, GVN 1 "planning and Infrastructure for liveable human settlements" is the most affected followed by "human and social security", "user data markets" and "remote interaction with people and machines". Three GVNs are comparatively little affected by RIBs namely: "Peer to peer based consumption decisions", "sustainable tourism", and "global capacity for social innovations".

[1124] This refers to the exact absolute values that were calculated.

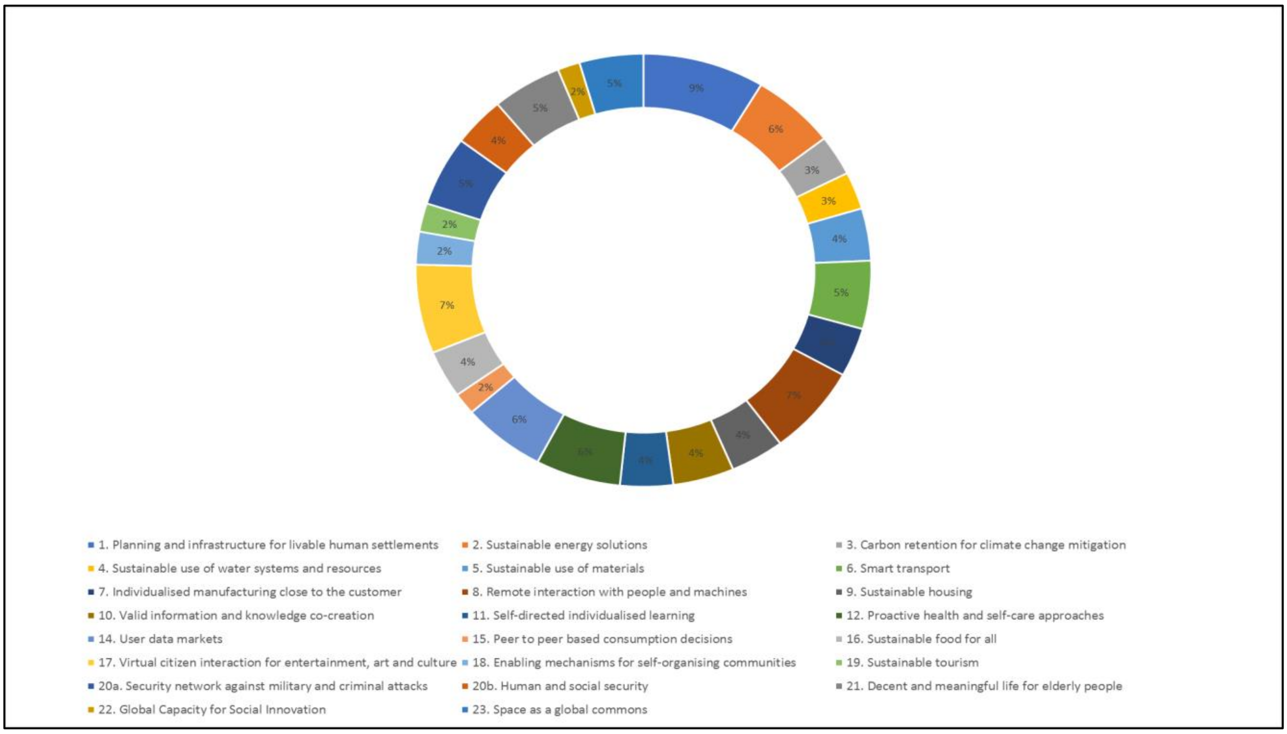

Figure 115: GVNs share in RIB influence

3. Societal RIBs shape techno-economic paradigms in interaction with technologies

Also, the emerging social practices are seen as impacting a number of GVNs. Especially three of them, namely "gamification" (impact on 14 GVNs) "collaborative innovation spaces" (13 GVNs) and "access economy" (10 GVNs), are expected to exert some impact across several sectors. At the same time, a social practice innovation largely independent from technology like "basic income" is also connected to nine GVNs. Some social practices do not spread across sectors but have a highly significant impact on specific domains. One notable example is the car free city that naturally makes a substantial difference for the two GVNs "smart transport" and "liveable human settlements" and forms an important context for the technologies in these sectors.

The following relationships between social and technological RIBs seem to emerge:

- Several societal RIBs can in fact be interpreted as a societal positioning towards IT based emerging technologies, indicating the dynamics of a social shaping of technology. Examples are "new collaborative innovation spaces", "new journalist networks", "access economy", "sharing health data", "read/write culture" and "reinventing education". Some of these practices are enthusiastically embracing new technologies (e.g. body 2.0), others, such as journalist networks, are taking critical positions against certain forms of emerging new socio-technical patterns. This type of interaction is also described in a few GVNs such as peer to peer based consumption decisions (14), knowledge co-creation (10), and enabling mechanisms for self-organizing communities (17).

- A specific example of societal positioning vis a vis technology RIBs is the "basic income" which has become prominent in the context of the discussion of automation of ever more jobs with the rise of AI and related technologies.
- Another set of technology and societal RIBs is situated around self-expression and creative content generation: Technology RIBs like emotion recognition, brain machine interfaces, creative computing and neuroscience of creativity on the one hand, and social practices like gamification, body 2.0 and life caching on the other, may be interacting towards new hybrid co-creation patterns.
- Another set of societal RIBs such as body 2.0 and local food circles is bridging the IT related with the biology cluster.
- Finally, a cluster of interaction may be emerging around autonomy of smaller groups of things and people. This cluster includes technology RIBs related to off-grid energy autonomy (energy harvesting, microbial fuel cell), 3/4D printing technologies that promise independence from manufacturers and, on the other hand, social practices like regional currencies and local food circles.

These types of conjunctions between social innovation and emerging technologies can be seen as signals for many of the new techno economic paradigms.

9 Conclusions

This report provides insights on 100 emerging developments that may exert a strong impact on global value creation, and offer novel solutions to societal needs in the future. Of these 100 "Radical Innovation Breakthroughs" (RIBs), 87 are emerging technologies and 13 upcoming social practices. We identified this set of emerging developments through a carefully designed procedure that combined machine learning algorithms and human evaluation. After successive waves of selection and refinement, the resulting list of 100 emerging topics was subjected to several assessment procedures including expert consultation and analysis of related patents and publications. Analysing this list we can draw some overarching observations and conclusions that seem of particular relevance for decision makers in policy, civil society and industry.

The notion that dominant techno-economic paradigms emerge in successive waves can be traced back to Freeman and Perez in (1988)[1125] and is backed up by the findings of Dosi (1990)[1126], and is also reflected in work on the so-called Kondratiev waves or cycles.[1127] It implies that there are specific periods of time where simultaneous change in social, technological and economic elements accelerates until a new techno-economic paradigm comes to dominate the overall landscape.

While most authors agree that we are currently still in the wave of information and communication technologies, perspectives on the next wave differ. Some regard holistic health as its core characteristics[1128]. Others, including Carlotta Perez herself, rather see us heading towards the wave of "sustainability" in a broader sense.[1129] In any case, it seems clear that while in the ICT wave the supply of science and technology was very important, the next one is driven by demand factors such as health or sustainability as they are represented in the UN Sustainable Development Goals (SDGs). Several scholars have argued that this shift has major implications for research and innovation policy paradigms.[1130]

[1125] Freeman, C. and Perez, C. (1988): Structural crisis of adjustment, business cycles and investment behaviour in Dosi et al., Technical Change and Economic Theory. London: Frances Pinter. pp. 38-66.
[1126] Dosi, G. (1990): The economics of technical change and international trade, New York, London et al., Harvester Wheatsheaf.
[1127] see e.g. https://www.kondratieff.net/kondratieffcycles
[1128] Nefiodow, L. and Nefiodow, S. (2014): The Sixth Kondratieff.
[1129] Drechsler, W., Kattel, R. and Reinert, E.S. (eds.): Techno-Economic Paradigms: Essays in Honour of Carlota Perez. The Anthem; Other Canon Series (2009), see also Moody, J.B., and Nogrady, B., 2011. The Sixth Wave: How to Succeed in a Resource-Limited World. New York: Random House.
[1130] e.g. Mazzucato, M. (2016): From market fixing to market-creating. A new framework for innovation policy. In: Industry and Innovation 23 (2), 140–156. DOI: 10.1080/13662716.2016.1146124; Mazzucato, M. (2018): MISSIONS. Mission-Oriented Research & Innovation in the European Union. A problem-solving approach to fuel innovation-led growth, European Commission, Directorate-General for Research and Innovation, Directorate A – Policy Development and Coordination, https://ec.europa.eu/info/sites/info/files/mazzucato_report_2018.pdf// doi:10.2777/360325 KI-02-18-079-EN-N; or Rogge, K.S. and Reichardt, K.: Policy mixes for sustainability transitions: an extended concept and framework for analysis, in: Research Policy 45 (2016) 1620-1635.

In line with this theory, the unfolding of an ICT based wave is clearly visible at the moment. Digitalisation and artificial intelligence are perceived as the key elements of this wave, often framed within and into the term "Fourth Industrial Revolution"[1131]. The RIBRI results highlight a number of elements within this wave and thereby confirm that it is still in full swing, and receives new impulses especially in the domain of artificial intelligence (AI). It also makes sense in the context of this theoretical background that some of these first wave elements such as speech recognition, augmented reality, chatbots and swarm robotics are already at the door.

These technologies are however closely followed by others with lower maturity today and less clear future shape, such as blockchain, flexible electronics and hyperspectral imaging. In addition, a few powerful transversal enablers such as neuromorphic chips, emotion recognition and, last but not least, next generation artificial intelligence with unsupervised learning approaches are following suit and may push the wave in unexpected directions. At the same time, looking at the social innovations, we see that society is already gearing up for creatively embedding these technologies with new practices, such as commons based economy, health data sharing and collective journalism. There are uses to reinforce existing relationships and uses to reform relationships as exemplified in a few of our GVNs such as "enabling mechanisms for self-organising communities" or "remote interaction between people and things". A core interface between social and technological innovations in this domain seems to be the use of data, which are generated in social practices, and at the same time fuelling the new technologies, most notably AI deep learning algorithms. New modes of trading these data as described in our GVN "user data markets" may be a major factor in defining the shape of this wave.

Another insight from the RIBRI analysis is that the AI domain is populated by many RIBs with a low maturity today, but a high potential to influence several different sectors. This implies that this wave is now rushing forward into many application arenas and may change established value generation patterns in several sectors.

Another core conclusion from the list of emerging RIBs is that the urge to address the Sustainable Development Goals (SDGs) creates conditions for a number of agendas relating to energy, materials, health and the bio-economy, while fundamental science promises important spill-overs. Along with this wave, creativity is already demonstrated in emerging new practices such as quantified self, local food circles and urban or even indoor gardening initiatives. This wave of developments is much less clearly visible. This is partly because the driving demand factors are necessarily more complex than the technologies dominating the ICT wave.

In addition, however, the technology side of this wave is also more blurred, because its innovations converge with the ones from the previous wave. A typical example are bio-hybrids that are situated at the interface of life

[1131] The fourth revolution is discussed from the digital and machine perspective in Brynjofsson, E. and McAfee, A.: The Second Machine Age, New York, N.Y., London: W. W. Norton & Co, 2014; now leading to new ways of higher education, Penprase B.E. (2018): The Fourth Industrial Revolution and Higher Education, in: Gleason N. (eds) Higher Education in the Era of the Fourth Industrial Revolution. Palgrave Macmillan, Singapore.

sciences on the one hand, and automation and robotics on the other. Within RIBRI such technologies were prominent in the "high dynamics group" of technology RIBs with low maturity today but high expectations on use in 2038. A large group of technologies within this wave directly relates to sustainability challenges. Most prominent are technologies for reducing carbon emissions by providing sustainable energy supply, storage and demand solutions. Others promise important contributions to waste reduction and preservation of clean water.

Another interesting cluster of developments in this wave is located around local autonomy and resilience. This includes technologies and materials of generative manufacturing such as 3D printing, technologies for disaster preparedness, automated indoor farming and local energy solutions such as energy from urine. Complementary elements can be found in social practices like local food circles and alternative currencies. The GVN "individualised manufacturing close to the customer" captures elements of this paradigm. This cluster may form a kind of "undercurrent" in this wave that may gain traction in situations of global emergencies. Overall, the findings within this wave are well in line with literature, arguing that the next wave will be driven by resource scarcity.[1132] It is interesting to note that in this wave there are only few technologies, such as bioplastics, expected to be mature already in 2038. This result seems worrying given the urgency of the challenges ahead. At the same time it could be argued that several of the potentially transformative sustainability innovations are already well under way and require implementation rather than identification and early stage support. Finally, it should not be overlooked that there is a strong group of health related technologies and some complementary social practices, which is underpinning views that the health sector may be a major driver within the next innovation wave.

Having analysed the potential importance of each of these innovations for Europe, their current maturity and the relative strength of Europe in related R&D, we can make some general policy recommendations that follow.

However, it is important to note that our recommendations are based on the extremes of the distributions, and thus not all RIBs are named under the recommendations. Yet, the totality of the set of Radical Innovation Breakthrough (RIBs) and Radical Social Breakthrough (RSBs) descriptions and their recent progress directions constitute an important collection of intelligence material that can inform strategic planning in research and innovation policy, industry and enterprise policy, and local development policy.

[1132] e.g. Moody, J.B., and Nogrady, B., 2011. The Sixth Wave: How to Succeed in a Resource-Limited World. New York: Random House.

Policy recommendations:

1. Position Europe strategically for the forthcoming AI wave

Artificial Intelligence is a cluster of innovations that will have huge impact on the future world economy and society. The EU should position itself strategically vis-a-vis these innovations. The following RIBs are either directly contributing to AI by providing new software or hardware solutions or by tailoring AI approaches for specific applications:

- Artificial intelligence (advanced deep learning algorithms)
- Computational creativity
- Artificial synapse/ brain
- Brain functional mapping
- Computing memory
- Neuromorphic chip
- Chatbots
- Speech recognition
- Emotion recognition
- Touchless gesture recognition
- Swarm intelligence
- Driverless
- Flying Car
- Humanoids
- Precision farming
- Automated indoor farming

Emotion recognition.

Emotion recognition has been traditionally applying advanced image processing algorithms to images (or videos) of the human face. But recent developments have extended the field to include other means of gauging emotions (text analysis, tone of voice, heartbeat and breathing patterns, etc.), and even extending them to other species. Applications cover areas like marketing (detecting minute, subconscious reactions to advertising or products), smart devices that adapt to our mood, and law enforcement (improved lie detectors).

In some of these areas, such as chatbots, Europe is already strong. These strengths should be fully exploited. In other areas, especially computing memory, capacities in Europe are weak and therefore efforts should be stepped up. At the same time, consolidating the application pathways emerging from the surge of innovations in algorithms and hardware in sectors like mobility, health, education and food seems at least as important as fostering the further emergence of newly upcoming innovations. Especially for Europe, it will be vital to pursue trajectories that unlock the potential of these technologies to support better solutions, which meet the needs of its citizens.

2. Fast emerging innovations

According to our results, there are 45 technologies (listed in table 7) that are currently at a low level of maturity, but are expected to develop fast and find important use in the coming 20 years. Among these, seven RIBs are especially fast moving:

- Neuromorphic chip
- Biodegradable sensors
- Hyperspectral imaging
- Warfare drones
- Harvesting methane hydrate
- Thermoelectric paint
- Neuroscience of creativity and imagination
- 4D printing

Neuromorphic chip

Neuromorphic chips are modelled on biological brains. They are less flexible and powerful than the best general-purpose chips, but highly efficient for specialized tasks. Neuromorphic chips can boost the development of AI based systems for specific purposes such as object recognition, voice and gesture recognition, emotion analytics, health analytics or robot motion, and moderate their power consumption.

In some of the 45 fast moving technologies, Europe's capacities show weaknesses:

- 4D printing
- Bioluminescence
- Automated indoor farming
- Water splitting
- Computing memory
- Molten salt reactors
- Graphene transistors
- Energy harvesting
- Hyperloop

4D printing

4D printing adds an additional element of time to 3D printing/additive manufacturing. 4D-printed objects can change shape or self-assemble over time if exposed to a stimulus – heat, light, water, magnetic field or other form of energy – that activates the process of change. Among the ground-breaking applications expected are drug devices reacting to heat changes of the body, shape memory materials allowing solar panels to auto-rotate towards the sun, and self-repairing infrastructures.

Energy harvesting

Converting energy from the environment into usable electricity involves an ever-expanding set of techniques that draw energy from the sun, the wind, natural heat, and the movement and chemistry of human bodies. Combining solar cells and fibre-based triboelectric nanogenerators, scientists have developed a “hybrid-power textile” that generates electricity from both sunshine and flapping in the wind.

In other such technologies Europe holds a leading position:

- Harvesting methane hydrate
- Underwater living
- Bioplastics
- 3D printing of food
- Lab-on-a-chip
- Chatbots
- Quantum cryptography
- Marine and tidal power technologies

Interestingly in the field of quantum cryptography, the EU leads in terms of patents, but China is taking the leadership in publications.

Bioplastics

Bioplastics use as a source of carbon renewable natural feedstock such as e.g. corn, rice, potatoes, palm fibre, tapioca, wheat fibres, wood cellulose and bagasse. Depending on their chemical composition bioplastics may or may not be biodegradable. Research efforts focus on bioplastics solutions with substantially reduced environmental footprint. Applications include different industries like food and beverage packaging, health care, textiles, agriculture, automotive or electronics.

Lab-on-a-chip

A lab-on-a-chip (LOC) integrates laboratory functions into a single device of small dimensions. Lab-on-a-chip promises better and faster diagnostics, especially in areas with poor healthcare infrastructure, a more active role of patients in monitoring their own health, as well as enabling citizens to engage in environmental monitoring.

In the following fast moving areas, Europe’s capacities are strong but not world leading:

- Speech recognition
- Neuromorphic chip
- Flexible electronics
- Gene editing
- Exoskeleton
- Swarm intelligence
- Blockchain
- Biodegradable sensors
- Hyperspectral imaging

Biodegradable sensors

Biodegradable sensors can be used as medical implants for temporary in-body sensing, drug delivery, tissue engineering, microfluidics, for tracking food and environmental sensing, whilst contributing to alleviating the problem of mounting electronic waste.

Fast moving areas hold a lot of promise for important applications and positive economic impacts but also involve the potential for controversy and serious unintended social and environmental consequences. They include, for example, gene editing, warfare drones, harvesting methane hydrate and molten salt reactors, which are already controversial.

3. Nourish capacities in highly speculative areas

The expectation of an increasing rate of change and uncertainty of techno-economic patterns means that radical innovations can unfold very fast. Therefore, we should not ignore capacities in highly speculative areas such as:

- Neuromorphic chip
- Neuroscience of creativity and imagination
- Plant communication
- Spintronics
- Bioelectronics
- Aluminium-based energy
- Airborne wind turbine
- Artificial Photosynthesis
- *4D Printing*
- *Asteroid mining*
- *Thermoelectric paint*
- *Artificial synapse/brain*
- *Flying car*

Bioelectronics

Bioelectronics is the use of biological materials and architectures inspired by biological systems to design and build information processing machinery and related devices. Researchers hope to develop bio-inspired materials (e.g. capable of self-assembly or self-repair) and bio-inspired hardware architectures (e.g. massive parallelism) to be used in new sensors, actuators and information processing systems that are smaller, work faster/better and require less power.

In the first eight RIBs of this list, Europe has promising capacities. In the other five (indicated in italics) its position is unclear or weak. To maintain and further advance the European position as a pioneering actor in newly emerging technologies it is important to create spaces where also highly speculative ideas with yet unclear perspectives find support and nourishment. This seems especially relevant for the three RIBs on this list that may contribute to the high impact AI cluster, namely neuromorphic chip, artificial synapse/ brain and neuroscience of creativity and imagination. The neuromorphic chip also deserves special attention because in spite of its low maturity expectations on its widespread use in 2038 are very high.

4. Review enabling frameworks for mature technologies

Some of the Radical Innovation Breakthroughs identified are quite mature - they have been known for a while, and are quite established in terms of R&D and patenting. At the same time, they have a great deal of unexploited growth potential in the perspective of 2038. Their technological maturity places them at the junction between research and innovation policy and industry policy concerns. These RIBs are especially located in the area of nanotechnology (nano-LEDs, nanowires, carbon nanotubes), but also hydrogels and holograms fall into this category. Their further development is not so much a matter of research and innovation policy but more a subject for industry policy or other policies concerned with the respective domains. It may be worthwhile checking whether appropriate regulatory frameworks and complementary social innovations are in place for successful and beneficial exploitation of these RIBs. Another question is whether an industry policy is needed to foster the European position in the weaker mature areas such as carbon-nanotubes, nanowires and hydrogels.

Hydrogels

Hydrogels are natural or synthetic polymeric networks capable of holding large amounts of water that can replicate the dynamic signalling involved in biological processes, such as cell/tissue development. In the near future, hydrogels will provide the basis for first-aid kits and innovative drug development concepts. In the longer term we can imagine curative soft robots performing surgeries at microscopic and sub-microscopic levels, and hydrogels in mobile phone screens sensing environmental pollutants and informing an app.

5. Understanding and harnessing the waves of change

In the results of our study, we see two distinct but interwoven waves of change. The first is the wave of information and communication technologies, which is still unfolding amidst important technological social innovations and concerns. The second wave is far less clear in its technological scope and is also shaped by substantially broader demand factors, such as the political and social imperatives associated with the UN Sustainable Development Goals (SDGs). We expect the value creating structures and processes of the future to be significantly shaped by the SDGs, often seeking to speed up positive technological transformations and to control negative externalities. The search for newly upcoming innovations in the SDG related arenas should be intensified. Interlinkages of environmental and health technologies with the ICT wave, and in particular the AI cluster, should be systematically explored in order to exploit synergies and avoid conflicts.

To sum up, European strength in science, technology and industry is necessary to ensure that Europe is competitive and able to achieve its objectives for its future. To be competitive, Europe needs to maximise the value and productivity of its investments in R&I, and this requires appropriate intelligence and coordination between relevant policies and strategies at EU, national and regional levels. We hope that the RIBRI study will nudge Europe's authorities to further develop their intelligence efforts, to identify key innovations of the future and to debate their usefulness and possible trajectories with maximum benefit for its citizens.

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This report describes 100 Radical Innovation Breakthroughs. They are potentially important cross-cutting, disruptive innovations that may exert strong impact on global value creation and offer important solutions to societal needs. This set of emerging developments was developed through procedure combining machine learning algorithms and human evaluation. After successive waves of selection and refinement, the resulting 100 emerging topics were subjected to several assessment procedures including expert consultation and analysis of related patents and publications.

Having analysed the potential importance of each of these innovations for Europe, their current maturity and the relative strength of Europe in related R&D, some general policy recommendations are made. The collection of Radical Innovation Breakthroughs constitutes important intelligence material that can inform strategic planning in research and innovation policy, industry and enterprise policy, and local development policy.

Studies and reports

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