

A WINDOW INTO THE FUTURE

DEEP TECH TRENDS BY hello tomorrow

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Foreword

What does the next decade hold? Making accurate predictions about the future developments of our society is a daunting task. Identifying the underlying forces, tipping points and opportunities for intervention in our complex world is challenging, and using this to gain precise foresight is nearly impossible. However, a look at the early-stage technological innovation landscape can offer a window into the future. Technology is never neutral, but instead mirrors, to a certain extent, the goals and power dynamics of society at the time of development.

This report seeks to map out the current deep tech innovation landscape. It will describe and showcase technological innovation, at times at the atomic-level, to give the reader a dynamic, yet profound idea of current technological advances.

At the same time, the report aims to contextualise innovations, putting them in perspective on a macro-level by shining light on how technological progress enables societal developments and, reversely, how societal goals drive innovation. This approach aims to both aid a better understanding of the processes that underpin future developments, as well as make informed predictions about the direction of those developments.

Before diving into the four themes of the report: Spaces, Planet, Humans, Machines, there are a couple of overarching trends to keep in mind when trying to predict developments over the next ten years and beyond.

Firstly, we have realised that we are exploiting our planet, which sustains all life, far beyond its means. The climate crisis, diminishing biodiversity and increased environmental pollution are all unmistakable signs that we have to, as a society, adopt a more sustainable way of life. For this reason, innovations face a twofold challenge: on the one hand they must be energy-efficient, renewable and non-polluting, while on the other, still offer significant value. This need to become more sustainable, combined with advances in the field of molecular biology, will eventually lead us into a bio-economy.

Secondly, the current era of surveillance capitalism, based on gaining actionable insights from (private) data, will continue to influence the development of technology. Collecting ‘machine-learnable’ data will become a priority across all industries and, on the bright side, will help to design improved artificial intelligence, resulting in more and more autonomous machines and processes. This will also help to accelerate research and development. Scientific discovery as a whole could undergo a paradigm shift, from hypothesis-driven to empirically-driven discovery.

Being aware of these two overarching trends, and having access to thousands of detailed, early-stage, deep tech project applications each year through our Global Startup Challenge, puts Hello Tomorrow in a unique position to analyse technological developments and their societal implications.

As cities become increasingly important, so does their connectivity

As cities become increasingly important, so does their connectivity

Today, about 4.2 billion humans live in urban areas, a total of 54% of the world's population. This proportion is expected to rise to a staggering 66% by 2050. Taking into account the projection of the world's population growth, cities, especially those in Asia and Africa, will become increasingly more populated, hosting 2.5 billion more residents by 2050 than they do today.[1] The agglomeration of people in cities is mainly driven by the presence of economic opportunities. In particular, innovative activities that require complex knowledge concentrate disproportionally in cities.[2] The implications of this projection are manifold - three of them are explored below.

Firstly, most megacities today already face increasing traffic congestion, and emissions produced by combustion engine-powered transport as well as by buildings, heating and cooling networks. Adding another 2.5 billion people will require reconciling the design of cities and transport means to become both more enjoyable and sustainable. Sustainable cities will

[1] United Nations, Department of Economic and Social Affairs, Population Division (2019): World Urbanization Prospects: The 2018 Revision.

[2] Balland, P., Jara-Figueroa, C., Petralia, S.G. et al. (2020): Complex Economic Activities Concentrate in Large Cities. **Nature Human Behavior**

feature electrified transport systems, including aerial drones and buildings which are constructed using nearly zero-waste 3D printing production processes and equipped with better insulation solutions.

Secondly, the agglomeration of people in urban hubs will further increase the interregional and cross border traffic of data. The digital transmission of information, communications, services, and transactions between cities will continue to surge, as will the need to better protect personal and other sensitive data. Both citizens and businesses will become increasingly aware of the threat posed by cyber attacks, leading to the progressive deployment of quantum communication technologies, offering a way to safely exchange digital information.

Thirdly, satellite constellations will provide global connectivity, thus significantly help to connect rural areas with urban hubs. Quick, laser-based transmissions of data between satellites and the ground will pave the way for new interactive reality formats, such as augmented and virtual reality, becoming increasingly standard. These new communication technologies may render digital, human-human interactions more natural, thus indeed connecting the world and its people more than ever.

Autonomously-managed, energy-efficient buildings will shape our cities

Reducing carbon emissions and increasing energy efficiency has driven innovation in building construction and management over the last years. While the building's floor area growth is increasingly decoupled from energy consumption and related emissions, the sector's overall carbon footprint is still dramatically high. In 2018, operating buildings still contributed 28% to the global CO2 emissions and accounted for 30% of global energy consumption according to the International Energy Agency. In comparison, the transport sector accounted for 23% and 28% of global emissions and energy consumption, respectively.[3]

[3] Global Alliance for Buildings and Construction, International Energy Agency and the United Nations Environment Programme (2019): 2019 global status report for buildings and construction: Towards a zero-emission, efficient and resilient buildings and construction sector.

For this reason, new, innovative solutions must not only make buildings of the future incredibly energy-efficient but also be applicable to retrofit existing infrastructure. Based on our view of the technology innovation landscape, there are two promising approaches to dramatically reduce the carbon footprint of the building sector: novel insulation materials and building management solutions based on digital twins, and/or IoT networks.

High-performing, low carbon footprint insulation materials significantly reduce energy consumption

When addressing the climate crisis, one key issue in buildings is insulation. However, most current insulating materials represent a trade-off between being fire-proof and well-insulating. The non-combustible solutions are constituted from minerals, whereas the thermally superior performing materials are based on oil or natural gas products. Both IPSIIS and Thermulon are overcoming the current limitations by providing a well-insulating mineral foam and powder, respectively, with an ultra-low carbon footprint. Based on redesigned synthetic processes starting from mineral waste material from other industries, both solutions offer more competitive pricing than aerogels, the only other material type that is both well-insulating and non-flammable.

Digital Twins and IoT networks allow for occupant-centered building management

Beyond better insulation, smart building management systems can help save energy from an otherwise complex-to-control infrastructure. Indeed, today's static solutions rely on sequence programming and prefixed parameters which don't allow occupant-centered and energy-efficient control of buildings.

Up to 30% of energy savings can be achieved using one of the following two approaches described below.

Enerbrain is developing an IoT solution for the dynamic management of HVAC (Heating, Ventilation and Air Conditioning) systems. Controlled by machine learning-based algorithms, wireless actuators set in motion the components of an existing HVAC system, for instance, opening the valves of a heating circuit. By integrating inputs from a number of outdoor and indoor environment conditions through its IoT sensor network, the system allows for real-time and predictive regulation of the building's indoor environment.

Like Enerbrain, Passive Logic's solution also integrates pre-existing HVAC systems into its platform. However, in contrast, it relies on the creation of a digital twin model to control the building's indoor conditions, which saves the installation costs of an entire IoT network. In combination with an automated building analysis device, such as the one developed by Lumoview Building Analytics, a digital twin model of the building, including its thermal properties, can quickly be generated.

Into the future: autonomous buildings producing and trading energy

Moreover, previously considered non-actionable building parts such as windows, walls, and roofs are turned, for instance, into power generating surfaces enabled by the ability to e.g. print solar cells onto various materials.

In the long run, those autonomously managed, energy-producing buildings will be connected to each other and could cooperate in city-wide energy and utility networks. The autonomous buildings will act as agents, trading energy and other utilities between each other and the district systems. This will be further driven by the advancement of generic data platforms which will ease the flux of utilities and other traffic in a city. Through real-time prediction of bottlenecks and surplus, platforms such as the one developed by Datategy will significantly contribute to more efficient use of resources.

[4] UN Environment and International Energy Agency (2017): Towards a zero-emission, efficient, and resilient buildings and construction sector. Global Status Report 2017.

[5] Barbosa, F., Mischke, J., Parsons, M. (2017): Improving construction productivity. **McKinsey**

Buildings will no longer be constructed – but instead printed and assembled

In its status report from 2018, the Global Alliance for Buildings and Construction stated that the sector will continue to grow. The number of buildings is expected to double by 2050. Over the next 30 years, we are likely adding more than 200 billion square meters in construction to the currently existing infrastructure which is twice the territory of South Korea or half the area of either Germany or California.[4] Despite the continuous addition of buildings, productivity in construction has increased by only 1% per year over the last two decades. In comparison, the manufacturing sector has averaged 3.6% productivity growth per year over the same time period which is largely attributed to the introduction of modularization and automation.[5]

Introducing modularization and 3D printing in the construction sector

It is likely that the construction sector will enter into a decade of significantly increased productivity growth, comparable to the manufacturing sector, due to the large-scale introduction of modularization and 3D printing. NEXII has created such a modular building technology consisting of pre-manufactured panels made of an ultra-high-performance composite with an insulating core suitable for all structures up to 12 stories. Conversely, Armatron Systems has developed a full-scale 3D construction printing system that uses a wide range of printing materials to yield reinforced concrete construction.

The ability to either prefabricate modules off-site or directly print parts on-site has obvious labor and material cost benefits over more traditional building methods. If combined, the technologies allow previous restrictions to be overcome by creating a factory-like environment thus advancing the construction independently of worker shift patterns or weather conditions. Furthermore, they reduce the number of materials, amount of energy and time needed to construct buildings. Additionally, 3D printing will enable the production of tailored shapes at almost zero waste. The avionics industry serves as proof of efficacy, as mass production of 3D-printed components is already common practice there.

Robots will increasingly assist in the interior finishing and building maintenance

Further automation of construction in the form of robots working collaboratively with humans on construction sites is highly anticipated by the sector. However, it still requires significant advances in the development of smart robots, since every construction project represents a unique challenge in a fairly unstructured environment. Thus, for the near future, robots will be limited to tasks in a more defined environment such as painting walls (Transforma Robotics) or the maintenance of hard-to-reach infrastructure like sewers (Watchtower Robotics).

The construction process will further be eased by solutions that bridge the gap between the computational model and the actual, physical construction site. Today, buildings are designed digitally by using Building Information Modelling solutions, and workers on-site follow the instructions laid out in construction blueprints, allowing for errors and misconceptions. LightYX's technology instead projects an Augmented Reality of construction blueprints onto the physical construction scene, thus enabling millimeter accurate implementation of any building part.

Into the future: 3D construction printing from in-situ harvested materials

Thinking long-term, the construction sites of the future will feature autonomous machines due to the advancements and convergence of digital technologies and robotics. The actual revolution will be delivered by material scientists and the 3D printing industry. The development of novel high-performance (bio-) composite materials and printing processes will enable 3D printing with in-situ resources. AI SpaceFactory is working toward the development of in-situ material harvesting (earth-to-printer) to dramatically reduce the carbon footprint of construction on Earth and to enable 3D printing construction in hard-to-reach areas including the Moon and Mars.

Aerial drones will provide another dimension to cities and transport

With transportation accounting for 23% of CO2 emissions and 28% of global energy consumption, the development of new mobility models to connect the various spaces humans occupy on Earth is more relevant than ever. Additionally, urban hubs increasingly suffer from traffic congestion, which has naturally created interest in shifting traffic from the ground into the air, initiating the idea of urban air mobility as a service.

Design advancements hold great promises for the aerial transport sector, such as allowing small aircraft to vertically take-off and land (VTOL) and the development of electric engines for aerial drones, offering reduced noise and emission footprint compared to aircraft powered by combustion engines.

However, in order to become an effective tool in decongesting urban areas rather than just widening

current transportation offers, urban air mobility solutions have to further increase their maximum possible air time, their ability to lift heavy payloads, and they need to semi-autonomously avoid collisions in increasingly busy airspace above cities.

Advanced control and piloting systems will increase drone flight safety

The drone flight safety is addressed using different approaches. For instance, Tekuma and Optinvent develop technologies to better control aircraft. Instead of a classic yoke, the pilot might hold an orb in one hand, allowing movements in every direction as well as force-feedbacks. Pilots might even wear a small device, very similar to glasses, which projects a virtual image of the flight path in front of their eyes.

Others envision software rather than human operators to control drone operations. Autonodyne is developing a flight software platform that enables fully autonomous operations of any aircraft or drone by using a variety of communication protocols. Hologarde's software solution answers the need for drone detection, localization, and potential threat assessment. Its software allows for operating collaborative drones as well as protecting installations or events from the entry of drones.

Drones will largely be made of composite materials

To increase air time, one approach is to reduce the weight of the aircraft itself by using light-weight composite materials for instance. However, the main limitation of composite materials is their build-up which relies on stacking straight-fiber layers at different orientations. In contrast, iCOMAT's solution can steer the fibers along curved paths without defects such as wrinkling by continuously shearing the tape during the lay-up process. This technology dramatically expands the design space for composite materials and can improve all aspects of structural performance.

Another limitation of composites, in general, is their sensitivity to damage. Composite materials are often brittle by design due to the resin chemistry available. Current repair solutions are costly and time-consuming, producing millions of tons of wastes. Based on new resin chemistry, CompPair's solution allows for repeated damage repair of composites while offering higher crack resistance than comparable materials and compatibility with current manufacturing processes.

Beyond improving the characteristics of existing composite materials, others work on making new materials available for additive manufacturing. For instance, AM 4 AM is developing a new aluminum alloy powder enabling unprecedented geometries of a very light but strong material which is naturally of great interest to the aerospace sector.[6]

[6] Martin, J., Yahata, B., Hundley, J. et al. (2017): 3D printing of high-strength aluminium alloys. **Nature**

Increasing the energy-density of batteries remains a challenge

Taken together, the solutions above will enable us to build lighter, yet stable aircraft. However, light-weight materials won't be sufficient to move - regulators and public opinion willing - passengers or heavy payload above cities in small air taxis. Doing so will still require extraordinary amounts of energy to generate sufficient thrust for lift-off and sustained flight. Larger electrically-driven aircraft will require significantly improved batteries with a high power-to-weight ratio, making battery energy density and innovative cooling systems such as developed by Cedrion the all-important elements.

To illustrate in detail, current jet fuel provides about 12000 Watt-hours (Wh) energy per kilogram (kg) fuel load. In comparison, current Li-ion batteries available have an energy density of 200 Wh/kg. Due to electrical engines being more efficient than combustion engines, experts argue that it needs a 3-5x increase in battery energy density for urban air mobility to become a viable transport alternative.[7] Advances in battery development

[7] Adams, E. (2017): The age of electric aviation is just 30 years away. **Wired**

are crucial because as of now, calculations show that a fully loaded diesel truck distributing hundreds of parcels on its route is less energy consuming than any drone solution. Since current drone solutions are limited in their flying time and payload, they would need to return to the central warehouse several times for recharging batteries and reloading parcels.[8] Nevertheless, in the long-term, drones are expected to offer a viable alternative to ground-based transport in cities.

[8] Lohn, Andrew J. (2017): What's the Buzz? The City-Scale Impacts of Drone Delivery. **RAND Corporation**

Into the future: electric, long-distant flights

Beyond current approaches in improving battery technologies which will be discussed in more detail in the next section, others are working on more futuristic technologies that may, one day, enable long-distance flights of electric passenger airplanes. Electric Sky is working on a novel ground antenna array that uses natural diffraction to generate a new electromagnetic-wave pattern that can supposedly transmit megawatts of power over several kilometers. The electromagnetic waves, first diffuse, then autofocus around a receiver onboard of the intended aircraft, thereby replenishing the aircraft's energy supply while it is in the air.

In contrast, Fast Flight Technologies envisions aircraft to open low-density tubes in order to slip through the air with minimal disruption, thus reducing fuel consumption, related emissions and noise compared to airplanes hitting the air head-on. The envisioned technology deposits pulses of energy at high frequency into the air just in front of the airplane. This results in the heated air rapidly expanding outward as a blast wave which pushes most of the air out of the flight path, thus constantly creating a low-density region and subsequently reducing the airplane's drag.[9]

[9] Kremeyer, K., Mickelson, P., Montano, E. (2017) Energy Deposition to Efficiently Reduce Sonic Boom and Drag, and Increase Control Authority in High-Speed Applications. **Meeting paper - 21st AIAA International Space Planes and Hypersonics Technologies Conference**

Deep dive: Hydrogen vs batteries – electrifying the transport sector

Since the industrial revolution at the beginning of the 19th century, fossil fuels such as coal and oil have become the primary source of energy powering factories, homes and transport. Consequently, the greenhouse gases released from the burning of those fuels into our atmosphere have reached unprecedentedly high levels.

Thus the key to stopping climate change in a world with ever-increasing energy consumption is to switch from greenhouse emitting fossil fuels to renewable sources of energy such as solar and wind power which are easily accessible, free and unlimited. Since the transformation of wind and sunbeams into other forms of energy is emission-free (apart from those emissions released when constructing solar panels and wind turbines), these energy sources are considered "green".

Over the last decades, we have made great progress in harnessing renewable energy sources. The number one alternative to combustion engine driven mobility is an electric motor powered by a battery. Today's standard, the lithium-ion battery, is widely used in smart devices and electric cars. However, lithium-ion batteries have plenty of drawbacks. Lithium is obtained through mining, is difficult to recycle, offers a low energy storage-density and is extremely flammable. The latter two features make adoption in large passenger aircraft nearly impossible.

To reduce the probability of lithium batteries from catching fire during operations, Calogy Solutions is developing a thermal management system that keeps the battery cell temperature uniform, thus increasing cell life span and safety. However, in order to make aerial drones a viable option for transport, batteries offering a higher energy density still need to be developed.

Similar to aircraft, the features of lithium described above also currently restrict the range of electric cars to about 300km. AC Biode intends to change this by developing an alternative current (AC) battery. This is a breakthrough considering that all other battery technologies store direct current (DC), and require conversion from and to AC in order to power an electric motor, thus lowering the energy-efficiency of the system.

Beyond the limited range, the adoption of electric vehicles is further constrained by the long recharging cycles of batteries. GBatteries is addressing this shortcoming by developing a fast charging protocol that can be applied to a range of products from drones to industrial robotics. The technology can fully charge off-the-shelf batteries within 15 minutes. Similarly, Enpower re-engineers the fundamental architecture of lithium-ion batteries to accelerate charging and prevent battery aging.

To sum up, scientists and companies work intensely to improve the charging and discharging performance of batteries and to increase their lifespan and energy density using new architectures and materials. Besides batteries that enable electrically powered mobility, the use of hydrogen as a fuel has been considered. Enabled by continuously improving fuel cells that allow efficient hydrogen gas-to-power transformations, hydrogen-based mobility, as well as hydrogen powered industries, has theoretically become a green alternative.

Used in an electric car, hydrogen offers an extended range of up to 500km and a fast replenishment rate of about three minutes which is much closer to the driver's experience today. Even better, there is no need to choose either batteries or hydrogen as a primary power source. Combining the fuel cell and a battery is a good strategy in order to absorb consumption peaks without oversizing the fuel cell.

On the downside, fuel cells make use of rare catalyst materials like gold or platinum. What's more, the overall energy efficiency of the chain is low due to the number of transformations, from renewable energy harnessed using solar panels or wind turbines to generate hydrogen, eventually delivered to an electric motor using a hydrogen fuel cell.

However, in light of the startups and their innovations we see at Hello Tomorrow, we believe the efficiency of each step will improve over the next few years. A few of the best solutions are summarised in the table below.

Table 1: Deep tech solutions enabling hydrogen-powered mobility. Startups include Celadyne Technologies, Ionomr Innovations, EIFHYTEC, and EH Group Engineering.

	Solution
Celadyne Technologies	Proton Exchange Membrane
Ionomr Innovations	Proton Exchange Membrane
EIFHYTEC	Thermal Hydrogen Compressor
EH Group Engineering	Redesign of fuel stacks

Satellites will provide surveillance & global connectivity from increasingly busy Earth orbits

Technological advances such as reusable rockets, miniaturization of satellites, and a wider supply of launch platforms have lowered the entry costs and, thus, the space sector – formerly dominated by national agencies – sees many new incumbents introducing novel applications.

Detailed surveillance data collected from space will allow Earth monitoring applications

The surveillance of Earth constitutes a common satellite application. High-resolution imaging of the Earth's surface allows for smart resource management. OroraTech is developing the first global real-time wildfire detection and monitoring service from space. Similarly, ConstellR provides high-spatial-resolution land surface temperature data. The daily revisit times allow for infrastructure monitoring, precision farming, and emergency response applications.

As the construction and launch of satellites equipped with better cameras and sensors gets easier, as well as more powerful machine learning solutions developed to analyse the large amount of data generated, privacy concerns must rise. A new regulatory framework that fosters responsible innovation and data collection from space needs to be developed.

Global, secure connectivity provided by satellite constellations

The instalment of a multitude of global satellite constellations will provide ubiquitous, low-cost connectivity for everyone and every smart device everywhere. The installation of ultra-fast, broadband connections will allow networks to transmit information nearly without any latency, thereby enabling autonomously operating robots and new reality formats, such as augmented and virtual reality, to become standard. Through a smarter choice of orbits, new incumbents will provide equally good broadband coverage with a smaller constellation while others specialise in globally connecting IoT devices via satellite networks (Table 2).

Table 2: Satellite constellations providing global connectivity. Startups include CB2.0 Communications, Astrome Technologies, HIoTee, and Kineis.

	Application
CB2.0 Communications	Broadband
Astrome Technologies	Broadband
HIoTee	IoT connection
Kineis	IoT connection

However, most satellites still run on the equivalent of dial-up internet technology to communicate with the ground. Skyloom and Xenesis aim at replacing radio-frequency communication by establishing fiberless optical internet infrastructure in space through laser technology. As lasers operate at much higher rates, more information can be

transmitted in the same time frame rather than using radio-frequency instead which will enable connecting everyone and every device to a broadband network.

Furthermore, laser beams are more confined than radio waves, covering less surface area and, in turn, are harder to intercept thus allowing for more secure data transmission. The fiberless, optical infrastructure also allows for the implementation of secure quantum communication. Instead of encrypting digital data and sending them and the digital keys to decode the information as bits, which can be read in transit by hackers without leaving traces, quantum communications uses qubits to transmit information. Unlike bits, qubits can simultaneously represent multiple combinations of 1 and 0. This quantum phenomenon, called superposition, is inherently fragile. If intercepted by hackers, the qubit quantum state collapses to either 1 or 0 which inevitably leaves behind evidence of tampering.

SpeQtral is building a satellite network to distribute quantum-proof encryption keys (Quantum Key Distribution; QKD) to secure communications against unwanted decryption. While the encrypted data is sent further as classical bits, the encryption key is transmitted in a quantum state using qubits, thus creating an ultra-secure way to protect data during transit.

Avoiding satellite collisions through in-orbit control

The applications described above will lead to a drastic increase in the number of satellites in Earth's orbit which makes unintended collisions more likely. For this reason, satellites will increasingly need to be equipped with thrusters to change their trajectory. Many different technology approaches are pursued to equip mini-satellites with thrusters in order to allow them to easily maneuver (Figure 1). It remains to be seen which technology offers the greatest competitive advantage. Additionally, the prospect of a multitude of satellite constellations creates the need to closely monitor

the movements of satellites such as proposed by Asgard Space who measures the position of satellites from a single ground station, thus eliminating the need for multi-location equipment.

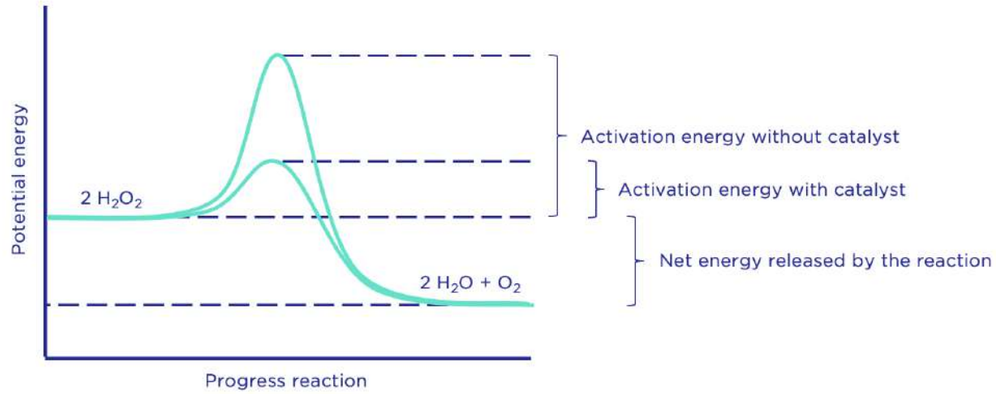


Figure 1a: Manastu Space Technologies is eliminating the need for the common yet toxic hydrazine fuel by shifting back towards the era of hydrogen peroxide. Initially phased out because no reliable catalyst for its decomposition was available, hydrogen peroxide offers a green fuel alternative. Manastu's proprietary catalyst can effectively decompose hydrogen peroxide, generating thrust through the release of heat, water vapor, and oxygen.

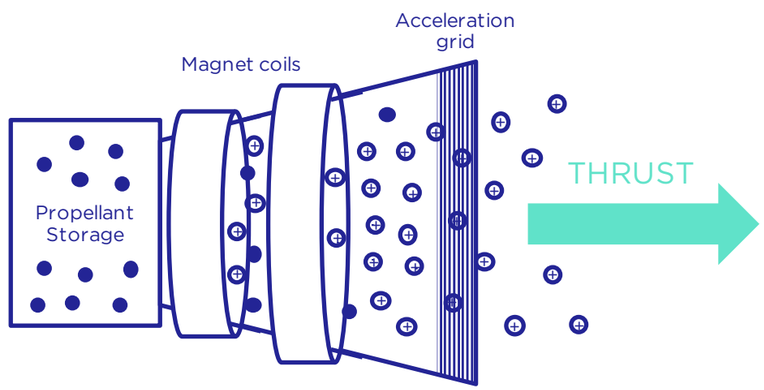


Figure 1b: Phase Four's propulsion systems rely on its proprietary radio-frequency (RF) plasma propulsion technology. The thruster operates by using RF to heat propellant into an ionised plasma that is then ejected away from a spacecraft by a permanent magnet, creating thrust. This simple design avoids high voltage electronics and eliminates components that are costly to manufacture.

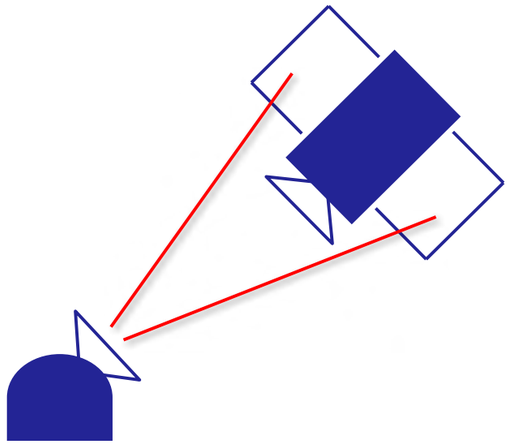


Figure 1c: Lumi Space envisions beaming power to satellites by using a network of lasers on the ground. This is achieved by combining existing, off-the-shelf technologies such as high-powered lasers and mechanical tracking systems.

Augmenting human interactions using new realities

Experiences are driven by perception, emotion, and thought. Our experience interacting with each other, our environment, and the digital world will undergo a significant shift. Augmented reality (AR) and virtual reality (VR) will increasingly change, amplify, and open more dimensions of perception unlocking new forms of collaboration, design thinking, navigation, and medical treatment.

The new realities promise to blend the digital world and reality effortlessly, thereby creating an immersive and fun experience. However, despite their potential they have not found widespread use in digital communication and other interactive formats yet. One of the main limitations of the adoption of VR outside the gaming industry is the limited realism of VR applications. VR relies mostly on visual and audio stimulation, thereby neglecting other senses. Moreover, the visual representation lacks refinement. The newest generation of new reality solutions, described below, addresses those challenges.

Creal3D resolves any visual conflict and related eye-strain in VR applications by developing a light-field projector. The projection allows the eye to focus naturally on virtual objects at different distances, experience their realistic blur, and feel their true depth. With the same goal in mind, LightSpace Technologies offers multifocal plane 3D technology whereas VividQ develops computer-generated holography to provide unparalleled realism. VividQ's proprietary algorithms allow scalable holographic displays to run in real-time on standard computing power.

Another critical factor for the adoption of VR for robotic teleoperations is the refinement of haptic feedback. The intuitive control of robotic arms requires the user to

feel objects and be aware of the environment. Valkyrie Industries develops a wearable technology providing sensations of weight and texture to human-computer interfaces while Holotron builds motorised exoskeletons and motion simulators to better interact with virtual avatars and humanoid robots. In order to convey realistic sensations, the two aforementioned solutions rely on companies like Ghost who create software development kits to assign objects in the virtual work certain haptics, thus creating haptic user interfaces.

SE4 develops software that allows the user to interact with the robot and the environment in VR. The software transforms 'semantic' instructions from the user, such as 'pick up' or 'dig', into robotic action adapted to a changing environment on the ground.

Visualix is enabling robust centimeter-precise mapping and localization at scale with commonly used smartphones. The Visualix Mapping and Localization software development kit allows businesses to map spaces (create AR-ready digital twins) and persistently attach AR content to any position on the map.

The rise of the regenerative economy

The rise of the regenerative economy

Humans have become the single biggest driver of planetary change affecting our own life-support system, the Earth. In our quest for growth we are wiping out biological diversity, and emitting dangerous amounts of greenhouse gases into the atmosphere. In order to not further endanger the foundation of our own lives, we need to learn to live within the means of our planet. Deep tech innovations will be key in securing our planet's future. These technologies will enable the necessary transformations of our industries towards more sustainable models.

Deep tech can help end the 200-year-long tradeoff between the wellbeing of the planet and our prosperity. If we allow ourselves to instead learn from nature, combining it with our ability to create machines that automate processes, we can create new tools to improve our quality of life, increase the productivity of our industries, and simultaneously reduce their environmental footprint. Deep tech solutions will lead us into an era where we can separate energy

and material use from the production of goods. By reinventing the way we design and manufacture materials, as well as rethinking our supply chains and trade networks, we can create a truly regenerative economy that respects the limits of our planet.

Over the last 4 billion years, life on the planet has continuously evolved, resulting in highly efficient cellular factories that build, recycle, and transform molecules atom by atom. By using the mechanisms of nature to manufacture molecules, we will be able to create a powerful, nature-inspired innovation engine enabling us to engineer biology at scale. Using nature's blueprints and turning cells into factories will allow us to produce any organic material, making it energy-efficient and without generating waste. Following nature's product design plan will also allow for rapid reconfiguration and reuse of every product, creating a universal material ecosystem in which any product can be transformed into another.

By leveraging the power of nature to produce organic materials, and with similar efficiency, manufacture products from inorganic materials using 3D printing, our industries will become more sustainable. If combined with our ability to tailor goods online and digitally distribute them, eventually manufacturing them in close proximity to the end consumer, we will also be able to reduce the number of goods circling the globe, and reduce transport-related CO2 emissions.

Automated manufacturing from the atom up will also allow us to repurpose land previously dedicated to food production or mining raw materials. As with the fabrication of goods, cells can be repurposed to produce nutrients such as proteins, fats, and sugar. By exploiting fewer resources, particularly land, we will be able to give space back to nature. Large scale afforestation and the redevelopment of agricultural land into savannahs could store gigatons of CO2 and pave the way to a truly sustainable, regenerative economy.

When looking at the deforestation, loss of biodiversity, rising temperatures and desertification currently taking place, the question remains: can we shift our economies quickly enough to eventually thrive in harmony with the planet?

Precision agriculture will allow for a smarter management of the Earth's resources

Agriculture is at a crossroads. The sector produces more calories per capita than ever before in history. Nevertheless, malnutrition has persisted and counterintuitively, obesity has become a severe, widespread problem. To feed the world's growing population, the agricultural sector needs to produce more (healthy) food in a decentralised manner, as well as reduce the negative environmental impacts of its techniques to conserve the biosphere of our planet.

Precision Fermentation will provide a sustainable, low-cost alternative to animal protein

Based on the analysis of deep tech innovations at Hello Tomorrow, we believe that animal protein will - to a large extent - be replaced by plant-based diets and proteins produced by engineered microbes. Lab-grown meats on the other hand, will remain a niche product for the next decade. From what we have seen, the high cost and limited scalability remain significant obstacles to the widespread adoption of cultured meat. Nevertheless, companies like Shiok Meats, who use stem cell technology to try to grow shrimp meat from shrimp muscle cells, contribute to an important understanding of how, in this case, invertebrate cells grow, proliferate and differentiate. Shiok Meats also pioneers the large-scale automation of these processes, which would make artificial shrimp meat more widely available for human consumption. This in turn would

directly relieve the pressure put on wild shrimp populations, that have seen a sharp decline due to their popularity as a food item. However, as of today, the price of lab-grown meat, even at large-scale and when largely automated, is 10x higher than protein produced by microbial fermentation, and up to 50x higher if calculated based on pure protein content (Table 3).

Table 3: Sustainable protein solutions. Startups include Alver Golden Chlorella, Inalve, Solar Foods, Deep Branch Biotechnology, and DryGro.

	Organism	Energy source	Infrastructure needs	Estimated pricing
Alver Golden Chlorella	Algae (heterotrophic)	Organic carbon + electricity	Bioreactor	
Inalve	Algae (autotrophic)	CO2 + sunlight	Aqua culture	
Solar Foods	Bacteria (hydrogen-oxidizing)	CO2 + hydrogen + electricity	Bioreactor	~ 5€/kg protein
Deep Branch Biotechnology	Bacteria	CO2 + hydroge + electricity	Bioreactor	
DryGro	Duckweed (autotrophic)	CO2 + sunlight	Aqua culture	
Insect protein	Grasshoppers, crickets, locusts, worms, etc.	Biowaste	Indoor farm	~ 30€/kg protein
Lab-grown meat	Muscle cells of e.g. shrimps	Tailored, semi-synthetic growth medium	Bioreactor	~ 250€/kg protein
Animal protein	Poultry, pigmeat, beef, etc	Largely plant-based, protein-enriched diet	Farmland	

Instead, we will increasingly adopt a process called ‘precision fermentation’ to provide protein more sustainably. Advances in molecular and synthetic biology mean that we are able to engineer microbes to produce almost any protein by fermentation, a process that can be easily automated and thus very cost-efficient. This means that we can use microbes as mini ‘molecular factories’ to directly produce tailored proteins, allowing us to bypass the inefficient system of producing livestock.

Different organisms are used to produce proteins through precision fermentation: autotroph and heterotroph organisms. The latter requires an organic carbon source but grows independently of sunlight, which makes them the best candidate for cultivation in a closed fermenter or bioreactor.

Precision fermentation produces significantly less CO2, and requires less feedstock, water, land, and energy compared to proteins produced from livestock. If compared with protein sourced from cows: 10-25x less feedstock, 10x less water, 100x less land, and 5x less energy is required. Moreover, fermentation technology could also replace soy as a primary source of animal feed for the remaining animal husbandry. This would reverse the loss of biodiversity happening as a result of converting savannah and forests into cultivation areas for soybeans. Last but not least, the protein content can be customised and tailored to increase health benefits, thus meeting today’s requirements for a sustainable, healthy food system.

Fermentation technology also holds a significant advantage over insect-based protein sources. Its end product has a neutral taste and can be mixed into existing foods such as bread or pasta. Whereas insect protein has a distinct taste, texture and a less suited amino acid constitution compared to engineered microbes that produce proteins with a tailored amino acid profile. If also compared in terms of protein only, insect protein is 5-10x more expensive than proteins obtained by

precision fermentation. However, it may play a vital role as animal feed, enabling the conversion of soybean monocultures back to grasslands and accelerating the transition towards a regenerative agriculture era.

What are the implications of this shift towards precision fermentation and in turn, our ability to design food from the molecule up?

Livestock farming is still the single biggest human land use on the planet, more than double that of crop agriculture. Pasture expansion has been one of the most significant challenges the world has faced in conserving biodiversity and mitigating climate change. It has been a major driver of deforestation in the Amazon and led to the degradation of much of the world's natural grasslands, releasing vast amounts of carbon stored in soils and plants into the atmosphere. By shifting to fermentation – consumer and farmers willing – we could recuperate pasture land and use it to store gigatons of carbon.[10]

Since precision fermentation is generally not reliant on the local climate or natural resources, food production can be even more decentralised and widespread. However, the high setup costs and technical knowhow it requires will likely prevent rural communities from adopting it. However, there is no reason that proteins from precision fermentation cannot exist alongside more traditional products and ways of producing them.

Turning farmland into a controlled, lab-like environment using precision agriculture tools

Besides precision fermentation, plant-based diets will become increasingly popular. In order to allow the vast majority of the world's population to adopt plant-based diets, the efficiency of crop growth will need to increase. In the Netherlands, the world's second-biggest exporter of agricultural products, tech-savvy farmers use hydroponic systems in greenhouses to

[10] Blaustein-Reyto, D., Blomqvist, L. et al (2019): Achieving Peak Pasture. **The Breakthrough Institute**

generate unparalleled yields using little resources. As an example, Dutch greenhouses use 25x less water than the global average, using only 8 liters of water to produce 1 kg of tomatoes[11]. This is made possible due to a controlled environment, where precise, reliable temperatures and humidities are achieved. For instance, UbiQD have developed a film technology that passively red-shifts the sun's spectrum to achieve optimal growth conditions, resulting in faster growth cycles when applied to the glass roofs of greenhouses.

The better control of environmental conditions is not limited to greenhouses however, as illustrated below (Figure 2).

[11] Walsh, NP. (2020): How the Dutch use architecture to feed the world.

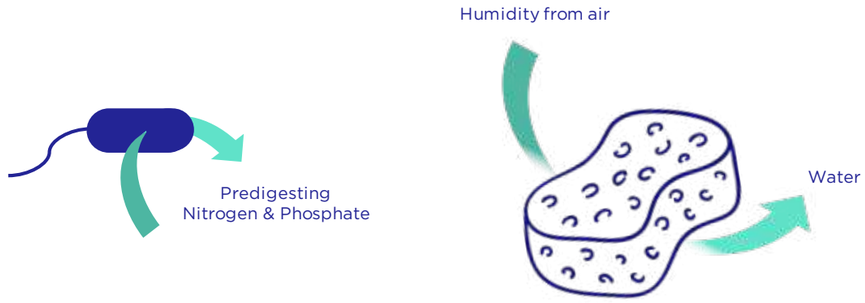


Figure 2: Biomineral Systems developed bacteria that "pre-digest", if you will, the soil's nitrogen and phosphate, thus making those essential nutrients more easily available for crops. Others develop solutions to ensure a constant supply of water. Sponsh's textile collects water from the surrounding air when relative humidity is 75% or higher at night and releases it with temperature rise during the day. Similarly, Soyl's polymer which can be included in seed plantings can absorb water 1000x of its own weight. Upon rainfall or irrigation, the gel absorbs water, swells, and continually releases water over the next few days, thus providing crops better growth conditions – also under changing weather conditions.

Besides optimizing growth conditions, deep tech innovations also aim at creating environmentally friendly alternatives to synthetic pesticides. Hazardous pesticides are replaced by bio-based solutions such as RNAis developed by Nanosur. RNAis are a class of biomolecules that can be designed to specifically target crop pests and are otherwise harmless, thus limiting the interference with nature while still very effectively eliminating undesired insects. Agrynex has another approach: its enzyme system produces free radicals, which are small reactive particles that manage to effectively kill bacteria, given that they have less defense and repair mechanisms than plant cells.

Smarter use of animal resources

Deep tech innovation is also contributing to an improved resource use in animal farming. And certain solutions can have a huge impact. As an example, every year the global poultry industry incubates 9 billion perfectly edible infertile eggs. Since they never develop into a chicken, this is a huge waste of resources. Moreover, since male chicks don't lay eggs and can't be sold profitably as meat, roughly 7 billion 1-day-old male chicks are killed each year. To reduce this waste, Orbem's accelerated MRI technology allows you to visualise and measure the structures within eggs without altering or damaging them. Combined with a machine learning-based algorithm, the egg's fertility status and sex can then be automatically detected, meaning only non-fertilised (and male) eggs can be sent to our grocery stores, and female eggs can be kept for hatching.

With the same goal in mind, eggXYt installs a biomarker on the male chromosome of a chicken population. Once the egg is laid, the sex of every subsequent chicken embryo is then detectable, by scanning the egg through the shell. EggXYt can in this way prevent the male chicks from hatching and being immediately killed, but current regulations don't allow for genetically modified eggs to be freely sold as food. If regulations should change in the future, this might present another valuable method of using our resources more efficiently.

Integrating these technologies into food production makes much better use of our resources, and would allow us to effectively overcome food scarcity. Widespread adoption of these precision techniques will, however, also depend on the consumer. At present, a consumer makes decisions based on taste, texture, convenience, and costs. Ecological compatibility and nutritional value have not been priorities, and thus are not optimised by the food and agriculture sector. Last but not least, we will also need to reduce food waste to feed ~8B people, all the while preserving our planet.

Utilising nature's book of life will lead to a green revolution in manufacturing

Due to the industrial revolution, since the beginning of the 19th century, manufacturing has been about using machines and large amounts of energy to shape raw materials into products. Driven both by our increasing understanding of biology and by our ability to automate processes, manufacturing will undergo another revolution.

Reprogramming microbes to synthesise valuable intermediates and products

Instead of exploiting our limited natural resources by breaking them down into relevant building blocks and reconstituting them in the desired way, advancements in molecular biology will allow us to build tailored materials from scratch. In particular, our ability to engineer microbes to produce a variety of valuable intermediates and industrial products enables us to design and build products from an atomic level, with fine-tuned properties. We are able to do this using nothing other than energy from the sun, CO_2 or an organic carbon source, minerals, and water as inputs. We have also

learned to extract enzymes, the manufacturing tools of a cell, and turn them into stable biocatalysts to enable the fabrication of increasingly complex materials. Both microbes and enzymes have evolved over billions of years, making them the most resource- and energy-efficient manufacturing tools nature has to offer.

The shift from our current production model to biology-enabled manufacturing, will directly reduce the environmental impact of our industries. The shift in paradigm for manufacturing is a great opportunity for highly polluting sectors to become sustainable. For example, Tinctorium engineers and utilises microbes to secrete an indigo precursor which, if combined with an enzyme reduction step, can then be used for dying fabric. This eliminates the need for petroleum or other toxic chemicals, thus turning the production of blue jeans into a more sustainable business.

Transforming algae-, fungi- or plant-based raw materials into novel products

Biology-enabled manufacturing does not simply mean creating the same materials in a more sustainable way, but it also gives rise to new materials with unrivaled characteristics that cannot be created using synthetic procedures. The toolbox that biology has to offer us for manufacturing is diverse, and opens up intriguing possibilities. Microbial enzymes are able to produce structures that can self-assemble into supramolecular, highly-ordered three-dimensional arrangements. These structures are not limited to the incorporation of organic elements, but can also be of inorganic nature, as demonstrated by Swedish Algae Factory. Their algae produce nonporous silica shells that make solar cells up to 40% more efficient, outperforming every synthetic material. The nonporous silica has evolved over millions of years to efficiently trap visible light, block UV radiation and funnel the remaining light efficiently, improving the cell's photosynthetic capacity.

Whilst less revolutionary, the use of renewable resources such as plants as starting points for manufacturing is an integral part of the upcoming green manufacturing era.

For instance, MycoTEX uses mycelium, the roots of mushrooms, to create sustainable fabric. The mycelium can be cultivated in a bioreactor and once harvested, shaped and dried in any form, meaning clothes can be produced without any sewing or cutting.

Equally fascinating, SurgePower Materials has identified a way to produce graphene from Cassava, an agricultural crop also known as Manioc. The common technology used for producing conventional graphene is based on mined graphite. The novel route however, would eliminate the detrimental effects the extraction of graphite has on the environment and yield graphene with increased pore volume, making it suitable for use in high-energy batteries and ultracapacitors.

Turning enzymes into highly efficient and stable biocatalysts

As mentioned above, the transformation of enzymes into biocatalysts is another key pillar in the green manufacturing revolution. Zymtronix enables more innovative and efficient enzyme processes across industries in lieu of both chemistry and fermentation. Its enzyme immobilization platform improves the activity, stability, and reusability of any enzyme. This is of particular importance, as current biocatalysts still all too often lose activity quickly and are difficult to implement at large scales.

Deep dive: Bioplastics – from polluting to readily reusable materials

The breakthrough of biology-enabled manufacturing across industries will be triggered by the production of an environmentally-friendly, equally versatile alternative to plastics. The matter of plastic pollution is well understood: more than 8 billion tons of plastic have been produced to date, microplastics are taken up by every animal, and can also be found in our own bodies. While 8 million tons of plastic flow into the ocean every year, the majority ends up in landfills where it takes up to 500 years to decompose – releasing toxic additives into the air and soil during its decomposition.[12] Bioplastics have emerged as a potential, environmental-friendly alternative. But can they live up to the hype?

[12] Gibbens, S. (2018): What you need to know about plant-based plastics. **National Geographic**

Traditional plastic is made from petroleum-based raw materials, contains toxic additives such as bisphenol A, and degrades very slowly. Bioplastics however, have a smaller carbon footprint and decompose, in most cases, much faster. However, some bioplastics consist of the same polymer chains as their conventional counterpart, with the same toxic additives, thus behaving just like plastic.

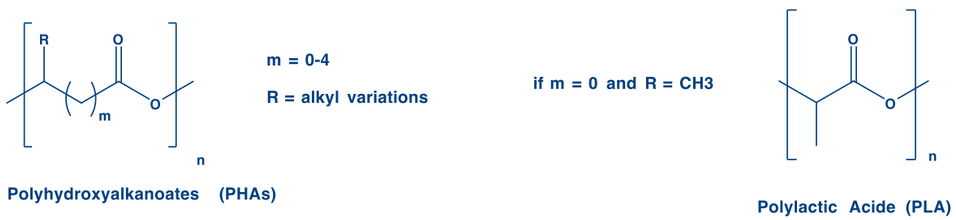


Figure 3: A truly different bioplastic polymer is polylactic acid (PLA) which is mostly derived from corn sugar, potato or sugarcane. For biodegradation, PLA needs industrial conditions, including temperatures above 58°C though. If properly managed and routed to specialised recycling facilities, microbes can turn this type of bioplastics into carbon dioxide and water within a couple of weeks. Without adequate composting infrastructure, PLA might stick around as long as regular plastics, despite being derived from plants. While there is currently no real competition with food and feed production, an increase in PLA-based bioplastics could also raise the pressure on arable land, potentially leading to loss of habitats and biodiversity.

Other bioplastic building blocks are polyhydroxyalkanoates (PHAs) which can be produced by microbes (technically PLA belongs in the same family). In a tropical environment, PHAs (with m>0) will degrade in a few weeks but in a less warm and humid climate, it can take more than 10 times as long.[13] As those building blocks are produced by microbial fermentation, there is no competition with food production.

[13] Krieger, A. (2019): Are bioplastics better for the environment than conventional plastics? **Ensia**

At Hello Tomorrow, we are confident that the efforts by governments, companies, and scientists will result in a true alternative to plastics. In fact, the newest generation of bioplastics (Figure 3) is increasingly biodegradable and some even compostable. The latter means that this type of bioplastics can be broken down completely into water, carbon dioxide, and organic waste by microorganisms in weeks at ambient conditions. Table 4 summarises ten of the most promising innovations in this field, featuring plastics from engineered plant proteins, to compostable plastics made from lignin or cellulose.

Table 4: Bioplastics solutions. Startups include Genecis Bioindustries, Xampla, Mobius, Bloom, Potato Plastics, Micro Rio, Cellugy, Cellulosic Technologies, Venvirotech, and Aqua Plastics.

	Production by	Building block	Source	Degradable
Genecis Bioindustries	Bacteria	PHA	Organic waste	Biodegradable
Xampla	Self-assembly	Supramolecular assembly of proteins	Pea protein	Compostable
Mobius / Bloom	Chemistry	Lignin based	Paper waste	Compostable
Potato Plastics	Chemistry	PLA	Potato	Biodegradable
Micro Rio	Bacteria	PHA	Methane / Methanol	Biodegradable
Cellugy / Cellulosic Technologies	Bacteria	Cellulose based	Plant waste	Compostable
Venvirotech	Bacteria	PHA	Organic waste	Biodegradable
Aqua Plastics	Chemistry	Supramolecular assembly of proteins	Bacterial protein	Compostable

A mix of renewable energies will drive our increasingly energy-efficient applications

The energy sector faces a well-known, two-fold challenge: meeting the rising demand for energy services while cutting its CO2 emissions. The next generation of energy solutions needs to provide energy to the one billion people who still do not have access to electricity, while reducing the energy-related share in global greenhouse gas emissions.[14]

The gap between the expectation of a fast, renewables-driven energy transition and the reality of today's energy systems, that still largely rely on fossil fuels, remains significant. However, the demand for coal, gas, and oil is stalling, because the cost of renewable sources, in particular wind and solar energy, are falling fast, and battery storage technologies continue to improve. Hence, fossil fuel demand is expected to peak in 2023, as even emerging economies are increasingly pursuing clean energy to reduce emissions and air pollution.[15]

Energy generation from renewable sources

To reach the climate targets outlined in the Paris agreement, about 6000 GW of wind power needs to be installed over the next three decades. This will simply not be possible with conventional wind turbines, due to their high costs and low public acceptance. For this reason, TwingTec unlocks stronger altitude winds in remote places, on-shore and in the open ocean. Such winds can be exploited using autonomous, tethered drones which require only 1/10 of the material than a conventional wind turbine does, thus having a minimal environmental impact and allowing quick deployment. While the drone flies in cycles driven by the wind, similar to a kite, the high tether forces are converted into electrical power.

[14] International Energy Agency (2019): World Energy Outlook 2019.

[15] Bond, K. (2018): 2020 vision: why you should see the fossil fuel peak coming. **Carbon Tracker**

Besides solutions to harness wind power, solar technologies are the most advanced. While scientists continuously try to increase the efficiency of solar cells to produce energy from the sun, CSAR Energy has developed a solution that harnesses the sun to produce hydrogen from methane and water. The reactor is integrated into a solar concentration system that provides enough heat to sustain the chemical reaction for hydrogen synthesis, thereby producing hydrogen at reduced costs. However, this hydrogen production method cannot be considered entirely sustainable, as it produces carbon dioxide emissions.

Making IoT devices energetically self-sufficient

Power production is often classified into two scales: large “utility” scale and small “off-grid” scale. However, there is a third level emerging with even smaller power requirements than the off-grid scale. The fast expansion of IoT and wireless sensor networks will add more than a trillion devices to the market over the next few years. These devices need an environmentally-friendly, micro-size, in-circuit power source that, unlike batteries, does not need a replacement every year. Alternative solutions, such as small solar panels, need constant maintenance. For this reason, Enervibe has developed a Micro-Electro-Mechanical System that can harvest energy from ambient vibrations, while Bioo is developing a biochemical battery. By using microbes and electrolytes that naturally occur in the soil, its battery could power agricultural sensors for an estimated 10 years – without maintenance and without using rare earth materials for its battery.

Storing energy while transforming CO2 into a less hazardous form

The decoupling of greenhouse gas generation from the production of power has been the main driver of innovation in the energy sector, and has eventually initiated the energy transition. But what about if we could go a step further, and not only decouple CO2 generation from energy production,

but instead produce energy while eliminating CO2 from the atmosphere? Imagine, the mitigation of CO2 emissions in conjunction with renewable energy generation and storage. Agora’s CO2 redox flow battery consumes industrial scale amounts of CO2 during its charging cycle, while providing clean electricity on demand during battery discharge (Figure 4).

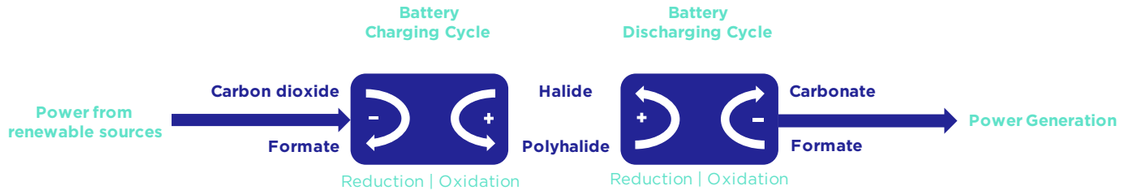


Figure 4: In the charge cycle, CO2 is reduced at the negative electrode with electrons supplied by renewable energy, generating a formate salt, whereas at the positive electrode a polyhalide is produced. Both the formate and the polyhalide solutions are safe and have long shelf-lives. During discharge, energy is released from the oxidation of the formate to a carbonate salt solution and reduction of polyhalide back to halide which is recycled. Thus, the CO2 redox flow battery acts as a net CO2 sink while providing more than 500 Wh/kg, which is more than double what Li-ion batteries offer.

Recovering waste energy is key to reducing global energy demand

The solutions above illustrate the efforts companies and scientists are making across the world to develop sustainable energy sources and reduce our dependence on fossil fuels. However, there is another source of energy that goes unused every day. This energy source is the waste heat produced in nearly every type of production process, including energy generation. Up to 50% of the

consumed energy is lost as heat. Recovering waste heat is one of the most significant means of increasing energy-efficiency, and reducing the environmental footprint of such processes. Under a conservative assumption, 20-30% of this waste heat could be recovered resulting in an overall 10-15% reduction in energy consumption.[16]

[16] US Department of Energy (2008): Waste Heat Recovery: Technology and Opportunity in the US Industry.

In principle, recycling heat is not a difficult process. Already, Thomas Edison's first commercial power plant in New York, constructed in the 1880s, channeled its waste heat in the form of hot steam to neighboring buildings for them to use as a heat source. Plants like this still exist today, known as combined heat and power plants.

Heat intensive industrial production processes have remained a primary focus of waste heat recovery solutions, but their nature is changing. While previous solutions aimed at using the energy of the waste heat for another application, more recent solutions accumulate the heat to enable the storage of such energy. However, current heat accumulators reach a maximum of 600°C, well below the temperatures at which, for instance, a steel manufacturing plant operates. Since most materials are not stable above those temperatures, the energy from waste heat from such heat intense processes is inevitably lost. Due to its phosphorous granulate which combines high-temperature resistance and high-energy storage capacity, Kraftblock overcomes this limitation. It enables the storage of large amounts of energy in a small place, coming from waste streams of up to 1300°C.

At the other end of the spectrum, processes producing waste heat between only 50-200°C, innovation is driven to recover the little energy left in these waste streams in an economically viable manner. Poligy's solution consists of two biopolymers with different heat expansion characteristics fused together, which creates a bending movement when changing temperatures. If a generator is attached, this rotary movement can then be used to produce electricity.

However, not only industrial manufacturing processes generate waste heat. The continuous digitalization of industries and the development of data-driven applications give rise to large data centers, which increasingly contribute to global energy consumption and produce a significant amount of waste heat. To reduce our energy demands, it will be key to also install efficient heat recovery solutions in data centers.

Into the future: energy-efficient cooling systems

Importantly, installing waste energy recovery solutions should never be aimed at capturing waste heat which could have been recovered as material, nor should it reduce the efforts to reduce energy use in the first place. The latter is of particular importance within the cooling sector. Within the context of global warming, maintaining the cooling chain for medical and food products will become increasingly important.

MagnoTherm Solution's solution replaces gas compressors for cooling, and instead makes use of magnetocaloric materials which can both heat and cool, by magnetizing and demagnetizing respectively. The solid-state refrigeration technology is 40% more energy-efficient, does not require toxic or environmentally-hazardous additives, and runs at much lower noise levels than a compressor.

To take it a step further: imagine a future in which cooling could happen without electricity. Imagine a future in which more sun radiation means less heat and instead, cooler temperatures. Solcold is developing a unique material, no thicker than a paper, which uses sunlight to cool things. The nanomaterial can be applied to various surfaces as a coating. Once sunlight hits the material, a reaction called "anti-Stokes shift" occurs which provides a cooling effect to the interior.

Thinking even longer term, PseudoFreeze could provide a novel refrigerating system that specialises in the

storage and transportation of vaccines. It explores a new way of natural refrigeration that uses a novel bio-nano compound to freeze water at up to 4 °C, and in turn cool the ice down to negative degrees Celsius. The bio-nano compound is based on ice nucleation active proteins, taken from bacteria which are able to freeze water. When immobilised on microbeads, those proteins are able to freeze water at 4°C. This can create more resistant ice with a higher melting point than conventional ice, resulting in a more stable cold chain that requires very low amounts of energy.

Deep dive: CO2 upcycling to achieve carbon neutrality

The 2015 Paris agreement states that each country has to take measures to mitigate global warming.[17] Most paths to ensuring global temperature increase does not exceed 2°C compared to pre-industrial levels as well as each path to reach 1.5 degrees, rely in some way on CO2 fixation, according to the IPCC, the UN expert body on climate change. In principle, the idea is simple: extracting CO2 straight from the air and storing it permanently underground.

Currently, we globally emit 1000 tons of CO2 per second into the atmosphere. These emissions add up to about 31.5 gigatons per year. With less than 500 Gigatons of CO2 emissions remaining to keep global warming below for 2°C, we have, at the current rate, 16 years left to reduce our CO2 emissions to net-zero. However, it is unlikely that we will transform our economies and lifestyle in such a way that doesn't produce any more CO2 from 2036 onwards. There will always be processes that will result in CO2 emissions. For this reason, it is essential to develop ways of removing CO2 from the air. The underground storage of CO2 represents the most efficient solution, but doesn't seem viable. Whilst they are unfounded, citizens have reservations about the storage

[17] United Nations (2015): Paris Agreement

of the gas within close proximity to their homes, and the increase in taxes that would be required to cover the costs render the CO2 underground storage very difficult.

However, there is another approach to prevent further CO2 accumulation in the atmosphere. Instead of seeing CO2 as a non-functional material that needs to be locked away, CO2 can also be used as a starting material to build valuable products. There are two approaches that have to be differentiated:

The first approach aims at trapping the CO2 in its current form in a solid material. Carbonupcycling's method relies on the chemical adsorption of CO2 emissions into easily accessible graphite to produce various graphene nanoparticles such as graphitic nanoplatelets or graphene oxides. Their technology sequesters between 50 to 250 kilograms of CO2 from the atmosphere per ton of product. Similarly, CO2Concrete's pioneering technologies cost-effectively transform flue gas borne CO2 into concrete construction materials. Both technologies allow for flexible and adaptable CO2 processing, while enabling CO2 uptake into construction products that are used worldwide. However, these methods do not definitively remove CO2 from the balance sheet. Instead, if and when those materials decompose, they release the CO2 back into the atmosphere. This means that they can only be considered as a temporary solution, assisting in biding us time until permanent CO2 removal techniques become viable.

These permanent CO2 removal technologies will rely on the transformation of CO2 into a different, less hazardous form of carbon, and thus effectively removing it from the atmosphere. For instance, Agora, explained in more detail in the previous section, transforms CO2 into a carbonate salt in its redox flow battery during the charging and discharging cycle.

In contrast, Cambridge Carbon Capture uses a

magnesium hydroxide slurry to capture and convert CO2 from flue gas. The CO2, SOx, and NOx from the flue gas are converted to stable, solid mineral by-products that are made up mainly of magnesium carbonate, with magnesium sulfide and magnesium nitrate. These can be used as fireproof construction materials, or as a chemical base for other products such as paints.

Others, such as Dimensional Energy, transform CO2 using a solar (photo)thermocatalytic, reverse combustion technology that enables the conversion of flue gas, rich with CO2, into commercially viable hydrocarbons. As the light enters the reactor through a solar concentrator, it is directed to the photocatalyst, which enables the transformation of carbon dioxide and hydrogen into more valuable products. Each photocatalyst has a unique chemistry, thus allowing the production of multiple chemical products depending on its kind.

Another approach that has attracted a lot of attention is the usage of CO2 fixing bacteria or algae to sequester and upcycle CO2 from the air. Due to the great plasticity of carbon metabolism, such microbes can be easily engineered to produce a wide range of valuable hydrocarbons.[18] However, even if microbial fermentation is increasingly used for the production of food and other bio-based materials, unless it is quickly and globally implemented at a large-scale it is unlikely to sequester enough amounts of CO2 to significantly contribute to the Paris climate goals.

To conclude, deep tech innovations open up a promising path to large-scale, economically viable CO2 sequestration (Table 5). However, if pursued, the aforementioned transition to more regenerative agriculture will likely have a bigger impact over the next decade. Reforestation and the repurposing of farmland into wild savannahs would enable the storage of gigatons of CO2, a scale that is not yet feasible using other CO2 removal techniques.

[18] Kanno, M. et al. (2017): Global metabolic rewiring for improved CO2 fixation and chemical production in cyanobacteria. **Nature Communications**

Table 5: CO2 trapping and transformation solutions. Startups include Carbonupcycling Technologies, CO2 concrete, Agora, Cambridge Carbon Capture, and Dimensional Energy.

	Solution	Application
Carbonupcycling Technologies	CO2 containing nanoparticles	CO2 storage
CO2 Concrete	CO2 containing construction material	CO2 storage
Agora	CO2 Redox Flow Battery	CO2 transformation
Cambridge Carbon Capture	Conerverting CO2 to solid minerals	CO2 transformation
Dimensional Energy	Photothermal-catalytic transformation	CO2 transformation

On-demand production of tailored, reconfigurable goods will give rise to a dematerialised economy

The industrial revolution has unlocked an era of unprecedented growth. Since 1800, the human population has increased about 8-fold, and enjoyed ever-increasing prosperity. Thanks to the mass

production of machines and goods from abundant raw materials, a global economy developed. Improved transport means allowed for international supply chains and trading. To sustain this growth, the natural resources of our planet were increasingly exploited – well beyond its limits. For too long, a tradeoff between our prosperity and the wellbeing of the planet seemed inevitable, and the concept of humanity thriving within a regenerative economy seemed utopian.

This view has rightfully started to be challenged, as deep tech innovations pave the way to decouple production from material use. By building materials atom by atom, reusing materials, and swapping atoms for bits wherever possible, a dematerialised economy is rising. Through digitalization, atomic-scale manufacturing, and recycling, humanity can thrive within the limits of our planet.

Utilising 3D printing to save raw materials

Besides biology-enabled production, one of the key technologies giving us the power to build materials from scratch, atom by atom, is additive manufacturing, also known as 3D printing. 3D printing has existed for about 40 years, but has largely been employed to produce prototypes and special-purpose pieces. In recent years, the number of materials that 3D printers can handle has expanded beyond plastics. A wide range of new processes and machines for printing have been developed, such as the 3D metal printer developed by MX3D. These advances have brought 3D printing into the realm of manufacturing in industries like aerospace, especially for the mass customization of functional parts. Unlike traditional manufacturing, additive manufacturing makes it economically viable to produce a high volume of parts where each one is different. By enabling the assembly of very small, custom-designed components, the generation of waste material is reduced to a minimum.

However, the limited printing speed, the low resolution, and imperfect finishes have remained significant pain points that the newest generation of 3D printers are aiming to overcome (Table 6).

Table 6: 3D-printing solutions. Startups include ValCUN, ATLANT 3D Nanosystems, Spectroplast, and Kumovis.

	Solution
ValCUN	Metal printing
ATLANT 3D Nanosystems	Printing at nanoscale resolution
Spectroplast	Silicon printing
Kumovis	Medical-grade implant printing

Given an improved speed and quality at a lower cost, more and more industries would adopt 3D printing. It could replace traditional mass-production approaches in the long term and significantly influence trade flows. The wide-spread introduction of automated production platforms such as 3D printing allows products to be tailored online, then digitally distributed and manufactured in close proximity to the end consumer. For this reason, these technologies could likely lead to the regionalization of trade, and eliminate the need to transport goods across oceans and thus, reduce transport-related CO2 emissions.

Developing novel recycling technologies will pave the way to a universal material ecosystem

Another key technology to achieve a dematerialised economy is the recycling of materials at the end of their lifetime. Instead of a part with a single function, materials will be part of a larger physical material ecosystem. Any component of goods and machines needs to be readily reusable and reconfigurable by design. This will require a new design approach, as well as innovation in recycling technologies. Plastic is a good example to illustrate this. While newly emerging bioplastics are, by design, recyclable, petroleum-based plastics, of which we have produced 8 billion tons to date, are not reconfigurable by design, and new energy-efficient methods are needed to recycle it (Table 7).

Table 7: Plastic recycling technologies. Startups include Néolithe, Pyrowave, Recycling technologies, and Biofy Spain.

	Solution
Néolithe	Use compressed plastics to build roads
Pyrowave	Catalytic microwave depolymerization of plastics
Recycling technologies	Pyrolysis of plastics
Biofy Spain	Transform plastics back into oil

Humans continue to push their biological limits

Humans continue to push their biological limits

Over the last 4 billion years, the Earth with its initially sparse and barren volcanic surface has transformed into a colorful biosphere. On a planet mainly consisting of inorganic matter, the ability to grow, reproduce and to adapt was unheard of - and unrivalled. Life on Earth was thriving and constantly transforming. From primitive, unconscious life forms evolved more advanced organisms, including us humans. Our unique level of abstraction through which we can reason and our ability to create larger networks of knowledge allowed our species to progress at a vastly accelerated pace, thus becoming the dominant life form on our planet.

The increase in average human life-span, scientific knowledge, and labor productivity over the last hundreds of years are exemplary of the unprecedented progress humans have achieved. In the quest to advance further, we seek to push our biological limits.

New generation of medicines, designed to overcome the most devastating diseases, allow for a more patient-centered approach. The possibility to sequence our DNA at high speed and low costs increasingly enables clinicians to elucidate the genomic profile of patients and assign, with the help of machine learning-based algorithms, the most promising treatment. Current patient-centered innovations go beyond administering medicines based on an AI-calculated probability score. Instead, new medicines allow for drug activation at the site of the disease. Cell and gene therapies have become technically feasible, thus making medical interventions more targeted with fewer side effects.

Similarly to the diagnosis and treatment of diseases, the development of medicines will increasingly rely on our ability to design powerful algorithms. We call upon machine learning and more powerful computers to extract the underlying forces of complex biological systems in order to generate new therapeutic drugs, cell and gene therapies, and other medicines that we have yet to imagine. The development of medicines has largely been based on trial and error. Significant advances in machine learning and causal data science permitted, the drug development approach could fundamentally shift towards pattern recognition within the many complex networks at work. This shift will be supported by the next generation of life science research tools which will enable us to interrogate and manipulate biology at higher spatial resolution.

To conclude, we are coming closer, step by step, to the long-standing dream of personalised medicine, a model that would see medical interventions being tailored to each individual. However, without further progress in automation and shorter build-test-learn cycles, they remain mostly unviable from an economic point of view.

Targeted therapies based on probability scores will account for everyone's unique biology

The genetic code of an entire human chromosome was revealed for the first time in 1999 as part of the Human Genome Project. Back then, many people expected to see a complete transformation in therapeutic medicine within 20 years.[19] This has not happened for one main reason: initial hopes for an era of personalised medicine tailored to everyone's genome were based on the unfounded assumption that each disease is directly linked to only a few genetic factors. Indeed, it is true that certain serious diseases are caused by an individual mutation, Huntington's disease is one of them. However, most debilitating diseases are caused by combinations of mutations, some accumulated during a lifetime, in hundreds of genes, each having a small effect. Thus, the dream of using gene therapy (i.e the replacement of a mutated gene against a normal copy) to cure diseases will come true for only a small number of disorders.

[19] Collins, FS. (1999): Medical and Societal Consequences of the Human Genome Project. **New England Journal of Medicine**

Advancing viral gene therapy technologies

For diseases caused by a single mutation, the "correction" of the mutated gene can be done via engineered enzymes, such as the already famous CRISPR/Cas or by virus-enabled gene editing. The latter technology is more advanced and already received approval to be administered as a cure to certain monogenic disorders. Beyond the enormous costs of such treatments, the technology is still limited by two factors: the patient's immune response to the viral vector, and an inefficient gene transfer from the virus to the relevant cells. To overcome the pre-existing neutralizing antibodies that are naturally present in many humans, and reduce the immune response to the administered viral vector, Chameleon's vector displays immune-inhibitory molecules that reduce the patient's immune response, overcoming one of the two major limitations.

Regardless of the technology used, these advances raise many ethical questions. Human germline engineering, meaning to modify a trait that can then be passed down to offspring, has huge implications that we can hardly fathom. A societal consensus regarding the use of gene editing in general and germline genome editing, in particular, will be needed to prevent the unethical use of these technologies.

Polygenic risk scoring

While not completely transforming medicine, the Human Genome Project still had a major impact on many research fields and most importantly, facilitated the development of fast, precise, and inexpensive sequencing and manipulation of DNA. The lowered costs of DNA sequencing, for example, has enabled clinicians to sequence the genome of tumor tissue, and thus build up large genomic databases. These databases are increasingly used to draw correlations between a person's unique genetic profile and discern their susceptibility to certain diseases and treatments. In order to understand the correlation between genetic factors and the likelihood of developing a disease, its progression and response to available treatments, scientists and companies are increasingly developing machine learning-based solutions (Table 8).

While algorithms are not yet able to identify causal relations between a genomic profile and disease, they will help physicians to choose the best available care based on the issued probability scores which indicate the patient's susceptibility to a certain treatment.

Table 8: Polygenomic probability scoring. Startups include Cambridge Cancer Genomics, Oncoshot, Nalagenetics, and Bilhi Genetics.

	Goal	Disease
Cambridge Cancer Genomics	Matching patients to most effective treatment	Cancer
Oncoshot	Matching patients to most effective treatment	Cancer
Nalagenetics	Prevent adverse drug reaction	-
Bilhi Genetics	Predicting risk for disease development	Liver cancer

The rise of theranostic solutions

Apart from choosing therapies with higher prospects of success, therapies themselves will become more targeted as well. Lumento Therapeutics aims to upgrade existing cancer drugs with a light-sensitive protection group that renders cancer drugs ineffective until activation with a certain light wavelength.[20] If a focused light source from outside the body is pointed onto the cancer tissue, the drug is locally activated, thus allowing for higher dosing of the cancer drug as it remains inactive in other body parts. Similarly, RS Research is developing a caging technology that would allow cancer drugs to regain activity only once inside the targeted tumor cell. If combined with e.g. Nanology Labs' technology which leverages manganese nanoparticles to indicate the exact position of early-stage (brain)

[20] Hansen, MJ. et al. (2018): Photoactivation of MDM2 inhibitors: Controlling Protein-Protein Interactions with Light. **Journal of the American Chemical Society**

tumors using MRI, it would give rise to a truly theranostic solution. Theranostics refers to the combination of specific targeted therapy and diagnostic tests which will likely become a more common tool in medicine on our way to truly provide personalised medicine.

Cell therapies continuously advance

Meanwhile, we're seeing incredible progress in cell therapies. Instead of correcting a single mutated gene, cell therapy aims at replacing malfunctioning tissue, organs or certain cell types by transferring live cells. The cells may be genetically engineered and either originate from the patient (autologous cells) or a donor (allogeneic cells). The most common and successful cell therapy used to date is the treatment of certain leukemia forms with engineered T cells. T cells are an essential part of everyone's immune system, normally fighting off viral and bacterial infections. In immunotherapy, the engineered T cells are reprogrammed to attack leukemia cells.

With the aim in mind to treat large skin defects caused by burns or severe skin diseases using cell therapy, Cutiss engineers autologous dermo-epidermal skin cells. A healthy skin cell is identified, then cultivated and reverse-engineered into a pluripotent stem cell. From this, many new skin cells can be generated, thus creating, from scratch, the living skin transplant that will replace the defective skin. The main challenges of this process are the engineering of the cells and automation of the procedure. Both are addressed by GC Therapeutics and TreeFrog Therapeutics which, respectively, develop novel stem cell differentiation and culture techniques. Overcoming critical manufacturing-related issues will enable millions of patients suffering from certain organ malfunctions, for instance, those with diabetes type 1, to benefit from cell therapies. Others like Ternion Bioscience further develop stem cell technology to better recapitulate the human body response and test drug toxicity. This can, in turn, reduce the need for animal testing in the long term.

While cell therapies may deliver on the promise of personalised medicine one day, it is still far away from being automated and thus widely-applicable.

Deep dive: Empowering computers to solve complex biological systems

Computers cannot yet reason and think like humans – a concept known as "general artificial intelligence". However, computers are increasingly able to interpret images and text as accurately as humans which opens up the possibility of using machine learning-based solutions to analyse biomedical data. Today, the diagnosis of medical images taken using MRI, CT scans, and X-rays is, in certain cases, already assisted by machine learning-based algorithms. Similarly, natural language processing algorithms have shown promising results in the areas of biomedical text mining or the development of medical decision support systems.

While this progress is exciting, the question remains whether machine learning can have a significant impact on drug discovery by improving research and development (R&D) decision making. Current drug discovery approaches can roughly be divided into two categories – hypothesis and discovery-driven. The first approach involves the design of a therapeutic drug against a cellular target that has been linked to a disease. The second method looks at restoring health in a relevant disease model by screening thousands of potential drug candidates for the desired effect.

Both methods could benefit from the implementation of AI. For instance, Iktos' deep learning-based algorithms have the ability to design new molecules. To guide the molecular generator in the infinity of the chemical space, Iktos has introduced fitness

functions for multiple objectives, among other features the candidate molecule has to be easily accessible using established synthesis routes, that the algorithm must fulfill. The final molecule is obtained in a reinforcement learning setting which rewards the optimization of the given multi-objective function.

Others like MabSilico use machine learning algorithms to select and optimise antibodies. Its solution is largely based on protein-protein docking methods, a proven technique to simulate in-silico protein-protein interactions, but uses machine learning to optimise the scoring function of the docking.[21]

[21] Bourquard, T. et al. (2018): MabTope: A method for improved epitope mapping. **The Journal of Immunology**

AI skeptics will point to this very example of docking methods. Although such in-silico modeling techniques are important in modern R&D, they have not delivered on the enthusiastic claims voiced when computer-aided drug design began in the 1980s. The next decade will show if the implementation of AI in current drug discovery approaches will accelerate the procedure or only contribute minimally.

However, scientists and companies willing, AI may still enable a fundamental paradigm shift in drug discovery. Based on data platforms that feature known and inferred relationships between genetic and molecular profiles, symptoms, diseases, tissues, species, and drugs, drug development will come down to a very sophisticated pattern recognition exercise. With the help of AI, these platforms can be queried like search engines to produce informed hypotheses of, for example, a medical condition and the genes that are associated with it, or the compounds that have been shown to affect it.

Nevertheless, there are two main challenges:

Firstly, most of the platforms won't feature annotated data. In the health domain, data labels can typically be given only by qualified specialists, in contrast to simple object recognition, where photographs can be labeled by legions of laypersons.

Secondly, these drug R&D platforms feature a wide variety of data. In contrast to classical big data platforms dealing with few characteristics for millions of subjects, wide data means a few subjects but much more information for each. This renders quasi-random tests for correlations useless.

In order to generate a manageable number of informed hypotheses from such databases and scientific literature, biotx.ai makes use of contextual information via natural language processing and deep learning. It maps genetic knowledge to the behavior of the corresponding proteins to identify which variate could have a bearing on the trait of interest and thus shall later be tested for correlation. Its proprietary algorithm is then able, for any given group of genes, to decide whether these patterns truly influence the disease in independent data or whether it is a false positive.

Similarly, Carta Biosciences develops machine learning algorithms to model and map the causal pathways in diseases. Based on gene activity data in tissues, its AI can identify sets of simultaneously active genes as likely drivers of disease states which in turn allows one to identify and develop drugs capable of reversing the activity of these genes.[22]

[22] Srivastava, PK. et al. (2018): A systems-level framework for drug discovery identifies Csf1R as an anti-epileptic drug target. **Nature Communications**

Beyond the adoption of AI for drug discovery, scientists and companies look to integrate a combination of AI and quantum computing to predict the structures of proteins based on the sequence of their primary building blocks. Proteins are large, complex molecules essential to nearly every function that our body performs. What a given protein can do depends on its unique 3D structure. Scientists and companies are working tirelessly to be able to predict these protein structures. To facilitate the design and development of therapeutic

and diagnostic proteins, Menten AI leverages machine learning and quantum computing. Finding the low-energy conformations of a protein is a core challenge in peptide and drug discovery. Menten AI addresses this challenge by transforming the search for the optimal configuration into a binary optimization problem yielding results superior to state-of-the-art classical methods.[23]

If the above solutions can live up to the expectations, machine learning and quantum computing will usher us in an era of quicker, cheaper and more effective drug discovery.

[23] Mulligan, VK. et al. (2019): Designing peptides on a quantum computer. **bioRxiv**

Increasing spatial precision to unlock the next level of biological understanding

Novel generation of sequencing solution retains spatial information

What began as fundamental research in the Chemistry Department of Cambridge University 20 years ago - allegedly fueled by a series of inspiring discussions in a local pub - has led to the revolutionary sequencing-by-synthesis technology which enabled many scientific breakthroughs, among them the newest generation of healthcare diagnostics.

The team behind Cartana's in-situ sequencing (ISS) technology hopes to drive a similar development by generating unprecedented insights into biology. ISS is a new type of nucleic acid analysis performed directly on the tissue section, preserving the spatial information. The technology uses gene-specific barcoded padlock probes that detect and amplify the targeted genes of interest within a tissue sample. The amplified genes are then sequenced and quantified. The result is a map featuring active genes and their abundance at a subcellular resolution on top of the natural morphology of the tissue section. The cost and time-efficient method will likely revolutionise how R&D, biomarker discovery, and validation is done today

Bioprinting tissue becomes a reality

Another approach to investigating human tissue is its reconstruction from individual cells. Following Richard Feynman's renowned statement: "What I cannot create, I do not understand", the 3D printing of living human tissue will enable us to recreate biological complexity to gain fundamental biological insights and advance regenerative therapies. 3D printing systems address the lack of implantable tissue solutions to help to overcome disorders such as type 1 diabetes. Aspect Biosystems is pioneering microfluidic 3D bioprinting, thereby enabling the rapid creation of 3D heterogeneous, structurally accurate, and functional tissues. The microfluidic printheads are capable of handling multiple biomaterials, living cells, extracellular matrix content, growth factors, and bioactive compounds during the printing process. Microfluidic printing is ideal for working with sensitive cells as it reduces shear forces resulting in high cell viabilities. In contrast, Cellbricks' 3D bioprinting technology is based on stereo lithography-bioprinting offering an unparalleled resolution of up 25 um at high speed making it an interesting solution for the large-scale fabrication of tissues.

Improving X-ray imaging technologies

Moving from tissues to proteins, the functional unit of cells. In order to understand how proteins work, how they malfunction in diseases and how they can be targeted with drugs, labs around the world have started using a technique known as cryo-electron microscopy. By bombarding flash-frozen proteins with electrons to produce a microscope image, their 3D shape and structure can accurately be reconstructed.

However, the workhorse in academia and industry revealing the structure of proteins remains X-ray crystallography, a technique that involves crystallizing proteins, exposing them to X-ray beams, and eventually reconstructing their shape from the resulting patterns of diffracted light. While it is not easy to get every protein to crystallize, X-ray crystallography still produces higher quality structures than any other method.

To further increase the resolution of X-ray technology, XRnanotech is working on novel X-ray nano-optics. Their nano-optics have twice the photon efficiency and unprecedented radiation stability which allows for reducing measurement times and applications using high-intensity X-ray lasers, respectively.[24]

Beyond elucidating the structures of proteins, X-ray technology also has applications in medical imaging like detecting diseases or the health status of organs and skeleton. NGS Detectors has developed a novel detector which increases resolution at a reduced radiation dosage. Current mammography systems lack adequate resolution to identify breast cancers during their early stages, which results in late detection and invasive surgeries. NGS Detectors' design prevents the generated photons from traveling radially in all directions, which is the limiting factor in current state-of-the-art X-ray detectors, and instead confines the photons into high-aspect-ratio channels which in turn increases the resolution of the image 10-fold.[25]

Increasing the reproducibility of laboratory science

Equally important, but very different from the solutions presented above, Panorama laboratories addresses the lack of precision in manual liquid handling in life science labs. Errors in liquid handling dramatically influence the results of life science experiments which result in a lack of reproducibility. By clipping a small add-on to any brand of micropipette, liquid handling is objectively scored and documented. Currently, deviations from expected protocol outcomes are assumed to be either a measured effect or random errors. The hardware systems offered by Panorama laboratories enable researchers to gain additional insight into what the real measured effect is by quantifying the actual amount of liquid dispensed, thus ensuring higher reproducibility.

[24] Rösner, B. et al. (2018): Exploiting atomic layer deposition for fabricating sub 10-nm X-ray lenses. **Microelectronic Engineering**

[25] Morse, TF. et al. (2018): Demonstration of a high resolution X-ray detector for medical imaging. **Conference paper - Radiation Detectors in Medicine, Industry, and National Security XIX**

The backbone of our industries will be autonomous

The backbone of our industries will be autonomous

The process of automation has successfully transformed our industries, allowing for large scale production at very low costs. For example, the introduction of advanced robotics and the ability to compute digitally have tremendously increased productivity in sectors like manufacturing.

However, not all sectors have equally profited from automation. For some industries, the automation provided by programming models is too rigid and not adapted enough to the realities on-site such as in construction or energy.

Driven by the need for more flexibility in automation, a new generation of machines will lead our industries in a new era of hyper-automation. By combining advanced sensors, machine learning models, and robotics, machines will be transformed like never before. The “caged robots” are in the past. New developments in technology will give machines advanced skills such as environmental awareness, the ability to adapt to events, and seamless interaction with humans.

While these machines will be given a basic level of selected cognitive abilities to collaboratively work with humans, we are still lacking a good theory of general intelligence. Thus, industries and society are able to capitalise on the use of machines through the complementarity of human and artificial intelligence – not by replacing one by the other.

Regulators and societal acceptance permitting, autonomous machines will increasingly be deployed in less-defined, more public spaces. We will see autonomous, stand-alone devices work in concert with humans or in the long-term future form a swarm of intelligent machines that work collaboratively together, independent of any human controller.

Furthermore, increasingly powerful computers optimised to solve certain problems or conduct specific tasks will serve as the foundation of our economies. More tailored computer architectures will allow us to compute problems more efficiently. Advancements in semiconductors tailored to machine learning will result in more potent algorithms. These potent algorithms will be run on noisy, intermediate-scale quantum computers to help us design new materials. The results of those first quantum computer applications will yield a better understanding of the implications quantum computing will have on our industries.

The shift to hyper automation and the related productivity gains will have manifold implications for our society in general and the labor market in particular. While up to half of the tasks workers currently do could technically be automated, it remains difficult to predict if this will result in an unparalleled increase in unemployment. It is certain that the optimization and maintenance of machines will absorb some of the workforces while others will find occupations in making the automated processes more widely available. Past industrial revolutions showed that

jobs lost due to efficiency gains in one sector were compensated by jobs created in new industries.

Using the characteristics of waves and atomic particles to create new sensors

We have undisputedly entered into a data-driven world in which sensors of all kinds allow the collection of information for improved decision-making. Enabled by our increasing understanding of the smallest units that make up our universe, we can harness the characteristics of subatomic particles, sound- and electromagnetic waves to remotely monitor industrial processes or the environment.

Remote sensors register stimuli that can be of mechanical, thermal, electrical, magnetic, radiant or chemical nature. The registered stimuli are transformed into a digital output, then transmitted, and eventually read by a computer. Furthermore, so-called “active sensors” are not limited by measuring physical quantities existing on-site but instead emit light or sound to grasp and analyse the surrounding. Along with the introduction of “smart” sensing”, this “active sensor” technology has increased the number of applications such as the predictive maintenance of machines.

It is important to mention that the use and scope of the term “smart” can be called into question. However, the integration of machine learning models into sensors enables both the transformation of multiple inputs into a coherent analysis and the initiation of a subsequent action. For this reason, smart sensors are becoming a key element of partially autonomous manufacturing floors and of environmental surveillance. Furthermore, sensors also allow robots greater autonomy by giving them the ability to adapt to their environment as described in the section “Industries will undergo hyper-automation”.

Smart sensors enabling non-destructive testing and quality control of materials

Today's sensing and testing methods are becoming less and less suited to cope with the increasingly fast-paced fabrication process. In certain sectors, the quality control of materials has become the rate-limiting step in manufacturing. The current fracture analysis methods are slow, often not penetrating the surface, and remain exclusively qualitative. Similarly, current mechanical characterization goes through expensive and destructive tests that require a large amount of material. The newest generation of sensors illustrated below (Figure 5) addresses these drawbacks, allowing for quick, non-destructive testing and thus overcoming a crucial pain point in today's quality testing.

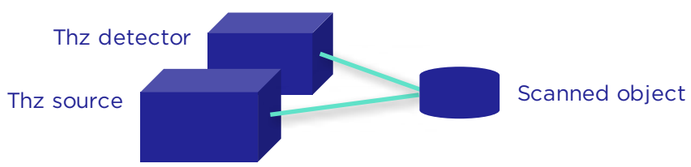


Figure 5a: Teratonics' solution to detect defects inside and on the surface of the objects under test is based on the reflection pattern of ultrafast terahertz pulses. The traditional approach slows down the acquisition speed, and also makes the measurement of materials sensitive to mechanical vibrations which has impaired the adoption of this technology. Teratonics ultrafast solution works at such a short time scale that the mechanical environment is completely frozen. This allows getting high-quality images even on moving objects, thus enabling rapid quality checks.

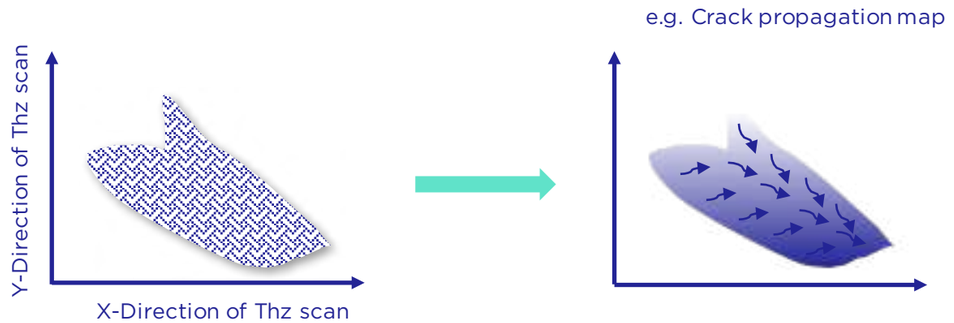


Figure 5b: With the goal to determine root causes of structural failures, Tortoise is developing quantitative fractography. By acquiring a topological fracture surface map and analyzing the fracture geometries, Tortoise can determine crack propagation speed and direction among other mechanical parameters. The obtained insights can, in turn, be used to iterate and redesign the functional part that caused the failure.

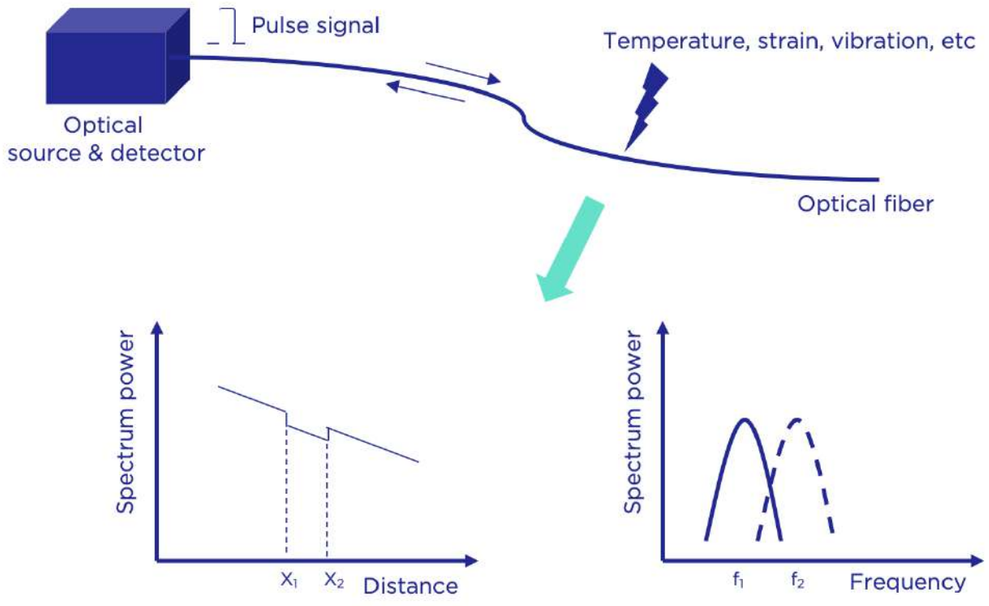


Figure 5c: In contrast to the above-mentioned solutions, Sentea uses optical sensing fibers with multiple sensing points to collect data about temperature, strain, and vibration of large constructions such as bridges. By emitting light and analyzing the changing characteristics of the reflected light, parameters like temperature, strain, vibration, and pressure can be obtained. Thus, Sentea's solution allows for monitoring of bridges, buildings, wind turbines, ships, trains and airplanes for structural integrity to prevent catastrophic failures.

Together, these sensor solutions will contribute to a more sustainable use of resources. Early recognition and analysis of damage will allow repairing machines and tools rather than replacing them completely, thus saving materials and costs.

Smart sensors enabling environmental monitoring
Beyond quality control, sensors have also proven valuable to monitor and analyse the environment in less complex and less intrusive ways underground. For instance, X-rays are widely used as a method to see through objects. Since X-rays interact predominantly with electrons, elements with a small number of electrons such as Hydrogen are nearly invisible to X-ray applications. In contrast, a neutron beam interacts with the nucleus of an element. Therefore the neutron beam is quite sensitive to atoms like Hydrogen which is exploited by NeutroTech who uses a neutron beam to screen for water sources underground. RANS, the accelerator-driven compact neutron source developed at RIKEN, can probe for water and other mineral resources up to several meters deep.[26]

Conversely, Plasmion focuses on the detection of organic compounds in the air. Its sensor uses a mass spectrometry method, characterizing volatile substances based on their specific mass. To measure the exact mass, and thus be able to detect particles

[26] Ikeda, Y. et al. (2017): Nondestructive measurement method to detect water/void inside slabs using compact neutron source by backscattered neutrons. **Journal of Advanced Concrete Technology**

abundant as low as one in one trillion, the volatile substances need to be ionised. Due to a new flow-through geometry direct screening of air for organic compounds is possible. Coupled to an AI-based software interpreting the data, Plasmion has essentially recreated an electronic nose that can be used to detect infectious agents in both the breath of patients or dangerous gas leaks on industrial sites.

Computers will increasingly become task-optimised, allowing for a better design

Today, our computers are largely based upon a single, universal design despite being employed to solve a variety of very different problems. The singular design of computers is about to change to reflect our needs better. Computers will differ in their fundamental architecture, tailored to a certain group of applications.

The most prominent example of a new computer architecture dominating the headlines from politics to science communities is quantum computing. Quantum computers exploit the characteristics inherent to quantum physics to compute complex problems more efficiently, thus differing significantly from today's computers. However, it doesn't mean that there aren't other, non-quantum physical properties that one may leverage to build more task-optimised, specialised computers.

Why do we need to develop radically new computing solutions? Beyond the quest for more powerful computing, the widespread adoption of machine learning as well as IoT solutions, each having individual computing requirements, drives the creation of diverging computing platforms. Furthermore, the need to reduce computing-related energy consumption, particularly in data centers, incentivises the development of energy-efficient solutions.

New computing processors based on the current design no longer yield exponential improvement in system-level performances. This is because of the fundamental limits of shrinking Silicon transistors, the primary building block of all computing chips. Aligned Carbon is addressing the need for improved performance of standard computers by integrating carbon nanotubes into processing chips. Such monolithic 3D nano-electronics will yield an unparalleled semiconductor performance. A similar performance leap is expected by introducing Magnetic Random Access Memory (MRAM), an ultrafast, high-density storage medium. The main limitation for wider use of MRAM is the presence of structural differences in magnetic materials, which reduces the storage capacity. Spin-Ion technology's process repairs the structural defects in MRAM by use of light ion beam irradiation which ensures its error-free function.

The above-mentioned solutions will in the long-term future be implemented in more computing platforms due to their universal benefits. In contrast, the solutions below address shortcomings of very particular applications, thus are unlikely to be universally incorporated in the future.

One of the current system-level roadblocks for data-intensive applications is the slow communication between memory and processing chips. To leap beyond the memory bandwidth limits and particularly enable applications such as machine learning and new realities (AR/VR), both MemComputing and UpMEM propose an entirely new circuit design. By integrating computing processors in memory, the previously limiting factor, the speed at which data could be moved between processor and memory, is eliminated. Leveraging computational memory shortens the required computational time to solve a problem while also decreasing the amount of storage necessary and energy used, thus offering a new design tailored to AI applications.

In an era of explosive data growth, it is crucial from an economical and environmental perspective for data centers to decrease their power consumption. Light allows us to compute at higher speeds and minimise power usage, thereby providing higher performance per unit power. Since optoelectronic processors need significantly more physical space, they are not in widespread use. However, the spatial requirements of light processing chips is not an issue for data centers which can accomodate more bulky computing chips. Conversely, it is very important for data centers to cut their energy-related costs. For this reason, optoelectronic processors might become the dominant hardware platform for data storage applications.

LightSpeedAI Labs' optoelectronic processors offer computation at light speed. Although more energy-efficient, a limiting factor for optoelectronic chips is their capacity to host enough high-bandwidth lasers per chip to achieve high performance at low power. Iris Light Technologies is developing a solution to print hundreds of lasers directly onto chips using a nanomaterial "ink", thus dramatically increasing data bandwidth capacity per chip.

Another computing paradigm with particular function and requirements is Edge Computing which brings information collection and processing closer to the data source, thus reducing latency and enabling greater autonomy at the edge. With the introduction of more sophisticated edge services such as collaborative robots or autonomous drones, the reduction of latency and greater autonomy will be of increased importance. This new generation of edge devices will host more sensors and larger AI models to enable a variety of new applications. Accordingly, the need for more computing and data storage resources rises while the physical space and energy supply to accommodate those resources is limited by the size of the edge device.

Particularly for time-sensitive applications, large data sets or operations that need to preserve data privacy and integrity, there is a growing need to make decisions without sending data to a cloud. Synthara is addressing that challenge by developing a special processing chip that allows AI-based applications to run at very low energy consumption. This low-energy consumption chip accommodates for the limited performance characteristics of batteries powering current IoT devices.

Deep Dive: The quest for practical quantum computing

The advent of quantum computing is imminent. The potential of this technology is often referred to as being unlimited, despite most current applications still looking like beta-tests of quantum computers themselves. Nevertheless, quantum computing is expected to make AI algorithms more powerful and allow for simulations of material behaviour and reactivity at a molecular level, thus yielding better batteries, industrial catalysts, and medicines.

Quantum computers take advantage of two known physical phenomena, superposition and entanglement, to efficiently compute difficult problems.

In contrast to bits in today's computers which can be either 1 or 0, the so-called qubits in quantum computers can represent various possible combinations of 1 and 0 at the same time. This admittedly pretty counterintuitive feature called superposition allows quantum computers to calculate a vast number of potential solutions much quicker.

The second phenomenon of quantum entanglement describes the fact that the state of one qubit influences the state of another one in a predictable way, even if they are separated by very long distances. Consequently, adding qubits increases the computing power of quantum machines exponentially whereas doubling bits in today's computers results only in twice the processing power.

These combined physical phenomena are the basis of the massive computing power of quantum computers. However, to control these phenomena, most quantum computers have to be cooled down to cryogenic temperatures and any vibration must be avoided to not disturb the state of superposition and entanglement, thus quantum computers won't replace desktop computers any time soon.

On a more molecular level, quantum computing faces two main challenges: increasing the time qubits remain coherent and correcting the errors. Hence, to make quantum computing more practical and robust, the newest generation of solutions needs to overcome these issues. Instead of achieving longer coherence time among qubits, IQM's superconducting quantum processors allow significant increases of the clocks speed of the system, thus ensuring more computational operations are performed per unit of time. As quantum information is inherently fragile, meaning it is lost over time, increasing the speed of operation likely allows for successful viable applications without quantum information loss. IQM achieves faster clock speed by initializing qubits on a nanosecond timescale compared to several microseconds required for alternative protocols. The IQM readout allows for a more accurate and faster qubit state determination compared to the conventionally used dispersive readout scheme.

Other quantum startups like Alice&Bob address the quantum error correction problem.[27] As quantum information is particularly fragile, it is necessary to encode the information of one logical qubit in the entanglement of several physical qubits. To achieve this, current methods need up to ten thousand physical qubits for one logical qubit. Alice&Bob's solution

[27] Lescanne, R. et al. (2019): Exponential suppression of bit-flips in a qubit encoded in an oscillator. **arXiv**

reduces the error correction overhead between physical and logical qubits from 10.000x to 30x. Their solution requires only 30 physical qubits to guarantee accurate information of one logical qubit. Thus, their solution would bring full-fledged quantum computers into the realm of reality, as it would allow using significantly fewer qubits for pharmaceutical applications than the current estimate by Intel of several million to billions of qubits.

However, a relevant, first-generation quantum computer will still need to have 100 000 qubits or more working in concert in order to be viable. We are not there yet.

C12 is developing a scalable solution for the production of quantum chips.[28] By incorporating carbon nanotubes into standard silicon chips their qubits come fairly close to the ideal «atom in a vacuum» quantum system, meaning even a small change of state can be attributed to an intended effect instead of representing background noise. This characteristic is otherwise only found in high-isotopically pure silicon which is laborious to obtain. C12's manufacturing process allows the preservation of the purity of carbon nanotubes, thus enabling in principle the production of chips with millions of qubits for computing intense applications, including full-fledged error correction.

Pasqal's quantum chip manufacturing based on atomic arrays[29] allows for the assembly of a few hundred qubits which is of interest when combined as a coprocessor with a classical supercomputer. First applications of stand-alone quantum computers will likely simulate the behaviour of larger molecules or assist in mapping mineral depots (Table 9).

[28] Cubaynes, T. et al. (2019): Highly coherent spin states in carbon nanotubes coupled to cavity photons. **npj quantum information**

[29] Chen, S. (2018): Atomic arrays power quantum computers. **Science**

Table 9: Potential Quantum Computing applications. Startups include Stratum AI and Menten AI.

	Application	Enabling	Primary Market
Stratum AI	Analyzing mineral deposits	Modeling element distribution along x, y, z coordinates	Mining Industry
Menten AI	Designing proteins	Profiling the conformational energy landscape of proteins	Pharmaceutical Industry

To conclude, quantum computing demonstrations will become more compelling and meaningful over the next few years. Those first results will contribute to a more nuanced debate about what exactly the superior computing power will enable society to achieve and whether it will usher us into an era of quantum computer-driven discovery.

Industries will undergo hyper-automation

Implementing automated processes has led to a significant rise in productivity across most industries over the last decades. The newest generation of automated solutions goes beyond the automation provided by rigid programming models. Instead, the combination of machine learning and advanced sensors enables complex behavioural patterns.

Equipping robots with basic cognitive skills
Providing robots with some cognitive skills is crucial in order to enable their adoption in spaces occupied by humans. Particularly, autonomous collaborative robots

need to comprehend the environment within which they operate in order to integrate seamlessly and not endanger worker's health. The recent breakthroughs in machine learning, sensors, and robotics collectively will bring forth machines with a basic level of cognitive abilities. Hence, the age of hyper-automation will see machines interacting more naturally with their surroundings and with people which will lead to significantly improved robotic operations as discussed below.

We have recreated most senses intrinsic to humans in robots – eyes, ears as well as sensors registering temperature, touch, and smell.

For instance, Visevi's collaborative robots exclusively rely on the sense of sight to obtain tactile data and joint angles from camera images for precise motion control. Current sensitive robotic manipulators and arms are very complex and costly systems, due to sophisticated mechanics and numerous sensors. By replacing most sensors with a camera and computer vision software, Visevi's robotics are lighter and simpler which should drive wider adoption.

Intsite's robotics solution follows a similar approach. By combining computer vision and machine learning, Intsite's retrofittable solution transforms any heavy machinery, such as cranes, into smart robots. This solution is of particular interest to numerous industries where the pace of work is limited by a single piece of delicate heavy machinery.

However, engineers are not limited to just the recreation of human senses but can also equip robots with any unique perception mode. For instance, Elwave is working towards equipping robots with an electrical sense. Certain fish are reported to have an electrical sense which they use to navigate turbid and cluttered waters in which sonar and vision are limited. The generated electric field is disturbed by objects in close proximity, thereby allowing

the fish to obtain a 360° real-time «electric image» of their environment. This could allow autonomous and collaborative robots to operate in complex environments in which current sensors are inefficient, thus permitting large-scale deployment of efficient and safe robotics thereby liberating humans from hard labor.

Into the future: from autonomous robots to a network of intelligent machines

In the long-term, based on advancements in real-time communication, robotic self-awareness, and near human dexterity, we will experience a transition from individual autonomous machines to a swarm of collaborative intelligent robots. By forming a network, multiple devices will be able to work in concert either with human input or independently. One of the first examples is Hydromea's untethered, autonomous under-water drone. Its drone can dive to 6000m depth to conduct inspections of complex flooded spaces such as sunken vessels. Their proprietary through-water wireless technology allows for control and wireless, high-bandwidth data transfer between an operator and an underwater vehicle or between several drones, thus enabling them to work as a swarm independently of a human controller.

Endnotes

If you would like to learn more about both the opportunities and risks that these technologies give rise to, and what this means for your business, we commercially offer to develop tailored, strategic technology roadmaps. These roadmaps allow you to understand when the next generation of technologies will enter your area of business, and to assess their implications. Please reach out to **nicolas.goeldel@hello-tomorrow.org** for more information.

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Building a collaborative ecosystem that leverages the power of deep technologies to tackle world challenges has been Hello Tomorrow's mission since 2011. Over the course of six editions, our Global Startup Challenge has received 20,000 applications from 132 countries, partnering with universities and research labs to identify deep tech solutions worldwide. We propel the pioneers driving these solutions and connect them with industry leaders and investors through conferences and networking events in over 10 countries. We also empower public and private organizations through innovation consulting services and learning programs, helping them to harness the potential of emerging technologies.

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