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Under the radar: 20 climate tech innovations you may have missed

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Foreword

James Gifford
Head of Sustainable &
Impact Investing Advisory
Credit Suisse

Michael van der Meer
Head of Sustainable
Investment Analysts
Credit Suisse

There is ongoing debate about whether the technology available today can mitigate the worst effects of climate change. Some experts believe no new technologies are needed and the only thing lacking is the political will to allow available innovations to gain market traction and mature. They cite the rapid growth of cheap renewable energy and the success of energy efficiency technologies as evidence.

Others, however, argue that current low-carbon technologies are expensive and unreliable, and that cheaper and better solutions are needed to tackle climate change. They argue the pace of innovation needs to increase with entirely new technology approaches.

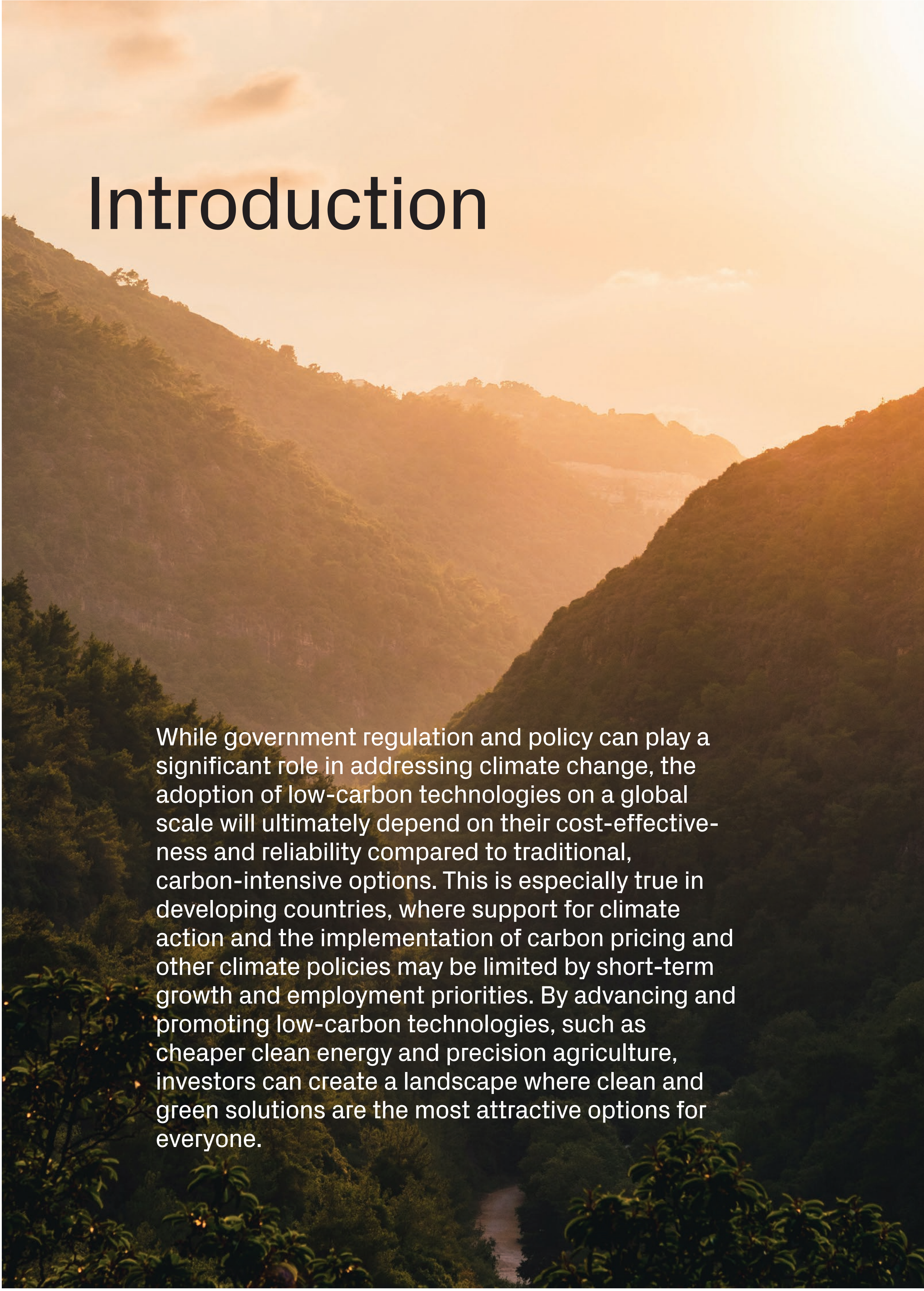
Regardless of where you may stand in this debate, the good news is that thousands of companies are developing and deploying technologies that can move the world toward a more sustainable economy in the coming decades.

While innovations in electricity production and storage are crucial to achieving the climate goals, other sectors and technologies with significant emissions should not be overlooked. For example, innovations in plant-based and cultivated meat, fertilizer replacement, sustainable crop protection and precision agriculture can help reduce emissions from the agriculture sector while increasing productivity.

There is also an increasing focus on climate adaptation solutions that can help cities and regions adapt to changing weather patterns and natural disasters, such as early warning systems and resilient infrastructure.

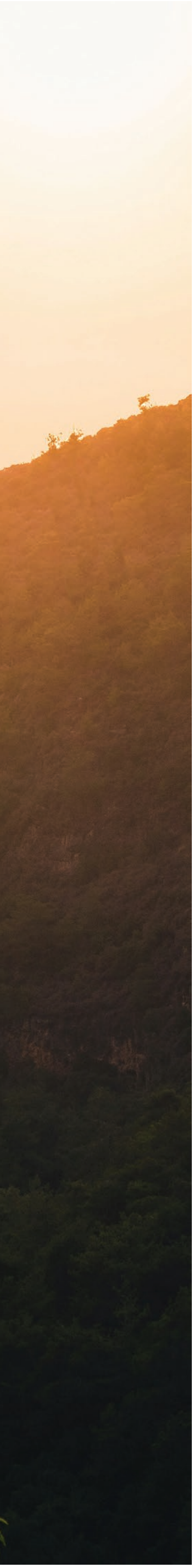
A deeper understanding of the climate challenge is also critical, and a plethora of technologies support research into its causes and effects. They include satellite imagery and advanced modeling tools that enable researchers to collect and analyze huge volumes of data on the climate system.

In summary, climate change needs to be tackled from all angles. There is no silver bullet to solve the climate crisis. We believe all technologies should be explored. In this spirit, our whitepaper outlines 20 lesser-known innovations that, taken together, we believe could make a significant contribution to combating climate change in the coming decades.



Introduction

While government regulation and policy can play a significant role in addressing climate change, the adoption of low-carbon technologies on a global scale will ultimately depend on their cost-effectiveness and reliability compared to traditional, carbon-intensive options. This is especially true in developing countries, where support for climate action and the implementation of carbon pricing and other climate policies may be limited by short-term growth and employment priorities. By advancing and promoting low-carbon technologies, such as cheaper clean energy and precision agriculture, investors can create a landscape where clean and green solutions are the most attractive options for everyone.



The transition to a low-carbon economy will require a range of technologies from electric mobility to renewable energy generation and storage. Many of the technologies to address these challenges are still in development, although significant progress has been made and many will reach maturity in the near future. By investing in these technologies, investors can accelerate the transition to a low-carbon economy. At the same time, many of these technologies will also deliver cost savings, increased productivity and economic security.

According to the International Energy Agency (IEA), rapid technological innovation will play a crucial role in achieving net-zero emissions by 2050. In its "Faster Innovation Case" scenario, the IEA projects that 45% of all emission reductions in 2050 will come from technologies that are not yet commercially available. This highlights the need for continued investment in and support for the development and deployment of new energy technologies.

Venture capital (VC) investment in climate technologies has surged in recent years, driven by investors with a long-term perspective. According to Climate Tech VC (CTVC), a data-sourcing firm, the volume of assets under management (AUM) dedicated to private climate investments increased by USD 94 billion in 2022[1] – an impressive achievement given last year's challenging market conditions.

Private wealth can be a crucial source of funding for these early-stage companies, as VC funds that specialize in sectors may be more attractive to patient private investors who do not have the same constraints as large institutional investors. Private investors who have developed expertise in these technologies are also well positioned to gain access to investment opportunities that may not be sufficiently de-risked for institutional investors.

The rapid pace of technological innovation can make it difficult to keep up with the latest developments. In this whitepaper, we examine 20 different "under the radar" technologies across key sectors where decarbonization is necessary. Within each sector, these "branches of decarbonization" point to new and existing technologies that can help us transition to a low-carbon economy (see page 7 for a graphical representation). These technologies range from advanced software and energy storage to fertilizer replacement and cultivated meat. Not all these technologies are at the same level of development – some are already commercially available while others are still in the lab.

We focused on lesser-known solutions to highlight new perspectives on the technological challenges in the fight against climate change. However, looking at their broader combined impact, we believe these technologies have the potential to not only help address the climate challenge, but deliver a broad range of additional benefits across the economy, society, and the environment.

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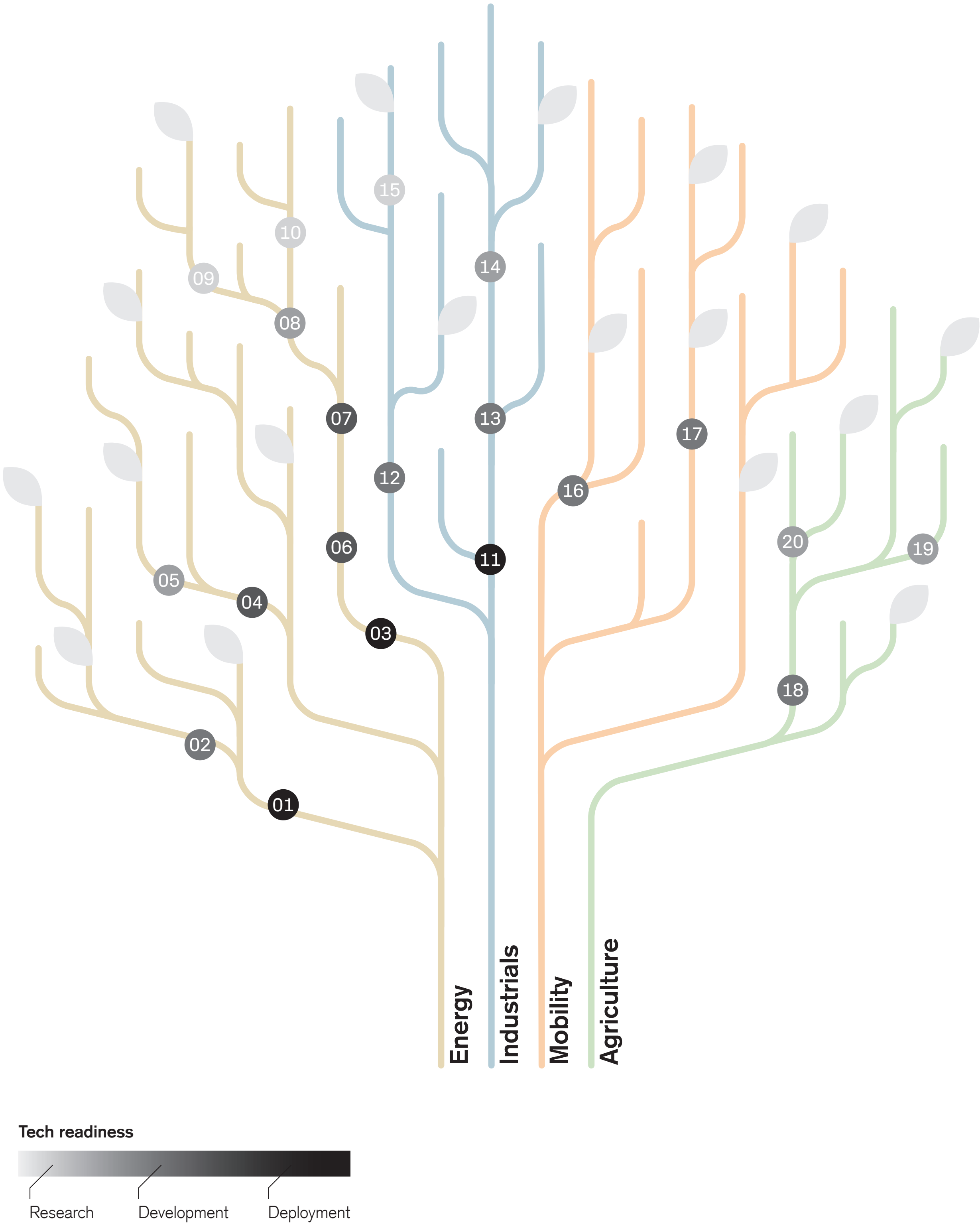


Note: In this visual representation, the maturity of various technologies is depicted through their placing along the length of the branches. The further along the branch, the less mature the technology. The hanging fruits on the tree represent technologies that we have identified as being crucial for efforts to achieve net-zero emissions. While this visualization only depicts a small portion of the larger picture, it is important to note that each technology will play a crucial role in reducing carbon in the atmosphere.

01

Energy

Interferometric satellites— If you can't see it, you can't manage it

The availability of enhanced satellite imaging of Earth is key to our ability to manage natural phenomena and anthropogenic activities. The analysis of frequent and high-resolution pictures with advanced techniques such as interferometric imaging is now being used for identifying deforestation and monitoring greenhouse gas emissions. The deployment of this technology is enabled by smaller satellites as well as cheaper access to space due to innovations such as reusable rockets.

Both governmental space agencies and commercial operators are increasingly specializing in the development of low Earth orbit (LEO) satellites, resulting in an expansion of earth observation applications. The proximity to the planet surface and the multiple orbits completed per day (1.5 to 3-hour orbits) are the two features that make such satellites an optimal solution for capturing high-resolution images. Spurred on by the adoption of small-scale CubeSats, which can be cheaply deployed using reusable rockets, the number of satellites has grown rapidly, along with an increasing risk of collision.[2]

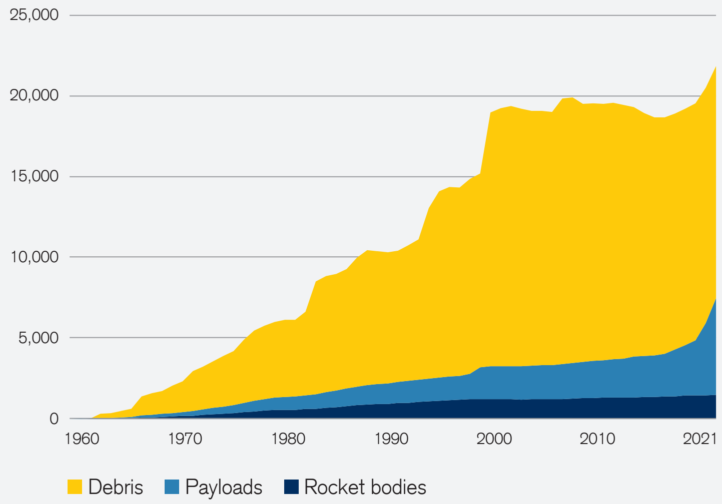
Recent satellite data suggests that greenhouse gas emissions (GHG) from oil and gas production are significantly underreported and may be as much as three times higher than reported.[3] One of the challenges is that methane emissions are difficult to detect without sophisticated equipment. Moreover, given the high global warming potential of methane compared with carbon dioxide (84 times more potent on a 20-year timescale),[4] independent GHG monitoring helps to enforce regulations but operators also have their own inherent incentives to reduce gas leaks. Some industry initiatives such as the Oil & Gas Climate Initiative (OGCI) have already started to tackle the issue by investing in methane monitoring from space using interferometric imaging. Interferometric satellites use interferometry to measure methane emissions. They send a beam of light towards the Earth's surface and measure the amount of light absorbed by methane in the atmosphere. This technique allows the satellites to create detailed maps of methane emissions on the planet's surface, including from specific sources.

A number of for-profit and non-for-profit organizations are bringing these satellite-based solutions to market.[5] Satellite sensors' capability to see across the wavelengths of the spectrum yields a vast amount of data. Artificial intelligence (AI) algorithms are now in development to identify, assess and measure a variety of emissions. For example, the Methane Alert and Response System from the UN's International Methane Emissions Observatory and the Global Emission Inventory from Climate TRACE are analyzing this data and detecting methane emissions with satellite-based systems in real time.

Other applications of Earth observation technologies include AI-powered vegetation management systems to support the reliability and safety of electricity grids. Given the increase in frequency and severity of wildfires and the damage they can cause to transmission lines, satellites allow electrical utilities to assess tree-level data on vegetation height and proximity to power lines. Satellites can also be used to monitor the health and growth of forests, allowing for early detection of illegal logging and deforestation. The same satellite imagery can be used to create accurate maps of forested areas, which can aid in the enforcement of protected areas and conservation efforts.

Increase in orbital objects larger than 10 cm in diameter

Payloads into orbit have grown exponentially in recent years – Cumulative objects



Source: 18th Space Defense Squadron, United States Space Force, Credit Suisse

02

Energy

Virtual power plant—The distributed energy platform adapted to renewables

Virtual power plant (VPP) is a digital platform that brings together numerous distributed generation and storage sources to provide reliable electricity with profit sharing incentives for the participants. VPPs can leverage electricity from distributed energy resources such as rooftop solar generation and in privately-owned storage to distribute power during peak grid price periods.

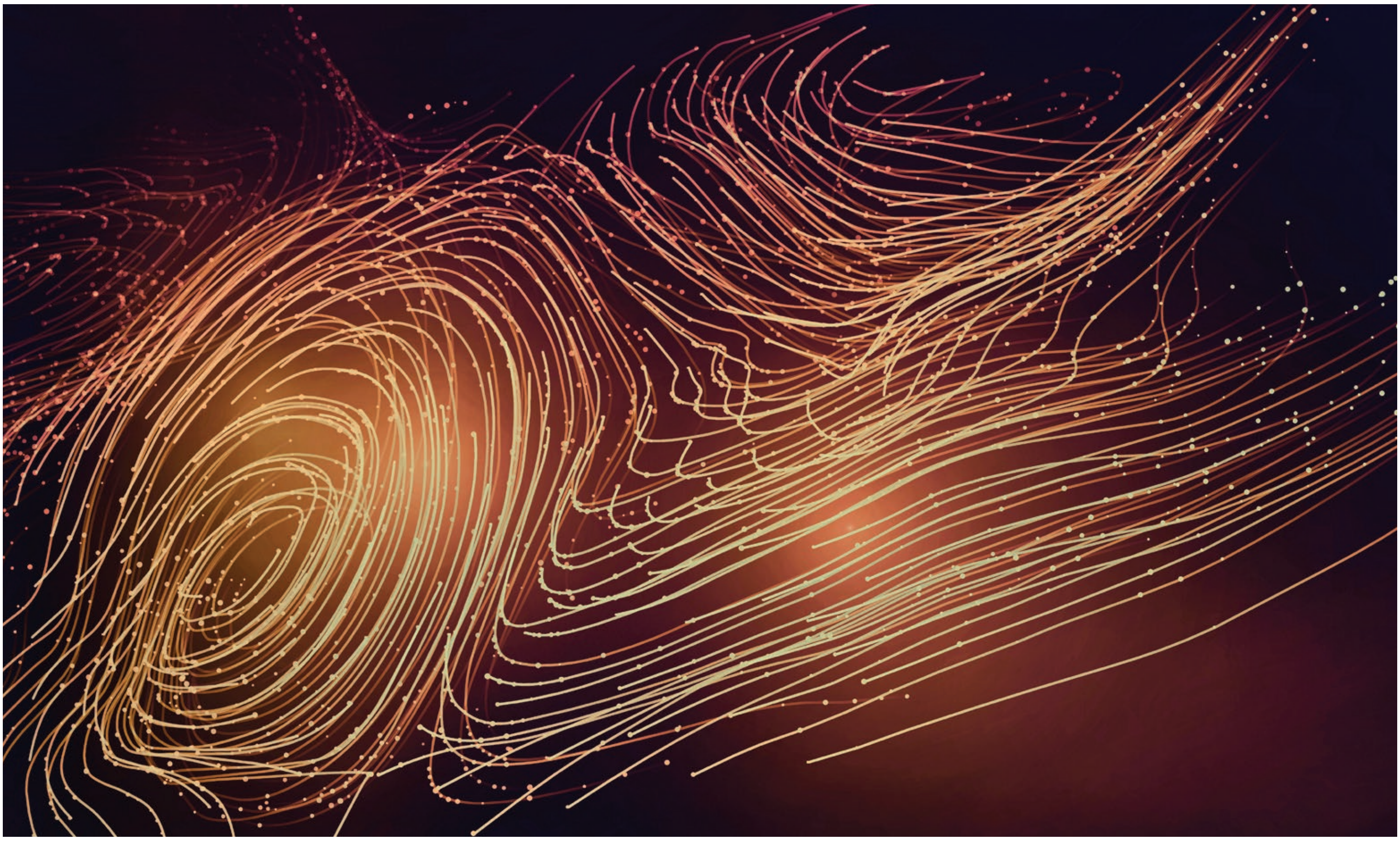
Utility-scale power plants generate large quantities of energy at centralized locations and distribute it via the electric grid. As energy systems evolve, renewables such as solar and wind, alongside batteries, are playing an increasingly important role in energy generation. However, the output of renewables fluctuates and there needs to be a way to manage this variability that optimizes incentives for storing and releasing electricity at optimal times.

Alongside centralized energy utilities, the widespread adoption of renewables and batteries has catalyzed what is called distributed energy resources (DERs). These comprise mainly small-scale, decentralized energy generation and storage capacity for commercial or residential use, including leveraging the capacity of electric vehicle batteries. However, while this small-scale capacity has mitigated consumption of grid-supplied power, it has not meaningfully added to the capacity of centralized systems. This is because the grid operators have no visibility around DER production and have limited options for distributing it. As DER assets increase, however, it will become increasingly important to integrate them into the energy grid in a more effective manner.

A VPP effectively functions as a connected generation plant with its own capacity comprised of DERs that are centrally managed by a virtual operator. The assets within the DERs can individually generate, store, or consume electricity. The VPP provides a platform for DERs to offer their aggregated generation or storage capacity to power markets. They can also curtail their demands by reducing the electricity used by connected appliances. The key to VPPs is sophisticated software interfaces that can monitor and control customer-based assets such as home solar panels or battery systems. Some VPPs go further and incorporate predictive tools for anticipating power generation and usage. The VPP brings a real-time control system that can aggregate the flexible capacity of thousands or millions of home or business-based renewable power systems and help the system better manage demand.

Individually, the DERs (e.g., a house owner with a solar and battery system or electric car) do not have sufficient capacity, flexibility and control to make it cost-effective or technically feasible to interact with the grid in a sophisticated way. At present, they can sell their power to the grid in some markets at a fixed, low price that does not allow them to profit when energy prices are high. By pooling many thousands of diverse small-scale participants through a software platform, VPPs can help DERs more actively participate in the energy markets and add capacity and flexibility to the system. Importantly, VPPs to the grid can help to reduce the infrastructure costs needed to mitigate the variability of renewable energy sources while maximizing the returns for participants' investment into electricity production and storage. In California, a VPP was activated for the first time in 2022, connecting the storage system of approximately 50,000 households. When the electricity grid is stressed, customers who choose to participate are paid USD 2/kWh for electricity exported to the grid.

VPPs are not without their drawbacks. There remains a lack of government regulation in most jurisdictions to support small DERs in coordinating their participation in the energy market. They also add complexity to the system, requiring the development of new infrastructure, accurate monitoring and system controls. Nevertheless, VPP is a promising technology that allows the optimization of a segment of the market that is currently underutilized.



03

Energy

Energy harvesting—Creating smart dust

Nikola Tesla demonstrated wireless power transfer more than a century ago in his famous Tesla coil experiment. The promise of wireless power is to make electricity available where conventional wires are inconvenient to deploy, but the technology never progressed due to its size and safety limitations. However, recent developments based on the same principles, known as Radio Frequency (RF) energy harvesting, have renewed the promise of wireless power.

Ambient RF energy is available all around us – from our natural environment as well as surplus energy from mobile phones, wireless networks and radio towers. An ambient RF system uses this wasted energy in a process that can be described as energy scavenging. This energy can be used in low-power applications where energy sources such as single-use batteries or solar are not viable. One potential application is in the development of “smart dust” – tiny sensors that can be dispersed in large numbers to monitor a wide range of conditions, such as temperature, humidity, pressure, or air quality. Another possible application is in the field of medical implants, such as pacemakers or insulin pumps. Low-powered devices to interact directly with human tissue can be used to monitor physiological parameters. RF energy harvesting would allow all these devices to operate indefinitely without the need for regular battery replacement.

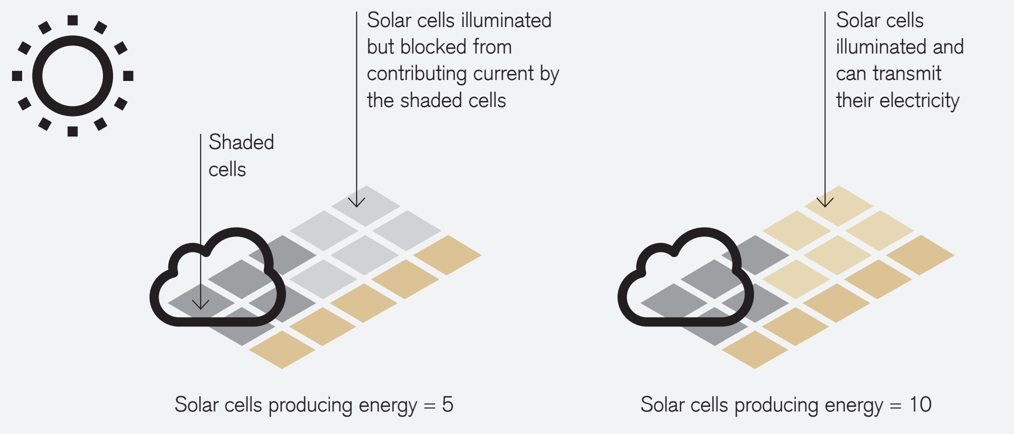
The alternative to ambient energy harvesting is dedicated RF energy harvesting, which transfers electricity between a dedicated power transmitter and its receiver(s). A novel way that this dedicated energy harvesting is being applied is in photovoltaic (PV) panels. A solar PV array is optimized by wiring several solar cells in a series and connecting them in parallel. The disadvantage is that the interconnected solar PV cells become vulnerable to power loss if there is shade in one cell. Like old-fashioned Christmas lights, when one panel is shaded the entire series will not produce power. Large obstacles such as buildings or clouds can block sunlight from reaching solar cells and even small objects such as leaves, snow, or dust can also create problems.

This cascading effect can be overcome by integrating a wireless power transfer system directly into PV panels. Instead of cutting off all PV cells in a chain, the system can “skip” over shaded cells and transmit their power to subsequent cells. This wireless power transfer is made possible by newly commercialized complementary-metal-oxide semiconductor (CMOS) devices. CMOS chips can both transmit and receive energy transferred in either direction without physical hardware or wires. These chips can even send relevant data to the central load management to make system signal adjustments in real time across the network of sensors.

Trials suggest that panels deployed in this way harvest on average 40% more power and reduce the costs of energy by 30%, while freeing up installations from conventional limitations such as wiring and additional electronics like inverters, optimizers and diodes. If efficiency and scaling challenges can be overcome, future use cases may include wireless charging for EVs and cell-based battery management.

Overcoming the shading cascade in solar cells

Individual wireless transmission frees cells from classic constraints



Source: Credit Suisse

04

Energy

Wind yield enhancement—Boosting the effectiveness of wind turbines

Superconducting magnets hold the promise of making wind turbine generators more compact. The reduction in weight allows for lightweight supporting structures and decreases construction costs. When combined with software that places these turbines at an optimal location, efficient and powerful turbines can take greater advantage of available wind resources.

Wind energy continues to expand at a breakneck pace across the world. As one of the main clean energy sources, it is a key ingredient in decarbonizing the electrical grid. Wind accounted for around half of the 522 TWh increase in renewable energy generation in 2021.[6] The trend in offshore and (to a lesser extent) onshore wind turbines has been to make them larger and more powerful. To maintain the growth in wind deployment, the industry needs to develop generators that are lighter and cheap – and a new generation of magnets hold the key.

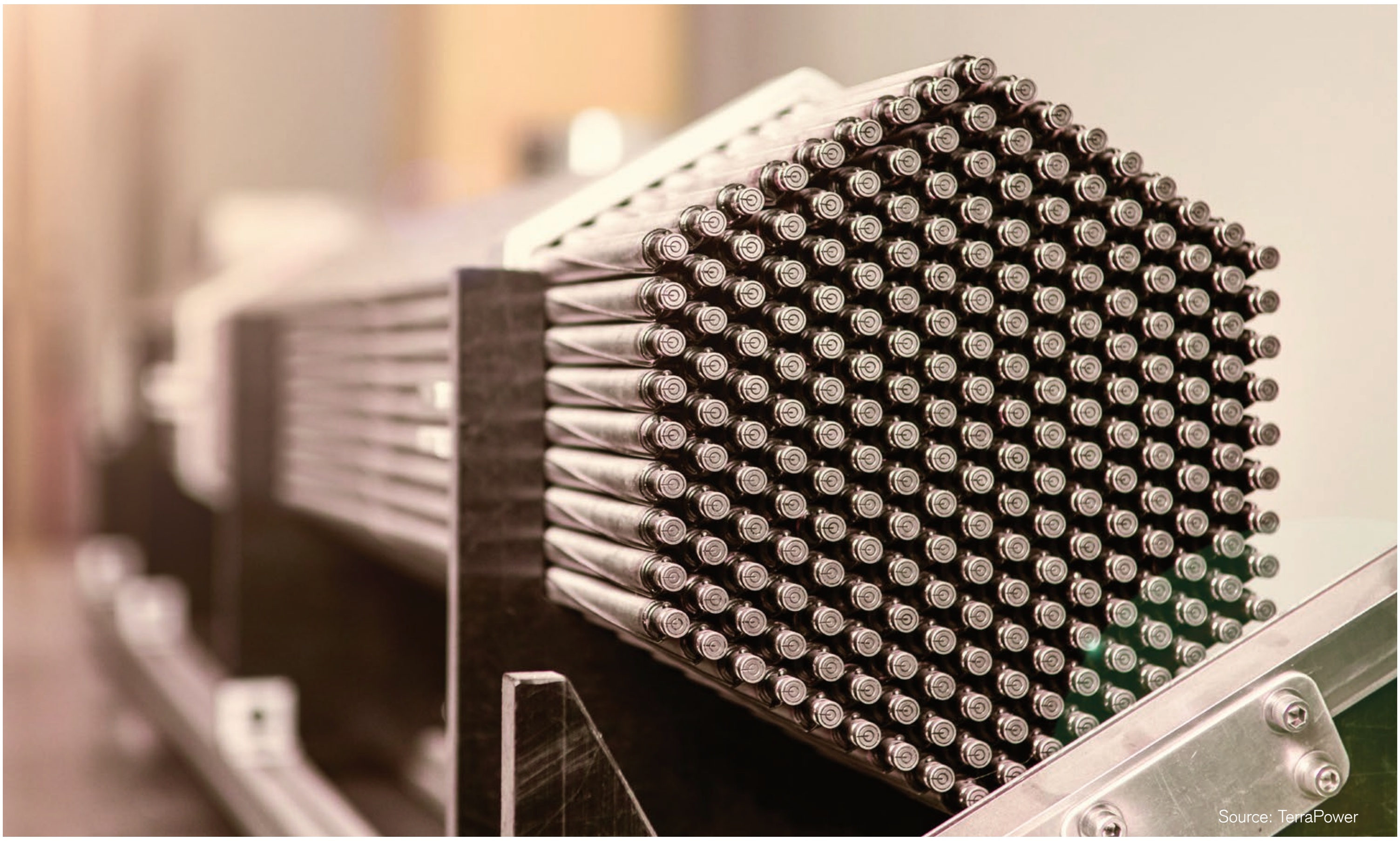
A conventional generator in a wind turbine converts the rotation of the blades into electricity. It consists of coils moving inside a magnetic field which together create an electric current. While the most common approach is to use copper coils, these cannibalize electric power to generate the magnetism, thereby reducing the efficiency of the turbine.

In recent years, permanent magnet-based generators have become increasingly popular as they do not require an external power source to initiate the magnetic field. Permanent magnet generators are lighter, which in turn allows for a lighter support structure that is advantageous in offshore applications. However, they need large quantities of rare earth minerals.

One alternative technology being developed is superconducting magnets. Discovered in 1911, superconductivity is a remarkable phenomenon whereby certain materials below a critical temperature carry an electric current without any resistance. These resistance-free, flowing currents can produce a powerful magnetic field using significantly less energy than could be produced using normal copper coils.

An advantage of superconductor-based turbines is that they can decrease the size and weight of the generator further. This would allow them to be made more powerful, improving their economic value. In addition, this technology can substantially reduce the average rare earth material content from 6 tons in a permanent magnet generator to 10 kg in a superconducting version. The engineering challenge is to effectively integrate the superconducting material and keep it at very low temperatures. Some working prototypes have been built, but the technology is not yet widely available.

Concurrently, software can further increase wind turbine performance by optimizing its yield. New developments in data analysis, showing distances to energy demand centers that can then be overlayed with meteorological and geographical data, increases the effectiveness of wind turbines through careful planning of the location. This will positively impact both the power generation capabilities (maximize wind power) and construction (minimize costs by having a site with optimal access).



05

Energy

Modular sodium reactors—Nuclear goes back to the future

The nuclear energy industry is seeking to counter the high cost of large-scale nuclear power by developing small modular reactors (SMRs). The hope is that a smaller form factor can drive down costs by reaping economies of scale through the standardization of production process. Additional innovations, such as sodium fast reactors can also utilize spent fuel rods from traditional nuclear generation, thereby turning nuclear waste into additional energy.

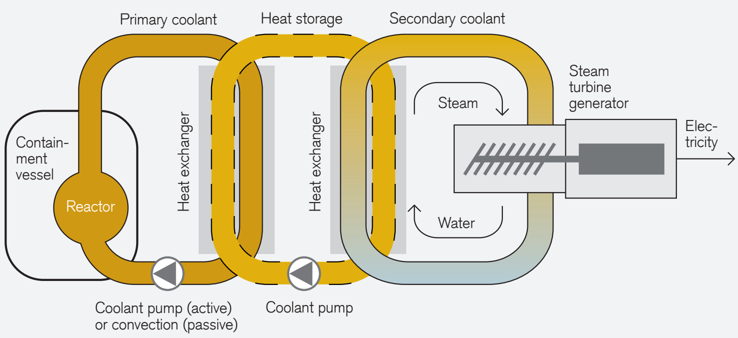
According to the IEA, nuclear power generated about 10% of the world's electricity in 2020 through 439 (mostly large-scale) power plants.[7]

Given the need to dramatically reduce fossil fuel use, the IEA expects that nuclear power will hold its global market share over the coming decades despite the proliferation of renewables. The energy crisis in 2022 sparked renewed interest in nuclear power, which proponents believe will lead to a renaissance for the industry.

During the industry's early days, nuclear power plants were relatively small. As the industry developed, operators started building significantly larger nuclear plants to gain economies of scale. Since the 1950s, typical reactors grew from 60 megawatts electrical (MWe) to more than 1,600 MWe in order to make the most of land, equipment and expertise.[8] Over time, regulation, political opposition and permit challenges increased, alongside a reduced appetite in many countries for large-scale infrastructure projects that often ended in delays and cost overruns. Security also became a concern after incidents such as the Fukishima accident in Japan in 2011, which highlighted the need to increase the safety of nuclear plants.

Extracting energy from a nuclear reactor

Coolant alternatives for transferring reactor heat



	Primary coolant	Heat storage	Secondary coolant
Pressurized water reactor	Pressurized water	–	Water/steam
Sodium fast reactor	Liquid sodium	Molten salt	Water/steam

Source: Credit Suisse

The nuclear industry is now seeking to drive down costs through economies of scale in production and modular deployment. While the small form factor of the new SMR reactors harks back to the 1950s, some reactors now rely on convective cooling of the reactor core rather than the traditional design of actively pumping water past the reactor to cool it down and generate steam. Convective cooling involves using air or water to transfer heat away from an object by creating a circulation of fluid around the reactor. Proponents argue that the increased safety of these "passive" systems allows for a more widespread deployment of such reactors, including closer to populated areas.

Another old nuclear technology – sodium fast reactors – has been reimagined. These reactors use liquid sodium instead of water to extract heat from the nuclear reaction, and can use spent fuel rods from conventional light-water nuclear reactors. Moreover, the reactor can be operated in a way that stores thermal energy to provide electricity on-demand, which may be leveraged for district heating. The spent fuel from sodium reactors has fewer long-lived isotopes at the end of its use, making it easier to dispose of.

Several challenges still need to be overcome before modular sodium reactors can be widely deployed. In the past, reactors using sodium have been vulnerable to sodium fires, while the reactor design has an enhanced risk of nuclear proliferation, requiring higher levels of physical security and political stability. If these challenges can be overcome, a reinvigorated nuclear power sector may bring back the atomic future that was once promised.

06

Energy

Perovskite solar cells—Pushing solar panel efficiencies to new limits

Perovskites is a family of materials that has shown potential for high performance and low production costs in solar cells. Perovskites may be used on their own but may also be able to significantly boost the efficiency of conventional silicon-based solar cells with minimal added costs.

Silicon-based solar photovoltaics (PV), from which conventional solar panels are made, have been optimized and improved over decades. As a result, solar power is a rapidly expanding industry that is achieving economies of scale. However, existing silicon technology cannot continue to increase its efficiency indefinitely, and it is already close to the hard, theoretical limit of around 30% solar energy to electricity conversion. Moreover, the production of silicon cells is energy intensive as they must be treated at high temperatures to achieve high purity, as energy conversion efficiency plumets with any defects.

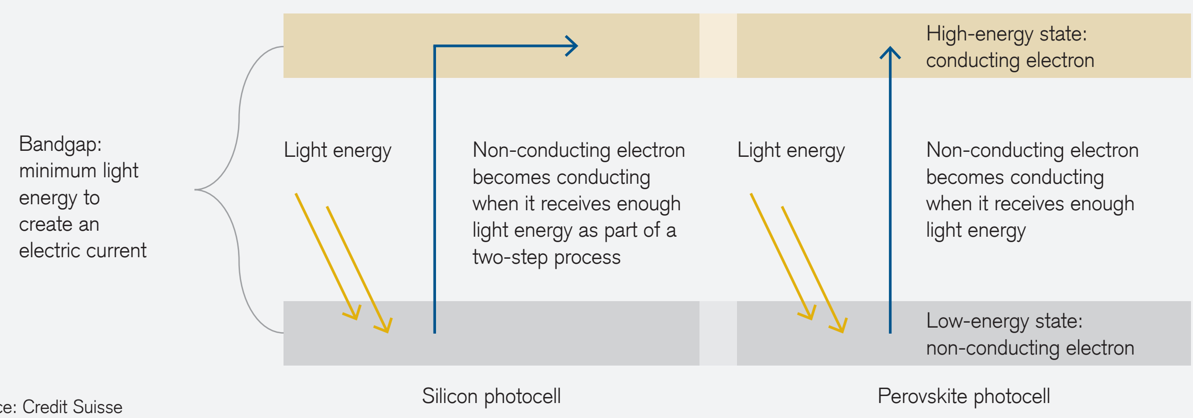
In the decade since their emergence, perovskite solar cells have advanced rapidly and increased the efficiency of silicon-only solar cells by around 20%. Perovskites share a common crystal structure. They can often be synthesized from a wide variety of cheap and readily available elements using low-temperature fabrication with a relatively small carbon footprint.

The ability to modify the perovskite using different elements allows scientists to tune its "bandgap," which is the minimal amount of energy required to liberate an electron and create an electric current. Visible light has slightly more energy than the silicon gap and so it can produce an electric current. Silicon has the right size of bandgap to efficiently capture light from the sun. However, the process is indirect, which makes it less probable and requires a layer of active material a few hundred microns thick. With perovskites, a current can be created directly in one step. This allows for the perovskite solar cells to be made much thinner (a few microns), which makes it flexible. The perovskites can be used alone or combined with other materials into layers. The layers can be combined with other perovskites of differing bandgaps or with traditional silicon solar cells as a thin coating on the top of the solar panel in order to increase the spectrum of light that can be converted. The multi-layered perovskite solar cells could in time more than double the efficiency of the current silicon PVs, and may be also more cost effective on a per kWh basis.

Perovskites still face some challenges, such as their use of lead, degradation when exposed to light and humidity and their industrial scaling up. Work is underway to mitigate the use of lead without compromising the cell's efficiency and stability. In terms of longevity, recent accelerated ageing tests show perovskite cell stability of 30 years or more. A number of companies are planning to bring perovskites to market within the next few years.

Silicon versus Perovskite

Perovskites generate an electric current more readily through a direct rather than two-step process



Source: Credit Suisse

07

Energy

High-temperature superconductors— Renewable energy is a dish best served cold

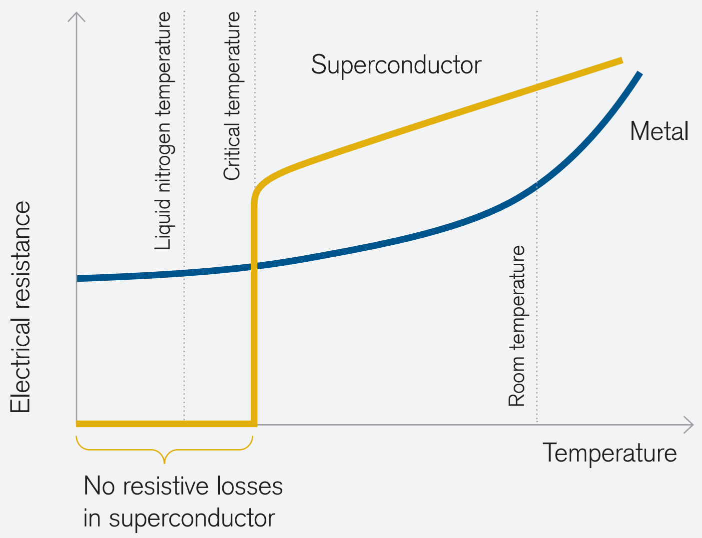
Global renewable energy capacity is set to dominate the world's energy mix by the end of the decade. In order to unleash its full potential, electricity generated from diverse renewable sources and locations needs to be transmitted in a more effective way over long distances. Power lines using high-temperature superconductors could be a solution: Carrying high current densities with no resistance, this would minimize losses and increase grid resilience.

Long-distance energy transmission is particularly important for renewables where resources may be geographically spread out (e.g., wind resources off the coast), or available at different times and seasons. Connecting renewables across different locations increases reliability, reduces the need for storage and enables a more constant and effective power provision. For example, linking solar projects along an east-to-west corridor extends the amount of daytime solar electricity available to the grid. Studies show inverse relationships between wind speed and solar irradiance in Northern European regions such as Britain.[9]

However, current technologies for transmitting electricity over long distances result in significant electricity loss due to inefficiencies, such as high resistivity and inadequate equipment.[10] In addition, developing new transmission systems to integrate renewable energy into the grid is often costly and time-consuming.

Superconductivity below critical temperature

Transmitting electricity without resistance



Source: Credit Suisse

Superconducting materials that transfer electricity over long distances may offset some of these challenges. Effective transmission of power is essentially related to the resistivity of the conductor, which in turn is affected by temperature. When cooled to a sufficiently low temperature, the resistivity of some materials drops to zero. High-temperature superconductors (HTS) are defined as materials that behave as superconductors of electricity at temperatures above 77 K (-196.2°C), the boiling point of liquid nitrogen. The temperatures for HTS are therefore still incredibly low, but their relative advantage could deliver substantial operating efficiency gains when successfully applied for transmitting electricity on a large scale.

Challenges remain to keep cables equipped with HTS cooled at a stable operating temperature as needed for effective power transmission applications. Solutions include applying subcooled liquid nitrogen along the cable system. However, this entails the need for mechanic subcooling equipment on the lines every few kilometers, which makes long-distance applications burdensome, expensive and energy intense.

Potential developments include the design of alternative cryogenic cooling systems to enhance the efficiency of the process. This could reduce the flow of nitrogen needed to maintain the cables at the desired temperature, and/or help minimize the large amount of energy needed to cool the cryogenic agent. Provided that temperature stability can be managed over large distances, superconducting power lines can result in a substantial increase in the flow of power. This technology could also be implemented in smaller-scale electricity transmission lines. Besides mitigating losses from lower resistivity, this greater efficiency also helps the grid become more resilient through the rerouting of power in a timelier manner.

08

Energy

Iron-air batteries—Long-duration storage that should rust in peace

Iron-air batteries are a promising alternative chemistry for storing energy at scale. This technology could make a renewables-dominated grid more viable by providing cheap, longer-duration and potentially even seasonal storage.

Solar and wind have become the cheapest form of electricity generation. Yet the variability of renewables is often cited as a limiting factor for their widescale adoption. The cost of large-scale storage determines whether excess electricity produced by renewables can be stored for later use. To store electrical energy, it needs to be converted to another form of energy. In the case of batteries, it is chemical energy. Different types of batteries can have different applications depending on the needed capacity, responsiveness and energy density (energy that can be stored per unit weight of the battery). Lithium-ion batteries offer high-performance energy storage, as they work well and are efficient with a fast frequency response. Although relatively expensive for larger-scale energy grid storage, they are increasingly used to shift hourly excess electricity generation to peak demand periods. Unfortunately, economical multi-day storage solutions remain elusive.

The iron-air battery was first conceived in the 1970s, but has recently resurfaced as demand for a low-cost solution to energy storage has become more pressing. Iron-air batteries store their energy through the reaction of iron with oxygen from the air. In the process, iron is oxidized as rust during which an electron is freed and creates a current. To store energy, the reverse process is to “unrust” the iron back to its original form in a process that draws electricity.

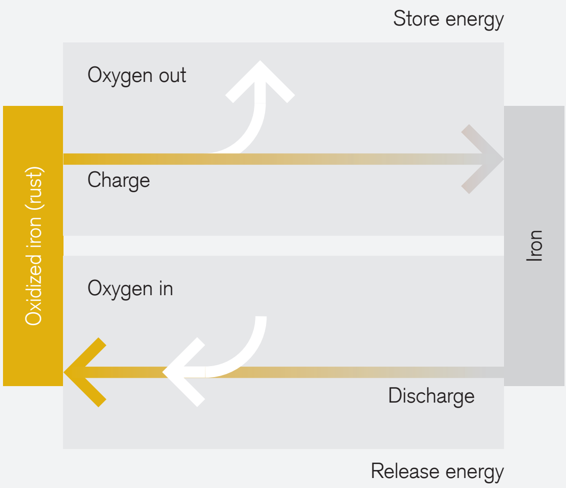
Using cheap and abundant non-toxic materials, the cost per energy stored could be a factor of ten lower than lithium-ion batteries. This would make iron-air batteries highly attractive in energy grid storage for renewables, allowing energy to be stored for days – and perhaps even seasons – rather than for a few hours, as is the case with existing batteries.

However, the oxidation process is slow in comparison to lithium-ion, meaning charging and discharging takes longer. The energy densities achieved are low and this is unlikely to change soon. The battery charge-discharge efficiencies are also lower at around 50% compared to lithium-ion rates of above 80%. This means half of the energy to be stored will be lost. The number of charge/discharge cycles that can be achieved before the battery degrades remains limited. Therefore, numerous technical hurdles still need to be overcome for the technology to be market-ready.

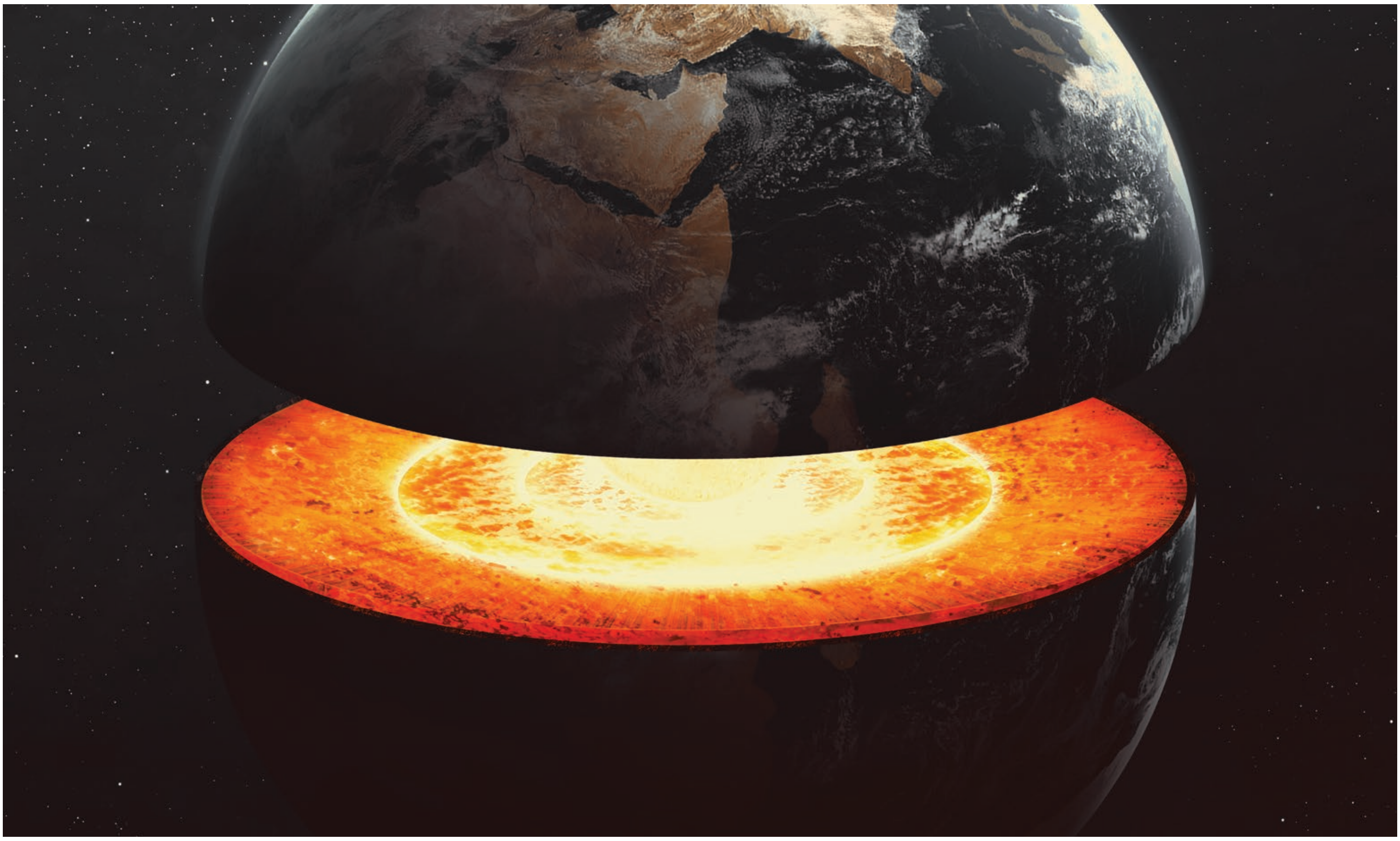
If these technical issues are achieved, iron-air batteries will play an important role in supporting the power output variability of renewable energy sources. That said, they are unlikely to completely replace lithium-ion batteries, which have other grid stabilization advantages, but are likely to be a complementary technology that enhances the availability of longer-duration energy storage.

Rusting and de-rusting stores energy

Using abundant, non-toxic elements can create an effective battery



Source: Credit Suisse



09

Energy

Heat-ray drilling—Finding the sun beneath our feet

The Earth's core, which is about as hot as the surface of the sun, is a major source of energy. Capturing even a fraction of the energy embodied below the Earth's crust could provide all of the world's energy needs. Heat ray drilling adopts a nuclear fusion technology to vaporize rock and reach depths not considered feasible until recently. If successful, heat-ray drilling may make reliable geothermal energy abundant almost anywhere.

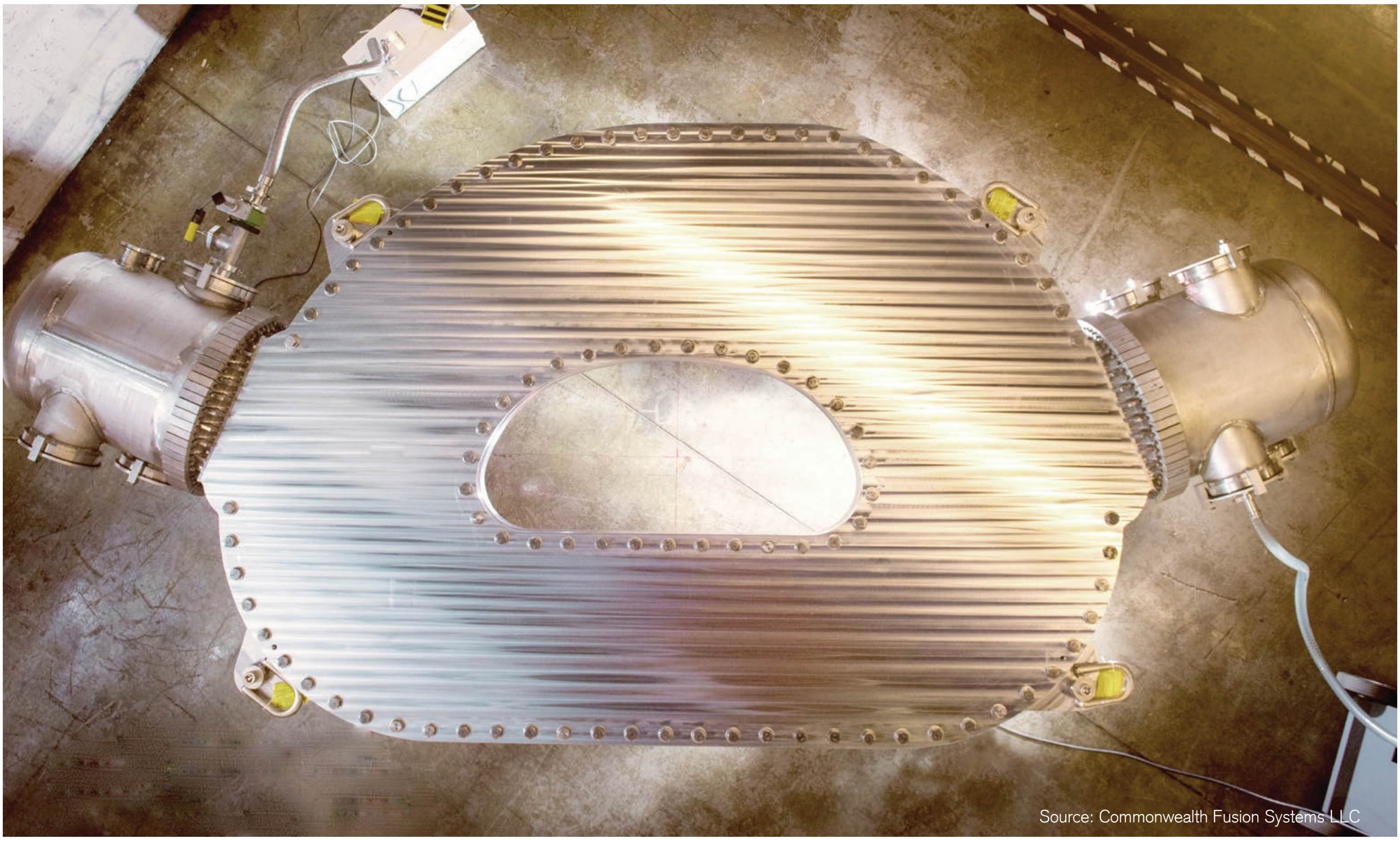
The natural geothermal heat that radiates from the Earth's inner core originated billions of years ago along with the formation of the solar system. Heat dissipates to the surface, with temperatures up to hundreds of degrees a few kilometers below homes and factories. Sometimes, it breaks through the Earth's crust; for thousands of years, humans have harnessed geothermal energy through hot springs, fumaroles and geysers. The last century also saw the development of geothermal electricity production and distributed heating and cooling applications. If successfully harnessed, this energy is practically limitless as the decay of naturally occurring radioactive materials in the Earth's core continuously replenishes the heat, a process that could last billions of years.

However, this enormous resource potential remains largely untapped mainly due to the cost of drilling. At present, geothermal energy represents less than 1% of the global power provision. Naturally occurring hydrothermal resources are relatively rare and location specific. About 90% of the current accessible geothermal energy is present in the form of hot dry rock as cold water needs to be injected into the rock to create energy. In addition, many locations require boreholes that are several kilometers deep in order to achieve sufficiently high temperatures for geothermal power generation (e.g., at least 150°C for flash or dry steam technologies). This is not technically or economically viable with current mechanical drilling technologies. Researchers believe record-breaking depths could be achieved by using a gyrotron beam. A gyrotron is a wave generator developed for fusion research that produces millimeter waves that are capable of melting or vaporizing rock.

For this technology to go beyond the lab, several hurdles need to be overcome. The deepest borehole ever drilled reached 12.2 km on the Kola peninsula in Russia. To take advantage of previously untapped geothermal resources, wells of anywhere from 5-20 km depth would be required, according to current estimates. More precise cost and viability projections are also needed, including the frequency and size of holes necessary to generate power at scale, and the corresponding energy used to power the gyrotron.

The application of gyrotrons for drilling could avoid costly replacements of mechanical equipment, creating an incentive to adopt the technology in traditional extractive industries. At 20 km depth, temperatures are expected to reach between 350°C and 500°C depending on the location. This allows water to reach a supercritical state, carrying it back up at high temperature and pressure. Drilling holes near existing power plants could help old fossil-fuel facilities extend their useful lifetimes, adapting them to use geothermal steam while retaining the generating turbines and power management infrastructure that was previously used for fossil fuel generation.

Finally, given the near 100% capacity factor of geothermal resources, they can provide reliable baseload power and grid balancing services, further paving the way toward 100% renewable power.



Source: Commonwealth Fusion Systems LLC

10

Energy

The tokamak stampede—Trapping million-degree plasma with magnets

A tokamak reactor is a doughnut-shaped device that produces power using magnetic fields to confine plasma in order to ignite and sustain a fusion reaction. The promise of fusion power is to provide virtually limitless clean energy without many of the disadvantages of conventional nuclear power, such as long-lived nuclear waste.

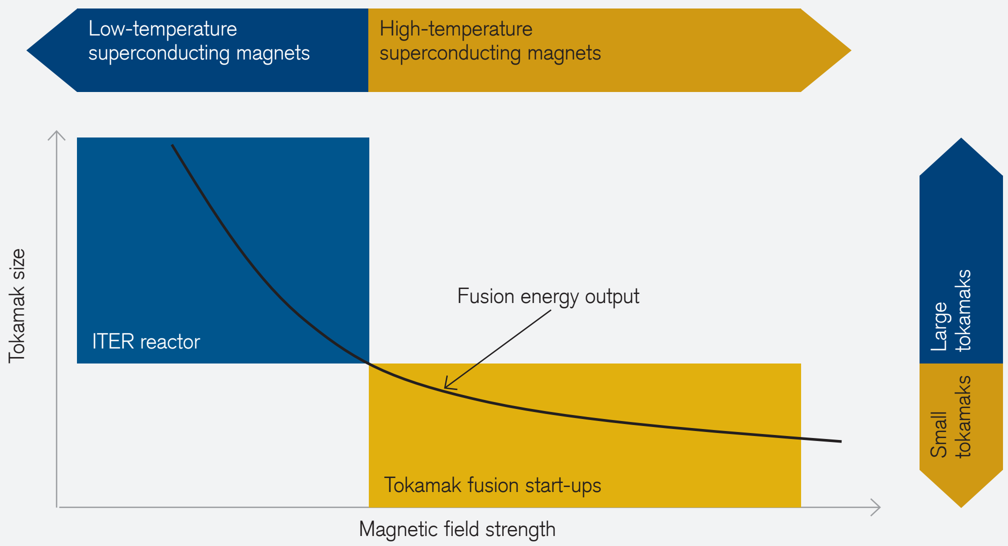
A few grams of hydrogen-type fuel could be sufficient to supply enough energy for one person in a developed country for 60 years.[11] This is the dream of clean, abundant fusion energy. However, achieving fusion is difficult as it requires overcoming the very strong repulsion of positively charged hydrogen-type atoms (plasma) for a sufficiently long period of time and in high enough densities with minimal interaction with the surrounding environment. While research into fusion began in the 1950s, no fusion reactor has managed to generate more energy than it consumes to date. Tokamak-based reactors have come the closest. A tokamak is designed to tightly confine and heat plasma fuel to a few hundred million degrees using very strong magnetic fields to sustain a continuous fusion reaction from which theoretically limitless clean electricity can be extracted. This remains the preferred approach for public and private fusion reactors being built today. The largest of these is the flagship ITER project, a collaboration between 35 countries to build a fusion reactor costing upwards of EUR 18 billion, which has been under construction in France since 2013. However, the lengthy and costly construction of such large-scale reactors could make them economically unattractive.

As a result, an increasing number of private fusion companies have entered the race to try to shorten the path to a net positive fusion energy output. We might call this a repeat of the "tokamak stampede" seen in the latter half of the 20th century. Central to this renewed momentum, has been magnet development – but this time around small-scale private companies willing to iterate fast are advancing this technology.

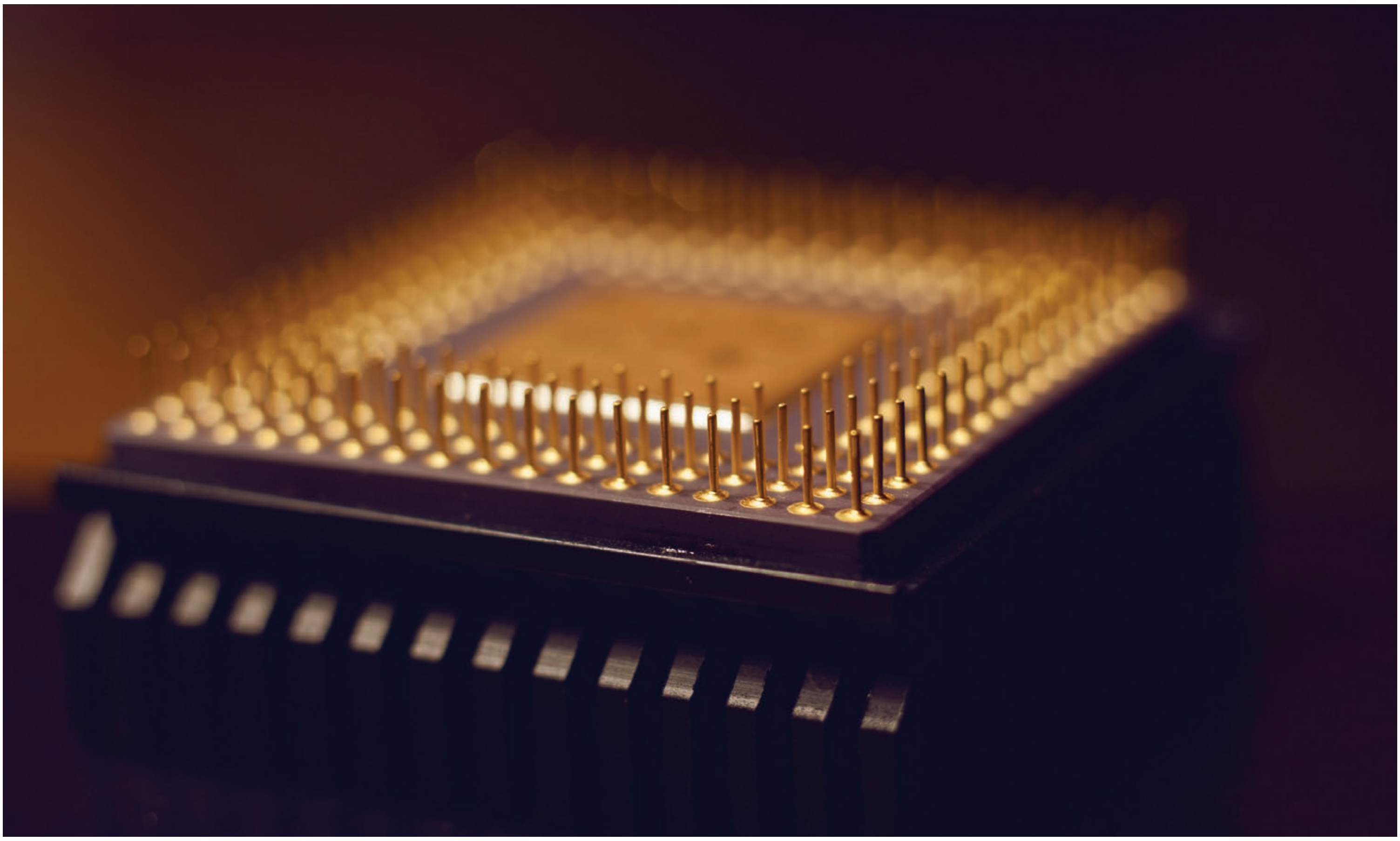
Stronger magnetic fields allow for better confinement of the plasma and smaller tokamak reactors. In addition to the economic benefits, this approach allows for more rapid prototyping of the technology. To create strong magnetic fields, commercial high-temperature superconducting (HTS) magnets have emerged. HTS magnets have remarkable properties that allow them to conduct much higher currents and generate much higher magnetic fields than more traditional low-temperature superconductors (LTS). The latter are made from a metallic-like material that is easy to make into wires, whereas HTS magnets consist of a ceramic-like material that is challenging to make into the required windings. Overcoming this technological hurdle will bring the strongest possible magnetic fields to the tokamak.

Traditional vs new fusion reactors

Startups are making smaller reactors with HTS magnets



Source: Credit Suisse



11

Industrials

Meta scaling systems—Underpinning a sustainable metaverse

A new type of processor, the data processing unit (DPU), is improving power consumption and reducing costs – both critical benefits given the pressure to make energy-intensive data centers more efficient. As cloud services have disproportionally driven up the load on host central processing units (CPUs), offloading these “housekeeping” functions onto specialized DPU processors helps ensure data centers are optimized for data-intensive services.

Data center infrastructure accounts for between 2% to 3% of global electricity use, and is expected to continue to grow due to increased digitalization ranging from streaming services to increasingly sophisticated metaverse applications.[12] While data-intensive processes such as artificial intelligence (AI) and machine learning (ML) use vast amounts of energy, they are also critical enablers of the clean energy transition.[13] More efficient chips and the increasing use of low-carbon energy by data centers have so far helped to mitigate the environmental impact. However, growth in data-intensive workloads such as big data, AI/ML, and virtual collaboration, entertainment and education will require new approaches to energy efficiency.

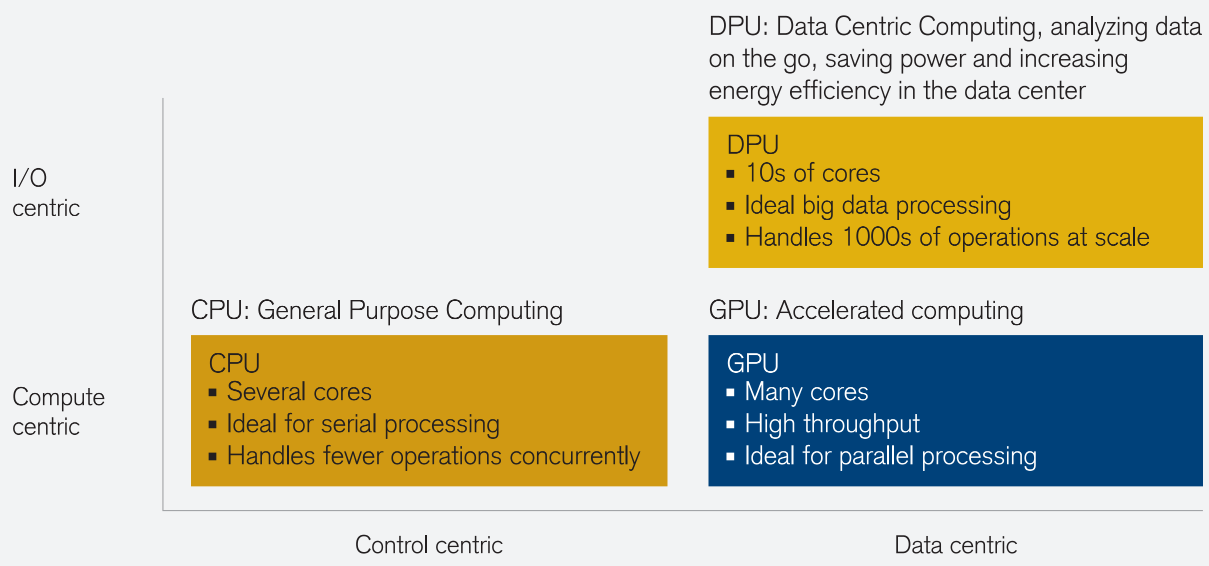
As the internet evolves into a more spatially immersive 3D experience, networking and storage risk becoming bottlenecks, and current architectures will need to become more efficient to accommodate increased data-intensive workloads. This can be achieved by offloading these services from CPUs, where they are consuming a growing percentage of processing capacity, to a new class of dedicated processors.

In the same way as graphics processing units (GPU) have been added for graphics computation and AI application processing, the new DPUs will take a range of functions away from the CPU and execute them more efficiently.

DPUs are programmable processors designed with dedicated hardware capabilities for accelerating networking, data encryption/decryption and offloading tasks that previously would have run as software on generalized CPUs, and by running the tasks in hardware there is potential for significant power savings. An independent review of commercialized DPUs demonstrates that power savings of up to 34% can be achieved.[14]

The DPU also reduces the load on the CPU so that more processing cycles are available to run applications. With key data and control functions isolated in a separate domain on the DPU, the server infrastructure is more secure in case the CPU or its software is compromised. Hyperscale cloud providers and telco/data communications applications will be the key markets.

Meta-scale performance with optimized processors
Data processing unit (DPU) specialization unlocks new data center efficiencies



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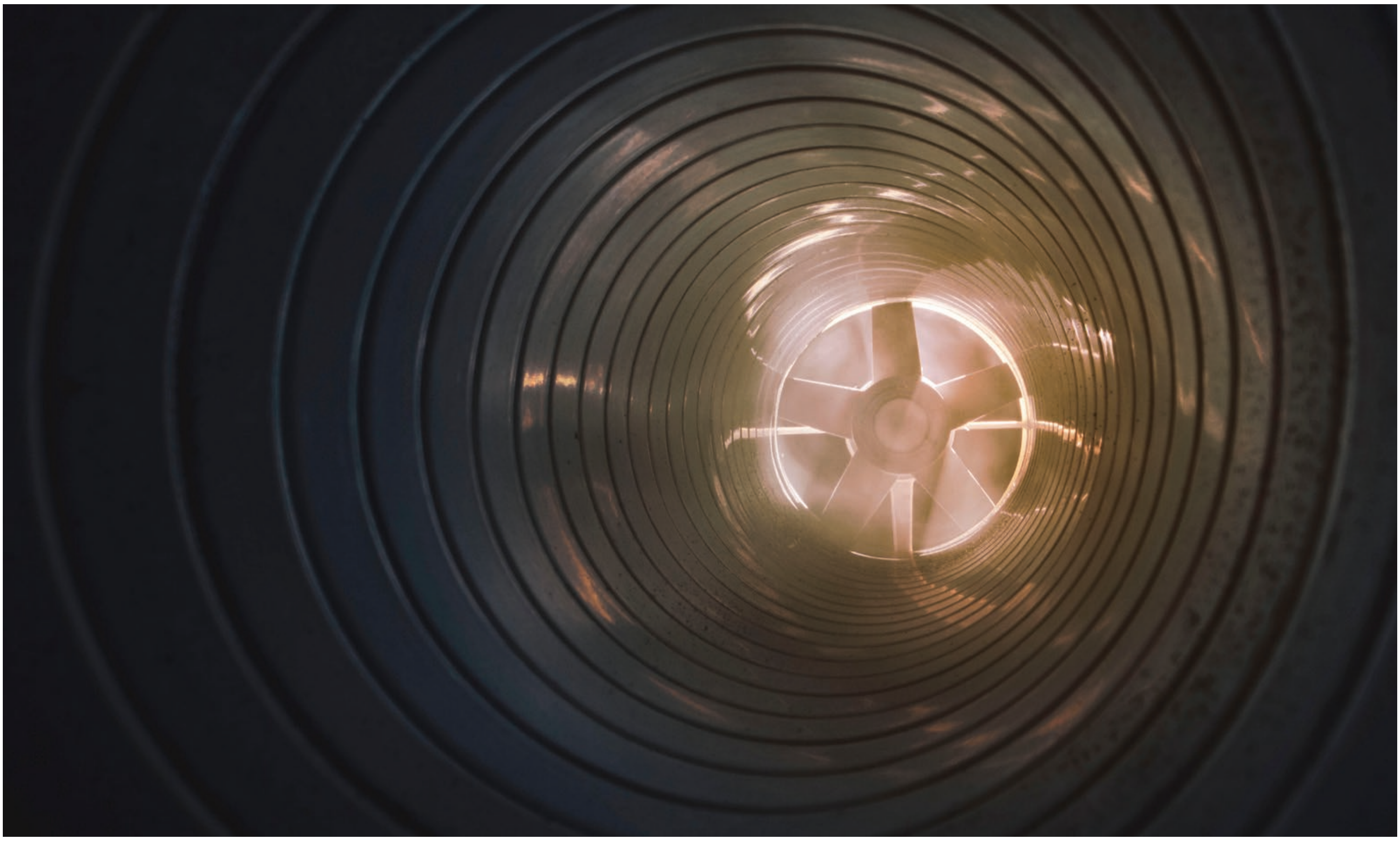


12

Industrials

Desiccant space cooling— Solving indoor climate change

Desiccant cooling has the potential to significantly reduce the energy consumption of buildings. It achieves this through highly efficient cooling and dehumidification through the absorption of moisture in the air. Unlike heat pumps, no harmful refrigerants are used and desiccant cooling uses less energy than better-known heat-pump systems that are already considered highly efficient.

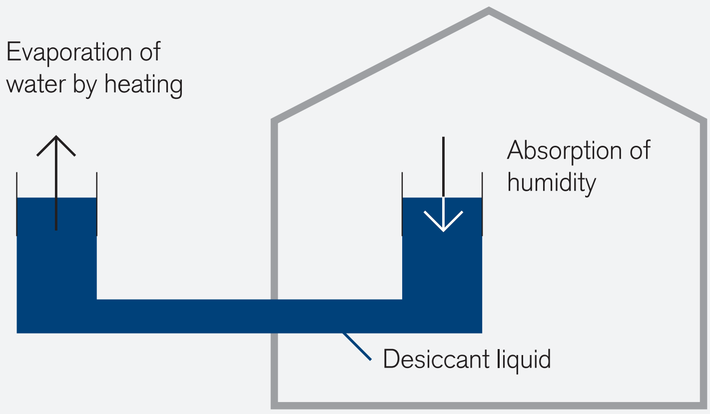
According to the IEA, space cooling today accounts for around 20% of the total electricity use in buildings.[15] Air conditioners globally use more than 2,200 TWh of electricity every year, which is equivalent to almost all the nuclear energy produced. Rising standards of living and technological advances are further driving demand. Most air conditioners are a type of heat pump that is among the most effective forms of cooling (and heating) available. However, the efficiency depends on internal and external temperatures: the bigger the difference, the lower the efficiency. This means that performance is worst on the hottest days when air conditioning is most needed. The air conditioning units also rely on hydrofluorocarbon (HFC) refrigerants that have often a very high greenhouse warming potential (GWP), which is several thousand times higher than carbon dioxide over a 100-year time period. The risk is that these chemicals gradually leak into the environment during the device's operation, when inappropriately disposing of the equipment at the end of its life, or during the manufacturing process. As a result, regulations in the USA and Europe are gradually tightening to eliminate the highest GWP refrigerants, which is leading to innovation to find more energy efficient and environmentally friendly technologies.

An alternative technology to improve the energy efficiency of air conditioning systems is to utilize heat-driven liquid (or solid) desiccant cooling systems. The main process in these devices is the absorption of water from the air by a liquid desiccant, such as a concentrated salt solution. In parallel, an indirect evaporative process provides cooling. The absorption of water reduces the salt concentration in the desiccant. A heat source is used to heat the liquid to evaporate the water and thereby regenerate the salt concentration, which is circulated back. The advantage of this approach is that the efficiency of the system is highest when the external temperature is the highest – exactly when it is most needed. The liquid desiccant can be heated to a high concentration but only used to absorb moisture to cool later when needed – making it well suited for storing renewable energy.

Despite these compelling advantages, some challenges need to be overcome for the technology to become widespread. One such challenge is the high cost of the system. Additionally, the system can be complex to install and maintain. The desiccants can potentially corrode metal alloys such as pipes and ducts of the system. In closed, indoor environments, this can corrode the ducts and ventilation systems, and can potentially be harmful to the occupants.

Dehumidification and cooling

Buildings use a desiccant to absorb moisture and cool down the interiors



Source: Credit Suisse

13

Industrials

Electrochemical cement—Electrifying low carbon cement production

Substantially reducing emissions in the cement sector is prohibitively expensive with current technology. However, several solutions are in development, from capturing CO_2 emissions to reformulating ingredients. A promising alternative is to produce electrochemical cement using an electrolytic process to convert limestone to lime. Electrifying the production process using low-carbon sources could result in cement production with close to zero carbon emissions.

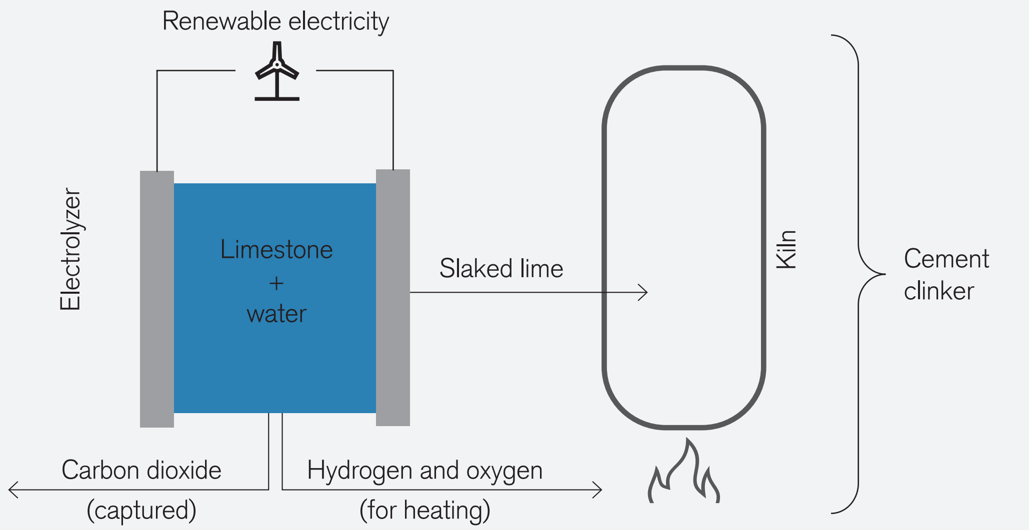
The production of cement is energy intensive and requires vast resources. It is responsible for 8% of the world's carbon emissions – the single largest source of industrial emissions globally.[16] If it were a country, cement production would be the third-biggest emitter in the world after China and the US.[17]

Cement production requires breaking down limestone in kilns under temperatures of up to 1,450°C (often powered by fossil fuels such as coal). Emissions are released both from the limestone heating and from the burning of fossil fuels to power the kilns. Efforts to reduce carbon emissions today are often centered around carbon capture and storage, or recycling construction and demolition waste. However, these options only partially reduce emissions and simply add to the cost of the cement.

The electrochemical cement process takes a different approach, using an electrochemical reactor that breaks calcium carbonate into lime powder at room temperature, replacing the energy intensive process used in traditional kilns. It first breaks calcium carbonate into a calcium hydroxide powder. The process then releases a stream of pure carbon dioxide, oxygen and hydrogen. The carbon dioxide can be captured relatively easily and used as an industrial gas. The oxygen and hydrogen by-products can then be used to generate electrical power to replace fossil fuels used to heat the kilns to create the chemical reaction combining calcium hydroxide power with sand and clay.[18] The output is identical to regular cement, and the hope is that this process will be cost competitive with traditional processes over time.

As with many new technologies in the carbon transition space, scalability remains a challenge, and some skepticism remains that the electrochemical cement production process can be scaled to the levels required to make a meaningful impact on the existing cement industry. Modern rotary kilns in cement plants have a production capacity of over 200 tons per hour, while electrochemical cement pilot plants can currently operate at a rate of only several kilograms per hour. Nevertheless, if these processes can be successfully scaled, the potential for emission reductions in this industry is significant.

Electrochemical cement production
Electrolysis significantly decreases carbon dioxide emissions



Source: Credit Suisse

14

Industrials

Digital twins for climate adaptation — Creating mirror worlds to achieve climate resilience

A digital twin is a dynamic virtual representation of an object, machine, or an entire process. In manufacturing, Digital twin (DT) technology has already been widely adopted to optimize industrial processes. DT technology is now being applied to build a replica of Earth. A sophisticated replica of the Earth's systems enables different users to interact with vast amounts of socio-economic and natural data.[19] This allows companies, investors and policymakers to formulate more robust adaptation and mitigation strategies.

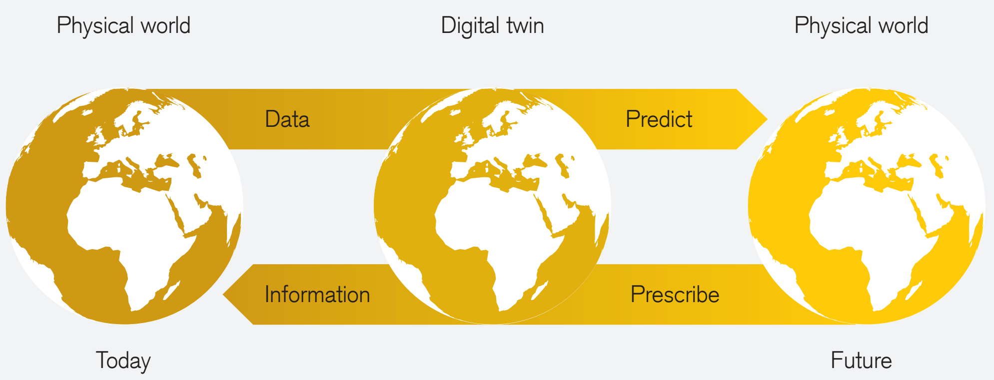
While pledges to mitigate climate change have gained significant traction, integrating assessments of adaptation into investment decision-making remains a challenging process since modeling and understanding climate-related risks is incredibly complex.

Using a DT to simulate location-specific climate scenarios, impacts of extreme weather events can be modeled and mitigation strategies developed. The creation of such a platform has become possible due to the convergence of exascale[20] computing, cloud and data-fusion techniques. These models can now provide reliable and granular information on how climate change will impact specific assets such as properties, households and geophysical features including flood-defenses, landslides, or coastal erosion. As the solution is scaled to cover more regions, machine learning (ML) algorithms can be used to fill in areas where less data is available. The development team of one start-up, Climate X, suggests that current models have an accuracy rate of more than 95% based on over one trillion data points tied to millions of locations for the UK alone. However, for planet-wide DTs to be fully realized, several challenges need to be overcome. These include incomplete access to accurate data to model the past, present and future state of the earth dynamically, as well as a lack of comprehensive collaboration platforms.

Destination Earth (DestinE) is an ambitious European Union-led initiative launched in early 2022 to build a platform to host digital replicas of the Earth's systems and natural phenomena using DT technology. At the heart of DestinE is a cloud-based, high-performance computing platform, a data lake of scientific data sets such as the Copernicus Earth Data, other real-time satellite data streams and sensor-based environmental data.

In this context, the early focus of DT technology will be on weather induced and geophysical hazards, which will aid in climate change adaptation. If the DT technology can reach planetary scale, it will become an important tool for planners in identifying the specific areas of the Earth that are most vulnerable to various changes in the climate, and allow these communities to respond and adapt in a timely manner.

Accurate climate simulation at a planetary scale
Digital twin of Earth guides solutions today by predicting the future



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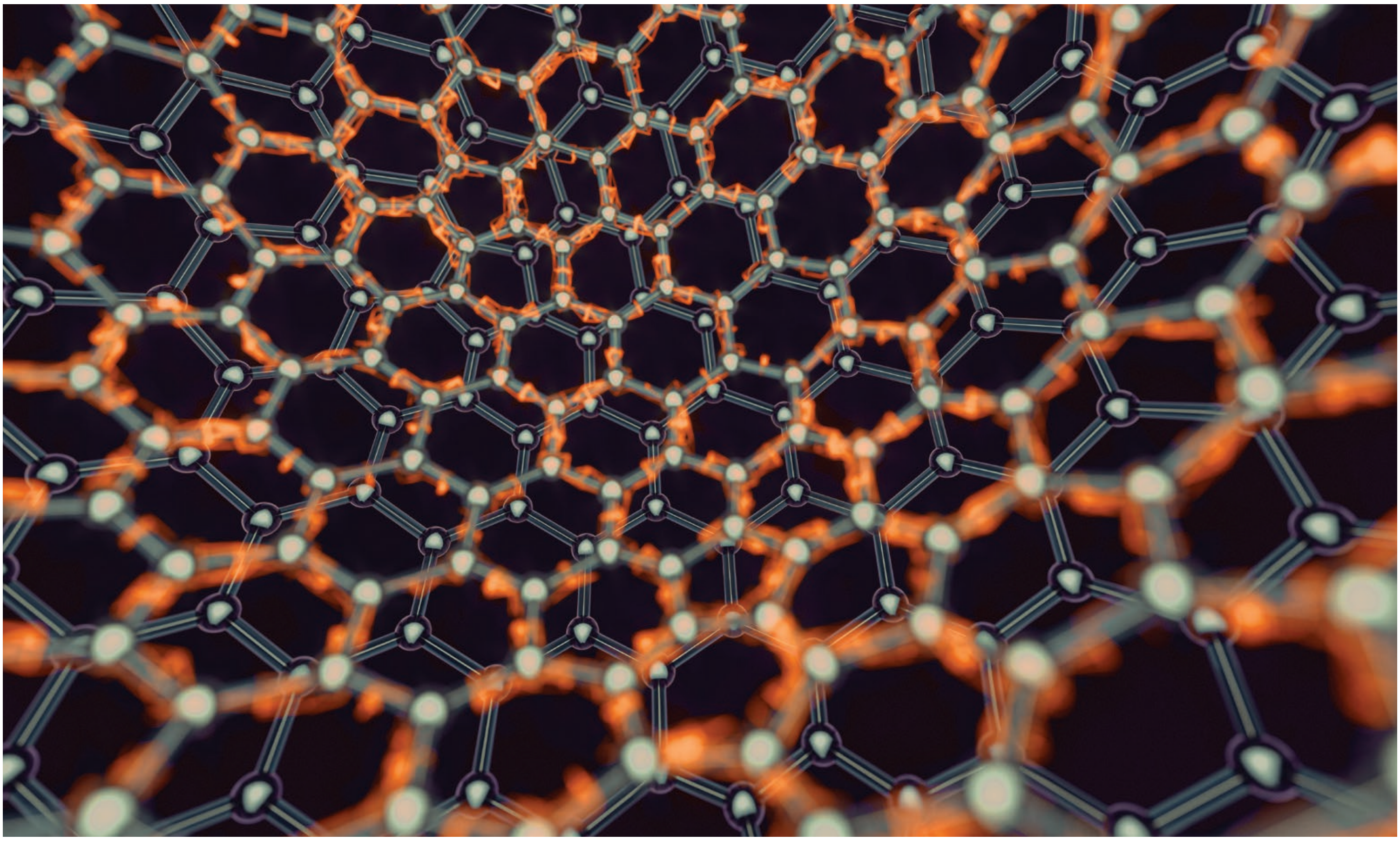


15

Industrials

Plastic membrane filters—Making separation processes more energy efficient

Separating chemicals on an industrial scale by using processes such as distillation is a highly energy-consuming process. Innovative polymer membrane materials could achieve high throughput and filtering efficiency while substantially reducing energy use.

Chemical separation is a critical and common industrial process that is used to separate components of a mixture of chemical compounds or gases into their purer forms. By some estimates, distillation accounts for 10%–15% of the world's energy consumption.[21] Uses include the extraction of gases from the air using an air separation unit (ASU). These work by cooling the air to cryogenic temperatures below the boiling point of the gas. Since each atmospheric gas has slightly different boiling points, this distillation process produces high-purity nitrogen, oxygen and argon – but uses significant amounts of energy in doing so. Other gas or chemical separation methods also need to heat the mixtures – an energy intensive process.

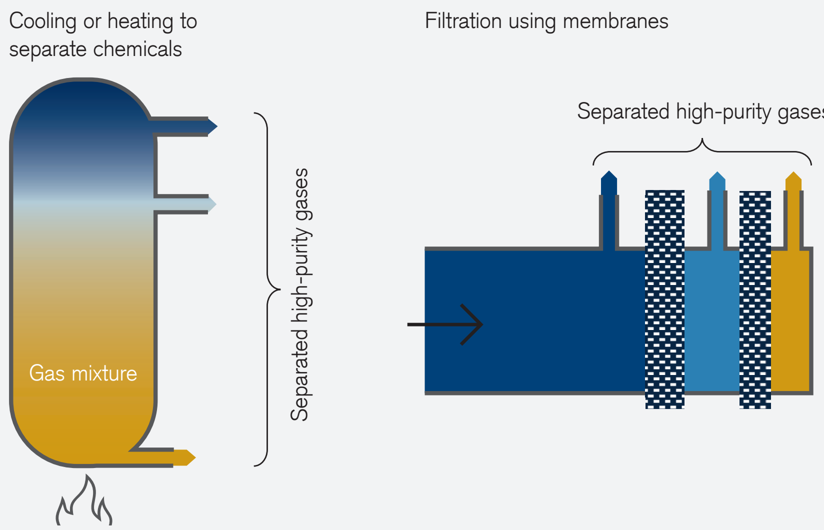
Membranes can serve a similar function by letting certain molecules or gases pass while blocking others. Without requiring heating or cooling processes, the membrane technology can reduce energy consumption by up to a factor of ten. However, there is usually a trade-off between how selective the membrane can be versus how fast the gases can penetrate through the material. The existing membrane technology is largely either underdeveloped or too expensive to scale up to handle industrial quantities of compounds. The challenge is to develop cheap, strong membranes that are mechanically stable and heat resistant while retaining their properties for a prolonged period.

Recent advancements in microporous hydrocarbon ladder synthesis that can be carefully tuned show promise for the separation of industrially important gas mixtures. It can provide high selectivity without compromising high permeability, dramatically improving the performance of these separation processes. The technology can be used in separating carbon dioxide and hydrogen molecules with applications in energy-efficient carbon capture and processing of natural gas and biogas. It was found to be two orders of magnitude more permeable and three times more selective for the removal of hydrogen from methane compared with currently available systems.[22] The membranes have also been shown in the laboratory to effectively separate oxygen and nitrogen – a formidable challenge as the two molecules differ in size by about a billionth of a meter.

As with other membrane technologies, a major obstacle to commercialization is the scaling up of laboratory-sized devices to full industrial production while maintaining the same level of performance.

Distillation versus filtration

Membrane filtration saves energy as it can work without heating or cooling to separate substances



Source: Credit Suisse

16 Mobility

Green methanol—Compacting hydrogen into an effective energy carrier

Methanol is a key ingredient in many industrial processes and products, as well as a potential energy carrier. The current challenge is to obtain and combine these elements in a sustainable way to produce green methanol. While we often hear about the “hydrogen economy,” hydrogen derivatives such as methanol may ultimately underpin a transition to more sustainable molecules due to their beneficial properties in terms of energy density and easier handling.

Methanol is an important substance in chemicals, construction, and plastics to make polymer fibers for use in textiles, plastics for packaging, glues, and solvents. It can also serve as a fuel or fuel additive in sectors such as long-haul shipping, where the technology to decarbonize the sector does not yet exist or remains prohibitively expensive. As a fuel it holds several advantages. First, it burns with lower GHG emissions than diesel or gasoline. Second, the transportation and shipping of methanol is far simpler and can use much of the existing infrastructure compared to some of the alternative fuels. For example, using hydrogen directly requires cryogenic cooling and has very low volumetric energy densities.

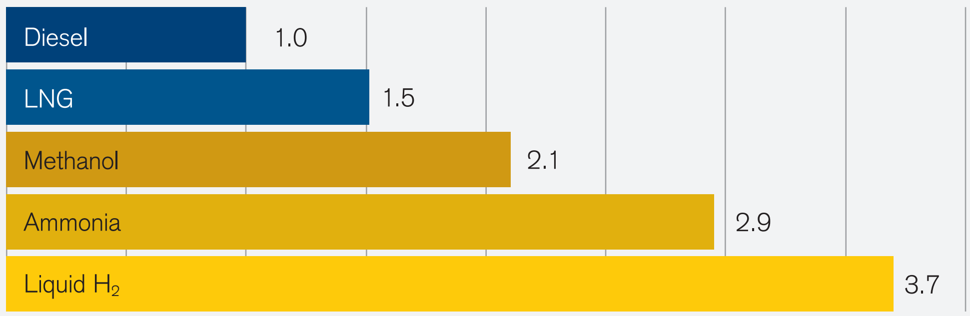
Methanol is conventionally produced from syngas (synthesis gas) which is composed of carbon monoxide and hydrogen. According to the IEA, around 99% of hydrogen today is made from fossil-fuel sources [23] – often natural gas that releases 9 kg of CO_2 for every 1 kg of hydrogen. Currently less than 0.2% of methanol comes from renewable sources.[24] Green methanol costs will always be benchmarked against natural gas-based methanol, the balance of which has so far been heavily in favor of using fossil fuels. However, changes in policies and volatility in gas prices may change this.

Different green methanol technologies exist today with bio-methanol and e-methanol among the most common. Bio-methanol uses biomass or biogas as feedstock. The former uses a gasification-type method in the way that coal is used to produce methanol but instead uses forestry or agriculture waste. The latter uses manure or waste-water sludge and a similar steam methane reformer process to that used with natural gas. The reliance on organic matter presents a challenge in terms of the scalability of the process.

E-methanol is most often created by obtaining hydrogen from water through electrolysis using alkaline water or proton exchange membrane electrolysis. However, it has a slow start-up, corrosion issues and complex maintenance drawbacks. The proton exchange membrane electrolysis has fast start-up, which makes it easier to combine with the variability of renewable energy sources, while its maintenance is simple and there are no corrosion issues. However, the manufacturing costs are high, mainly due to the use of precious metals in the system.

The other required feedstock for methanol is CO_2, which could be captured from industrial processes. For renewable CO_2, biological sources such as the conversion of biomass with carbon capture or potentially direct air capture are needed. Locking the CO_2 into methanol does not eliminate it. However, provided the CO_2 can be obtained in a sustainable manner alongside green hydrogen, it comes close to being carbon neutral.

The green fuel adoption challenge
Ammonia and hydrogen need twice the storage capacity of liquefied natural gas



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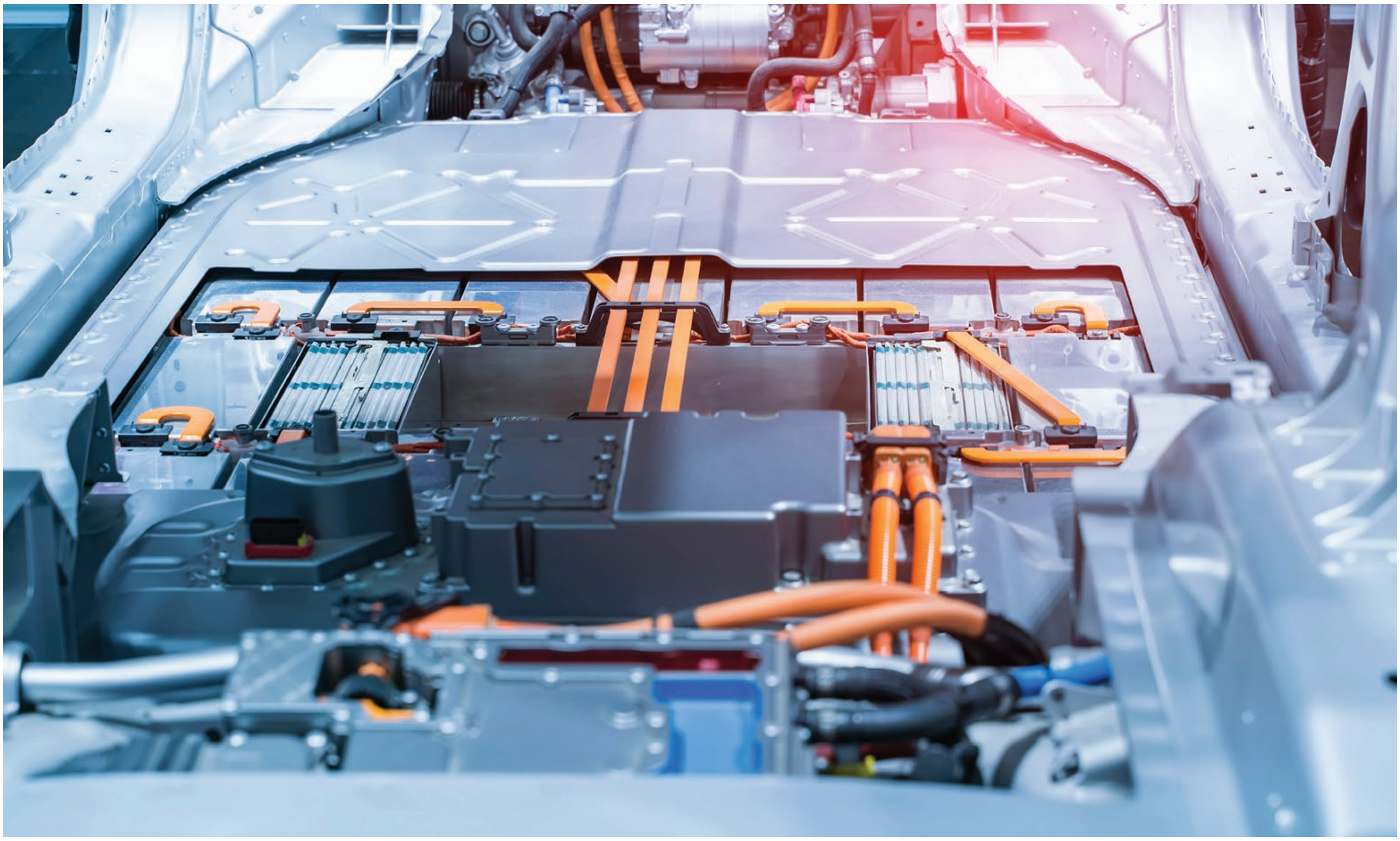


17

Mobility

Electro-extraction— Supercharging the circular economy

To meet the growing demand for critical minerals needed for electric vehicles and energy storage we need to recycle batteries. But batteries can only be made sustainable if a circular economy infrastructure is created to ultimately “close the loop” on mineral use. While current approaches to battery recycling are often harmful for the environment, new approaches such as electro-extraction are showing that significantly reducing refining emissions and long-term demand for virgin materials is possible.

The electrification of the transportation system currently consumes the majority of global lithium-ion battery capacity, with demand for lithium expected to exceed two million tons by 2030.[25] Nickel, cobalt, manganese and graphite are also critical materials for the manufacturing of batteries. Without recycling these materials, it is unlikely that mining and refining will be able to keep up with demand.

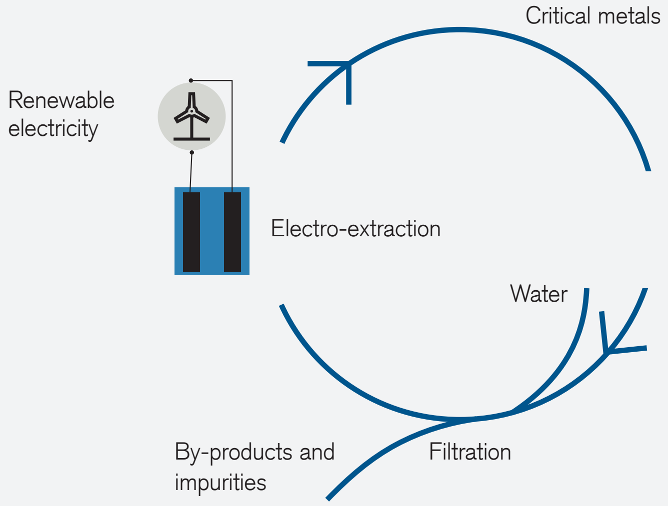
With car batteries lasting 10–20 years on average, it is estimated that there will be several million tons of batteries available for recycling by 2030. Hydrometallurgy and pyrometallurgy are currently the main technologies used for metals processing. However, traditional hydrometallurgy uses harmful chemicals to process the used batteries and creates large amounts of environmentally damaging chemical waste. Pyrometallurgy uses high heat to process materials, which is very carbon intensive, and has the further disadvantage of not being suitable to extract lithium or manganese.

Electro-extraction is an innovative new technology to recycle used batteries. It combines three key processes: electrowinning (passing an electrical current through solutions); precipitation (pulling solids out of a solution); and filtration (isolating the material) – into a single unit for the extraction of critical minerals from used batteries and mining material. The technology works by applying electricity to passing dissolved metal ions from e-waste (comprising crushed and shredded end-of-life battery materials) through an anode. There, the metal precipitates onto a cathode as a solid. Once the substrate reaches a certain level of saturation, the pure metal can be collected from the cathode. Eventually, the metals can be re-used for new batteries. The technology can currently recover over 90% of the target critical minerals.[26] By adding electricity, electro-extraction technology makes it possible to extract a large range of metals from various input sources (e.g., end-of-life batteries and mining materials, such as low-grade ores), with less chemical waste and energy than traditional pyrometallurgy and hydrometallurgy facilities that are currently being used to recycle used or scrapped batteries.

To date, electro-extraction has only been demonstrated in the lab, and further research is required before it can be scaled up for commercialization. But if it can be commercialized, the supply chain risks around sourcing materials for batteries would be reduced. Recycling batteries where they are used reduces transportation costs and emissions while making battery supply chains more secure.

Electro-extraction

Closing in on a closed-loop process



Output examples:
- Transition metals (nickel, manganese, iron, etc.)
- Rare-earth metals (caesium, neodymium, etc.)
- Nobel metals (gold, silver, etc.)

Input examples:
- Lithium-ion batteries
- Catalytic converters
- Stainless steel
- Mine tailings

Source: Credit Suisse

18

Agriculture

Microbiomic agriculture—Gene-edited microbes pave the way for more environmentally-friendly fertilizers

Microbiomic agriculture uses synthetic biology to create an alternative to traditional fertilizer that mitigates negative environmental impacts. It uses modified microorganisms that enhance the ability of the soil's bacteria to naturally fix critical nutrients to plants, thereby improving overall soil fertility and reducing the need for fossil fuel-based fertilizers.

Emissions of N_2O, a greenhouse gas that is 300 times more potent than CO_2, have increased by 30% over the last 40 years. Its growing concentration in the atmosphere is due to the use of fertilizers in agriculture. Farming is vulnerable to climate change, which directly influences rainfall patterns, animal health and, overall agricultural productivity. The Intergovernmental Panel on Climate Change (IPCC) estimates that even if global warming can be kept to just below 2°C, up to 8% of the world's farmland may be unsuitable for agriculture by 2100.[27] Additionally, a growing, affluent global population will increase demand for food including meat. At the same time, hundreds of millions of people suffer from food insecurity and malnutrition. Even if the global population peaks at between 10 to11 billion, the global food system needs to become significantly more productive and less environmentally damaging.

Recent advances in molecular biology and gene-editing techniques have the potential to revolutionize agricultural production practices, drive productivity and reduce reliance on fossil fuel fertilizers. Biotechnology is finding ways to enhance natural mechanisms that support plant growth. Nitrogen, a critical element for plant growth, is naturally abundant in the atmosphere in its gaseous form (N_2). However, plants cannot directly absorb atmospheric nitrogen; it must first be converted into organic compounds by nitrogen-fixing organisms, such as the Rhizobia bacteria. Derivative compounds such as ammonium can then be taken up by plants, providing them with a key building block to develop proteins.

Legumes such as peas and beans already have a symbiotic relationship with these bacteria, which colonize their roots and provide plants with high levels of organic nitrogen in exchange for carbohydrates that the microbes use as food. Scientists have now recreated the phenomenon with cereal grain crops, which do not naturally pair up with microbes. Leveraging genome editing technologies, researchers can now improve the capacity of selected soil microorganisms to make nutrients available to cereal grain crops, creating a natural fertilizer. Unlike traditional fertilizers, these microbes stay in the soil and do not wash away with irrigation or heavy rains.

Challenges remain in fully replacing synthetic fertilizers with nitrogen-producing microbes, including scaling up production and making them effective for a wide range of crops. Nonetheless, as the science progresses, the modification and improvement of nitrogen-fixing microbes and their application to a broad range of crops could promote a lower-carbon, more productive and more sustainable agricultural industry.

19

Agriculture

Cultivated meat on a veggie diet—Beyond lab-grown meat

Producing meat in a high-tech factory has both environmental and animal welfare benefits. “Cultivated meat,” as it is now called by the industry, is part of the transition to a sustainable food system. However, the technology has several critical hurdles to overcome before a juicy cultivated burger appears on every dinner table.

As demand for food has increased with the growing global population, the consumption of resource intensive, animal-based food has surged. According to the Food and Agriculture Organization of the United Nations (FAO), 26% of the world's vegetated land is used for livestock grazing, and 33% of farmlands are used for livestock feed production.[28] Indeed, the continued expansion of land used for livestock has become one of the largest threats to the climate. Research has shown that the livestock industry is responsible for almost 18% of the world's GHG emissions.[29] Moreover, livestock farming accounts for nearly 20% of freshwater consumption globally,[30] and is also one of the main drivers of deforestation.

Cultivated meat, also referred to as cellular or lab-grown meat, could help address some of these sustainability challenges. Instead of slaughtering animals, stem cells of animals are cultivated in bioreactors. During this process, nutrients and oxygen are optimized for greater cell expansion in order to form muscle tissue that is shaped into edible scaffoldings.

This makes it possible for cells to keep growing several times more than in live animals, while mitigating the negative environmental and welfare impacts of animal farming. Besides those benefits, growing food in a sterile environment avoids animal diseases and associated antibiotic use.

While a cultivated chicken product is already on the shelves in Singapore, many challenges remain before other types of lab-grown meat reach supermarket shelves across the world. Scaling up production requires advanced biotechnology capacities and high-cost inputs. Reaching industrial scale remains the key challenge, and global bioreactor capacity represents a tiny proportion of the volume of animal meat consumed annually.

Another challenge is keeping these large bioreactors sterile, as a few microbes can spoil an entire batch, thereby halting production. The process is also highly energy intensive, and meaningful reductions in GHG emissions require low-carbon sources of energy for these facilities. Finally, there is a risk that these products fail to gain a broader acceptance among consumers, who may perceive this lab-grown meat as unnatural and potentially unhealthy.

The biotechnology around cultivated meat continues to address these challenges. Modifying essential nutrients such as vitamins or minerals, or controlling fats can make cultivated meat healthier than animal meat. Nutrients for lab-grown cells can now be based on vegetarian ingredients rather than fetal bovine serum or animal proteins, which further improves animal welfare, reduces costs and mitigates the potential for zoonotic diseases. We are also seeing plant-based "scaffolding" used to create more realistic fibers and textures. Together, these innovations could eventually make cultivated meat increasingly appealing, accessible and sustainable.

20

Agriculture

Treeless wood—Avoiding deforestation with lab-grown timber

Researchers at the Massachusetts Institute of Technology (MIT) have developed a pioneering plant-cell cultivation technique in their lab to generate conditions for a plant-based, wood-like culture that can be cultivated to grow timber and timber-derived products.

Wood is a renewable resource and offers an alternative to plastics, cement and steel. Humans have felled and replanted trees for thousands of years. However, demand for timber is exceeding the ability to regrow forests quickly, and primary forests continue to be exploited. Trees are a slow growing crop, sensitive to climate change, disease and pests, and certain types of trees can only grow in specific regions. In addition, illegal logging accounts for 15%–30% of global wood consumption. Although the rate of deforestation has slowed globally by around 29%, an area of forest approximately twice the size of Switzerland was lost annually between 2015 to 2020.[31] New afforestation and natural forest expansion has failed to compensate for these losses, not only from a climate perspective but also in terms of biodiversity and other benefits.[32] The need for transportation, milling and processing leads to further waste and energy use in the timber supply chain.[33]

A novel approach is to create plant-based products which can be cultured and grown on demand. In contrast to the bioengineering of animal tissue which has been of scientific interest for 50 years, the engineering of plant-cell cultures has just started. Using 3D printing techniques, researchers have shown that the plant material could be grown in exactly the required shape and size, thus removing the need to do any subtractive manufacturing (sawing, milling) and reducing waste and energy.

Future applications could include bioengineering valuable rare wood, products such as resins and oils. Today an entire tree might be processed to yield only 0.5 liters of the final product, whereas a bioreactor could be used to grow only the useful part to improve the yield.

Further improvements in development and manufacturing are needed to take this concept from the lab into production. Early use cases could include lower value, higher volume plant-based products such as cellulose pulp used in textiles and paper. As a next step, researchers plan to replicate the cell structures of commercial usable woods, eventually growing plant cells in the final form for furniture, ready-made beams, or other typical uses. Initially this process is likely to be more expensive than traditional wood. However, lab grown plant tissue will grow considerably faster, and may find interesting markets in specialist areas.

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Editor-in-chief
James Gifford
Michael van der Meer

Contributors
Angela Saxby
Peter Babkevich
Francesco Mazzeo
Karim Sayyad
Mette Gahr
Davide Paliaga
Anita Bhagat
Riccardo Cavinato
Timothy Oehmigen
Richard Bettermann
Sophia Bieri

Editorial Support
Catherine McLean Trachsler

Project management
Camilla Damm Leuzinger
Laurence Lam
Serhat Günes

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