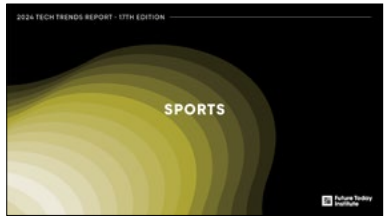
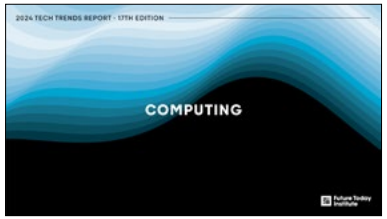
ENERGY · CLIMATE

FUTURE TODAY INSTITUTE'S 2024 TECH TREND REPORT

Our 2024 edition includes nearly 700 trends, which are published individually in 16 volumes and as one comprehensive report with all trends included.

Download all sections of Future Today Institute's 2024 Tech Trends report at **http://www.futuretodayinstitute.com/trends.**





THE YEAR AHEAD: TECH SUPERCYCLE

The theme for our 2024 report is Supercycle. In economics, a "supercycle" refers to an extended period of booming demand, elevating the prices of commodities and assets to unprecedented heights. It stretches across years, even decades, and is driven by substantial and sustained structural changes in the economy.

We believe we have entered a technology supercycle. This wave of innovation is so potent and pervasive that it promises to reshape the very fabric of our existence, from the intricacies of global supply chains to the minutiae of daily habits, from the corridors of power in global politics to the unspoken norms that govern our social interactions.

Driving this seismic shift are the titans of technology and three of their inventions: artificial intelligence, biotechnology, and a burgeoning ecosystem of interconnected wearable devices for people, pets, and objects. As they converge, these three macro tech segments will redefine our relationship with everything, from our pharmacists to our animals, from banks to our own bodies. Future Today Institute's analysis shows that every technology—AR/ VR/ XR, autonomous vehicles, low Earth orbit satellites, to name a few—connects to the supercycle in some way.

The ramifications are stark and undeniable. As this tech supercycle unfurls, there will be victors and vanquished, those who seize the reins of this epochal change, and those who are swallowed whole. For business leaders, investors, and policymakers, understanding this tech supercycle is paramount.

In this 17th edition of FTI's annual Tech Trends report, we've connected the supercycle to the nearly 700 trends we've developed. Our research is presented across 16 technology and industry-specific reports that reveal the current state of play and lists of influencers to watch, along with detailed examples and recommendations designed to help executives and their teams develop their strategic positioning. The trends span evolutionary advancements in well-established technologies to groundbreaking developments at the forefront of technological and scientific exploration. You'll see emerging epicenters of innovation and risk, along with a preview into their transformative effects across various industries.

We've visually represented the tech supercycle on the report's cover, which is an undulating image reminiscent of a storm radar. Vertical and horizontal lines mark the edges of each section's cover. When all 16 section covers converge, the trends reveal a compounding effect as reverberating aftershocks influence every other area of technology and science, as well as all industries.

It's the convergence that matters. In isolation, trends offer limited foresight into the future. Instead, the interplay of these trends is what reveals long-term change. For that reason, organizations must not only remain vigilant in monitoring these evolving trends but also in cultivating strategic foresight—the ability to anticipate future changes and plan for various scenarios.

Our world is changing at an unprecedented rate, and this supercycle has only just begun.

Amy Webb
Chief Executive Officer
Future Today Institute

TABLE OF CONTENTS

TABLE OF CONTENTS

TOP HEADLINES

Private and public climate efforts widen and accelerate in the light of the most extreme weather we have ever experienced

01 Investment is shifting from clean energy to enabling technologies

As wind and solar provide more power, venture capital is targeting bottlenecks in supporting infrastructures such as the grid and monitoring technology.

02 Extreme weather sets new records

2023 was the hottest year in the history of humankind; as the ocean warms, the collapse of the Gulf Stream is projected to be much more likely.

03 Tracking carbon has become popular with regulators

Regulators have shifted their focus from establishing the carbon market to adding transparency, standards, and verification frameworks.

04 Polluters being held accountable

A slew of groundbreaking litigation set precedents for holding governments and companies accountable for the effects of climate change caused by their (in)action.

05 Governments are considering a broader set of tools

Regulators are exploring solar geoengineering, considering softer regulations for CRISPR crops, and redesigning urban concepts to adapt to hostile environments.

STATE OF PLAY

From revolution to evolution: The global focus shifts to the creation of an enabling ecosystem for climate action at scale.

In 2023, attention shifted from scaling of renewable energies and electric vehicles to ensuring that these scaled technologies could be viably integrated into existing systems. Venture capital moved from transportation, energy, and food and land use to the built environment and heavy industry decarbonization, making significant innovation likely. Governments tightened ESG regulations, putting pressure on companies to bring transparency into carbon emission reporting, even while standardization frameworks for measuring and reporting these emissions along the entire supply chain are still being developed. These increased reporting pressures run the risk of leading to a focus on the wrong metrics, crippling effective environmental initiatives.

Environmental impacts are now defined more broadly, which increases companies' responsibilities. The framework passed at the 2022 UN's Biodiversity Conference amplified the protection of biological ecosystems, equitable access, and human rights. In 2023, COP28 had its first-ever health day, and nations committed to include food systems into their updated Nationally Determined Contributions. Further responsibilities might come from a series of lawsuits which decide if actors can be held responsible for the effects of climate change they caused. If courts rule they are, prepare for drastically changed efforts in regulation and business practices.

KEY EVENTS

MARCH 8, 2023

Carbon injected in the sea
Denmark became the first nation to import CO2 for the purpose of burying it in the North Sea.

MARCH 14, 2023

Forever chemicals ban
In the US, toxic PFAS are banned from water while the EU backpedals.

JUNE 29, 2023

Fraud task force for ESGs
The Commodity Futures Trading Commission announces a task force to combat ESG related fraud.

JULY 5, 2023

Looser GMO rules in EU
The European Commission proposes looser restrictions in light of innovation in the field.

DECEMBER 3, 2023

First Ever COP Health Day
The acknowledgment of the interconnectedness of health and environment at the UN Climate Change Conference gives hope for integrated actions.

LIKELY NEAR TERM DEVELOPMENTS

CHANGE IS THE NEW NORMAL

Two opposing forces will make the corporate landscape highly volatile and unpredictable. On the one hand, active regulatory bodies, scaling of renewable energy production, and increased investment in innovation that aims to solve the remaining bottlenecks will require and empower corporations to integrate sustainability in ways not imaginable just a few years ago. On the other hand, economic headwinds in the form of heavy inflation and a looming recession might lead consumers to prioritize affordability over sustainability, and escalating geopolitical tensions could strain the supply chain, increase the price of raw materials, and hinder collaboration in research—slowing down innovation.

Price Beats Ethics

As inflation soars and the fear of a recession festers, consumers might put affordability above climate considerations, at least when it comes to their wallets. This will put additional strain on business owners, as they determine how to adjust for climate demands.

Rethinking Supply Chains

Governments are expanding their requirements for reliable and consistent reporting of direct and indirect emissions (scope 1, 2, and 3), putting pressure on corporations to curate their vendor networks and on the vendors to ensure their operations are still profitable under increased standards.

From Early Bird to Night Owl

Excessive heat impacts daily lives around the globe, forcing people to stay indoors during the day and only leave their houses in the evening. As these heat phases expand, industries dependent on people's physical presence will have to rethink operations as habits and timing of activities shift.

Shifts in Mobility

More and more people, at least in Europe, are committing to not use air travel. The resulting smaller spheres of mobility could lead to an increasing need for companies to have local hubs, especially as the terms of remote work are still being negotiated.

Accountability Changes

The resolution of a number of upcoming court cases will begin to determine government and corporate responsibility for climate change. If verdicts fall on the side of holding institutions responsible, we could see fundamental changes in how climate is addressed.

Climate Upskilling

With climate regulation expanding and evolving, and climate technology innovation accelerating (thanks to AI) and scaling, companies need to make sure they have the necessary know-how in-house to understand and monitor relevant developments.

11 MACRO SOURCES OF DISRUPTION

Technology | Media & Telecom | Demographics | Environment | Government | Public Health | Education | Geopolitics | Infrastructure | Economy | Wealth Distribution

WHY ENERGY & CLIMATE TRENDS MATTER TO YOUR ORGANIZATION

Opportunity for Innovation

Energy and climate technologies can help businesses transform in revolutionary ways that increase profitability significantly: Changed processes, new materials, updated supply chains, a different set of partners and collaborators, and investment in research can lead to new products and services—and a competitive edge.

Cost Savings & Efficiencies

Embracing climate technology brings long-term savings. Reduced energy use and operational expenses enhance overall efficiency, positively impacting the bottom line. This positions the company for sustainable growth, demonstrates commitment to a green future, and fosters a culture of environmental responsibility.

Climate Risk Resiliency

Increased frequency, severity, and wider occurrence of extreme weather events force all businesses to think about how to mitigate impacts, not just those in disaster-prone regions. Flexible measures are needed to maintain continuity, protect assets, and promote sustainable growth in the face of an increasingly unpredictable climate.

Investment & Financing Opportunities

As climate-conscious funding continues to surge, businesses with innovative climate solutions gain greater access to capital, enabling them to scale operations and accelerate the transition to a more sustainable future. This provides a unique opportunity to stay ahead of regulatory requirements and tap into growing green markets.

Energy Independence

Businesses that invest in their own renewable energy production can achieve a high degree of energy independence, reducing their vulnerability to fluctuations in pricing and increasing grid failures. They'll gain greater control over energy supply, with insulation from market uncertainties and enhanced long-term stability.

Attack on Profitability

Implementing climate technologies and adhering to environmental regulations may raise production costs, due to upfront investment or compliance expenses, impacting profitability. Strategic planning and collaboration are crucial to navigating this transition successfully.

WHEN WILL ENERGY & CLIMATE TRENDS DISRUPT YOUR ORGANIZATION?

Forecasted Time of Impact

0-4 YEARS	5-9 YEARS	10-14 YEARS	15+ YEARS
Agriculture	Pharma	Space exploration	All trends will be relevant
Energy generation	Financial services		
Transportation	Consumer goods		
Construction	Health care		
Insurance	Information technology		
Real estate	Water management		
Hospitality	Infrastructure development		
Retail	Waste management		
City management			
Manufacturing			

OPPORTUNITIES & THREATS

Threats

Assessing the existing expertise and hiring or training employees with the necessary skills to integrate climate technologies is a must yet can be challenging in an already tight labor market and an overworked workforce.

Companies might be confronted with a much higher cost of doing business after integrating sustainable processes and raw materials. This might pose existential risks or fundamental shifts in operations and threaten profitability.

Geopolitical tensions and a higher frequency of extreme weather events increase the risk for supply chain disruptions, as well as rising prices and scarcity of necessary base materials and labor.

As tracking capabilities expand through scope 1, 2, and 3 emissions, businesses should be prepared to find that their carbon emissions footprint is much more significant than expected (and less under their control).

Proactive regulators are needed to ensure we reach our climate goals. However, new regulations as well as changes to existing rules will redesign business environments and create a strain for companies as they try to navigate their operational transformation.

Opportunities

Look for new partners to collaborate with and selectively outsource activities for implementing sustainability measures as part of a new supportive ecosystem. This keeps costs at bay and expands the opportunity for cross-pollination of ideas.

Price volatility and stricter regulation will trigger a rethink of business operations. This can lead to new efficiencies in tangential contexts outside of environmental considerations and positively affect margins.

First movers will be able to define the new normal. They'll build competitive advantage by transforming common business procedures in their industry and setting standards as they improve their business operations.

Think beyond the changes necessary to comply with sustainability requirements by also considering structural changes that could make the company more flexible and responsive to innovation.

Energy and captured CO2 emissions are just two examples of products that the integration of climate technologies can add to a company's portfolio. Thinking expansively can open up avenues into new industries, including but not limited to energy.

INVESTMENTS AND ACTIONS TO CONSIDER

1

With innovation making huge strides in carbon tracking, invest time into finding the platform and sensor ecosystem that's the best fit for your business and supply chain. These technologies will touch every aspect of your business, making the implementation of new hardware and software very expensive.

2

Consider all workforce aspects: Companies need to weigh the skills and expertise available, where to hire or upskill, whether structure and hierarchies need to evolve, as well as where employees should be working. All these factors are relevant for the carbon footprint but also need to be considered for maximizing profitability.

3

Sustainability is becoming a broader effort and now includes biodiversity, ethical practices, and protection of indigenous communities. Work toward gaining insights about these areas throughout your entire supply chain to prepare for regulatory pressures.

4

Explore new avenues to not only stay on top of innovation but to become part of the ecosystem of investing, research and development. This ensures that the bottlenecks and problems specific to your business are being solved, and might even lead to new business models licensing the developed technology.

5

Global demographics will change significantly over the next few decades, with migration, aging, and overpopulation all contributing factors. Investigate how this affects your current customer base, and where new markets, either in regards to location or customer profile, could emerge globally.

6

Clearly define goals, benchmarks, and deadlines for the assessment and implementation of climate technologies in your company. Identify a sensible organizational structure, relevant stakeholders, responsible parties, and how the company will efficiently integrate the findings and technologies.

CENTRAL THEMES

Proactive Regulators

On both sides of the Atlantic, regulators stepped up to enable significant climate action. The EU's Green Deal Industrial Plan includes easier access to financing, simplification of permitting processes, regulatory sandboxes for member states, and the announcement of the European Hydrogen Bank to quickly scale the fuel's use in the region. In the US, regulators banned certain forever chemicals (PFAS) in drinking water, strengthened pollution standards for cars and trucks, and widened eligibility for clean-energy tax credits. To avoid greenwashing, the EU proposed the Green Claims Directive to eliminate misleading messaging. In the US, the Commodity Futures Trading Commission created a task force to combat environmental fraud, and the Securities and Exchange Commission proposed stricter climate disclosure rules for publicly traded companies.

Focus on Enabling Technologies

After passing the $1 trillion investment mark in 2022, overall venture capital in climate tech dropped 40% in 2023. However, most of that decrease took place in later stages and growth funding; seed funding actually grew 23%, and the number of deals rose by 34%. In addition, investors are showing enthusiasm for solving new problems, after renewables have moved into the scaling phase. Investment in the big three—transportation, energy, and food and land use—saw significant drops, while investment in industry processes and the built environment, both historically underfunded, saw gains. But there is still much to be done: Transforming the grid to accommodate non-dispatchable energy sources; searching for alternative materials for batteries, solar cells, and wind turbines; capturing and storing carbon; tracking emissions; and bringing transparency and validity to carbon markets are just some of the bottlenecks that urgently need innovation.

Alternative Materials

The race to find alternative materials for renewable energy production and tangential technologies (such as batteries) is on. In a tense geopolitical environment where the location of needed raw materials is limited to areas often plagued by political and economic instability, there's an increased desire for nations to be resource independent. Recently, Sweden and Norway made inroads on this independence when the largest rare earth and mineral deposits were found in the region. While China responded to the US's 2022 export controls on advanced computing and semiconductors manufacturing equipment with its own restrictions on exporting gallium and germanium (needed for solar technologies), impact is less significant thanks to the ability to expand in alternative markets in the mid-term. Innovation intensified last year around finding alternative materials for climate technologies, predominantly in electric vehicle motors (rare earth) and batteries (metals).

CENTRAL THEMES

Looking Beyond Carbon

While carbon dioxide emissions are front and center in the climate conversation, a more holistic approach has gained significant traction and increased public awareness. Both the US and the EU have taken steps to control methane emissions, and global leaders came together during the United Nations Biodiversity Conference (COP 15) in December 2022 to agree on global action on addressing biodiversity loss, restoring ecosystems, and protecting indigenous rights. As a result, 30% of the planet and 30% of degraded ecosystems will be under protection by 2030. EU regulators have agreed on the Nature Restoration Law, which requires countries to work toward restoring at least 20% of land and sea areas, and the US expressed its intention to join the High Ambition Coalition on Biodiversity Beyond National Jurisdiction, supported by the UN. Currently, 95% of the ocean falls beyond national jurisdiction, and the coalition represents a group of countries that have pledged to protect that ecosystem. Rewilding efforts have also increased, often on state, local, and even individual levels.

Tracking Climate Change

The tightened regulatory requirements for companies to reduce their carbon footprint increases the need for cohesive and reliable emissions tracking, as well as common measurement standards. In the carbon credit market, frameworks to verify actual results of carbon projects and create a viable rating system are crucial for credibility and effectiveness. As extreme weather becomes more frequent, severe, and widespread, governments have increased their efforts to build better prediction systems to protect lives and ecosystems. Amid a landscape where insurers are pulling out of states like California and Florida because risks deemed uninsurable, these systems can provide the industry with the data necessary to calculate risks. The development of these monitoring technologies is being accelerated by artificial intelligence and innovation around imaging, such as hyperspectral imaging. Also helping to unify the integrity frameworks are joint efforts by various stakeholders in the voluntary carbon markets.

Blue Economy on the Rise

Originally used by small developing island states, the term “blue economy” today encompasses socially equitable, environmentally sustainable, and economically profitable ocean-based industries and spaces. In 2023, the US launched a global initiative of more than $800 million to protect oceans and support developing nations. This follows the EU’s previous efforts to create the Atlantic Smart Ports Blue Acceleration Network to transform Atlantic ports, the G20 Supreme Audit Institutions cooperating to meet the challenge of auditing the blue economy, and African funds’ focus on innovation to advance blue economy solutions for the continent. These initiatives triggered a flurry of innovation focusing on the ocean, from means and devices to collect data underneath the surface, to platforms that synthesize and analyze the data and make it available to all relevant stakeholders, to advanced desalination methods and increased support for sustainable fishing. As the ocean is also moving more into the climate conversation for carbon sequestration and power generation, we can expect to see an acceleration of not just technological advances but also novel business activity in this space.

ONES TO WATCH

Dr. Stefaan De Wolf, professor of material science and engineering of the KAUST Solar Center, for setting the world record for tandem solar cell efficiency.

Alexander Bormann, founder of EnerKite, for expanding the EV-charging infrastructure with airborne wind.

Dr. Motiar Rahaman, research associate at University of Cambridge, for leading research on a solar-powered reactor that converts CO2 captured from industrial waste or air into sustainable fuel.

Andrew Ponec, co-founder and CEO of Antora Energy, for developing thermal energy storage that turns renewable energy into on-demand power usable by the heavy industries.

Xiaomeng Liu, researcher at University of Massachusetts Amherst, for his research on creating energy from air.

Mateo Jaramillo, CEO of Form Energy, for building a 1 gigawatt hour demo system of an iron air battery, expected to come online in 2025.

John Connell, senior scientist at NASA Langley Research Center, for advancing research on a solid state battery to be used in aviation.

Lee Suk-bae, Ji-Hoon Kim, and Young-Wan Kwon of the Quantum Energy Research Centre, for their preprint on developing the first room temperature superconductor.

Hudson Gilmer, co-founder and CEO of LineVision, for creating the only non-contact overhead power line monitoring system, used by UK's National Grid.

Isabella Arzeno-Soltero, postdoctoral scholar at Stanford University, for determining that seaweed farming cannot scale enough to meet climate goals.

Dr. Graciela Chichilnisky, co-founder of Global Thermostat, for creating one of the largest direct air capture machines ever operated.

Talal Hasan, CEO of 44.01, for leading the first CO2 mineralization project in the Middle East that utilizes seawater.

Pasi Vainikka, CEO of Solar Foods, for creating food out of renewable energy and carbon dioxide.

Freddie Lintell, founder and CEO of Reewild, for creating a carbon tracking app for consumers.

Josh Dorfman, co-founder and CEO of Plantd, for transforming perennial grass into carbon-negative building materials.

Virginia San Fratello, architect, for 3D printing houses out of indigenous materials such as salt and clay.

Dr. William Dichtel, chemistry professor at Northwestern, and Brittany Trang, Sharon Begley Science Reporting Fellow at STAT, for developing a low temperature, inexpensive method to break down PFAS.

Shimrit Bar-El, co-founder and CRO at Novella, for growing botanical ingredients without the plant.

Hunter Swisher, founder of Phospholutions, for reducing the amount of phosphorus in fertilizer by 50%.

Nathalie Berezina, founder and CEO of Norbite, for transforming plastic waste into sustainable products with the help of moths.

Khaled Hassounah, co-founder and CEO of Ample, for providing an alternative to EV charging: battery swapping.

Tim Duehrkoop, co-founder and CEO of Xilva, for developing a methodology to assess forest sequestration projects.

Dr. Tom Jackson and his team at Loughborough University, for the creation of the "Data Carbon Ladder," which enables the tracking of digital emissions.

Bob Mumgaard, CEO of Commonwealth Fusion Systems, for being a frontrunner in the nuclear fusion race.

IMPORTANT TERMS

Ammonia
A compound of nitrogen and hydrogen. It can be used directly as a fuel in direct combustion processes, as well as in fuel cells or as a hydrogen carrier. To be a low emissions fuel, ammonia must be produced from low-carbon hydrogen and the nitrogen separated through the Haber process using electricity generated from low-carbon sources.

Bioenergy
Energy content derived from biomass feedstocks and biogas. It comes in solid, liquid, and gaseous form. Its liquid form is often labeled biofuel.

Biogas
A mixture of methane, CO2, and small quantities of other gases produced by anaerobic digestion of organic matter in an oxygen-free environment.

Carbon capture, utilization, and storage (CCUS)
The process of capturing CO2 emissions from fuel combustion, industrial processes or directly from the atmosphere. Captured CO2 emissions can be stored in onshore or offshore underground geological formations, or used as an input or feedstock in manufacturing.

Direct air capture
A technology that captures CO2 from the atmospheric air through a chemical reaction.

Dispatchable generation
Dispatchable generation is a source of electricity that can be turned on or off, such as nuclear, meaning it can be controlled. Non-dispatchable energy sources, such as wind and solar photovoltaics, cannot be controlled by operators.

Electrolysis
Electrolysis is a process where electric current passes through a substance to effect a chemical change. In hydrogen production, electricity is used to split water into hydrogen and oxygen. If the power used for the process comes from sustainable energy sources, the process does not produce greenhouse gas emissions.

Energy intensity
Energy intensity is the amount of energy used to produce a certain level of output.

Hydrogen
Hydrogen is the simplest and most abundant element in the universe. It can be produced from a variety of resources such as water, fossil fuels, or biomass, and used as a source of energy or fuel. Depending on the resource and energy type used to produce it, hydrogen production can be emissions-intensive or carbon neutral.

Liquid bioenergy (biofuel)
Liquid fuels derived from biomass or waste feedstock. They include ethanol, biodiesel, and biojet fuels.

Conventional: Fuels produced from food crop feedstock such as sugar cane or vegetable oil, among others.

Advanced: Fuels produced from non-food crop feedstock that don't directly compete with food and feed crops for agricultural land.

Process emissions
Emissions from industrial processes that involve chemical or physical transformations (separate from fuel combustion).

Pyrolysis
Pyrolysis is the process of heating organic materials, such as biomass, in the absence of oxygen.

Solid bioenergy
Charcoal, fuelwood, dung, agricultural residues, wood waste and other solid wastes.

Traditional: Refers to the use of solid biomass with basic technologies, such as a three-stone fire, often with no or poorly operating chimneys.

Modern: Refers to the use of solid bioenergy in improved cook stoves and modern technologies using processed biomass such as pellets.

Solar photovoltaics (PV)
A process which converts sunlight into electricity using a technology based on the photoelectric effect. With the photoelectric effect, materials absorb photons (light) and release electrons, generating electricity.

Zero carbon-ready buildings
A zero carbon-ready building is a highly energy efficient building. It uses either renewable energy sources directly or energy sources that can be decarbonized, for example electricity or district heat.

Zero emission vehicles (ZEVs)
Vehicles that operate without emitting CO2 emissions (such as battery electric and fuel cell vehicles).

ENERGY PRODUCTION

NEW SOLAR

Concentrated Solar

Concentrated solar power (CSP) uses parabolic mirrors or "heliostats" to focus sunlight and generate extremely high temperatures. A common implementation of CSP is the "power tower," in which concentric circles of heliostats all focus on the receiver of a single, central tower hundreds of meters off the ground. Although the concept was first developed in the 1970s and '80s, new methods and plant designs have inspired a modest resurgence, particularly in Australia and Africa. Bolstering the case for CSP plants is the dispatchability of the energy generated. Because CSP generates thermal energy, it can be transferred using liquid sodium and stored long term in molten salt reservoirs. Due to the abundance of the elements required, large-scale thermal storage would be relatively cheap when compared with the rare earth elements needed for electric batteries, such as lithium and cobalt. For this reason, concentrated solar is being viewed as an economical alternative to photovoltaic solar for nighttime use.

Multitasking Solar

Companies are building new solar installations with a mind toward additional benefits beyond electrical power generation. When installed in tandem with wind turbines, solar panels are arranged to take advantage of the Venturi effect, essentially creating wind tunnels. These configurations increase airflow and wind turbine output by up to 60%. Solar windows are becoming transparent enough not to impact aesthetics in building construction, thanks to organic semiconductors that can be liquified and spread as a coating on glass. In California, a pilot program dubbed Project Nexus is placing solar panels above irrigation canals in the San Joaquin Valley. Researchers estimate that placing similar solar panel canopies above the state's 4,000 miles of open canals would generate 13 gigawatts of power while simultaneously saving 63 billion gallons of water annually in a region that has seen severe drought over the past decade. The solar canopies cool water temperatures, halt evaporation, and prevent the growth of water-based plants.

Dispatchable Solar

Dispatchable power enables a generation source to scale up or down based on fluctuations in demand. Solar power installations, traditionally implemented in a way that always maximizes energy output, are getting smarter, able to adjust individual panel angles to change their aggregate power generation and better accommodate the needs of the grid. On large-scale solar farms, this system of dispatching can go so far as to independently adjust subsections of panels, or even individual panels, to compensate for others that are temporarily obscured by cloud cover or experiencing operational issues, thus ensuring a responsive and consistent output. Counterintuitively, many of the problems with static solar power generation stem from creating too much power: When the sun is at its zenith and solar generation peaks, solar plants can potentially produce so much energy they overwhelm local electric grids. Dispatchable solar power eliminates this problem, creating a more dynamic and responsive source of power.

Perovskite Cells

Perovskite is a crystalline compound that can be used as a semiconductor in solar cells as an easier, cheaper, and more sustainable alternative to silicon. Furthermore, it is transparent and flexible, making it easier than silicon to integrate into the landscape. In April, researchers at the King Abdullah University of Science and Technology in Saudi Arabia developed a new combination silicon/perovskite solar cell, which achieved an efficiency of 33.2%, a new world record for two-junction solar cells. Advances in perovskite-based cells are occurring quickly, and the technology is regularly setting new efficiency and lifetime records.

NEW SOLAR

Dye-sensitized Solar Cells

Dye-sensitized solar cells (DSC) are made using organic dyes that capture photons from light. They are cheaper to manufacture than silicon solar cells, more flexible in their design, and can even be semitransparent. Further, they operate on a wider spectrum of light than traditional silicon solar cells. Ambient Photonics, an Amazon-backed startup, has completed construction on a new, large-scale DSC manufacturing facility. The company claims its products can operate at low levels of light, such as indoor environments, and is aiming to eliminate the need for batteries in small electronic devices.

Organic Solar Materials

Organic solar materials that can be printed or stuck onto surfaces have continued to shrink in size. These photovoltaics can be 50 microns thin, less than the width of a human hair, and can be adhered to surfaces after they're manufactured, ostensibly making any surface a power-generating opportunity. Because of the small footprint of organic solar cells, they can also be adhered to transparent surfaces. As a result, solar windows are reaching the point where they are transparent enough not to impact aesthetics and could be used more widely in buildings. Recent experimentation aims to increase these organic solar cells' viability for power production on larger areas.

Solar Thermophotovoltaics

While normal photovoltaic cells respond only to less than half of the sun's rays that are visible, solar thermophotovoltaics create electricity from heat waves. Antora Energy, a US-based startup, has completed a large-scale manufacturing facility that produces thermophotovoltaic cells with 40% efficiency. Meanwhile, researchers at the University of Houston have developed a new design for thermophotovoltaic cells with an improved intermediary layer, which prevents thermal energy from being wastefully radiated away. This development could push efficiency levels even higher.

Flexible, transparent solar cells might soon be adhered to building windows.

NEW WIND

Offshore Floating Wind Turbines

Offshore floating wind technology is growing with changes in base designs, innovative turbine configurations, and strengthened regulatory backing in the US and Europe. In recent years, "super-sized" structures have become popular as major players unveil groundbreaking designs. Among these is Wind Catching Systems, a 2017-established entity situated near Oslo, Norway. Pioneering the multi-turbine approach, the company focuses on a "floating wind power plant." The Dublin-based Gazelle, a company focused on advanced offshore wind platforms, has introduced a new hybrid dynamic mooring system—this revolutionary platform design promises unmatched stability, courtesy of its lightweight and compact structure and flexibility as it can be seamlessly assembled at global port facilities. In the realm of US regulation, the Biden administration has announced a comprehensive 20-month study of the West Coast's burgeoning floating offshore wind potential. This investigation aims to optimize transmission networks and connect the grid with pioneering floating wind projects; it will be supported by a $100 million public fund.

Vertical Wind Turbines

Vertical wind turbine innovation reached a milestone with Norway's March 2022 approval of a vertical-axis floating wind pilot project. SeaTwirl and the Marine Energy Test Centre will test the prototype for five years near Lauplandsholmenoff. The project's progress stalled due to appeals from environmental and fishing groups, but Norwegian regulators' rejection of the appeals ensures SeaTwirl's S2X pilot can move forward without further challenges. Additionally, 3D-printed vertical wind turbines are growing, with several companies experimenting.

Going Bladeless

New innovation in wind turbines includes evolving designs beyond traditional blades. O-Wind has pioneered an omnidirectional design that simultaneously captures winds from all directions, a breakthrough that uniquely blends horizontal and vertical flows to cater to the chaotic wind patterns of urban areas. Available in varied sizes to suit diverse buildings, O-Wind turbines can connect to the grid or operate independently with battery units. From Xenecore, a design that incorporates I-beam ribs and microsphere structural foam amplifies power generation with its fan-shaped wind blades. And because the future needs wind technology that will work at relatively low wind speeds, the fastest-growing energy sector across the globe is bladeless wind energy. It leverages vortex shedding, a vorticity phenomenon, through a vertical cylinder affixed with an elastic rod. It oscillates within the wind's range and powers an alternator system to generate electricity. Prominent players include Vortex Bladeless, Tyer Wind, Agile Wind Power, Silent Wind, and Sway Turbine AS in Europe; Saphon Energy in Africa; and, Mag-Wind Vertical Axis Turbine, Atmocean, Enomad, and SheerWind in the US.

Airborne Wind Energy

Kitemill, a Norwegian enterprise, is pioneering the advancement of airborne wind energy, which involves attaching a turbine to a flying device, to revolutionize wind energy's effectiveness, versatility, and affordability. Its latest triumph, the KM2 system, is double the size of the KM1 prototype, has a 16-meter wingspan, and integrates four propellers for vertical takeoff. The system can generate an average power cycle of 100 kilowatts. In another promising collaboration, EnerKíte and Volkswagen embarked on a feasibility study to explore the potential of a mobile e-charging station. These innovative airborne wind turbines hold the promise of charging electric vehicles even in the remotest regions, reducing reliance on conventional power grids and enhancing green mobility.

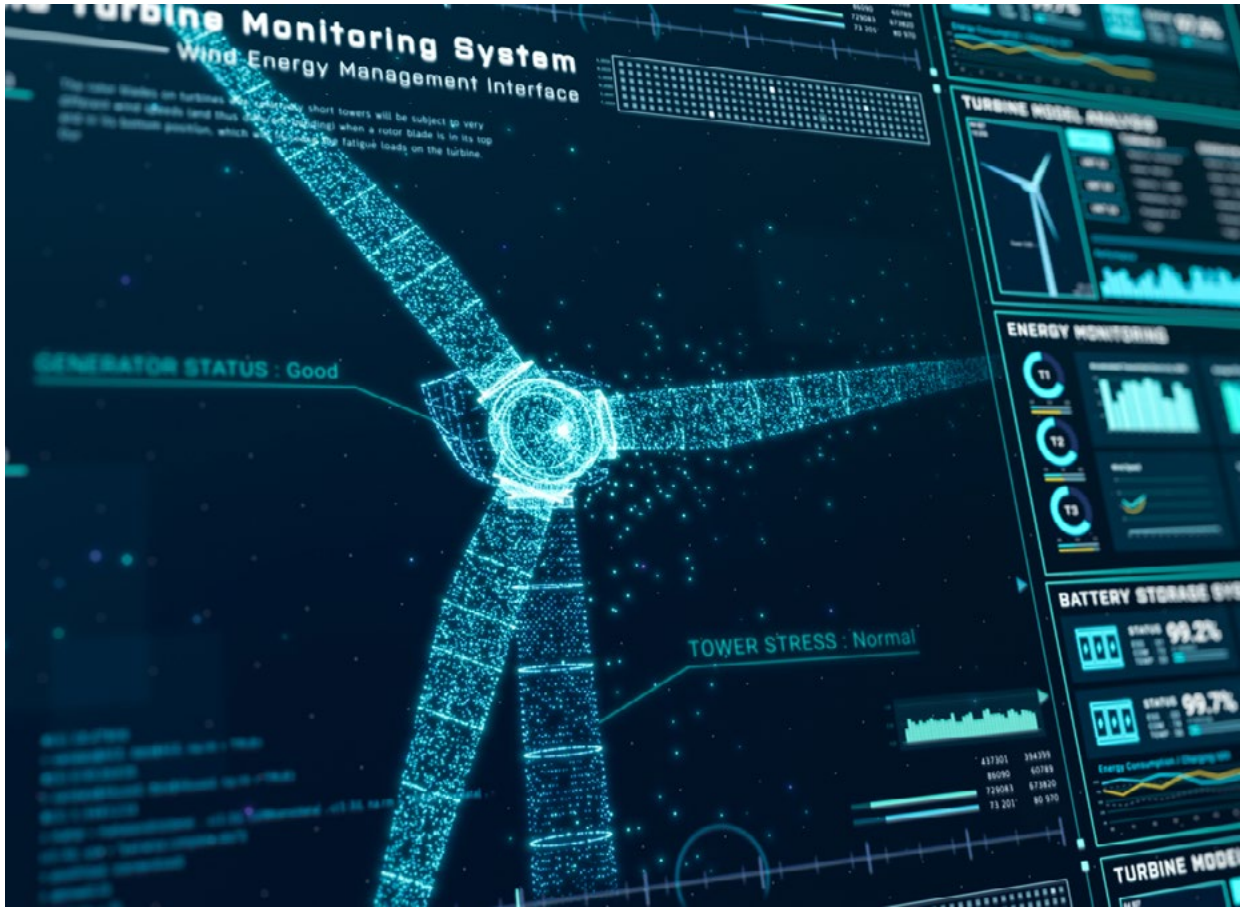
NEW WIND

AI Wind Farms

Like most other industries, AI is also reshaping renewable energy. Israeli company vHive has introduced an advanced tool for wind turbine inspections, leveraging autonomous data collection and a novel digital twin platform. This innovation empowers wind farm operators to strategically digitize assets, elevate operational efficiency, and curtail output decline. UK's Cognitive Business is working with RWE's Robin Rigg offshore wind farm, delivering an AI-powered package that encompasses pattern recognition and production forecasting to ensure precise maintenance predictions and optimal performance. AI has also proven pivotal in the setup, upkeep, and enhancement of offshore wind farms. The Dhalion Inspection System by Perceptual Robotics is an interesting example with a fully autonomous solution for wind blade inspection, encompassing data acquisition, insights, and decision-making.

Dispatchable Wind Energy Production

As scientists find more ways to store wind energy, it will grow as a dispatchable electricity solution from which power grids can demand electricity based on market needs. One way to ensure such storage is by fusing hydrogen with the grid, like what's being done in the Netherlands. There, an alliance of prominent partners led by Shell is using hydrogen from offshore wind energy plants to stabilize the electricity grid, and aims to maintain 70% renewable electricity by 2030. The FlexH2 consortium, which includes TNO and other industry players, collaborates closely on joint research and pioneering technology development, expediting integration into the energy matrix.



AI helps to make Windfarms more efficient and maintain and optimize performance.

OTHER RENEWABLES

Geothermal

Unlike other renewables, geothermal energy represents a stable source of power that doesn't fluctuate with time of day or weather patterns. This energy can be harnessed by tapping into hot water and steam reservoirs beneath the Earth's crust. Once accessed, it can be used for direct heating or to generate electricity through geothermal power plants.

Supercritical Geothermal

Supercritical geothermal energy production requires going deeper into the Earth's crust than conventional geothermal, tapping into the extreme temperatures and pressures present there (in excess of 374 degrees Celsius and 221 bar, respectively). While containing enormous power generation potential, these conditions also present extreme technological challenges. Some of those may be alleviated by recent research, which has focused on tapping into supercritical geothermal fluids at sites adjacent to volcanic activity. At these sites, extreme temperatures and pressures can be found closer to the Earth's surface, greatly reducing the risk and investment required to utilize them. In Japan, the New Energy and Industrial Technology Development Organization has been experimenting in volcanic regions of Hokkaido. Meanwhile, new geothermal research and startups push the boundaries of existing technologies. Researchers are testing working fluids composed of supercritical carbon dioxide to transfer and pump heat back to the Earth's surface. Companies are developing new tools, like Thermochem's probe and logging tool rated to operate at temperatures up to 400 degrees Celsius. Barriers to development remain, however, mainly in the form of policy and international cooperation.

Using Geothermal for Energy Storage

Geothermal energy storage techniques hold energy in the form of increased temperature and pressure which is "pumped" into the earth and released as needed. Researchers and government agencies are looking closely at this option for storing sustainably generated energy in lieu of massive banks of electrical batteries, which require large quantities of rare earth elements and are not as efficient. Multiple research efforts have recently focused on using carbon dioxide as the storage medium, which has the added benefit of sequestering greenhouse gases. In the US, the National Renewable Energy Laboratory has begun efforts to identify high storage potential sites, and in Germany, the Karlsruhe Institute of Technology is evaluating how geothermal energy storage might be integrated into the existing grid.

Ocean Thermal Energy Conversion

Ocean thermal energy conversion generates power from the temperature difference that exists in ocean water. Because this difference is unaffected by weather and climate conditions, it represents a reliable source of sustainable energy. Furthermore, the seawater output from the process is usable in commercial applications such as fisheries, agriculture, and air conditioning. Japanese shipping company Mitsui O.S.K. Lines has announced a pilot program that would pump water from a depth of 600 meters at near-freezing temperatures to be used in a titanium heat exchanger; the process is expected to generate 1 megawatt of electric power by 2026.

Hydropower

Accounting for more than 15% of global electricity generation in 2022, hydropower continues to be the largest source of renewable power, contributing more than wind, solar, and biofuels combined. New opportunities for hydropower manifest in efficiency, storage, and small scale (but widespread) deployments.

Digitalization

Hydro plants have invested significantly in digital management for their equipment and systems, all with the aim of optimizing energy output and safety. Utilizing cloud computing and big data, operators hope to build machine learning models to guide automated decision-making in these complex environments. Given the risk involved with such a digital transformation, some operators have even

OTHER RENEWABLES

opted to create digital twins of their plants, enabling a safe environment for training the algorithms of the future. Spain has made significant investment so far, and officials plan to onboard 160 of its power plants to a digital management platform. China, too, is making strides, and officials have put all data from the Three Gorges Dam (the largest hydroelectric project in the world) into the cloud of Chinese company Huawei Cloud.

Small Scale Hydro

Small scale hydro projects are allowing energy suppliers across the globe to add more renewable energy generation to their portfolio without the need for massive, upfront investments of capital. In California, a pilot program led by startup Emrgy places small, modular turbines into irrigation canals to produce modest amounts of electricity, between 2 and 10 megawatts. The turbines operate in a manner that does not require damming the water. This, paired with the fact that all the canals used are pre-existing, means the impact to the local environment is minimal.

The European Union has also funded pilots for small scale hydro in sites across Central Asia. Though this region has the world's second largest potential for hydroelectric power, larger hydro developments there have been slow due to political, economical, and legal factors, such as water rights claims and concerns about environmental impact. Small scale hydro has the ability to simultaneously provide a significant source of power while avoiding many of those pitfalls.

Hydro as a Water Battery

Hydro storage, or "pumped storage," involves pumping water into uphill reservoirs when energy is cheap (or when renewables are operating) and then allowing that water to flow downhill and generate energy as needed. Recently, large investments in the field have been made across the globe. Switzerland just opened a 20-gigawatt-hour plant in the Swiss Alps that can transition from energy storage to energy generation in less than 10 minutes. In Utah, a $2.5 billion project broke ground that could provide 9GWh in capacity by 2031. Spain started building a 200 megawatt plant in the Canary Islands. China, meanwhile, continues to lead the world in pumped storage capacity, with 51 gigawatts currently in operation and more planned to come.

New Turbine Design

Companies continue to innovate on the design of hydro turbines. Turbulent, a Belgian engineering company, has developed an underwater vortex turbine capable of operating in remote locations. With low maintenance and water flow requirements, it is ideal for rural communities with simple irrigation. Similarly, Emrgy is working on hydrokinetic turbines that can be dropped into canals and other low pressure, low flow environments. Voith Hydro in Germany made adjustments to the centuries-old Pelton Wheel design, which allows its turbines to operate in a horizontal configuration, as opposed to vertical. More injectors can be utilized in its operation, increasing its overall output. Additionally, companies such as Natel are working to minimize the environmental impact of hydropower. Its latest turbine implements a curved blade design aiming to drastically reduce the rate of marine life fatality for creatures passing through.

CLEAN FUELS

Hydrogen

Hydrogen fuel technology has been around since the 1950s, and for the past 75 years, it has served as the main propulsion source for spacefaring vehicles. Recent developments, including updated designs for hydrogen fuel cells, have reignited conversations of using the fuel source closer to home. In particular, "green hydrogen" (hydrogen fuel produced using renewable energy), has been viewed as an emissions-free alternative for long distance naval, aerial, and ground transportation. However, issues of economics and scale remain.

Reducing the Cost of Hydrogen Production

Researchers are making progress in reducing the cost of green hydrogen generation. Many of these efforts focus on improving the materials coating the electrodes used to extract pure hydrogen from water. Separate research teams, both in Korea, have perfected protective titanium oxide coatings that reduce corrosion in the electrodes and have experimented with using cheaper iron nitride as a coating alternatives. An Oxford-based team has pursued similar coating-based improvements, focusing on alkaline electrolyzers. Meanwhile, American company TFP Hydrogen has announced plans to scale up its electrolyzer coating capacity threefold over the next year, up to 600 megawatts annually. Canada-based Loopflow has developed a new fuel cell design with a unique geometry and flow field properties that increase the stability of internal conditions and efficiency.

New Base Materials

Currently, hydrogen is typically extracted from treated freshwater. As issues of water scarcity continue to grow, hydrogen power companies have sought to harness alternative sources. Efforts in Guam, the Netherlands, and Australia have focused on using seawater, both treated and untreated, for hydrogen generation. A large EU pilot program will explore using wastewater as a base material. Other efforts are looking into an even more direct method: accessing "geologic hydrogen," or sources of pure hydrogen trapped in the earth, in gaseous or other forms.

Biofuels

Biofuels encompass any fuel made or derived from organic matter—typically corn, sugar cane, or soy. These fuels include ethanol, biodiesel, and biogas. While biofuels represent an alternative to fossil fuels, concerns have arisen over the amount of farmland needed to provide significant amounts of energy and the impact large scale operations might have on food systems.

Biofuels From Hemp

Hemp represents a unique opportunity for biofuels. It can be turned into multiple types of fuel (e.g., ethanol, methanol, biodiesel) and boasts one of the highest energy densities of any land-grown crop. However, the plant's association with cannabis is often seen as hindering widespread adoption (industrial hemp has only a fraction of the THC associated with recreational marijuana). A bipartisan bill in the US hopes to change that by deregulating hemp and legally decoupling it from cannabis. Meanwhile, researchers at Texas A&M are breeding new

Hemp's high energy density makes it a great source for biofuel.

CLEAN FUELS

strains of hemp that are both suitable for the state's dryer climates and fall within THC compliant ranges.

Biofuels From Algae

Through photosynthesis, certain kinds of algae can produce biofuel. As added benefits, they absorb carbon dioxide and grow organically. In spite of this, scaling biofuel extraction from algae is slow and expensive. Researchers in Brazil have conducted experiments with microalgae in which they "stress" the culture to induce it to make more lipids, the key component in biofuel production. Other experiments have focused on genetically modifying algae to optimize their efficiency and survivability characteristics. United Airlines has invested $5 million in biofuel startup Viridos, which focuses on producing sustainable aviation fuel from algae in seawater.

Syngas From the Sun

Synthesis gas, or syngas, is a mixture of hydrogen and carbon monoxide that can be used as fuel and in the production of methanol. Researchers at the University of Cambridge have devised a solar-powered reactor that extracts carbon dioxide from industrial waste, or even from the atmosphere, and converts it into syngas using what they describe as "artificial leaves." By infusing ceria (a common material used in syngas production) with a nickel catalyst, researchers at the University of Florida have demonstrated the ability to create syngas at lower temperatures—700 degrees Celsius instead of 1,000 degrees—a reduction that provides economic benefit to producers.

Scientists are exposing algae to stressors to increase lipid production, the key component for biofuels.

FOSSIL FUEL INNOVATION

Rededication of Contaminated Land

Abandoned coal mines could be the solution to warming homes in Europe, where homes across the continent are sitting on top of old mines filled with warm water. The water gets warmer the deeper it goes and can be brought up through boreholes, run through heat pumps and extractors to increase the temperature even more, and then sent through heating networks to warm homes. Once the water is used, it can be redirected back into the mines where it is heated again. The UK is currently exploring this project beginning with 12 preliminary boreholes in Glasgow.

Reducing the Carbon Footprint of Fossil Fuels

In many countries, regulators and researchers are attempting new ways to reduce fossil fuels' impact on the climate crisis. The US Environment Protection Agency has proposed new regulations on limits for pollutants from American coal and gas power plants, forcing facilities to track and report emissions. Korean companies have successfully operated a gas turbine with a cleaner 60% hydrogen blend fuel. Japan is turning coal into "clean hydrogen" through the Hydrogen Energy Supply Chain project, which uses carbon capture and storage technology and has attracted $2.35 billion in investment. Botswana is working with South African-based Sasol's extensive coal resources to produce synthetic fuels to support Europe's energy crisis. And in the UK, Net Zero Teesside Power is on track to be the world's first commercial-scale gas-fired power station with carbon capture. The project will drive the UK government toward its decarbonization goals and produce enough electricity to power 1.3 million homes per year.

Methane Emissions Reductions

Methane, a potent greenhouse gas, plays a major role in trapping heat in the Earth's atmosphere. Recognizing its importance as a driver of climate change, regulators and scientists are turning their attention to finding ways to reduce methane emissions. The Inflation Reduction Act contains the first ever greenhouse gas fee in the US. Oil and gas companies will pay a fee if they emit more than 25,000 tons of carbon dioxide equivalent per year into the atmosphere, thus spurring innovations in methane emission monitoring to avoid the fee. A team of Princeton University researchers has developed extremely agile drones with remote-sensing lasers to detect gas leaks up to 25 times smaller than can be detected using traditional methods. The drones only require a small mirror and laser and can be outfitted to measure other gases such as carbon dioxide and ammonia as well as methane. Swiss-based Distran, an innovator in ultrasonic camera technology to detect gas leaks, has recently closed $8.3 million in funding to diversify their products and tap into new markets to expand the safety of industrial plants and reduce their environmental impact.

Abandoned coal mines could support warming homes in Europe.

NEW NUCLEAR

Fusion

Long considered the "holy grail of energy production," nuclear fusion technology would allow humans to emulate the atomic process that powers the stars. Most experimental fusion reactors today seek to fuse hydrogen atoms into helium, the same reaction our own sun has been conducting for billions of years. This reaction creates substantial amounts of energy in the form of extremely fast moving atomic particles, which can be converted to heat and then used to power generators. The only byproducts are heavier (potentially useful) elements and trace amounts of radiation at harmless levels. Given the cosmic abundance of hydrogen, nuclear fusion would provide a virtually limitless source of energy.

Fusion Momentum

Following the Lawrence Livermore National Laboratory's landmark achievement in 2022, when researchers created the first human-controlled, net-positive energy-producing fusion reaction, conversations around the technology have reignited, capturing the attention of both private and public sectors. Lawrence Livermore has already repeated—and improved upon—its initial experiment. Startups funded by tech millionaires have begun to enter the field. However, large obstacles remain—namely the massive amount of investment and lengthy timelines needed to develop the technology into something meaningful. Even the most generous estimates place large scale nuclear fusion over 30 years away, a sobering reality check given the planet's immediate need for sustainable sources of energy.

Privately led Fusion Projects

The US Department of Energy injected capital into a growing ecosystem of private fusion projects, by distributing $46 million in funding to eight companies. Incumbent players, such as TAE Technologies, continue to iterate and produce new reactor designs while newer ventures, such as the Sam Altman-backed Helion, aim to bring a Silicon Valley-esque sense of disruption to the industry by targeting small scale reactors. German startup Proxima Fusion has raised $8.6 million to pursue a twisting, new reactor design, one drastically different from the widely used, toroidal tokamak design.

Molten Salt Reactors

Although the idea of using molten salt as a coolant for nuclear fission reactors has been around since the 1950s, it was more or less abandoned as most commercialized nuclear installations opted for water cooling instead. Now, companies and researchers are revisiting the concept, seeing it as a way to increase efficiency (by making it easier to extract thermal energy), generate additional fissile material (which can then be used in subsequent reactions), and reduce radioactive waste. Researchers at MIT plan to explore the practicality of molten salt reactors while companies such as Kairos Power and TerraPower are developing commercial models.

Laser-Driven Fusion

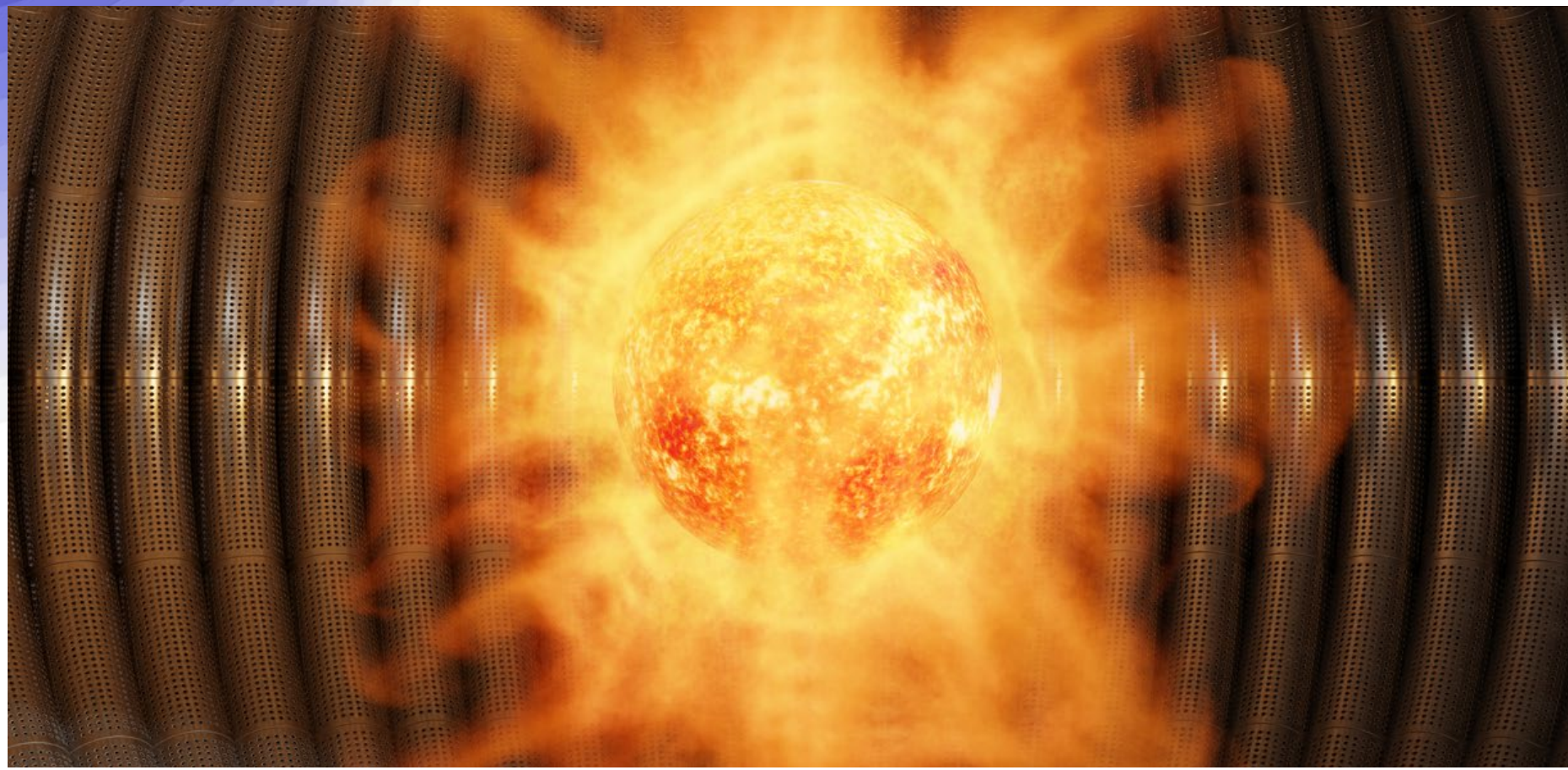
Laser-driven fusion, also known as "inertial confinement fusion," is a means of triggering fusion reactions by firing high energy laser volleys at small pellets of deuterium and tritium to increase temperature and pressure. Following the landmark net positive fusion reaction from Lawrence Livermore in 2022, which utilized laser-driven ignition techniques, additional funding is finding its way into the space. Marvel Fusion, a German startup, plans to build a $150 million high-power laser and fusion research facility at Colorado State University. With an expected completion date of 2026, the facility will be the most technologically capable research site for laser fusion energy and high-energy density physics.

Small Modular Reactors

Early in 2023, the US Nuclear Regulatory Commission certified the first design for a small modular reactor capable of nuclear fission, meaning utilities can now select it when building a new power plant. This could represent a major opportunity for new nuclear proj-

NEW NUCLEAR

ects, especially as a complementary solution to less reliable emissions-free generation, such as solar and wind. Conventional nuclear power plants are bespoke, heavily site-dependent, and must be constructed on-site. These small modular reactors can be factory made and integrate much more easily into existing grids. The approved design is rated at 50 megawatt output though the company behind it, Nuscale, is hoping to get higher capacity models approved soon.



Extraordinary sums of money continue to flow into nuclear fusion, however, timing for scaling remains elusive.

EMERGING FORMS OF ENERGY PRODUCTION

Energy From Thin Air

New technology is being developed to create clean energy from the materials in the Earth's atmosphere. At KU Leuven University, Belgian researchers have created solar panels that produce hydrogen from the water vapor in the atmosphere and convert it into electricity via a hydrogen fuel cell. The hydrogen panels will be on the market through the startup Solhyd; they can produce up to 250 liters of hydrogen a day, and the gas can be stored in a tank to use later. At the University of Massachusetts Amherst, researchers have developed a device that harnesses the same technology as lightning, by using electricity generated from water droplets passing through the generator's porous material. The "air generator," or Air-gen, can make clean electricity almost anywhere and runs only on ambient humidity, providing a completely sustainable energy source. And in Australia, an enzyme has been found by scientists that can do something similar, by turning air into energy. The enzyme, commonly found in soil, can create electrical currents using low amounts of hydrogen in the atmosphere.

Wave Power

Wave power, or using wave energy to create electricity, is a growing industry that is expected to increase 4.7% to $30.44 million by 2030. In Australia, Wave Swell Energy has done this with floating devices. The company uses the concept of oscillating water columns to power its turbines: As waves push water up and down into a hole at the bottom of the floating devices, the air in the space is pushed out of the device and in turn spins a turbine that creates electricity. Closer to shore, Eco Wave Power uses"floaters" that can be attached to existing man-made structures. These floaters rise and fall, moving a piston, accumulator, and hydraulic motor to create power in a generator. The company's floaters were added at the Port of Los Angeles and are currently being scaled up; they could generate up to 69% of California's electricity production if fully scaled. And on the support side, AWS Ocean Energy, who is currently working with Wave Energy Scotland, is providing technology and services for those in the marine energy industry. The company services oilfield infrastructure, aquaculture, and renewable energy resources to maritime communities.

Tidal Turbines

Underwater, companies are turning the movements of the tide into electricity. Scotland's MeyGen tidal power project, an array of four underwater turbines about 66 feet below the ocean's surface, has generated 50 gigawatt hours of electricity as of February 2023, the first of its kind to do so. This is roughly equivalent to the annual electricity consumption of 4,700 US homes. Off the coast of Eastport, Maine, Ocean Renewable Power Co. is beginning to test turbine generators that could be commercially viable. The turbine will have a 12 month test period, and then the company plans to implement a full scale four turbine system further along the coast. There are also many other tidal energy startups that have secured substantial funding, showing a trend in attention returning to tidal power, including Sustainable Marine Energy, which raised $11.3 million; Orbital Marine Power, which raised $11.4 million; and Verdant Power, which raised $8.73 million.

Mimicking Photosynthesis

Researchers at the University of Cambridge have made a groundbreaking discovery in the photosynthesis process that could change how we generate renewable energy and clean fuel. Photosynthesis powers a majority of life on Earth, and it was previously believed that the chemicals that can extract electrons occurred later in the photosynthesis process. However, researchers discovered it takes place much earlier and pathways exist to move electrons that were previously unknown. This new discovery opens up new ways of using power and the ability to mimic photosynthesis to create clean fuels from water and sunlight. This ability to regulate photosynthesis could also increase crops' ability to tolerate sunlight in a world facing climate change.

ALTERNATIVES TO MINERALS AND RARE EARTHS

Local Sourcing

Chinese mines account for about 60% of the global supply of germanium and 80% of gallium—minerals used in everything from smartphones to electric car batteries. Last year, in what appeared to be retaliation for American technology trade limitations, China enacted heavy export restrictions on these materials, sending many nations scrambling to find alternate sources. These actions have raised concerns that restrictions on rare earths, which China also dominates (70% of global production), might not be far behind. As a result, in recent years Australia, Canada, the US, and the EU have all invested in finding domestic sources of rare earths. For example, mining company Northern Minerals has invested $80 million in the exploration of the Browns Range in Western Australia and plans to use the site to add dysprosium and terbium to its current offerings of neodymium and praseodymium. The demand for rare earths has also kicked off a heated debate over deep sea mining and which countries can lay claim to the rich resources on the ocean floor; however, international law does not yet permit such large scale operations, and the environmental impact is not well understood.

Alternative Materials

As another strategy to decrease dependency on rare earths, researchers have begun developing alternative materials to replace them. A number of Japanese companies claim to have developed valid substitutes in the magnet space. Proterial has produced a “high performance ferrite magnet” made from iron that claims to replace neodymium magnets in electric vehicle motors. Automotive parts manufacturer Denso has purported a similar breakthrough, making a magnet using iron and nickel. Others have developed a design using iron and samarium. It is perhaps not surprising that these companies are all based in Japan; that nation was the first to feel the brunt of China’s rare earth trade restrictions in 2010.

Rare Earth Avoidance

Certain manufacturers have attempted to strengthen their supply chains by reducing, or completely eradicating, their need for rare earths. Vitesco Technologies, an electric vehicle parts manufacturer, has developed an “externally excited synchronous machine” (ESM) motor design that can replace the permanent magnet synchronous motor (PSM) design that currently dominates the EV market. In high-performance vehicles, which often require larger or more powerful magnets, the ESM design offers an economic advantage over the PSM design due to its reduced dependence on costly rare earth elements. Tesla has likewise announced a powertrain design that reduces the company’s dependence on rare earths, citing economic, stability, and environmental motivations.

Countries are looking to diversify their sources for rare earth and minerals.

SCENARIOS

SCENARIO YEAR 2035

What If the World Runs on Thermal Energy?

In 2035, Thermal Symphony Networks power our world with renewable energy. This technology's dual capabilities are leveraging temperature contrast for clean electricity generation and provide heating and cooling with no moving parts. Initially designed to enhance urban energy production and efficiency where wind and solar were not as easily integrated, Thermal Symphony Networks quickly transcended their purpose: sidewalks paved with thermoelectric tiles captured footfall heat to power nearby buildings, and architectural facades lined with thermoelectric panels balanced indoor temperatures while generating electricity.

As the networks gained traction, industries experienced a paradigm shift. Farmers established "Energy Orchards," where temperature-controlled environments enclosed by thermal tiles optimized crop growth while generating power. Global maritime transport saw the implementation of thermoelectric ship coatings, converting temperature differences between ocean water and cargo into energy. Electric vehicles equipped with thermoelectric systems harnessed the heat generated during braking to recharge their batteries, extending their range. Airports showcased runways embedded with thermoelectric materials, converting the temperature contrast between asphalt and air into additional power for terminals.

The benefits of Thermal Symphony Networks even extend underwater: The technology's heat exchange mechanisms promote coral reef health, reversing the damage caused by rising sea temperatures.

ENERGY INFRASTRUCTURE

ENERGY STORAGE

TPV Batteries

Given the inherent intermittency of wind and solar power, electricity generated from these sources needs a more dependable energy storage system that would work irrespective of weather patterns. TPV batteries are one such solution to bottle and store renewable energy.

Experiments are being conducted across the world to find storage alternatives that are affordable, eco-friendly, and scalable. In Italy, Enel X and Magaldi Group are building a 13-megawatt-hour thermal energy storage using patented fluidized sand bed technology. This stores heat that is then used to release steam at 120-400 degrees Celsius. In Spain, researchers created a battery that uses renewable power to melt metals like silicon, storing latent heat that powers a thermophotovoltaic generator to produce electricity. In the US, Antora Energy has innovated on TPV (thermophotovoltaic) technology to convert carbon block light back into electricity, offering cost-effective and emissions-free heat and power innovation. Using wind and solar energy to heat solid carbon blocks over 1,500 degrees Celsius, Antora can also provide its technology to industrial processes requiring high levels of heat. In line with the idea of ensuring high-temperature stability, a novel nanophotonic material—embodying structural variations on a scale comparable to the wavelength of light—has shown promising potential for efficient production and control of thermal radiation. Scientists at the Lawrence Berkeley National Lab and Scripps Research are also exploring new ways to handle high energy levels in extreme conditions.

Iron Batteries

With its abundance, iron continues to be a reliable source for energy storage, and companies are devising new ways to use iron batteries to do this on a large scale. Form Energy, a startup, will supply iron-air batteries to Xcel Energy's 1-gigawatt-hour project that is slated for operation in 2025. Lithium-iron batteries are also gaining popularity. While their environmental and geopolitical significance has always been central to growth, technology has also bridged the performance gap with materials like nickel and cobalt. Our Next Energy, a startup, is launching production of lithium iron phosphate (LFP) batteries in Michigan. It plans to expand via a new $1.6 billion plant that will supply 200,000 electric vehicles with LFP batteries by 2027. Among the larger companies, Ford has chosen to license LFP battery technology from China-based CATL to provide more cost-effective options for customers, while General Motors is also exploring using LFPs to cut costs. Delta has introduced an outdoor lithium-iron battery system meticulously tailored for megawatt-level energy storage applications, addressing the pressing requirements for grid ancillary services, solar plus storage, and backup power assurance.

Solid State Batteries

Introducing a groundbreaking leap in making battery-powered flight a reality, NASA's Solid-state Architecture Batteries for Enhanced Rechargeability and Safety (SABERS) team has unveiled a sulfur selenium prototype battery with a high energy density of 500 watt-hours per kilogram. With a storage capacity twice that of traditional lithium-ion batteries, these batteries offer the rapid discharge capabilities necessary to be used in aircraft. Toyota has set its sights on launching solid-state batteries in its mass-produced EVs by 2027. The company has discovered a new way to simplify the production of solid-state batteries and enable shorter charge times with an extended driving range. Nio, an EV company, in an update to its user manuals, has introduced a new 150 kilowatt-hour semi-solid state battery pack alongside its existing battery lineup. The Nio ES6 model in China will incorporate these solid-state batteries. Factorial Energy, a solid-state battery developer, has forged collaborative partnerships with Hyundai, Kia, and Mercedes-Benz to implement its vision of scaling solid-state technology by 2026. The company has expanded beyond the US to South Korea, Japan, and Germany. Furthermore, the realm of 3D-printed solid-state batteries holds transformative potential, promising enhanced energy storage solutions for various applications.

ENERGY STORAGE

Gravitational Energy Storage

In exploring innovative energy storage solutions, gravitational energy is gaining traction as a way to create kinetic energy. Swiss company Energy Vault is nearing completion of gravity battery installations in the US and China that are projected to produce 36 and 100 megawatts, respectively. Australian startup Green Gravity has joined forces with mining contractor RUC to fast-track the adoption of its gravitational energy storage technology. Their technology moves ultra-heavy weights in mine shafts to turn turbines and create electricity. Meanwhile, UK-based Gravitricity is set to initiate pilot demonstrations of its gravity energy storage systems in India, with plans for broader deployment in the future.

Flow Batteries

An emerging idea, flow batteries leverage the flow of special liquids to generate electric current. Pacific Northwest National Laboratory is using β-cyclodextrin, a basic sugar extracted from starch, in a flow battery formulation. This innovative sugar can be synthesized within laboratory settings, offering a sustainable and environmentally friendly alternative to currently used materials. The US Army collaborated with Lockheed Martin to test a new flow battery that aims to store energy for a longer duration and at scale. Called GridStar Flow, this rechargeable flow battery will use engineered electrolytes to charge itself. Energy Dome, an Italian startup, is using "CO2 Battery" to store energy. With fresh funding secured, the tech company plans to operationalize two standard 20MW-200MWh frames by the close of 2024.

Capacitors

Supercapacitors store and release electrochemical energy using a flow of electrons between two conductive plates separated by an electrolyte. Skeleton Technologies, an Estonian company working on energy storage technology, has introduced the SuperBattery, which combines the attributes of supercapacitors and batteries. This innovation boasts an extraordinary charging speed 100 times faster than lithium-ion batteries, coupled with an impressive life cycle of 50,000 cycles and higher safety standards. Additionally, a research group at Japan's Osaka Metropolitan University has developed a highly deformable solid electrolyte. Being touted as the world's first bulk-type all-solid-state capacitor, this capacitor can function at high current densities and promises higher efficiency and performance.

Compressed Air Storage (CAES)

These systems use high pressure air to spin turbines and generate electricity. Currently, only two commercial CAES plants exist globally: the Huntorf plant in Germany and the McIntosh plant in Alabama. They utilize diabatic processes, where off-peak electricity compresses air for storage, later mixing it with natural gas for combustion during peak demand. Hydrostor, a Toronto-based developer, has devised an innovative plan scheduled for completion in 2028; it involves drilling three deep shafts that are about 100 yards high and as long as two football fields. The company will use excess renewable energy to compress air into them, later releasing high-pressure air to generate power. Stanford University researchers have developed a model to gauge the required compressed air storage for deep decarbonization of power systems. Testing their model on California's energy grid, the group has highlighted the cost-effectiveness of compressed air storage on a dollars-per-kilowatt-hour basis as compared with other sources of energy.

ENERGY TRANSPORT

UHV Power Lines

Ultra high voltage (UHV) power lines can efficiently carry electricity over long distances with minimal loss, enabling energy optimization across vast areas. While China leads UHV use, other countries and alliances across the world are exploring projects to use this technology. One example is the North Sea Wind Power Hub, a collaboration from nine European countries to generate 120 gigawatts of wind power by 2030 and 300GW by 2050. The project aims to support Europe's transition to a low-carbon energy system through wind power and uses UHV transmission lines to interconnect the electricity grids of these different countries. Beyond Europe, India, Brazil, and Russia are also exploring UHV implementation.

Superconductors

Superconductors can unlock high-speed energy transportation without resistive loss. In a feat first hailed as groundbreaking, scientists at the University of Rochester seemed to have crafted a superconductor from nitrogen-doped lutetium hydride that was able to transmit electricity at low temperatures and pressure. However, the experiment couldn't be replicated. If successful, superconductors could scale technologies such as levitating high-speed trains and make long-distance energy transport (including wind and solar energy) a feasible alternative. The SCARLET initiative, supported by the EU, unites 15 partners from seven countries to develop superconducting cables, enhancing cost-effective and efficient power transmission of renewable energy along with hydrogen in the same pipeline. The project took off in September 2022 at the Institute for Advanced Sustainability Studies in Potsdam, Germany. Focused on further improving long-distance energy transmission through superconductors, SuperNode, an Irish renewables technology company, has partnered with CERN. CERN, a leader in superconductivity research, will bring its cryogenic and vacuum expertise to analyze sample materials and subsystems.

Ultra high voltage power lines are needed to effectively distribute energy from renewable resources.

THE GRID

Dynamic Line Rating (DLR) Systems

With climate change, energy grids across the globe are under more pressure, and grid operators are increasingly using new technologies like dynamic line rating (DLR) systems to enhance the grid. Using sensors, the technology delivers real-time information on factors affecting grid performance, such as wind speed and temperature. In the US, PPL Corp. has been sending hourly forecasts to PJM Interconnection, the regional transmission organization, since 2022. UK's National Grid has collaborated with LineVision, the only company specializing in noncontact power line monitoring, to deploy sensors and a DLR platform. This advancement aims to optimize grid performance by accurately assessing power line conditions. In Australia, the Renewable Energy Agency granted Infravision $732,000 to support the development, testing, and trial of the "Next Generation Line Monitoring System," thus enhancing electrical transmission grid performance.

Balancing the Flow of Power Within the Grid

Balancing the flow of power within the grid is important to ensure that electricity demand is met in real time with supply. The University of Applied Sciences of Western Switzerland has pioneered an optimization algorithm that can identify the coordinates of electric current surges in power grids without knowing the grid's overall structure, thus reducing outage costs. Another grid-enhancing technology is the Advanced Power Flow Control, where devices can rapidly push or pull power from over or under-utilized lines within a transmission network. The National Grid Electricity Distribution, a project aimed at decarbonization, has launched the Planning Regional Infrastructure in a Digital Environment (PRIDE) project to bring together key stakeholders on a unified platform to analyze data and make decisions on energy systems. Collaborating with the West Midlands Combined Authority and Advanced Infrastructure, PRIDE explores the potential of digital twins to understand the regional energy demands and enable decision-making based on this data. The project explicitly highlights the importance of local and regional decision-making in decarbonization. In Ireland, the transmission system operator EirGrid has partnered with Smart Wires to implement advanced power flow control devices that automate and optimize the grid and increase the use of new renewable energy.

As the percentage of renewable energy in the grid increases, we need smart technologies to ensure stable distribution and supply.

EMISSIONS REMOVAL

CARBON CAPTURE & STORAGE

Natural CSS

One method of naturally removing carbon dioxide from the atmosphere is the mass farming of seaweed, which sucks the gas from the air. However, a new study has revealed that the amount of seaweed needed to make an impact (a million square kilometers) may be too much for turning this solution into a widespread strategy for combatting climate change. Mosses are showing substantial promise after a new study revealed that moss-covered soil can store 6.43 billion metric tons more carbon in the soil beneath it than soil can on its own. The total potential amount of carbon dioxide that could be stored by mosses is about six times the annual global emissions caused by activities such as deforestation, urbanization, and mining. A French startup is trying to grow genetically modified house plants to better filter the air around them. In Georgia, foresters have begun planting acres of the first genetically engineered trees, which are designed to grow faster and capture more carbon than their traditional counterparts.

Direct Air Capture

Directly capturing carbon dioxide from the atmosphere is expensive and requires a lot of energy. But because the industry is so visible and young, it's attracting new innovators such as ex-Tesla Director Douglas Chan who founded Climeworks with the goal of being able to remove carbon dioxide by the gigaton by 2050. Climeworks has announced plans to scale up its US operations after successfully running several European plants. California-based HolyGrail uses electrically powered modular scrubbers to remove carbon dioxide from the atmosphere and turn it into mineralized cubes, which can be stacked on top of each other above ground. Global Thermostat is at the forefront of carbon removal technology and has unveiled its new Direct Air Capture machine—one of their largest yet, the unit can remove 1,000 tons a year. The company provides customers with the main components and associated design plans of the machine, so that the actual building and implementation can be done by a construction company of their choice. Japanese utility company Tokyo Gas is investing in Global Thermostat in pursuit of its net-zero goal for decarbonization.

CO2 Storage

Denmark made history last March with Project Greensand, which captured carbon dioxide at a site in Belgium, transported the liquid gas to the Danish North Sea and then injected it into the seabed at a depth of about 1,800 meters. Project Greensand is also working with Danish company Resen Waves, which created buoys that generate power through the ocean waves and can be used to monitor the seabed-injected carbon dioxide, detect leaks, and also work as Wi-Fi hotspots at sea. The project 44.01, involving partners Abu Dhabi National Oil Co., Fujairah Natural Resources Corp., and Abu Dhabi Future Energy Co., eliminates carbon dioxide by turning it into a solid rock formation. It is the first mineralization project to use seawater and the first carbon-negative project by a Middle Eastern energy company.

Seaweed captures carbon, but it's questionable if there is enough to make an impact.

CARBON CAPTURE & STORAGE

CCS-as-a-Service

As the demand for carbon capture and sequestration services increases, CCS-as-a-service business models continue to spread. EnQuest, a UK oil and gas company, secured carbon storage licenses from North Sea Transition Authority in the UK's first-ever carbon sequestration licenses. The company plans to ship carbon dioxide in liquid form to the Sullom Voe Terminal in Shetland, a 1,000-acre future carbon storage hub, before sending it via an existing pipeline for injection and permanent offshore storage. Due to the flexibility of shipping carbon dioxide in liquid form, this should make it easier for EnQuest to service more isolated carbon emitters that may not otherwise have access to this type of storage. Ørsted's Asnæs biomass power station and Northern Lights JV have signed a carbon dioxide Transport and Services Agreement to store 430,000 tons per year of biogenic carbon dioxide from two Danish power plants. This is a major milestone for both the European commercial CCS market and Northern Lights JV. Charm Industrial, a company that turns agricultural remnants into bio-oil, will be getting $53 million from carbon-removal credits to turn its agricultural waste into oil that can lock up carbon dioxide for a million years and be stored underground.

First carbon storage licenses have been secured for the North Sea.

CARBON UTILIZATION

Carbon-Based Food

Traditional farming methods cause mass damage to our environment in the forms of habitat loss and deforestation—using up land, drying up water sources, and releasing a third of all greenhouse gas emissions. Solar Foods wants to change that by making food directly from carbon dioxide. The company is aiming to start production in 2024 in the first commercial-scale factory in Finland. Solar Foods' technology involves bacteria that use hydrogen as their energy source; it creates a yellow powder that is 70% protein and can replace animal sourced proteins, such as eggs in noodles and pasta. The process will use 200 times less land, 600 times less water, and emit up to 200 times less carbon dioxide than traditional protein sources.

Diamonds

Diamonds come with a shady history that can frequently involve corrupt governments and exploitative working conditions. Aether is providing a completely conflict-free option by making diamonds out of atmospheric carbon dioxide. The US company captures carbon dioxide from the atmosphere with a thermochemical process, purifies it, adds green hydrogen to create atmospheric methane, and then puts it in specialized chambers where diamond material can begin to form. The diamond material is cut and polished with traditional methods and can be placed in a variety of jewelry from engagement rings to earrings. The diamonds themselves are carbon-negative.

Hair Care, Soap, and Laundry Detergent

Theoretically, carbon can be sequestered in household products, and CleanCO2 has found a way to do that. The company captures carbon dioxide from building heating systems using a device called CarbinX and processes it into potassium carbonate (a non-toxic pearl ash). This pearl ash is used in the soap formula to create a sudsy lather when used, and ends up in everyday products such as hair care, soaps, and laundry detergents. Founded in Alberta, Canada, the company has now expanded to the US and Japan and is deploying its CarbinX units globally.

Chemical Production

The research team at RWTH Aachen has developed a new chemical reaction that uses carbon dioxide in the creation of a chemical compound called aromatic carboxylic acids. This compound has a variety of uses from herbicides to plastics—but most importantly, it is used in medicine. In the pharmaceutical industry, a common type of aromatic carboxylic acid is salicylic acid, which is used in aspirin. The RWTH Aachen team's discovery not only opens the door to many new industries but creates the opportunity to utilize waste carbon dioxide and more sustainably turn it into a chemical compound that can be used globally.

US Company Aether is manufacturing carbon-negative diamonds.

CARBON TRACKING

Funding Influx

The rapidly growing climate technology industry is facing an overall mass increase in funding initiatives. Microsoft's Climate Innovation Fund has pledged to distribute $1 billion by 2024, and Amazon's Climate Pledge Fund has pledged $2 billion; these projects vary from concrete that can trap atmospheric carbon to portable batteries that could replace diesel-burning generators. Venture capitalists are investing more than $140 million in startups, resulting in unprecedented funds for climate technology: Persefoni raised $114 million, Watershed raised $85 million, SINAI raised $36 million, and Sphera raised $21 million.

Tracking Platforms

Large, established companies are seeing the value in carbon tracking software, and many are creating their own or expanding their services to cover carbon data. SAP's Sustainability Data Exchange will allow companies to securely exchange sustainability data in a standardized format with suppliers and partners in order to quickly reduce carbon emissions in supply chains. EY has released the beta version of EY OpsChain ESG on its EY Blockchain SaaS Platform; the product will provide verifiable and accurate carbon dioxide emissions information and allow clearer tracking of an enterprise's carbon footprint, providing companies and regulators with a transparent, trusted platform for carbon emission and credit traceability. Microsoft has introduced the Microsoft Cloud for Sustainability to help organizations more easily track their emissions and is continuing to add capabilities and updates to the platform, including a way to track indirect carbon emissions that frequently go untracked. Amazon Web Services has customizable solutions that use AI, machine learning, data analytics, and the Internet of Things to capture, analyze, and manage a company's sustainability data.

Government Investment and Regulation

The US General Services Administration's Green Proving Ground program is on a mission to decarbonize federal buildings, and nZero, a carbon management and accounting platform, is at the forefront. The company will track federal buildings' electricity usage in real time in an effort to make them net-zero. The agency, along with the US Department of Energy, will invest $30 million toward this net-zero buildings goal. The EU enacted its Corporate Sustainability Reporting Directive, which requires companies to report scope 3 (indirect emissions) and double materiality—the implications on the company's financial value as well as impact to the environment and world overall. This directive also includes stricter rules on corporation's social and environmental disclosures.

Individual Consumer Tracking

A variety of new tools are encouraging individual consumers to consider carbon footprint when making decisions. Reewild, a UK company, has created an app for consumers, food brands, and retailers to see the carbon footprint of a variety of food products. They simply need to scan an item's barcode while using the app, which is still in its beta phase. While it is only in the UK, the company plans to scale the app to the EU and the US. American Express and MasterCard have introduced an emissions tracker for consumers to see how their actions, habits, and spending behaviors impact their personal carbon footprint based on purchases. Google Flights and Uber have also rolled out emissions data tools for individual consumer tracking. Australian bank Westpac developed a tool with Cogo, a carbon footprint management fintech, that will provide customers with personalized carbon emissions trackers based on their spending. The bank hopes the transparency will help close the knowledge gaps that are preventing individuals from making more sustainable decisions. Consumers can also track their waste using Bintracker, a software company, that uses QR codes to track waste streams down to individual tenants and then analyzes and reports on trends and data down to the source, day, and composition.

SCENARIOS

SCENARIO YEAR 2050

What If CO2 Is the Foundation for Consumer Products?

In the year 2050, consumer goods conglomerates such as Walmart and Amazon have utilized the scaling of nanotechnology to not only effectively integrate carbon capture, utilization, and storage into their operations but also to provide the delivery of personalized products at scale. A network of specialized nanobots, which the companies release into the atmosphere en masse, attract and bind carbon dioxide molecules from the atmosphere and transport them to central processing units. Within these central processing units, the carbon dioxide is converted into versatile carbon-based raw materials that can be tailored to various applications. The processing units receive customer orders within a 30-mile radius in real time and are equipped with hundreds of 3D printers, as well as a wide range of other raw materials and chemical components. Based on the order of each customer, the carbon dioxide raw materials are integrated into the appropriate material concoction and printed into everything from highly specific building components to carbon-based foods and intricate consumer goods.

EMISSIONS REDUCTIONS

GREEN PROCESSES

CONSTRUCTION

Carbon Neutral or Negative Building Materials

From plant-based building materials to more sustainable concrete, companies are experimenting with new ways to construct buildings. Plantd, a sustainable building materials company, creates strong, moisture resistant carbon-negative building materials from fast-growing perennial grass. With $10 million from recent funding, Plantd's products will provide a direct substitute for traditional home construction materials and lock in 80% of the atmospheric carbon dioxide the plants captured in the field. Elsewhere, a new type of engineered wood that traps carbon dioxide, strengthens the material for use in construction—the natural material goes through a process that makes it carbon dioxide-sorbent and stronger than its more natural state. The company MAA'VA is creating eco-concrete, a sustainable carbon negative construction material, by transforming nonplastic and plastic waste. This eco-concrete is adaptable to both conventional and 3D printing construction, which can create housing for one-tenth the cost and half the waste.

3D Printed Houses

The use of 3D printing methods to build housing is expanding rapidly, and the use of natural materials is expanding with it thanks to designers Ronald Rael and Virginia San Fratello. They created Potterware, a browser-based application that allows for 3D designing without the need to understand 3D modeling software; it also allows the use of natural materials such as clay, salt, mud, sawdust, or Chardonnay grape skins in designing and printing. In Europe, the continent's largest 3D printed building is being built in Heidelberg, Germany, to house a data center. The construction is expected to take 140 working hours of robots applying layers of concrete, instead of dozens of human workers. In Round Top, Texas, the seasonal tourist town is about to see five vacation rental homes that are being called the world's first "near-zero-carbon, 3D-printed homes." These homes are the result of a partnership between Eco Material Technologies—a cement alternatives company—and Hive 3D—an automated construction company. The result will be a building process which will emit 92% fewer emissions and cost 30%-40% less than a traditional construction project of the same size.

Companies are increasingly using materials such as clay and sawdust for the 3D printing of houses.

GREEN PROCESSES

HEAVY INDUSTRIES *(Steel, Chemicals)*

Steel and Iron

Steel production is responsible for 7%-9% of the world's total carbon emissions, and investments in green steel companies are ramping up. While more resources are coming into the industry than product rolling out, that may soon change. Hydrogen is playing a role in advancing the steel refinement process: The first large-scale green steel production plant is being built by H2 Green Steel in Sweden, aiming to cut greenhouse gas emissions by 95% during the production process. Using hydrogen technology instead of blast furnaces, the plant plans to start shipping its first commercial batches of steel by 2025. Across Europe, companies like France's GravitHy, Germany's Thyssenkrupp, and Spain's ArcelorMittal are constructing hydrogen-based plants. Another advancement to soon enter the steel industry is the use of Molten Oxide Electrolysis, a process that uses electricity to separate oxygen from iron ore, leaving oxygen instead of carbon dioxide as a byproduct. Boston Metal hopes to bring this technology to the steel industry within the next two to three years. The US has a goal of a net-zero steel sector and is on its way to that, claiming to have the cleanest global emissions footprint due to the steel it produces being roughly 70% made from recycled scrap.

Chemicals

As US regulators move to restrict two forever chemicals in drinking water, companies are experimenting with the technology to do it. Also known by their proper name of perfluoroalkyl and polyfluoroalkyl substances, PFAS are in everything from waterproof clothing to dental floss and can cause cancer, liver damage, fertility problems and more. While the removal of these chemicals with conventional filtering techniques is nearly infeasible and can be costly, researchers at Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB have found a way to use plasma-based technology to reduce the chemical's molecular chains and remove them at a low cost. Johns Hopkins University's Applied Physics Laboratory has applied "nanowhiskers," aluminum-based membranes that attract PFAS contaminants and are designed with a cost-effective coating. Northwestern University chemists have found a process that uses low temperatures and common, inexpensive reagents can remove two major types of PFAS chemicals and leave them as benign products—this powerful solution from a simple technique could be the key to removing the chemicals at a large scale. University of British Columbia has also discovered a scalable solution in the form of a filter that uses a unique absorbing material to trap and hold the chemicals.

A variety of research institutions have come up with promising filtering systems to remove forever chemicals from our ecosystem.

GREEN PROCESSES

AGRICULTURE

Plants Without Plants

Novella is creating plants without the whole plant by growing botanical ingredients with necessary macronutrients through nutrient cultivation—no plant needed. This will help address the increasing demand for necessary macronutrients, help overcome supply chain disruptions, expand plant's life cycles, and reduce climate impact. While typically a majority of a plant could be discarded, just to get to the specific bioactive compounds, this avoids that waste. This process costs less, wastes less, and provides more safe, natural botanicals without chemical additives than current processes, rising to meet the global demand.

Fertilizer Innovation

New developments in fertilizer technology are helping ensure stronger, healthier plants—and experimenting with new uses for waste material. EnGeniousAg has received a grant of $1 million to create soil nitrogen sensors that are low cost, provide instant readouts, and can help farmers measure nitrogen levels in their crops in a matter of seconds. Along the same lines, startup Phospholutions recently won the Africa AgTech Startup Showcase by showing fertilizer efficiency can be increased to maintain crop yield by reducing the phosphorus in it by 50%. Tracegrow Oy, a Finnish cleantech startup set to expand operations, is creating certified organic fertilizer from alkaline batteries. Taking the used batteries, extracting micronutrients needed by crops, and placing them in fertilizer has not only enhanced crop productivity but also reduced carbon dioxide emissions compared to traditional fertilizers.

CRISPR Edited Crops

CRISPR is a technique that allows for the editing (such as addition or deletion) of an organism's DNA—it's a different technology from what's used in genetically modified organisms, or GMOs. While many international governments have strict GMO regulations, they've responded differently to crops that have genes edited with CRISPR. Under a new law, the UK will allow for gene-edited crops to be planted, Canada will not regulate crops that have gone through changes, and the European Commission is considering next to no regulation for genetically modified crops. This is a dramatic change from the European Commission's previous stance, which put in place an intense and expensive approval process for such crops. But regulators see a lot of possibilities in gene-edited crops, including saving many from famine due to climate change and high demand for food. Already, gene editing is beginning to help expand the yield and temperature resistance of staple foods like rice and cowpeas to meet demand.

Waste

Organic waste used to be something to be disposed of, but now opportunities are arising to utilize this material in new ways. Wasted, a Vermont-based company, created portable toilets that transport the human waste it captures to nutrient recovery facilities that process the waste and turn it into fertilizer. Mill Industries is doing something similar but with household waste. The company offers a food waste bin and service for $33 a month where the bin will collect, grind, and dehydrate the organic matter. The company then notifies the owner when the material, in the consistency of coffee grounds, needs to be shipped to a processing facility to be turned into chicken feed.

DIGITAL EMISSIONS

Reducing Carbon Emissions

The increased interest in machine learning has also raised questions about the carbon footprint of developing and using such technology. Google published the "4Ms"—Model, Machine, Mechanization, and Map Optimization—four practices the company believes can reduce emissions involved in machine learning by 1,000 times and energy by 100 times. Model refers to selecting model archetypes for machine learning that can produce quality while reducing computation by 3-10 times. Machine refers to using processors specifically for machine learning that can improve energy efficiency by 2-5 times. Mechanization refers to using cloud computing in data centers customized for that type of processing which use higher efficiency servers resulting in less emissions. Finally, Map Optimization refers to allowing customers to select locations with the cleanest energy, which will increase demand and thus the growth of such green data centers, reducing carbon footprint by 5-10 times.

Measuring Emissions

With Google employing the "4Ms," the rest of the tech giants are also stepping up to address emissions from devices. Taken together, all devices globally linked via the internet have a similar electric consumption to that of the entire country of France. Amazon, Meta, Microsoft, Samsung, and Sky have teamed up with the Carbon Trust to set an industry standard for measuring and cutting carbon emissions from their devices while they are being used by consumers. The group aims to find a baseline to report energy efficiency improvements, apply technology to reduce energy use of connected devices, and drive toward its ultimate goal of industry-wide net zero emissions. Researchers from the Loughborough Business School have also created a new tool that helps businesses determine the carbon footprint of their data and allows them to create data strategies that are environmentally sustainable.

Google hopes to reduce emissions caused by machine learning by 1000 times through its 4M practice.

RECYCLING

AI Waste-Sorting Robots

AI's accuracy is being used to improve the sorting of recycling in order to cut costs. After a two year trial, Google's AI-driven recycling-sorting robots have showcased a high degree of accuracy. The reinforcement learning system used on the robots in the study increased accuracy by providing feedback through rewards and penalties, and the AI improved the robots' decisions to maximize the amount of rewards received. A UK start-up, Recycleye, has developed an AI-based waste-sorting robot, which recently won $17 million in funding. The robot uses "vision" to sort waste into plastics, aluminum, cardboard, and paper with greater accuracy than humans. Recycleye also announced a partnership with Il Solco, an Italian company that plans to use the AI-based waste-sorting robots in that country.

Food

Organic waste in landfills eventually builds up, breaks down, and produces methane, a powerful greenhouse gas. The company Divert recently received $1 billion to increase the use of microbes to break down this organic waste; this process is called anaerobic digestion, and it could help reduce the 40% of methane released from landfills by avoiding sending the waste there in the first place. Another method is biohydrogen production, which turns waste into a renewable, clean energy source. Many processes can be used in this production but all use microorganisms to break down organic waste materials and create hydrogen gas. Water is the only byproduct.

Plastic

The startup Norbite uses the greater wax moth (Galleria mellonella), which naturally digests plastic, to get rid of the material. It also uses the moth's larvae for a variety of products, such as protein for animal feed, and the moth's feces for biofertilizer. Researchers at Leipzig University have discovered an enzyme that can degrade lightweight PET plastic packaging. The enzyme is able to compost this plastic type at a higher efficiency than previously seen in other enzymes, including those discovered in Japan in 2012 that were dubbed "plastic eaters." Enzyme PHL7 was discovered to be the fastest enzyme to break down PET plastic by 90% in 16 hours, and the byproduct of this enzyme can be rebuilt into new plastic.

The greater wax moth digests plastic, the feces can be used for biofertilizer.

GREEN MATERIALS

Cross-Laminated Timber

Cross-Laminated Timber is a minimum of three layers of timber glued together with grains that cross. Typically, timber can become structurally unsound if enough force is applied along its grain, but with cross-laminated timber this is far less of an issue. The material is lightweight, has increased strength, and has even shown to have a higher resilience to seismic forces than traditional timber. But the product is also a way to use smaller trees, the types of trees that are usually removed from forests in order to make them less prone to fire. Mercer Mass Timber, a company that specializes in CLT, is preparing for an increase in demand due to building codes in Oregon, Washington, and California now classifying it as a new class of construction. OPAL Architecture has created a unique, all-electric home using cross-laminated timber and wood-fiberboard insulation to achieve the goal of creating a home with the lowest-possible carbon output. The Maine-based company cited the new timbers as the only material that would work due to its structural capacity, dimensional stability, and carbon-storing capacity. Besides being strong, the cross-laminated timber panels provided such air sealing that heating or cooling the interior space would only require one-third of the typical amount of energy.

Mycelium

Mycelium, a natural fiber from mushrooms, can be used as a plastic alternative in items such as textiles, building materials, packaging, and health care products. Completely biodegradable, this material can be used to replace plastics such as polyester, building polymers, concrete, packing materials, and threaded wound covers. Mushroom Inc. is focused on finding new ways to use mycelium hyphae to reduce toxic plastics and waste while creating more carbon-neutral products. Researchers at Newcastle University have been able to grow construction materials using mycocrete, a composite paste of mycelium. Using a knitted framework, the composite is fed and allowed to grow until it reaches the needed density, and then it is dried out and used as an eco-friendly alternative to plastic, timber, or foam.

Mushroom Plastic

New research has focused on the fungus Fomes fomentarius and the way its multiple layers could soon replace a multitude of plastic products. The mushroom has three layers: a hard outer layer, a soft middle layer, and an inner layer similar to the texture of wood. These multiple layers can potentially be used in many different products, from windshield impact-resistant coating using the hard outer layer to leather-like materials using the soft middle layer. Led by a scientist from VTT Technical Research Centre of Finland, a research team was able to create prototype headphones using the mushroom's structure. The applications for the different parts of this mushroom are vast, and the researchers' hope is that this will soon be the more sustainable alternative to many plastics.

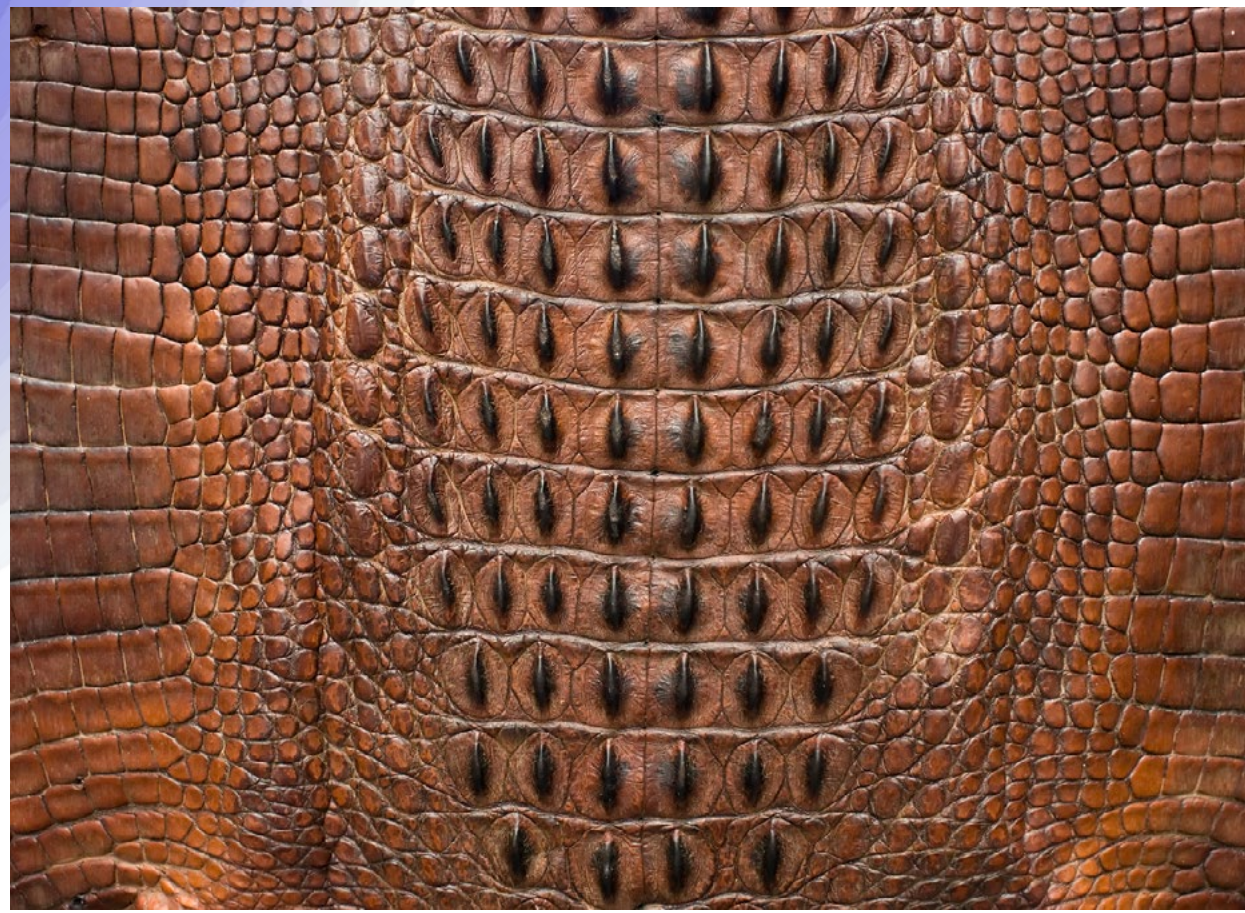
Self-Healing Materials

There's a lot of historical precedent in this field—ancient Roman concrete structures have long been known to be self-healing. The structures contain lime clasts, which were originally believed to be an unfortunate byproduct. But reevaluations of the durability of Roman concrete structures have concluded that this was an intentional choice: As cracks formed in concrete, the liquid that reached these lime clasts would reactivate calcium sources and create calcium carbonate to refill the cracks and keep the structure sound. Now, researchers are experimenting with engineering different materials to similarly heal themselves. While performing experiments on how cracks form and spread, researchers at New Mexico's Sandia National Laboratories saw cracks in copper and platinum spontaneously heal. The team believes this self-healing could be engineered into metals to react this way to stress and cracks. At North Carolina State University, researchers have created self-healing composite material that allows its structures to be repaired in place without having to be removed from service. There is also research underway to create self-healing plastic at the University of Michigan, and scientists have successfully created self-healing solar panels for use in outer space using the mineral perovskite.

GREEN MATERIALS

Lab Grown Leather

Vegan leather is becoming more popular as a sustainable alternative to traditional leather, but the material typically uses polyurethane which is toxic. The material innovation company Von Holzhausen has created Liquidplant, a top coating for textiles that can help make vegan leather more durable without using harmful chemicals. Other companies are experimenting with using different materials for vegan leather, including TômTex's work with shrimp shells. Using shrimp shells ground into flakes and then turned into a liquid, the company is creating vegan leather for wallets, mimicking leather and its durability without any petrochemicals. ProjectEx, a Singapore lab-grown exotic leather producer, is aiming to raise $1 million in order to create a sustainable, cruelty free exotic leather for the luxury market. The first leathers are expected within two years of completed funding with plans of scaling afterwards. The project is a partnership between designer Adrian Furstenburg and deep-tech startup Cellivate Technologies. And 3D Bio-Tissues has successfully grown leather "skin" in a lab without any need for animals. The company believes that lab-grown leather technology could be market-ready in five years.



A Singapore project aims to create cruelty free exotic leather.

GREEN TRANSPORT

Micromobility

Micromobility refers to compact personal transportation, like bicycles, skates, and scooters, and companies are making it easier for people to use these devices for greener daily commutes. French-based startup AtmosGear has created the first set of electric inline skates; they have a range of 20 miles on a fully charged battery that is stored in a fanny pack, bringing back the Rollerblading aesthetic. The skates connect to the battery via a wire that travels down the back of the leg and allows the wearer to go up to 20 mph. Another startup increasing micromobility options is electric bike and scooter company Yulu. Its app shows rentable scooters' availability in real time. Lime is doing something similar by focusing on electric scooters and bike-sharing. The California startup is a leader in the space, and is operating in 250 cities across 30 countries. It has backing from Uber and other investors that could help this startup expand even more.

Cars

Until now, charging electric vehicles (EV) has been the primary way of keeping them on the road. But startup Ample has a battery-swap system that can swap out an empty EV battery for a fresh one in 5 minutes, far less than batteries take to charge. With many other companies pursuing the idea, battery swapping could bring the ease of a gas station to EVs on the road. For combustion cars, there may be a new alternative that can keep them on the road in the EU despite the 2035 deadline to phase out polluting vehicles—running on e-fuels. E-fuels are synthetic fuels made from hydrogen and carbon dioxide, and can be processed in today's combustion engines. While e-fuels do still emit carbon dioxide when they are burned, the amount taken out of the atmosphere to produce the fuel offsets the amount that is created when the fuel is burnt. Luxury car company Porsche has also created its own synthetic fuel made of carbon dioxide and water that can be used in its current cars. The Porsche e-fuel is among the many seeing the potential in the fuel market.

Heavy Trucks

Truck platooning, where one driver and truck are connected to a convoy of autonomous trucks via a network and drive close behind each other, could ease passenger traffic on motorways. This use of autonomous vehicles would increase fuel efficiency through lesser air resistance and would save costs for long-haul trucking. This technology is in the trial phase in several countries and could soon see the road, with an expected cost savings of up to 45% compared to today's trucks and drivers. Wireless charging is another technology that so far has been mainly explored within freight transport. Electreon, a company specializing in charging electrical vehicles in motion, has an agreement with France to equip a portion of a southwest Paris motorway with its Wireless Electric Road System. Currently pursuing similar projects in Sweden, Germany, Italy, and the US, the company says its product will increase power transfer capacity and include real-time monitoring software for all types and classes of vehicles. However, for now the focus remains on commercial EV fleets.

Tesla's purchase of Wiferion, a German-based wireless charging company, further signals that the technology is prone to enter passenger driving sooner rather than later.

Trains

Sun-Ways is making trains green by going beyond the locomotives themselves. The company is using the spaces between railway tracks to lay out solar panels "like carpet." Sun-Ways estimates that a terawatt-hour of solar energy per year could be produced from the national rail network in Switzerland, equivalent to 2% of the country's total energy consumption. Meanwhile, Polish company Nevomo is exploring hyperloop-inspired technology for the potential future of rail freight. Nevomo uses MagRail technology, magnetic propulsion that could be a traction enhancer. While capacity, reliability, and frequency are more important factors than speed for rail freight, this technology could have a revolutionary impact on the industry—especially considering it would allow trains to work on both the company's MagRail system and traditional tracks. Nevomo also signed a deal with the French rail

GREEN TRANSPORT

operator SNCF to evaluate if its technology can increase train efficiency and capacity.

Air

When it comes to air travel, any part, no matter how small, can make a big difference. SWING has its focus on the front flaps of planes, creating them out of thermoplastic polymers and decreasing their weight by about 20%. While this is just a first step with this type of material, SWING hopes that eventually the polymers could be used to craft entire aircrafts, reducing emissions by up to 20%. Autonomous aircrafts could first see their application with unmanned cargo planes. Dronamics, a UK-based company, released of one of the first unmanned cargo aircrafts at the end of 2023. The aircraft takes less time to operate, saves money, and emits less carbon dioxide than traditional cargo freight, catering to underserved areas and multiple industries. Startup ZeroAvia has completed a record test flight in a 19-seat aircraft half powered by hydrogen fuel cells. With investment from commercial airlines, it's now looking to move into commercial tests.

Ocean

With shipping being such a large part of global trade, many ships are looking to reduce their carbon footprint due to new carbon efficiency regulations. To do this, many are looking to wind and developing wind propulsion technologies to decrease fuel usage. US food company Cargill announced it will install two folding sails in its bulk carrier's deck, and container shipping group Maersk installed two 30 meter-high rotor sails on one of its tanker ships. In an effort to make fuel cleaner, a viscosity meter has been developed to test the oil used in ship engines, which is typically full of impurities. The ultrasound device is meant to improve shipboard monitoring and lower the cost.

Tankers might soon be equipped with sails to make them more fuel efficient.

ENVIRONMENTAL MANIPULATION

EARTH

Rewilding: Animals/Nature

Countries across the world are initiating rewilding efforts, an ecological restoration approach that involves restoring natural ecosystems and habitats by reintroducing native plant and animal species. A NASA-supported initiative in Idaho uses remote sensing data to forecast the streams that could support beavers and monitor the biodiversity shift once beaver populations are introduced. In the Netherlands, Marker Wadden is a 1,300-hectare archipelago built with the mud and sand of the lake that now houses diverse plants, fish, insects, and breeding birds. Meanwhile, Scotland, aiming to be the world's first rewilded nation, has created countrywide wild lands and natural corridors. This rebuilding of ecosystems in Scotland has been enabled by land ownership laws that allow a few to own most of the land. (In contrast, in Ireland, where land ownership is limited to several acres, natural woodlands make up only 1% of the island, compared to 80% long ago.) In Mexico, tequila company Tromba strives to rewild and reforest land damaged by blue agave over-cultivation, targeting 1,000 hectares in a decade. Citizen-driven initiatives are also growing. Designer Kiki Grammatopoulos has introduced "Rewild the Run," featuring bristly running shoe outsoles that aid plant and seed dispersion in cities. Agricultural rewilding has also grown, combining rewilding with agriculture to maintain food self-sufficiency and promote sustainable and ethical high-quality meat production.

Bioengineering

Scientists predict that almost a quarter of all species on Earth are at risk of being lost within the next few decades. De-extinction is a scientific method to bring back and resurrect extinct or close to extinct species. Organizations like nonprofit Revive & Restore and for-profit Colossal Bioscience, are pioneering these efforts. For instance, Colossal is using gene editing to revive the dodo bird, while Revive is focused on the passenger pigeon. In both cases, the newly created animal will be a hybrid and not a replica of the predecessor, qualifying for patent protection and thus producing immense financial prospects. At the National Black-Footed Ferret Conservation Center in Colorado, Dr. Della Garelle of the US Fish and Wildlife Service is spearheading the revival of America's endangered ferrets. Over 4,000 genetically similar ferrets have been released into the wild since 1991; this helps ecosystem restoration, but the limited gene pool makes them vulnerable to disease. To maximize breeding success, biologist Robyn Bortner picks and matches ferrets based on their genes. In this context, the San Diego Frozen Zoo is essential, as it leads the de-extinction field with the world's largest living animal cell bank, enabling DNA collection and storage for future restoration efforts.

*For more on rewilding in cities and municipalities, please see our the Rewilding trend in our **Built Environment** book.*

The black footed ferret is one of the species that is being rewilded in the US.

SKY

Geoengineering

Geoengineering refers to environmental manipulation—manipulation of Earth's resources including oceans, rivers, soil, and atmosphere. Although it's in an early stage of development, geoengineering technology is already being commercialized, leading to criticism from scientists across the world. The regulation around it is also mired in conflict, with different countries adopting contrasting approaches. In Mexico, the company Make Sunsets is sending gas-filled balloons into the atmosphere and selling "cooling credits" without much scientific validation. The lack of regulation is allowing such companies to function despite low credibility. On the other hand, the European Union is grappling with the complexities of this issue and considering potential regulations. Meanwhile, in China, geoengineering is being considered as a tool for hybrid warfare strategy. Especially in the realm of regional geopolitics, China could amplify its gray zone capabilities and use weather modification for military purposes, obstructing river water flow, and even creating artificial islands.

Solar Geoengineering

Still in a nascent stage, solar geoengineering is very controversial. It theorizes that by reflecting more sunlight into space, global warming can be controlled, but countries and international institutions are grappling with how to regulate the space. The US government, recognizing the need for further research, has proposed a study of risks associated with deploying solar geoengineering techniques. The EU, while formally disqualifying solar geoengineering as a climate solution, also recognizes the need to deepen understanding of the implications associated with the technology. More recently, the United Nations convened a panel of climate experts to deliberate international regulation of the stratosphere, stressing the need to manage risks associated with spraying aerosols to reflect sunlight. In the UK, a first-of-its-kind solar geoengineering test flight has been conducted, showcasing ongoing exploration of the concept. As a part of it, scientists launched a high-altitude weather balloon into the stratosphere that is low-cost, controllable and recoverable. Keeping up with innovation, MIT scientists have proposed a unique approach to use a fleet of "space bubbles" to reflect sunlight from space instead of injecting particles into the atmosphere, potentially reducing harmful effects. Meanwhile, startups are considering iron particle spraying above the ocean to combat climate change by breaking down methane, a natural phenomenon that may have influenced ice ages. However, scientists stress that more fundamental research is needed before considering large-scale implementations.

Cloud Seeding

Cloud seeding is a decades-old weather modification technique that enhances precipitation by dispersing specialized particles into the atmosphere. With increased focus on climate change, new and improved cloud seeding techniques are being developed and embraced across the world, including in the US, China, Russia, and parts of the Middle East. India recently made strides in this field by embarking on its first cloud-seeding initiative where an aircraft released chemical powder to stimulate rain in clouds. Experimentation continues in other countries as well with diverse seeding materials. The United Arab Emirates, at the forefront of innovation, has been using cloud seeding for more than two decades, leading to a 25% annual increase in optimal precipitation. Researchers are now employing nanotechnology and harnessing algorithms to optimize cloud seeding conditions, and they are exploring the use of drones to amplify the efforts. In Texas, Dan Martin from the Department of Agriculture's Agricultural Research Service is investigating the use of electrically charged particles to trigger cloud condensation. In an experiment, an aircraft with tanks of water released a spray of electrically-charged water particles into the cloud to see its effect on precipitation. The United Kingdom, meanwhile, is pioneering the use of electrical pulses as a potential seeding technique.

OCEAN

Microplastics

Innovative ideas are surfacing in the battle against microplastic pollution, offering hope for a cleaner ocean. One such initiative, GoJelly, harnesses the mucus produced by jellyfish species to craft filters that effectively trap plastic particles from wastewater, preventing their entry into the ocean. The project is innovatively using the growing jellyfish population to curb microplastics. Another breakthrough comes in the form of sound wave technology. Recent research reveals that pulsing sound waves can efficiently dislodge microplastics from the ocean's depth including tiny small specks that may otherwise be easy to miss. The team experimented with a prototype comprising sturdy 8 millimeter steel tubes and a powerful transducer. With the sound waves, even the small particles vibrated and accumulated.

Living Breakwater

Living Breakwater is an innovative approach to coastal protection and ecological restoration that utilizes nature-based solutions. A remarkable milestone has been achieved in the Port of Rotterdam, where 17 Reefy ReefBlocks have been successfully installed in the river Meuse. The project experiments with innovative nature-based wave barriers to safeguard the shores from the impact of large ship waves while preserving and restoring regional biodiversity. By reviving the intertidal environment, the living breakwater provides a vital sanctuary for migratory fish species like sturgeons and European eels, facilitating their journey between the Atlantic Ocean and major European rivers. In New York, the "Living Breakwaters" project off the south shore of Staten Island aims to protect coastal communities and promote ecological restoration by creating habitats for marine life and fostering biodiversity. Encompassing a series of eight in-water structures stretching 2,400 linear feet, the project was initially slated for completion by the end of 2024 but is currently ahead of schedule.

Ocean Chemistry

Ocean chemistry is a multidisciplinary field that delves into the chemical processes and composition of Earth's biggest bodies of water. Researchers at University of California, Santa Barbara have recently been exploring a proposal to enhance ocean alkalinity for accelerated carbon sequestration. By enriching the ocean with minerals and increasing alkalinity, they aim to stimulate geologic processes that efficiently remove carbon dioxide from the atmosphere. Promisingly, their study reveals that crucial plankton groups in the marine food chain respond positively to this treatment, encouraging further research in this climate change intervention. Despite the positive outlook, concerns have increased about using minerals such as basalt to increase the alkalinity of seawater: These methods may disrupt nutrient cycles and affect marine ecosystems. Acknowledging the significance of marine geoengineering in climate change mitigation, the Australian Labor government has taken a proactive step by introducing a bill to regulate "marine geoengineering" activities. The proposed legislation seeks to govern and control interventions in the ocean environment. Listed marine geoengineering activities would require permits, ensuring proper oversight and safeguarding against ecological consequences.

Gene Editing

Gene editing coral refers to the scientific practice of using advanced genetic engineering techniques to modify the DNA of corals. The goal is to introduce specific changes to its genetic code, which can enhance its resilience to environmental stressors, such as rising sea temperatures, ocean acidification, and disease. Scientists, including Carnegie Science's Amanda Tinoco, have employed genome editing tools to unlock a pivotal discovery in coral development. Their research highlights the significance of a specific gene known as SLC4X, which is essential for the growth of skeletons in young coral colonies. This gene, exclusive to stony corals, encodes a protein responsible for transporting bicarbonate across cellular membranes, a crucial process in coral skeleton formation. This breakthrough offers opportunities for further research into coral resilience and conservation strategies.

SCENARIOS

SCENARIO YEAR 2045

What If a Sunshield Leads to a New World Order?

As the effects of climate change became more dire and governing bodies noticed that conventional climate mitigation efforts would not be sufficient to prevent catastrophic impacts to their populations, the most impacted nations launched “Project Celestial Shield.” The core of this initiative involved launching an array of solar reflectors into space, positioned to intercept a portion of the sun’s energy and redirect it away from Earth to counter rising global temperatures. Initially celebrated as a revolutionary solution, Project Celestial Shield successfully attenuated the planet’s temperature rise. However, with the reduced influx of solar energy, regions that once relied on specific temperature patterns faced abrupt shifts in climate. Agricultural cycles even in thriving regions have been disrupted, leading to decreased crop yields and global food shortages. Ecosystems accustomed to specific temperature ranges experienced upheaval, resulting in mass migration of species and a ripple effect throughout food chains.

As atmospheric dynamics adjusted to the altered energy balance, unforeseen weather patterns have emerged. Rainfall distribution has dramatically shifted, causing both unexpected droughts and deluges in areas previously not affected by these extreme weather events. Diplomatic tensions are high as the geopolitical power dynamics fundamentally shifted in response to the newly defined ecological realities, resetting the political stage for the coming decades.

EFFECTS OF CLIMATE CHANGE

MONITORING CLIMATE CHANGE

Emissions

With increasing recognition of greenhouse gases (GHGs) as a significant driver of climate change, there is a pressing need to reduce these emissions. The United Nations' World Meteorological Organization (WMO) is taking the lead in ensuring standardized, real-time tracking of GHGs that can be used to influence policy making. WMO uses weather prediction and climate analysis to monitor greenhouse gases in an integrated framework. Another initiative is the Global Greenhouse Gas Watch, where WMO is collaborating with the global greenhouse gas monitoring community to ensure sustained and regular monitoring of GHGs. In this context, methane, a potent greenhouse gas, is important. Scientists posit that 60% of atmospheric methane results from human actions. To better monitor methane emissions, Harvard researchers, private space companies, activists, and philanthropists are launching the MethaneSAT project. Scheduled for 2024, the satellite will revolutionize methane monitoring by providing a comprehensive view of emissions across vast areas, surpassing existing aerial and ground-based methods. The core instrument of MethaneSAT is a spectrometer, a sophisticated device capable of precisely detecting methane concentrations. By monitoring methane emissions at a global scale with higher speed and efficiency, MethaneSAT can shed light on emissions' sources, pinpointing areas for targeted climate mitigation strategies.

Extreme Weather

The increasing frequency and severity of extreme weather events is causing significant challenges for insurers and communities worldwide. In states like Florida and California, insurance companies are withdrawing from offering homeowner insurance due to the growing risks associated with extreme weather events like hurricanes and wildfires. In Germany, insurers are demanding that house-building cease in flood-prone areas to mitigate potential damages. More accurate weather prediction could be helpful in such cases. Recent advancements in artificial intelligence have shown promise so far: Researchers from Nvidia, Google DeepMind, and Huawei have introduced machine-learning methods capable of predicting weather patterns as accurately as conventional methods and with much greater speed. However, given the unpredictability associated with future weather events, it remains to be seen if these AI-powered forecasting models trained on historical weather data can make proficient predictions. For extreme heat, Google is taking a proactive approach by partnering with the Global Heat Health Information Network to push notifications to users in affected locations. Addressing flooding risks, companies like C2S are leveraging technology to help insurers better understand and underwrite flood risk and monitor flood events in real time. Using machine learning, the company analyzes data from satellites, historical flood maps, and on-the-ground intelligence to provide insights into flood extent and impact.

In another initiative to decrease flooding risks, the National Digital Twin program is creating an interactive demonstrator tool to showcase how connected digital twins can enhance infrastructure resilience to flooding. Additionally, real-time flood sensors developed by the FloodSense project at NYU and the CUNY Advanced Science Research Center aim to provide hyperlocal street-level flood event information to stakeholders, including policymakers, government agencies, emergency response teams, and citizens. In the face of hurricanes, the National Oceanic and Atmospheric Administration is equipping forecasters with a new model called the Hurricane Analysis and Forecast System. The model offers earlier warnings of rapid intensification and improved predictions of impacts like rainfall and storm surge, empowering communities to better prepare for and respond to hurricanes.

Crops

In Africa, scientists are using artificial intelligence to predict the yields of vital crops by harnessing satellite remote sensing and machine learning. The tool can analyze vast agricultural landscapes, providing real-time predictions of crop yields and offering farmers and policymakers valuable insights into crop productivity.

MONITORING CLIMATE CHANGE

Community-based Efforts

With climate change becoming a global phenomenon, community movements have grown. In an attempt to make climate modeling easy, researchers from Northwestern University and Argonne National Laboratory have deployed Nvidia's Jetson-driven Waggle devices worldwide. Waggle is an open-source platform, empowering scientists and researchers globally to join climate studies using edge computing and sensors. The platform collects hyperlocal climate data, enabling communities to access crucial information for climate resilience. Parallely, a new collaborative, is blending indigenous knowledge with earth science to bolster climate resilience in vulnerable coastal communities by bringing indigenous knowledge-holders and university-trained scientists together. In India, a crowdsourced initiative brought together community scientists and professional researchers to develop a meteorology-based landslide prediction system called "Satark" for India's Western Ghats mountain range. With an impressive 76.5% accuracy, Satark predicts landslides along the southwestern coast a day in advance, safeguarding lives and livelihoods.

Digital Twins of Earth

To tackle climate change, researchers are experimenting with digital twins of Earth as part of a strategy to combat warming. The Nvidia Earth-2 initiative's digital twins could revolutionize weather predictions, climate projections, and the development of effective mitigation and adaptation strategies using data-driven analysis at the global scale. Powered by machine learning and accelerated computing, this groundbreaking project uses the largest supercomputing systems to make unprecedented advancements in weather information and climate emulation. The European Commission's flagship initiative, DestinE, is equally ambitious. Using technology to ensure high accuracy, local detail, access-to-information speed, and interactivity, this digital model of the Earth will monitor, simulate, and predict interactions between natural phenomena and human activities. It aligns with the European Commission's Green Deal and Digital Strategy, furthering the goals of green and digital transitions and contributing to a sustainable future.

A digital twin of the earth is aiding with strategies against global warming.

LIVING IN A NEW REALITY

Floating Cities

The Institute for Economics and Peace predicts that by 2050, more than 1 billion people may have to deal with inadequate infrastructure due to sea-level rise. Floating cities will thus become a part of our new living reality. Projects like Oceanix City in Busan, South Korea, Baltic Sea islands developed by Blue21, and Maldives Floating City are great early examples of this. Oceanix, in fact, is built from biorock with the ability to self-sustain and self-repair. Another example is Waterbuurt, or the Water District, in Amsterdam, where 100 floating houses have been built by Dutch architect Marlies Rohmer on Lake Eimer.

Other Concepts for Cities

Smart Forest City, an ambitious project by Italian architect Stefano Boeri, was revealed in 2019 near Cancún. This visionary metropolis, deeply rooted in the region's Mayan heritage and culture's reverence for nature, is designed to house 7.5 million plants, creating a harmonious blend of urban living and green spaces. The company behind the project says the goal is to create a "perfect balance between the amount of green areas and building footprint." Equitism is the idea of an economic model empowering citizens with land ownership. Inspired by this idea, billionaire Marc Lore aims to establish a new American city called Telosa to "set a global standard for urban living, expand human potential, and become a blueprint for future generations." While the exact location is yet to be determined, the city's design by Bjarke Ingels Group places pedestrians and bikers at the forefront, supplemented by a few "slow-moving autonomous vehicles." Sustainability is at the city's core, with renewable energy, protected green spaces, and on-site water recycling. Targeting a population of 5 million by 2050, Telosa is poised to redefine the paradigm of urban development.

Underground Climate Change

Underground climate change is a silent hazard. In general, cities and urban areas release and hold heat more than rural areas. As cities heat up, the ground also traps more heat, affecting building foundations and, in some cases, leading the ground to expand, contract, and crack. Recently, scientists from Northwestern University have verified this phenomenon based on data from sensors in urban basements, subway tunnels, and underground parking garages. The study predicts that underground climate change in cities poses long-term challenges for urban structures, and researchers anticipate these issues will persist for years.

Indonesia's New Capital

Acknowledging climate change as an essential issue, Indonesia is building a new capital—Nusantara—that aims to transcend typical planned cities. The intent is to fulfill the Indonesian president's vision of "a new work ethic, new mind-set, new green economy." It will stand as a green metropolis powered by renewable energy, free from suffocating traffic jams, offering serene paths for strolling and biking amid lush greenery. Embodying adaptation to a warming planet, the high-tech city, also known as I.K.N., intends to attract digital nomads and millennials, who will embrace cryptocurrency to invest in chic apartments. Nusantara seeks to set a paradigm for a sustainable and forward-looking urban lifestyle.

Domed Cities

Cities with sealed bio-domes that control air temperature, air composition, and air quality are also being explored as a potential solution for cities affected by climate change. Saudi Arabia's Prince Mohammed bin Salman has a new vision for the country's capital in line with this idea: it will include a redesigned downtown with a 400-meter-high cube or "Mukaab." The cube will offer its residents immersive experiences, including changing landscapes and holographic technology. The project is called "New Murabba" and is scheduled to be ready by 2030. The city Riyadh will expand by 19 square kilometers as a part of the project. The country also has other futuristic projects underway, including Neom City, which plans to include robot maids, flying taxis, and a giant artificial moon and The Line, a huge project that will house 9 million people.

CLIMATE ECONOMY

CARBON CREDITS

Investment From Traditional Banks

Interest in carbon credits and green investing has increased as companies strive toward their net-zero emissions goals. Nine global banks have invested $45 million toward scaling a new platform called Carbonplace that will be able to handle more transactions of voluntary credits and make it easier for bank customers to participate. Carbonplace will connect credit buyers and sellers through the banks. The investors, UBS, National Australia Bank, BNP Paribas, and Itaú Unibanco among them, have invested $5 million each in the interest of accelerating corporate climate change through visible and secure means.

Verification Methodology

With increased interest in carbon credits, it's necessary to make sure the methods are sound to avoid greenwashing. One company, Isometric, is planning to do just that by launching a platform that can vet carbon removal companies and review new ones. It will include a list of fully verified carbon removal companies and the ability for scientists and researchers to view and comment on data provided by new companies, namely startups, that enter the industry. The Integrity Council for the Voluntary Carbon Market and the Voluntary Carbon Markets Integrity Initiative are joining together to craft a market integrity framework. This framework is built to instill confidence in investors using the Voluntary Carbon Market for their carbon credits and ensure top quality of all companies on the market. Governments are beginning to create their own frameworks as well, with the EU creating a Carbon Removal Certification Framework, which will influence the rules set in the Voluntary Carbon Market. Xilva, a Swiss company, is pursuing a similar verification but specifically for forest projects. The company provides an evidence-based assessment of a project's impact by considering multiple criteria such as economic viability, ecological integrity, and social equity in order to provide a holistic assessment on their platform.

Focus on Asset Management

Investors are frequently unsure if their credits are going to a verified company or one that is simply greenwashing. Sylvera, a UK-based startup, is on a mission to provide transparency and trust to carbon offset projects by using data and assigning ratings to the projects. Its goal is to ensure the projects with the best credibility receive investments in order to make a real climate impact. The company's recently closed Series B funding of $57 million will be used for US expansion.

Blockchain Integration

CarbonKerma is a platform that is embracing blockchain technology and combining it with a carbon capture marketplace in order to provide companies with trackable, quality, measurable carbon credits. The platform's listed credits are highly regulated and vetted through a stringent process. CarbonKerma offers a deeply needed value to the market: transparency. Each credit can be tracked, traded and, once removed from circulation, retired to never be used again. The visibility and auditability of this platform provides full transparency along with reputable carbon removal companies to ensure the quality of carbon removal.

Measuring Carbon Sequestration

The New Acre Project, which recently partnered with Albo Climate and ALUS, is an investment platform for corporations that is identifying carbon stocks and sequestration for trees using a remote sensing-based platform. This AI-powered product will be directed at four Canadian provinces: Alberta, Ontario, Quebec, and Saskatchewan. The participating sites are private lands managed by ranchers and farmers in the ALUS program. The credits will be "ecosystem credits" and will allow investment in any project that involves carbon removal, biodiversity, and other environmental benefits to the provinces.

BLUE ECONOMY

Blue Economy

The term "blue economy," originally championed by developing small-island countries including Fiji, Palau, and the Bahamas, was coined to describe the benefits of ocean industries. This includes establishing and supporting socially equitable ocean spaces and industries, ensuring they are environmentally sustainable, and that they can have an economic profit. The US highlighted a newly launched global initiative at the Our Ocean Conference, which would total more than $800 million to protect its ocean and support developing countries. The initiative focuses on securing and protecting marine areas and improving the resilience of coastal areas that could be impacted by climate change. European ports have received funding from the European Maritime and Fisheries Fund through the Atlantic Smart Ports Blue Acceleration Network to support the growth of new and sustainable business at more than 40 ports to grow the blue economy. The goal is to reduce the current carbon footprint of the port and increase the diversity of activities. Africa's blue economy is receiving attention after venture launcher Triggering Exponential Climate Action awarded $55,000 to seven startups to make an economic impact at a local level.

Blue Carbon Offsets

Blue Carbon Offsets are the management of marshes, mangroves, kelp, and seagrasses in ocean ecosystems for carbon offsetting. Indonesia and the World Economic Forum have signed an agreement aimed at improving the country's efforts by supporting a blue carbon roadmap. The blue carbon credit financing will help ocean conservation and restoration efforts. Researchers in China called the "Blue Carbon Catchers" are a collaboration between Tencent's Carbon Neutrality Lab and Xiamen University. The group is dedicated to understanding the ocean's capacity to act as a carbon sink and the future of its capacity.

Ocean Land Mapping

Marine Spatial Planning (MSP) is the ocean equivalent of land zoning planning and is helping to ensure the ocean is sustainably used. In a space that is used by so many, so frequently, and is home to so much wildlife, conflicts of interest are bound to arise when it comes to ocean activities. MSP serves as a clearly defined line for any disputes to ensure that all activities remain sustainable. It is frequently used to detect marine life or habitats and restrict building to the oceans' least impactful locations. MSP is frequently used by Manna Farms, a fish farming company, to ensure their practices remain sustainable.

Foundational Data US

The National Oceanic and Atmospheric Administration is providing free and open-source ocean and coastal data that provides a perfect foundation for the future blue economy. This data is used by a broad variety of organizations, from federal, state, and local governments, to academia and business and especially offshore aquaculture and wind farms. Open Ocean Robotics, a Canadian company, received $1.75 million to create an uncrewed, solar-powered surface vehicle that can capture information via sensors and cameras, and relay it instantly to researchers. The company's robot vehicles can travel on the surface of the ocean for months without stopping, producing carbon dioxide, making noise, or risking oil spills.

Data Platforms

Cognizant, a technology services and consulting company, has partnered with Tidal to make the company's ocean information platform available to the wider aquaculture market to allow companies to make more informed decisions. Tidal uses machine learning, artificial intelligence, underwater perception, and automation innovations to gather and analyze data sets. True Ocean, a German company, is also looking to provide companies with more maritime information and has already become a prominent maritime data platform. The platform offers solutions for data processing and management, empowering organizations to see the value of the data they hold by providing a suite of services with the goal of increasing efficiency and sustainable practices, and facilitating more educated decision-making.

BLUE ECONOMY

Fishing

GAIN (Green Aquaculture Intensification in Europe) is an EU project that has monitors and sensors located around fish farms and placed into fish to help track and understand the activities in the farms. Paired with machine learning and IBM analytics, this real-time information will help farmers make more informed decisions when it comes to protecting fish, as well as detecting and preventing problems such as fish escapes, environmental issues, and excess feed. There is also an increase in transparency in the life journey of fish, from the farm to the table. Atea, with the partnership of the Norwegian Seafood Association and IBM, is bringing this transparency by using the blockchain to track Norwegian salmon's journey including buyers and trips through customs. They believe that transparency is the key to sustainability and engaging society's awareness.

Desalination

Ocean Oasis, a Norwegian company, has found a way to use the oceans' natural wave power to produce fresh water. The company uses waves off Norway's coast to power their desalinator units and then fresh water is sent to shore through pipes along the ocean floor. This method of producing fresh water is sustainable and creates no emissions. EVOVE in the UK has developed technology to make the desalination process of water easier. Its Direct Lithium Extraction system removes the lithium from highly salinated water which increases the ease of the desalination process. The company is aiming to scale its technology to provide more efficient desalination processes on a global scale.

North Sea waves are aiding Nowergian company Ocean Oasis to desalinate water without causing emissions.

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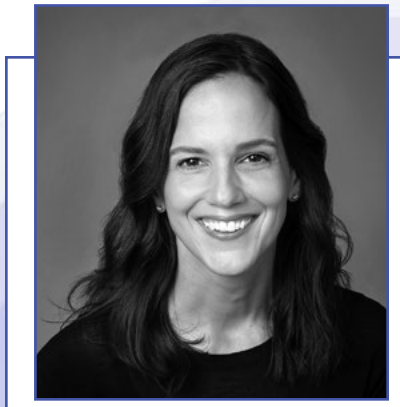

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Christina von Messling leads our European client portfolio and our Life Sciences practice area at Future Today Institute. She is renowned for her expertise in strategic foresight and an unparalleled ability to navigate complex industry landscapes. With a career spanning over two decades, she has guided multinational corporations through transformative strategies, leveraging his deep understanding of market dynamics and future trends.

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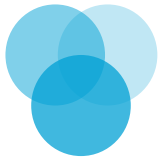

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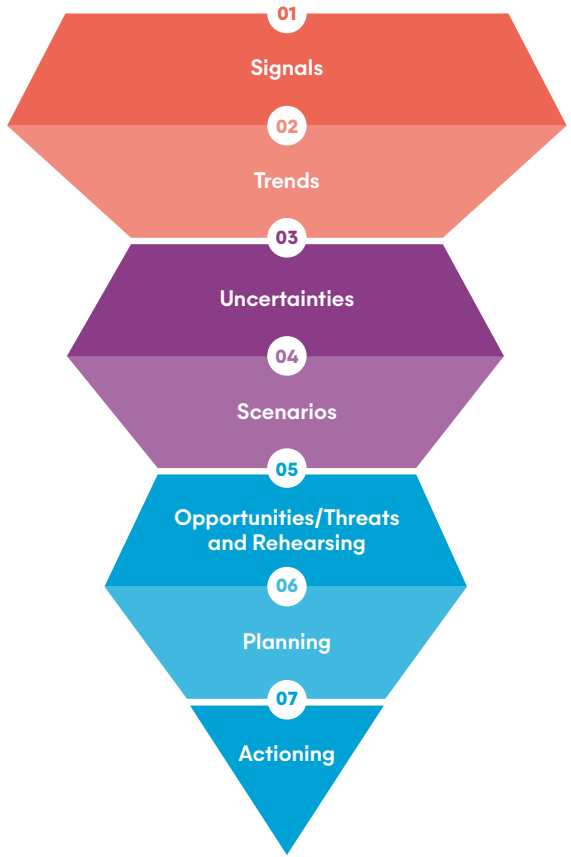

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