WORLD ECONOMIC FORUM

Accelerating the Global Transition to a Bio-based Economy: The Strategic Role of Policy

WHITE PAPER

SEPTEMBER 2024

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Contents

Foreword

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The blending of the digital, physical and biological worlds is reshaping society. Policy is at the forefront: for decades, policy has been structuring the responsible transition of biology into a commercial technology. As tools evolve to more reliably harness biology, the interplay between policy and innovation has never been more important – to safeguard the human-centred transition to a resilient, bio-based economy.

Although not always recognized, this interplay is not new: effective policies have propelled groundbreaking technologies from the laboratory to widespread societal use for centuries. Without the foundational support of well-crafted policies, even the most promising innovations risk stagnation or failing to reach those who would benefit the most. As the journey to a bio-based economy advances, policy will be key in fostering resilient and equitable economies through the commercial application of bio-innovation.

At the core of this transition, the recipe for success, is biology. Bio-innovation has provided us with rapid responses to human health crises and solutions to reverse diminishing agricultural productivity due to climate change. Even Ozempic, the diabetes and weight-loss drug, is a product of biomanufacturing. Beyond human health and agricultural applications, bio-based approaches have also provided early-stage alternatives for many daily necessities historically associated with polluting or high-emissions production. In addition to technological progress, **policy is the key driver that will define the magnitude of the impact that bio-innovation is capable of achieving**.

As we build a future where bio-innovation increasingly delivers better commercial alternatives, without increased policy intervention, bio-solutions will be incapable of delivering upon their ultimate potential. The goal is clear: to ensure that the innovations – not only of today but of tomorrow as well – can effectively address the pressing challenges facing humanity and the planet. By examining past successes where timely and supportive policies have saved lives and improved environmental outcomes, it becomes clear that evolving these frameworks and delivering them efficiently is crucial.

Bio-based approaches will continue to provide the tools and means necessary to deliver innovative solutions to human health, industrial practices that shrink our reliance on extractive processes, and the ability to reimagine sustainable food systems. In a world fast approaching climate tipping points where society requires practical human-centric alternatives, what role will policy play in amplifying bio-solutions for better planetary and human outcomes? This paper spotlights pivotal policy interventions in three key areas for biotech application: health; energy and chemicals; and food and agricultural systems.

Executive summary

Policy is a fundamental enabler of the tech-driven bioeconomy.

For centuries, innovation has fuelled economies and given rise to new markets and industries, bridging gaps in education, healthcare and human prosperity. For example, the digital transformation has permeated every aspect of daily life, redefining how people communicate, work, connect, build communities and engage with the world. The internet as it exists today was not only a paradigm-shifting innovation, but also constituted a major political achievement owing to visionary policy-makers who created the legal and policy frameworks that enabled its exponential growth.[1]

Well recognized for establishing rules and regulations for the betterment of society, policy sets forth guidance and best practices across organizations, governments and institutions.

Bio-solutions represent one area where the digital, physical and biological worlds are coalescing to introduce bio-based options into everyday life, with policy playing a central role in making this all possible.[2] Due to rapid technological progress and historical investment in incumbent processes and products, enabling policies for bio-solutions have, at times, struggled to keep pace with innovation. The catalytic role of supportive policies around bio-solutions can take many forms, but increased attention is necessary to ensure that innovation can efficiently deliver societal interventions, especially in those cases where there is no Plan B (e.g. diseases without viable treatments, or commercial alternatives that operate outside of planetary boundaries). This paper highlights the opportunities for, and the potential impact of, enabling policies for biotechnology. It focuses on the supportive policies that have provided significant societal and environmental benefits. It explores how:

- streamlined regulatory approval saved millions of lives during the pandemic.
- regional policies are opening up opportunities to move beyond petroleum-derived chemicals.
- the powerful synergy between policy and innovation is helping biotech crops restore the planet and reduce emissions.

Furthermore, it spotlights areas where policy development could serve as a multiplier for impact, along with the key obstacles that must be addressed to enable biology to provide transformative solutions more effectively – for humanity and the planet.

Introduction

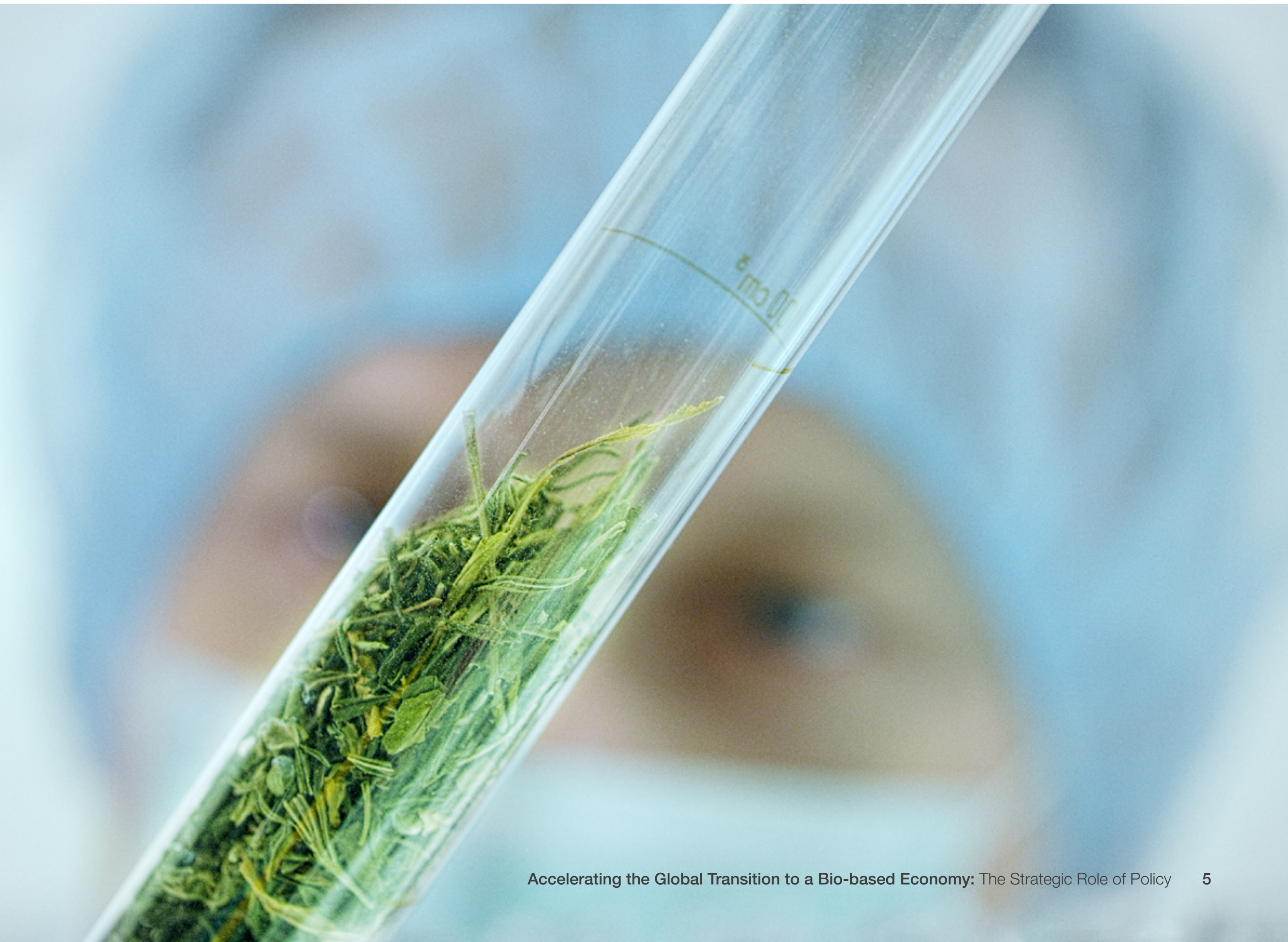
Policy: Bio-innovation's fundamental enabler.

The capacity to read, write, edit and, increasingly, functionalize DNA is expanding the reach of application areas for the tech-driven bioeconomy.[3] Up to 60% of physical inputs to the global economy could be produced with biology.[4] Typically taking the form of a law, regulation, procedure, administrative action, incentive or voluntary practice of government and other institutions, the role of policy in amplifying innovation is often underemphasized and undervalued. This paper shines a spotlight on the importance of policy in amplifying bio-solutions, as well as areas that can benefit from enhanced policy focus, to ultimately realize the full potential of a bio-based economy for society and the environment.

Agility in policy-making is crucial to promote a responsible transition: it is imperative to enable the unforeseen potential of emerging technologies, and to ensure policies can better co-evolve with the technology itself while paving the way for responsible, human-centred adoption.

The following sections highlight examples of the key bio-innovation areas underpinned by existing and/or emerging policy frameworks. These policies have been instrumental in enabling bio-solutions to save millions of lives, boost agricultural productivity and deliver sustainable energy alternatives.

These cases bring to the forefront the significant societal benefits that can result from the harmonization of policy and innovation, while highlighting further areas of development for transformative outcomes. At a time when the capabilities of programming biology are rapidly evolving, bringing policy to the forefront of the discussion has never been more crucial: it is through policy that a responsible, human-centred transition will take place to deliver upon all that bio-innovation has to offer.



1 Streamlining regulation: The role of policy in unlocking the promise of genomics and human health

Did you know? Emergency regulatory approval of the COVID-19 mRNA vaccine saved nearly 20 million lives in the first year of use.

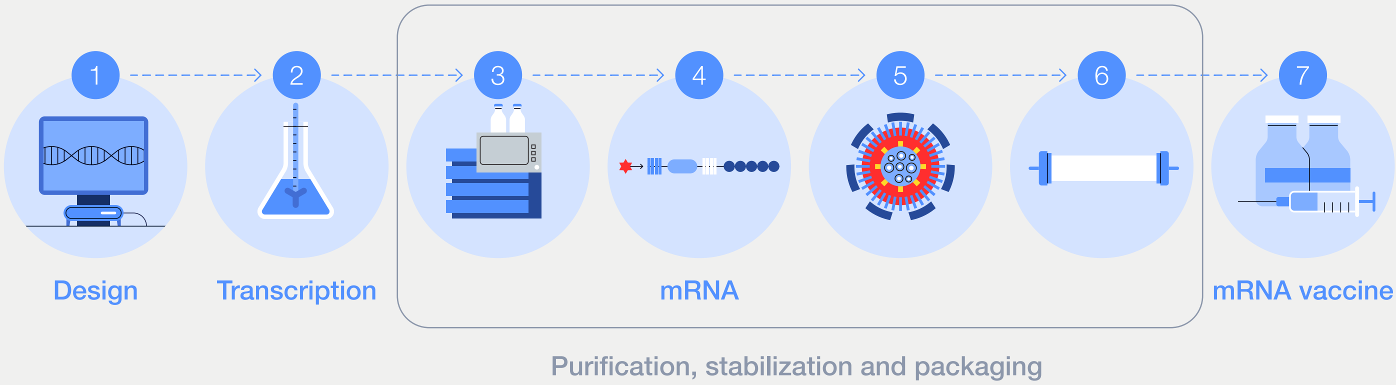
And what else? Policies supporting the sharing of data on human health can help facilitate better patient outcomes through genomics.

In December 2019, COVID-19 triggered a human health crisis and impacted lives in ways that changed how people worked, lived and socialized, and claimed over 3 million lives in 2020 alone.[5] Given the nature and scale of the crisis, the need for innovation to deliver immediate action across the globe was felt like never before.

An innovative solution had been decades in the making: the ability to *de novo* synthesize RNA (ribonucleic acid, a molecule essential for most bodily functions), as both public and private biotech research and development (R&D) were pushing the boundaries of how mRNA (messenger RNA, which carries instructions for cells) could be deployed in vaccines (Figure 1).

Spurred by data-sharing portals such as the COVID-19 data portal,[6] and owing to decades of foundational R&D, mRNA vaccines for COVID-19 were produced in record time of less than a year.[7] The unprecedented development of mRNA vaccines and the vaccination of millions of people was an innovation triumph that was instrumental in controlling the COVID-19 outbreak.

FIGURE 1 **mRNA vaccine commercial production**



After designing *in silico* based on the intended target, mRNA vaccines are produced using enzymes in large-scale reactions. The resulting mRNA is then stabilized, packaged and purified through a series of downstream steps to create the final mRNA vaccine that is delivered to patients.

Yet, the scientific innovation behind mRNA vaccines alone would have been insufficient to address a human health crisis of this magnitude. On 18 December 2020, the Food and Drug Administration of the United States (US) issued an emergency-use authorization for the Moderna COVID-19 vaccine.[8] Policy, and in particular emergency-use approval, was the real triumph that permitted vaccines to address the pandemic, the groundwork for which was being laid for decades before.[9] In that first year alone, vaccinations are estimated to have saved nearly 20 million lives.

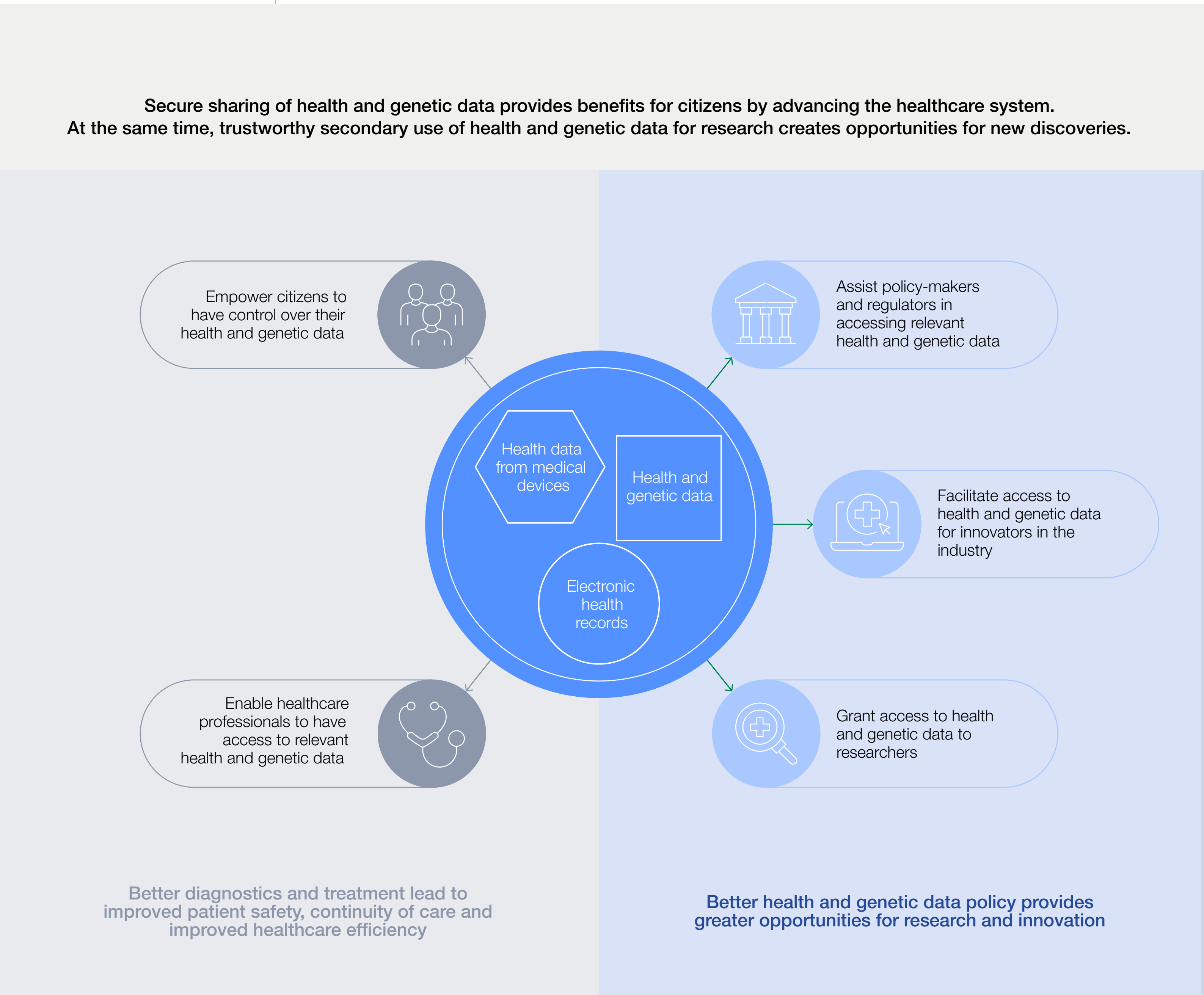
Since their introduction in 2020, COVID-19 vaccines have reduced deaths due to the pandemic by at least 57%.[10] Beyond fast-track approvals, long-term enabling policy frameworks including accelerated approvals, priority reviews, as well as breakthrough therapies are encouraging an influx of innovative bio-solutions for patients in need.[11] Such an approach has enabled a fundamental shift away from a single, emergency-focused policy response to a more comprehensive, ongoing policy framework capable of addressing a multitude of healthcare challenges.

And while public views on vaccines still vary and vaccine distribution remains inequitable,[12] without prompt policy intervention, the outcomes and the number of lives saved during this critical moment in global history would have been drastically different.

Beyond emergency regulatory approvals, policy has also played an instrumental role in data sharing to drive forward scientific innovation. As technology advances, data sharing remains central to scientific and medical progress. Advances such as the Human Genome Project, CRISPR-Cas9 and AlphaFold illustrate how sharing data across borders, institutions and organizations drives breakthroughs in biotechnology for the betterment of humankind.

For decades, human genomic data has promised to revolutionize disease diagnosis, treatment and prevention through personalized healthcare (Figure 2). One area holding tremendous potential is the application of genomics to treat cancer and rare diseases. Cancer continues to be the foremost cause of mortality globally, responsible for nearly 10 million deaths in 2022, equating to approximately one-fifth of all global deaths.[13] At the same time, 7,000 types of rare diseases affect 300 million people around the world.[14]

FIGURE 2 **Benefits of sharing health and genetic data**

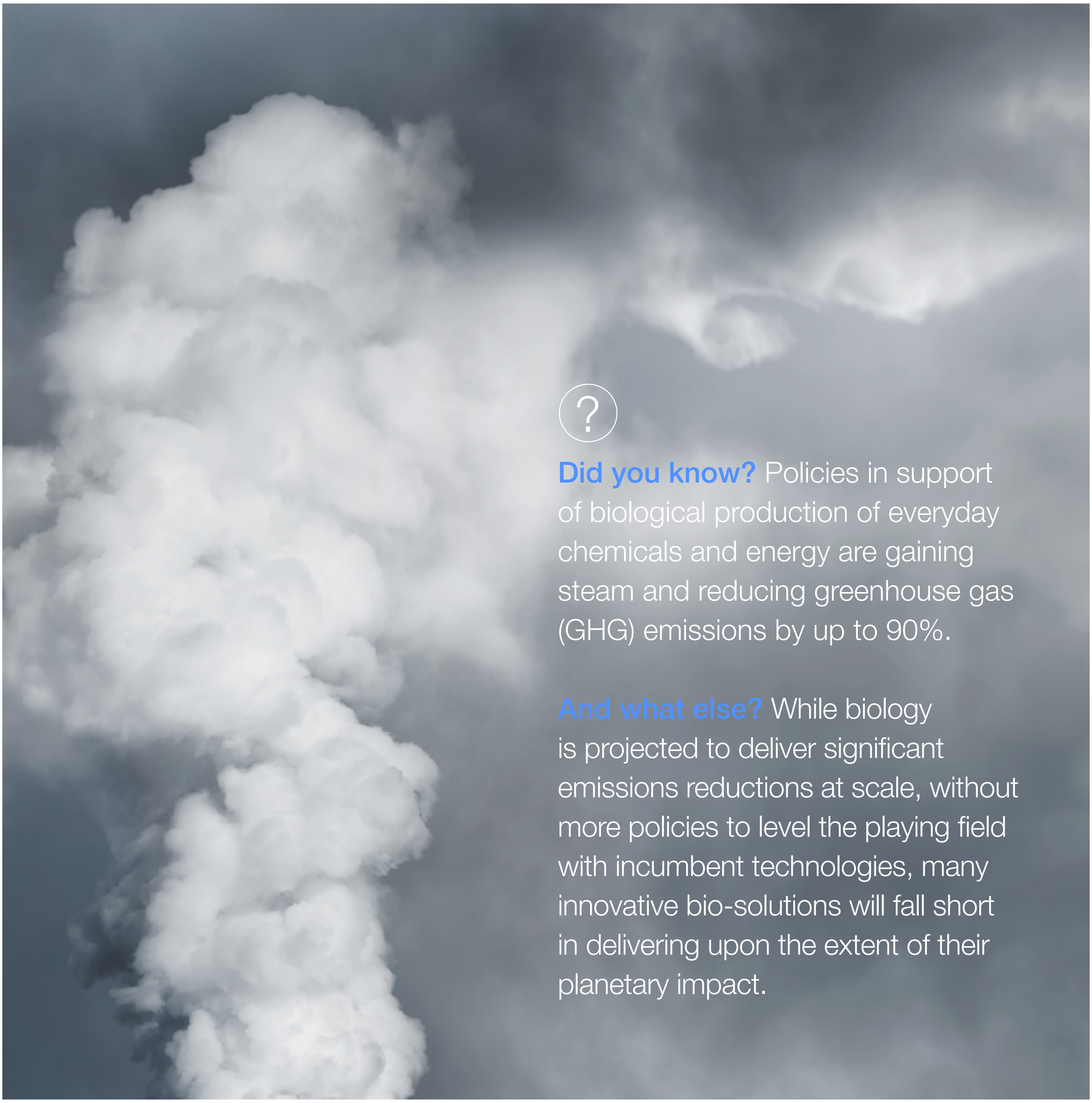


Despite its promise, leveraging human genomic data for better patient outcomes faces significant obstacles, including high costs, storage and computational requirements, as well as the challenge of integrating genetic data with other clinical data, to name a few. The government of the Republic of Serbia is laying the foundation for a successful integration of genetic and health data.[15] Legislation enacted in October 2023 supports the creation of a biomedical data registry and a centralized national electronic health record system.[16] Other consortia, such as the Global Alliance for Genomics and Health,[17] are laying the foundation for responsible use of genomic data by setting standards for responsibly collecting, storing, analysing and sharing genomic data. Safeguarding responsible use of genomic data for healthcare and research is of paramount importance in ensuring that genetic data can be used ethically and optimally.

Other efforts, such as Together for CHANGE (Changing Healthcare for People of African Ancestry through an InterNational Genomics & Equity initiative), are aimed at addressing inequities in genomics research.[18] With the goal of establishing the most extensive genomics research database of African ancestry to date, the project uses de-identified genomic and phenotypic data from up to 500,000 volunteers. Such coalitions underscore the importance of creating more streamlined frameworks for collaboration to ultimately accelerate the pace of bio-innovation and expand their beneficiary base with targeted and tailored therapies.

Other efforts aimed at addressing the barriers associated with cross-border data sharing are also being implemented. For instance, China recently introduced new regulations aimed at unlocking the value of data for cross-border transfers.[19] As countries and institutions continue to evolve policies and practices for cross-border data management and flow, data sharing will continue to play a pivotal role in delivering scientific breakthroughs for better, more equitable outcomes for patients.

2 **Scaling sustainable alternatives:** The role of policy in delivering sustainable alternatives for hard-to-abate industries



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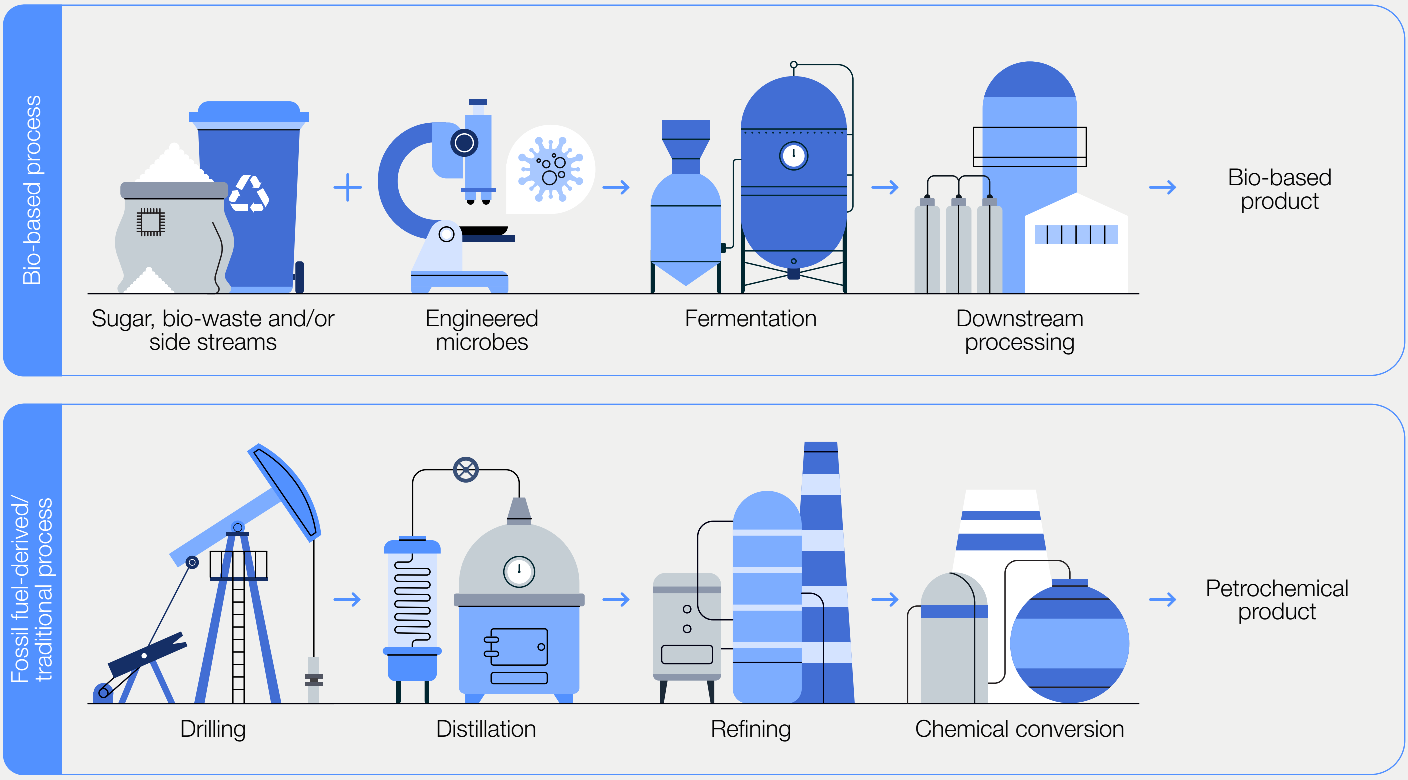
Did you know? Policies in support of biological production of everyday chemicals and energy are gaining steam and reducing greenhouse gas (GHG) emissions by up to 90%.

And what else? While biology is projected to deliver significant emissions reductions at scale, without more policies to level the playing field with incumbent technologies, many innovative bio-solutions will fall short in delivering upon the extent of their planetary impact.

Beyond improving human health outcomes, biology can be applied in the production of everyday products to deliver more environmentally conscious alternatives.[20] Owing to the inherent programmability of the genetic code, biology has long been applied as commercial technology in the production of many of the goods used on a daily basis.[21] One area where biology has delivered myriad alternatives at scale is in the production of common everyday chemicals (Figure 3).[22]

For instance, commercial bio-production of organic acids has been shown to reduce GHG emissions by up to 90% as compared to conventional chemical synthesis and fossil-based processes.[23] Enzymes also play a significant role in commercial chemical production, and enzyme-produced bio-ingredients have been estimated to reduce carbon dioxide (CO_2) emissions by as much as 23%.[24]

FIGURE 3 **Bio-based production of chemicals**



Bio-based chemicals can be produced from sugar or other waste, and other side streams. Commercial-scale fermentation with optimized microbes is followed by downstream processing to deliver the desired bio-based products.

Traditional alternatives make use of drilling to extract fossil-fuel substrates, which are then distilled, refined and chemically converted to render the final product. The chemical industry is currently responsible for 6% of global GHG emissions.

Source: Gabrielli, P., Rosa, L., Gazzani, M., Meys, R., Bardow, A., Mazzotti, M., & Sansavini, G. (2023). Net-zero emissions chemical industry in a world of limited resources. *One Earth*, 6(6), 682-704. https://doi.org/10.1016/j.oneear.2023.05.006

Historically and still today, the commercial synthesis of chemicals has relied on petroleum-derived feedstocks.[25] Commercial production of chemicals requires high temperature and pressure, consumes fossil-derived energy, and generates significant quantities of hazardous waste. Amid growing environmental concerns, regional policies now support the adoption and scaling of bio-based commercial practices as a sustainable alternative.[26]

While bio-based processes have been running at scale for decades, commercial adoption remains relatively niche as compared to incumbents. This is one area where policy can play a significant and influential role, and policy-makers are responding. With a call for supportive regulatory frameworks and more European-based financing opportunities, the European Commission has set forth greater efforts in expanding European biotechnology and biomanufacturing.[27] Governments have also taken notice and implemented procurement policies, such as the European Green Public Procurement (GPP) criteria, which prioritize bio-based products and stimulate market demand to support industry growth.[28]

Yet despite these and other policies aimed at supporting commercialization of bio-solutions, reaching commercial scale still requires significant capital expenditure and production capacity remains in high demand.[29] The role of policy in accelerating the transition away from extractive technologies to a bio-based economy cannot be overstated. Support tools such as the Pilots4U open database, a network of open-access pilot and multipurpose demo-infrastructures in Europe, aims to help bio-based processes reach commercial scale by highlighting available infrastructure assets.[30]

Given the lack of cost parity and the significant costs associated with commercializing bio-based technologies, as well as the sheer scale of manufacturing required, additional policies in the form of financial incentives such as tax credits and grants encouraging investment in bio-based industries are still needed. These and other incentives will go a long way in offsetting the capital-intensive costs associated with R&D, technology adoption and infrastructure development, as well as commercial deployment and scaling.

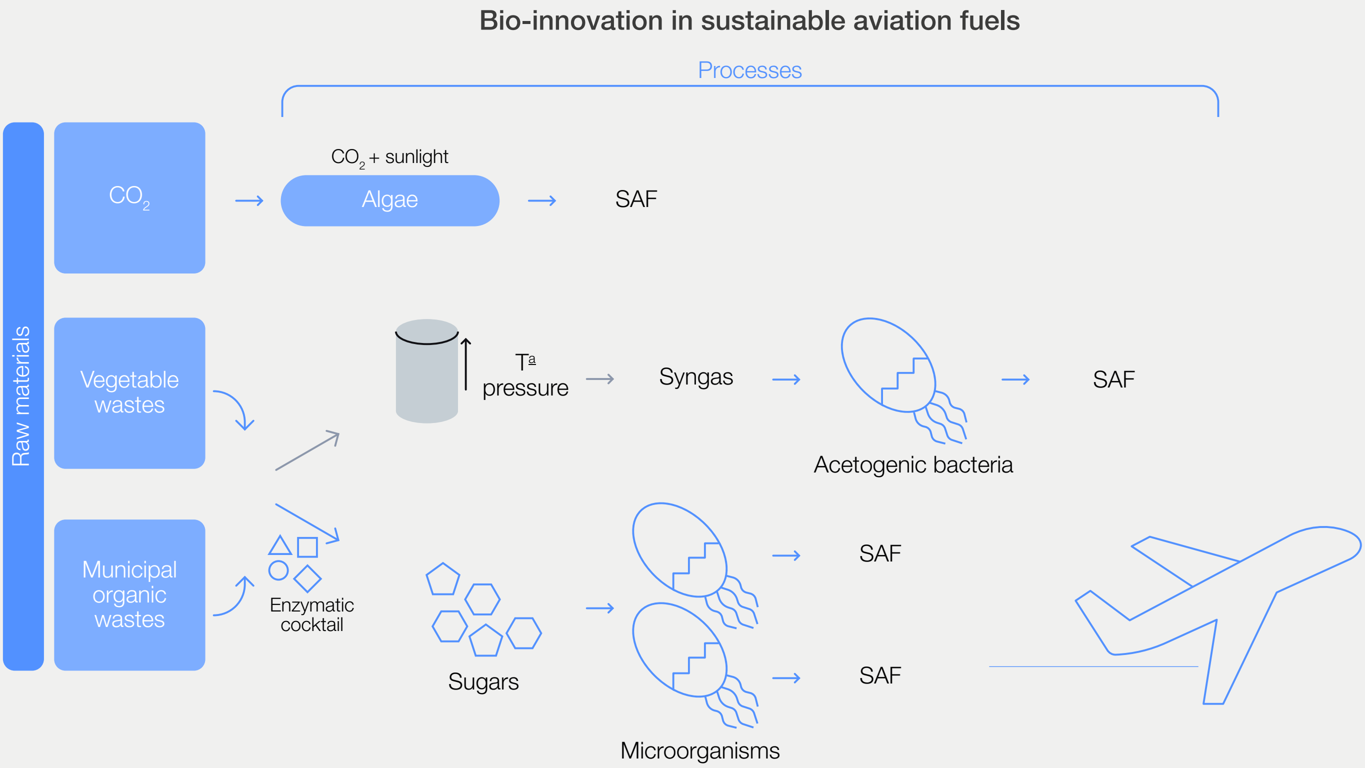
Biology's ability to deliver game-changing production alternatives isn't limited to chemicals, as bio-innovation has long been applied to meet energy needs across industries. One area receiving renewed enthusiasm is the application of biotechnology to sustainably produce aviation fuel.

The global aviation industry is estimated to be responsible for human-induced CO_2 emissions totalling 2.5%,[31] and air travel shows no signs of slowing: flights are expected to surpass 16 million by the year 2050, representing an increase of 44% from 2019.[32] And while the aviation industry targets net-zero by 2050, drastic advances in sustainable aviation technologies will be required to decouple the industry's growth from carbon emissions.[33]

Sustainable aviation fuel (SAF) represents a promising path to reduce emissions and consists of bio-based and synthetic fuels that serve as "drop-in" replacements for jet fuel.[34] Biology can be employed in the production of SAF, which can be produced from various biological inputs and production methods (Figure 4A).[35] Current estimates suggest that SAF can reduce the industry's emissions by 80% as compared to conventional jet fuel.[36]

However, SAF usage made up only 0.2% of aviation fuel consumption in 2023.[37] Formidable obstacles must be overcome in order to realize the industry's short- and longer-term emissions goals with SAF.[38] Increasing supply and adoption as well as excessive costs remain at the forefront of these challenges, as SAF costs are currently 120-700% higher than those of conventional jet fuel.[39]

FIGURE 4A | **Powering aviation and energy needs with bio-solutions**



This is a schematic representation of various sustainable aviation fuel (SAF) production processes employing bio-innovation. Biological inputs and processes are deployed across a variety of SAF production methods.

Note: Ta: Tankage pressure

Source: Segura, A., Jiménez, L., & Molina, L. (2022). Can microbiology help to make aviation more sustainable? *Microbial Biotechnology*, 16(2), 190–194. https://doi.org/10.1111/1751-7915.14191

Policy will continue to influence commercialization and adoption of SAF (see box below). In addition to grants that support early-stage R&D,[40] mandates aimed at increasing demand have also started to take shape in Europe[41] and beyond.[42] Further subsidies and direct financial support aimed at lowering production costs and facilitating infrastructure development (investments totalling $1.45 trillion will be required to deliver the quantities needed),[43] as well as sustainability mandates for the aviation industry, will all be necessary to scale SAF production to meaningfully decarbonize aviation. The role of policy is paramount in ensuring that SAF is both affordable and widely adopted across the industry.

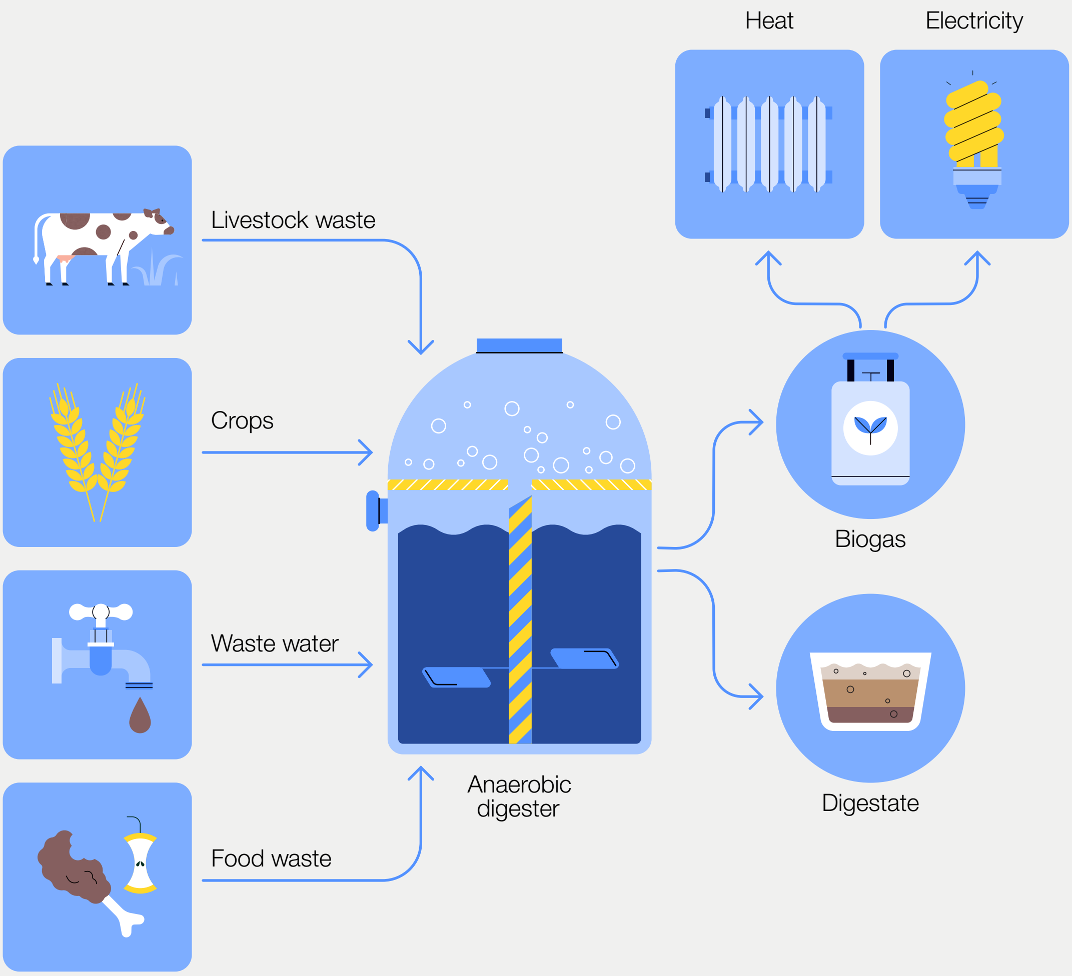
Policy spotlight

ReFuelEU Aviation promotes the increased use of SAF as the single most powerful tool to decrease aviation CO_2 emissions. The measure is part of the "Fit for 55" package aimed at achieving a 55% emissions reduction by 2030.[44] It mandates that aviation fuel suppliers progressively increase the proportion of SAF blended with conventional aviation fuel at airports in the European Union.[45]

Policy is also being applied to enable biology to meet energy demands in areas extending beyond aviation.

Energy and heating represent another area that has long relied on fossil inputs: in 2019, energy and heating generated 34% of global GHG emissions.[46] Disruptions to natural gas supply chains have only further extended the need to identify alternative sources. By capturing methane from waste streams, biogas represents an energy alternative that holds the potential to reduce GHG emissions by up to 90% to generate electricity and heat (Figure 4B).[47]

FIGURE 4B | **Powering aviation and energy needs with bio-solutions**



Inputs such as livestock waste, energy crops, waste water and food waste can be used in the production of biogas. By making use of an anaerobic digestor, anaerobic microbes process these inputs into biogas, which provides a sustainable and alternative source of heat and electricity.

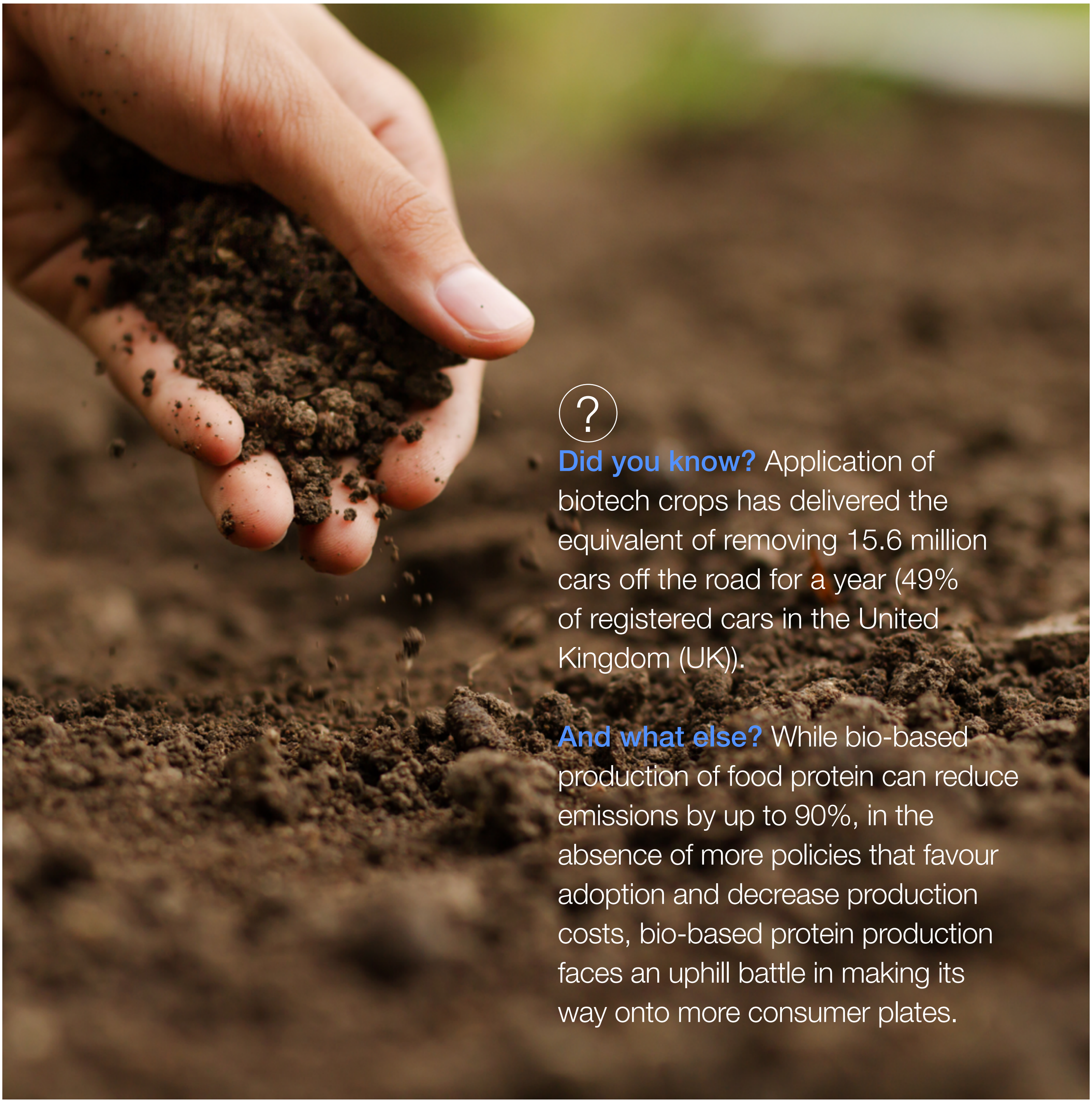
How does it work?

Processing of agricultural waste to break down organic matter results in the production of biogas, which is primarily composed of methane (CH_4) and carbon dioxide (CO_2). Refined from these products, biomethane represents a concentrated, storable and versatile energy source with promising GHG mitigation potential. The chemical composition of biomethane is very similar to methane, and biomethane can be seamlessly integrated into existing gas infrastructure.

However, before biogas can meet growing electricity demand and heat homes, costs must be reduced significantly. Limited financial incentives and subsidies hinder cost competitiveness against fossil fuels, impeding broader market adoption. The Biomethane Decree of Denmark represents a supportive policy aimed at boosting production of biomethane by 2030 and replacing 100% of natural gas imports with biomethane while also allocating incentives to support its production.[48]

Policies in other countries crafted in a similar vein will be essential to achieving biogas cost parity with extractive production methods, and to establish biogas as the sustainable energy solution of the future. Akin to the other bio-innovations that have yet to make their way into the commercial mainstream, a combination of strategic deployment, supportive policies and technological advancements is needed to maximize the environmental and economic benefits of biogas.

3 **Commercialization and adoption:** The role of policy in shaping sustainable food and agricultural systems



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Did you know? Application of biotech crops has delivered the equivalent of removing 15.6 million cars off the road for a year (49% of registered cars in the United Kingdom (UK)).

And what else? While bio-based production of food protein can reduce emissions by up to 90%, in the absence of more policies that favour adoption and decrease production costs, bio-based protein production faces an uphill battle in making its way onto more consumer plates.

For decades, biotechnology has been applied to food and agricultural systems to decrease the reliance on fossil inputs across many fronts, and to produce options that are healthier and/or have lesser environmental impact. Alongside myriad policies to responsibly deploy game-changing innovations across the food system, much ground remains to be covered before GHG emissions associated with agriculture and food production can be meaningfully reduced.

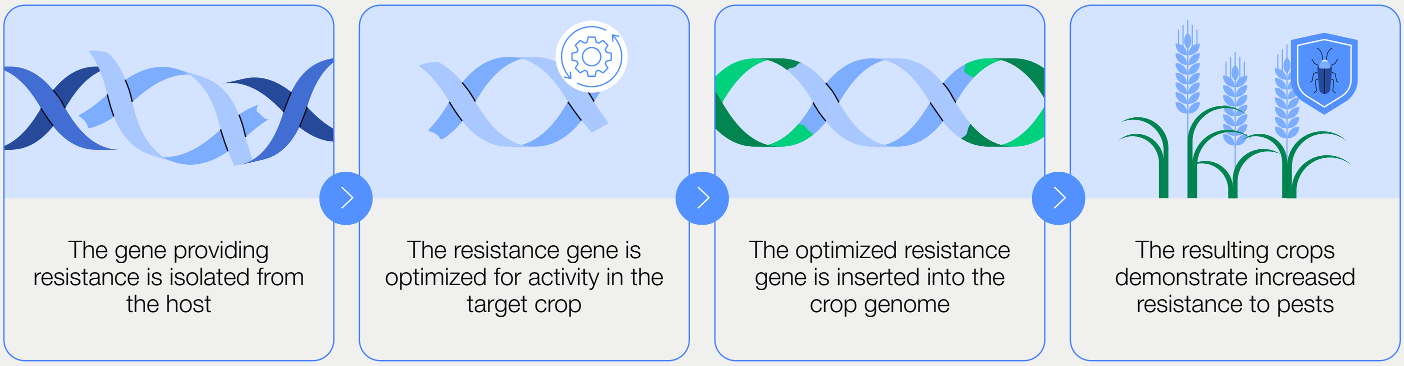
Even so, policies put into place across regions have ensured that these innovations are already making progress in sustainably feeding the population and providing healthier choices through innovative, bio-based approaches.

Delivering healthier, bio-based options

The European Commission has agreed on regulations that limit the amount of trans-fat in foods on the European market.[49] Bio-innovation provides a safe and environmentally-friendly solution for food producers to meet this demand by using enzymes that render oil free of trans-fats.[50] Historically produced through industrial chemistry, the biological process eliminates the need for chemicals and post-bleaching, reducing the generation of wastewater.

In agriculture alone, bio-innovation has provided crops with many important self-sustaining properties (Figure 5A); biotechnology continues to improve sustainability of global agricultural practices in ways that are not always appreciated by the consumer. For example, emissions reductions from decreased production of small-molecule chemistries (think pesticides and herbicides) and the reduced number of field operations required when applying biotechnology to agriculture, continue to reduce the fossil reliance of existing agricultural practices and have delivered considerable benefits to the planet.

FIGURE 5A **Application of biotechnology in agriculture**



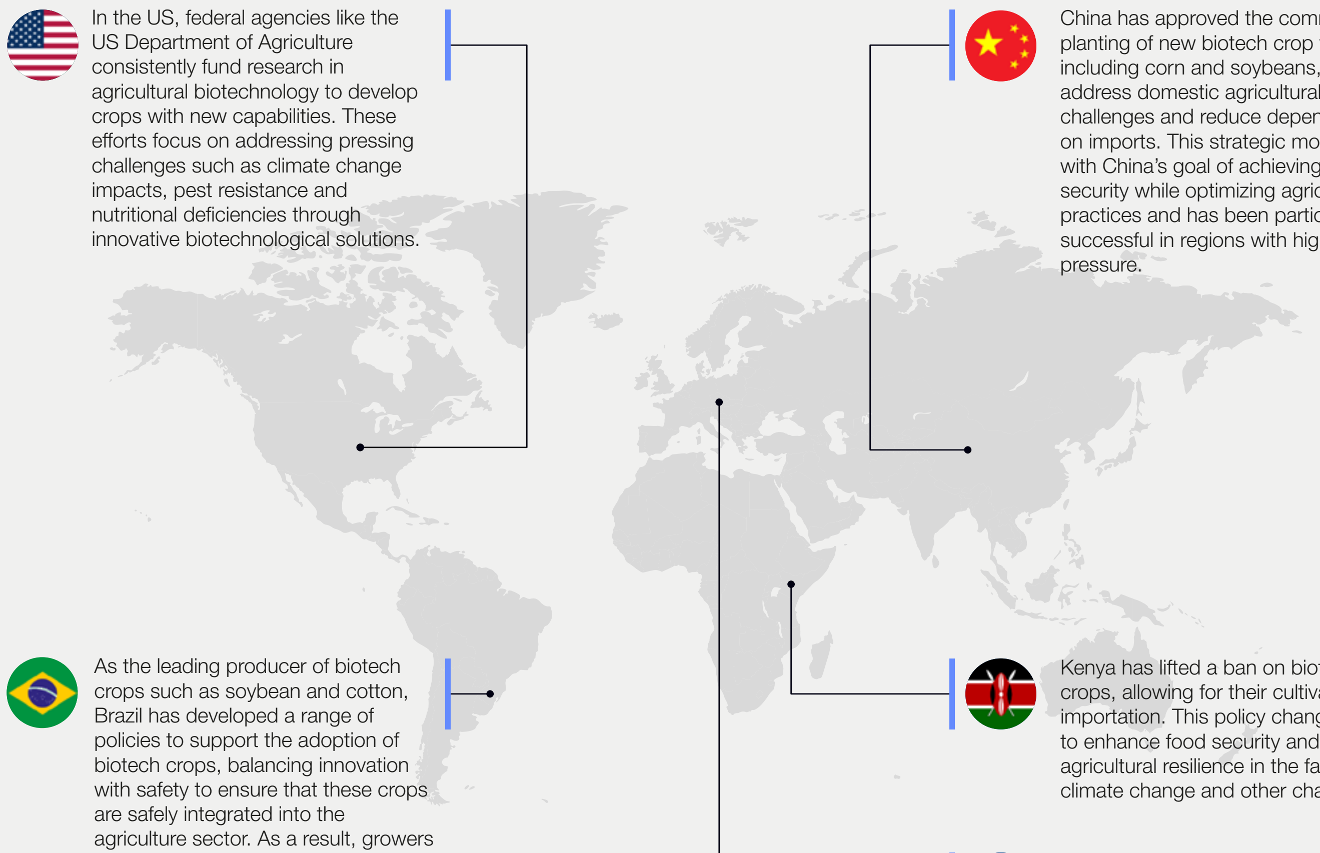
How does it work?

Commonly derived from petroleum, the production of herbicides and pesticides requires fossil fuel inputs. Biotechnology has enabled crops to become more self-sustaining. The results include reduced pesticide and water usage as well as improved harvests and yields in those regions where policy supports responsible adoption.

Supportive policies in regions such as Africa, India, China, US and Brazil (Figure 5B) have delivered reductions in pesticide use ranging from 50% to 70% for specific crops, e.g. cotton containing a gene providing insect resistance (Figure 5B). These approaches are estimated to have achieved a significant reduction in the release of GHG emissions over the last two decades, equivalent to removing 15.6 million cars from the road for a year (49% of registered cars in the UK).[51]

The reduction in pesticide use due to biotech crops has been significant, contributing to more sustainable agricultural practices globally.[52] Between 1996 and 2016, the use of genetically-modified (GM) crops reduced pesticide spraying by nearly 671,400 tonnes, equating to an 8.2% reduction. This has decreased the environmental impact associated with crop protection practices by 19% as measured by the Environmental Impact Quotient (EIQ).[53] However, these achievements have only been made possible by corresponding policy frameworks that facilitate their commercial use.[54]

FIGURE 5B **Policies in support of agricultural biotechnology worldwide**



In the US, federal agencies like the US Department of Agriculture consistently fund research in agricultural biotechnology to develop crops with new capabilities. These efforts focus on addressing pressing challenges such as climate change impacts, pest resistance and nutritional deficiencies through innovative biotechnological solutions.

China has approved the commercial planting of new biotech crop varieties, including corn and soybeans, to address domestic agricultural challenges and reduce dependence on imports. This strategic move aligns with China's goal of achieving food security while optimizing agricultural practices and has been particularly successful in regions with high pest pressure.

As the leading producer of biotech crops such as soybean and cotton, Brazil has developed a range of policies to support the adoption of biotech crops, balancing innovation with safety to ensure that these crops are safely integrated into the agriculture sector. As a result, growers have benefited from increased agricultural productivity and efficiency. Brazil is also experiencing an increase in the number of applications for registration of biopesticides, forcing regulatory authorities to adapt procedures and legislation to meet the unique requirements of products. As a result, the number of registered biopesticides has skyrocketed, with an overall increase of 404% in recent years.

Kenya has lifted a ban on biotech crops, allowing for their cultivation and importation. This policy change aims to enhance food security and bolster agricultural resilience in the face of climate change and other challenges.

With an eye on creating an enabling environment for research and innovation in identifying solutions to sustainably feed the population, the European Commission has adopted a proposal for new regulations on plants produced through novel genomic techniques, part of the broader legislative efforts to support the EU's farm-to-fork and biodiversity strategies.

As climate conditions escalate, so too do the challenges associated with preserving and maintaining food and agricultural systems. Agricultural biotechnology plays a pivotal role not only in ensuring adequate food supply, but also in addressing the growing risk of crop extinctions worldwide due to climate change-related factors. For instance, biotechnological tools offer effective interventions to preserve crop cultivars and combat biodiversity loss.

Addressing biodiversity loss

About two plant species vanish each year on average, a rate that is 500 times faster than the natural rate of extinction.[59] Species critical to human food sources, such as bananas, papayas and certain cocoa varieties, are also facing heightened threats. Inbreeding depression[60] among endangered species further diminishes genetic diversity, hastening extinction. Biotechnology, particularly through gene editing, provides rapid solutions to mitigate biodiversity loss.[61]

While regulatory frameworks have extended the ability of biotechnology to provide meaningful intervention in combatting biodiversity loss, policy-makers continue to grapple with related crucial questions such as the conservation status of modified species and the appropriate regulatory bodies. Harmonization of policies across regions is essential in preserving biodiversity and responsibly safeguarding food security for the growing population.

At the same time, the stress on the food system to provide enough nourishment for the growing human population remains one of the biggest challenges facing humankind. Similar to agriculture, life-science breakthroughs can also be applied to the way that food is produced beyond the cultivation of crops, such as cultured post-harvest protein.

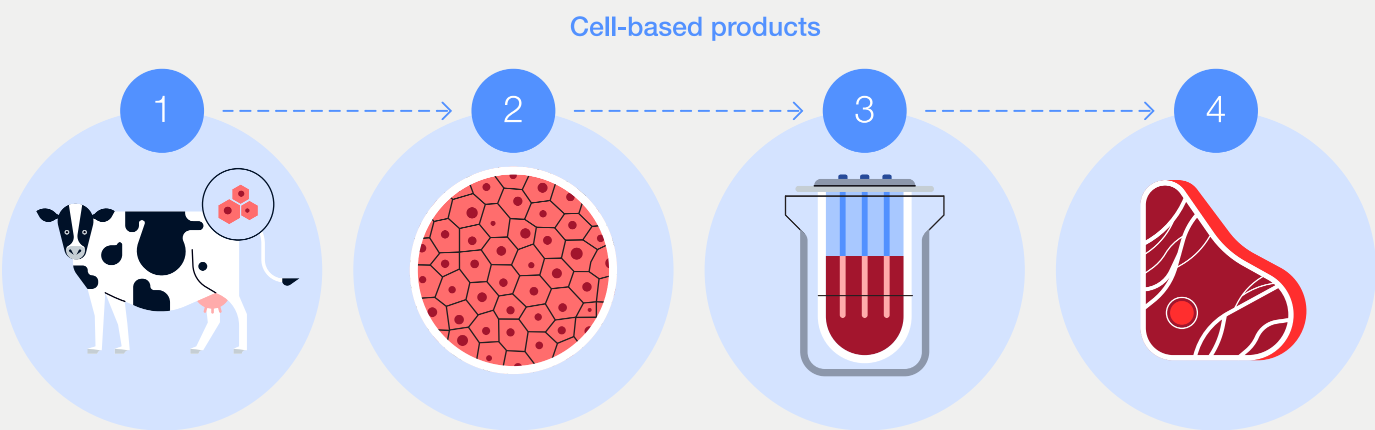
Despite global efforts, over 9% of the world's population experienced chronic hunger in 2022 alone.[62] A fundamental shift in trajectory is essential to achieve the United Nations' Sustainable Development Goal of Zero Hunger by 2030.[63] Adding to the growing climate challenges, food and agriculture contribute to over one-third of global GHG emissions,[64] with animal agriculture alone responsible for 15-20%.[65]

Emissions from livestock production have reached an all-time high, and biotechnology is increasingly being deployed as a source of protein innovation for consumers. Furthermore, the demand for protein is set to double by 2050.[66] As with other bio-innovations, coordinated policy solutions are required to transform current food systems and responsibly deliver such innovations to the masses.

Such tools are being applied to expand the portfolio of offerings and reduce environmental impact;[67] food protein production through fermentation has shown much promise, and in some instances is associated with reducing GHG emissions by up to 90%,[68] and reducing land and water usage overall.[69] Dairy proteins, egg proteins, meat proteins and collagen are just a few now being produced commercially in an animal-free fashion.

The production of animal-sourced foods from cell culture represents another tool to help meet the growing demand for sustainable and ethical food sources (Figure 6). Produced through cellular agriculture, the carbon footprint of cultivated meat is 92% lower than that of conventional beef, 44% lower than pork and equivalent to chicken when produced using renewable energy sources.[70]

FIGURE 6 **Cultivated meat**



Cultivated meat is typically produced through harm-free harvesting from the animal. The resulting animal cells are grown in a lab environment and further processed to produce cultivated meat products for the consumer.

The environmental benefits extend well beyond carbon emissions, as lab-grown protein production requires significantly less land and water than conventional production, making it a sustainable alternative for addressing global food security and environmental challenges.

Important policy milestones

- Singapore has established regulatory frameworks for the approval of cultured meat for the market, a global first that highlights the urgent need for clear guidelines;[71] other regions are investing in infrastructure for production.[72]
- The US Department of Agriculture (USDA) and Food and Drug Administration (FDA) are safely bringing cell-based meat products to market faster through a series of efforts to proactively address the safety of cultivated meat.[73]
- Israel and other countries have also been proactive in developing comprehensive strategies to regulate novel foods, aiming to foster a robust innovation ecosystem, attract capital investments and maintain a leadership position in food technology.[74]
- In an important step, the EU's "farm to fork" strategy has recognized the role of bio-based products in improving sustainability of food systems through innovation, and the European Food Safety Authority (EFSA) has released a scientific opinion requested by the European Commission: "New Developments in Biotechnology applied to microorganisms" which could have far-reaching implications for more sustainable ingredients and food systems generally.[75]

Policy has played a powerful role in responsibly bringing more sustainable food options to the masses through standardization of safety protocols to prevent health risks, facilitating international trade by harmonizing standards, and promoting consumer confidence through rigorous testing and transparency. However, the implementation of further supportive policy frameworks – around regulation, commercial production and fiscal incentives – is urgently required to decrease costs, extend the benefits of lab-grown protein and to bring these innovative solutions to the plates of more consumers.

Conclusion

Supportive policies are recognized for their ability to increase adoption, drive cost reductions, provide benefits to the environment, spur economic growth and so much more. The rapid adoption of solar panels represents one prominent example of the power of policy: due to the confluence of technological advancements, economic factors, increasing environmental awareness, and above all else, supportive policies, the adoption of solar panels has skyrocketed.[76]

The world stands on the brink of a revolution through the convergence of the biological, digital and physical worlds. What role will policy play in bringing tech-driven bioeconomy innovations into the mainstream and enabling a better bio-future that is accessible to all?

Regardless of what has been delivered, as well as the benefits that innovation is on the cusp of providing, one thing remains clear: without technological interventions and supportive policies, the impacts of global crises like COVID-19 would have been much worse, and far fewer viable options for addressing climate change would exist.

While bio-innovations to address planetary human challenges continue to gain commercial traction, it is the corresponding policies that hold the keys to the timeliness of response and the efficient delivery of outcomes for better human and planetary outcomes.

This paper has highlighted the impact of biotechnology policy in key areas – health, energy and chemicals, food and agriculture – that offer significant societal and environmental benefits. It also makes the case for policy to extend its reach and outlines key obstacles that must be overcome to enable biotechnology to deliver transformative solutions more efficiently.

Overcoming these challenges through coordinated public-private partnership, and seizing such opportunities is essential to unlocking biotechnology's full potential to drive innovation and address the urgent, unforeseen global issues of this era.

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