Biotechnology 1 for tomorrow's world: Scenarios to guide directions for future innovation

Marc Cornelissen, Aleksandra Malyska, Amrit Kaur Nanda, René Klein Lankhorst, Martin A.J, Parry, Vandasue Rodrigues Saltenis, Mathias Pribil, Philippe Nacry, Dirk Inze, Alexandra Baekelandt

▶ To cite this version:

Marc Cornelissen, Aleksandra Malyska, Amrit Kaur Nanda, René Klein Lankhorst, Martin A.J, Parry, et al.. Biotechnology 1 for tomorrow's world: Scenarios to guide directions for future innovation. Trends in Biotechnology, 2021, 39 (5), pp.438-444. 10.1016/j.tibtech.2020.09.006 . hal-02968513

CellPress
OPEN ACCESS

Trends in
Biotechnology

Opinion

Biotechnology for Tomorrow's World: Scenarios to Guide Directions for Future Innovation

Marc Cornelissen,[1,@] Aleksandra Małyska,[2,*] Amrit Kaur Nanda,[3,@]
René Klein Lankhorst,[4] Martin A.J. Parry,[5] Vandasue Rodrigues Saltenis,[6]
Mathias Pribil,[6] Philippe Nacry,[7] Dirk Inzé,[8,9] and Alexandra Baekelandt[8,9,@]

Depending on how the future will unfold, today's progress in biotechnology research has greater or lesser potential to be the basis of subsequent innovation. Tracking progress against indicators for different future scenarios will help to focus, emphasize, or de-emphasize discovery research in a timely manner and to maximize the chance for successful innovation. In this paper, we show how learning scenarios with a 2050 time horizon help to recognize the implications of political and societal developments on the innovation potential of ongoing biotechnological research. We also propose a model to further increase open innovation between academia and the biotechnology value chain to help fundamental research explore discovery fields that have a greater chance to be valuable for applied research.

Developing Scenarios for Biotechnology in Complex Social Systems

Biological science is expanding its knowledge frontiers at an ever-accelerating pace. The progressing insights into biological processes offer a broadening array of options to develop incremental and differential innovations across the medical, agricultural, and industrial biotechnology sectors.

As timelines from understanding basic biological processes to the conception of an innovation and the development of a marketable product may range from 10 to 25 years, a prime question for today's biotechnology discovery research is 'innovation for what future world?' (Figure 1).

To this end, in 2019, we conducted a first-of-its-kind scenario analysis with a 2050 time horizon to understand the option space of agricultural biotechnology.[i] Forty-five trends and 22 uncertainties dealing with the entire agricultural socioeconomic system were reviewed to map the range of directions the future may take and to narrow down how agricultural biotechnology could best future-proof food, nutrition, and health security. Trends ranged from consumer and demographics, farming and technology to politics, economy, and societal developments while identified uncertainties were clustered around three themes: needs for adaptation, priorities in the value chain, and the role of science (Figure 2).

In order to identify toward which scenario today's world is heading, relevant indicators need to be developed [1,2]. For this, the critical developments or events that will be necessary for a scenario to arise need to be named, put in a chronological order through narratives, and checked for their informative value. Learning scenarios are reusable, and the scope of the indicators identified will depend on the diversity of expertise within the team exploiting the learning scenarios (Figure 3).

Highlights

Identifying most relevant social, economic, and technological trends can help us understand in which direction future worlds could develop.

Extrapolating long-term impact of current developments on the way we live may open avenues of biotechnology discovery research that would provide the starting basis for research and innovation addressing future needs.

Maximizing innovation output in biotechnology requires a continuous cross-stakeholder interaction to timely share know–how obtained from discovery research in formats tailored to stakeholder use requirements

[1]BASF Agricultural Solutions Belgium NV, Gent, Belgium
[2]European Commission DG Research and Innovation, Brussels, Belgium
[3]Plants for the Future' European Technology Platform, Brussels, Belgium
[4]Wageningen University and Research, Wageningen, The Netherlands
[5]Lancaster University, Lancaster Environment Centre, Lancaster, Lancashire, UK
[6]Copenhagen Plant Science Centre (CPSC), Department of Plant and Environmental Sciences, University of Copenhagen, Copenhagen, Denmark
[7]Biochemistry and Plant Molecular Physiology CNRS/INRAE/SupAgro/Univ. Montpellier, Montpellier, France
[8]Ghent University, Department of Plant Biotechnology, Gent, Belgium

https://doi.org/10.1016/j.tibtech.2020.09.006

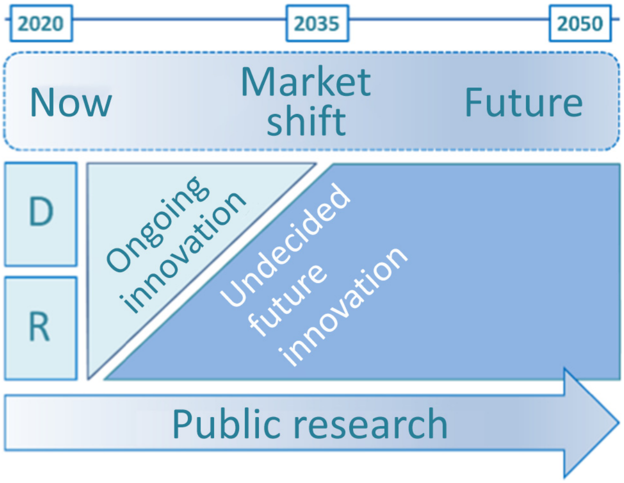


Figure 1. Innovation Flow. In the coming 15 years, the market will be served by R&D that is performed today. Different biotechnology sectors address changes in demand by repositioning and emphasizing what is in today's pipeline. New R&D and public research ideally address the demand of the future market. Scenario analysis is well suited to narrow down the most promising fields of investigation and to address the unmet needs of future markets. Abbreviations: R, research; D, development.

[9]VIB Centre for Plant Systems Biology, Gent, Belgium

*Correspondence:
Aleksandra.Malyska@ec.europa.eu
(A. Małyska).
[@]Twitter: @Plant_ETP (M. Cornelissen, A.K. Nanda) and @Alexandra_Bkldt (A. Baekelandt)

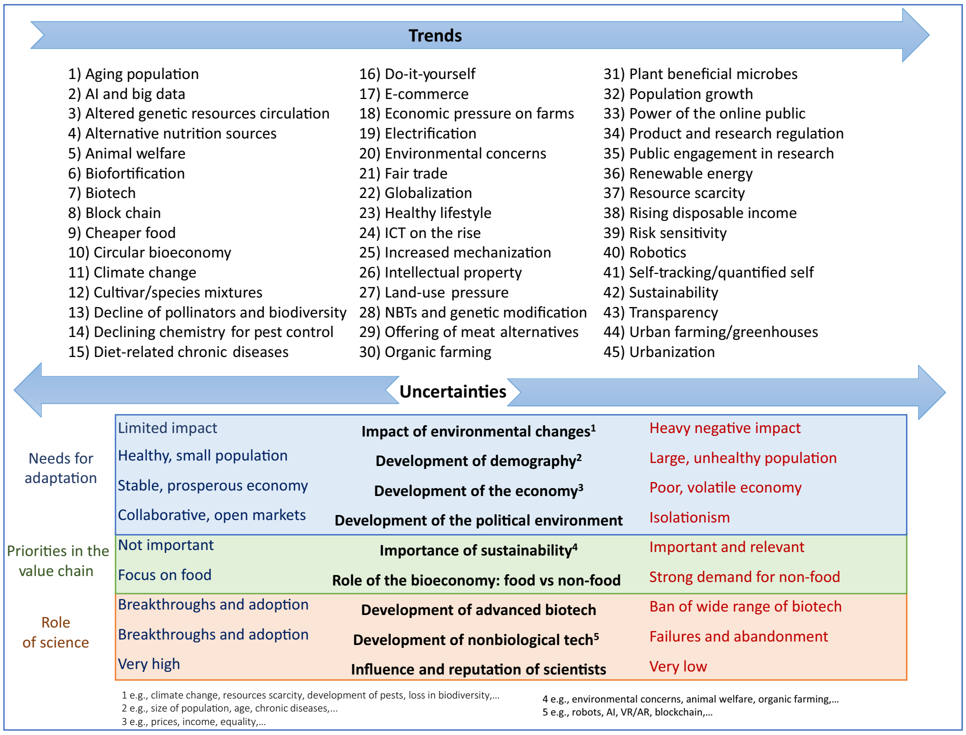
Obvious examples of indicators are the developments around the legislation related to gene editing in the Bio-innovation and REJECTech scenario or personal data protection regulations in the My Choice scenario, while for instance the evolution of water availability in a particular country can be an indicator for Food Emergency, as well as for Bio-innovation or REJECTech.

Steering Focus in Biotechnology Discovery Research with Scenarios

The way the world will evolve will depend on a myriad of developments. Examples are the transition to renewable energy and decentralized storage, the global policy approach to enable the use of new genomic technologies, patients embracing new treatments, society buying into preventive medicine or demanding transparency about food properties, dietary shifts, development of new high-tech materials, shifts in lifestyle, and progress in robotics and artificial intelligence. Following such developments and extrapolating their long-term impact on the way we live may inspire scientists to take a translational step and to open avenues of biotechnology discovery research that would provide the starting basis for research and innovation (R&I) addressing future needs.

Biotechnology discovery research will undoubtedly be at the core of numerous innovations that will reach society by 2050. However, depending on how the future will unfold, today's progress in biotechnology research has a greater or lesser potential to be the basis of subsequent innovation. In addition, the lack of a widespread open innovation culture between industry and academia increases the risk of missing out on innovation that trend-wise is likely to meet industry or consumer demand.

For example, it is clear that the demand for climate change-related biotechnology innovation will be high, and will be supported by policy makers [3,4]. However, what the unmet needs will be for the different stakeholder groups is still unclear. Effects on cities, gardens, parks, lakes, and crop fields linked to shifts and volatility in weather and the resulting new environmental conditions, including new pests and diseases, are not yet fully appreciated. Consequently, a translational step from innovation opportunity to required new knowledge is not obvious. Similarly, it is not clear how to incorporate innovation into products [5]. It may range from gene editing to novel knowledge-driven, societally accepted workflows that are not yet in place. The first activity,



Trends

1) Aging population
2) AI and big data
3) Altered genetic resources circulation
4) Alternative nutrition sources
5) Animal welfare
6) Biofortification
7) Biotech
8) Block chain
9) Cheaper food
10) Circular bioeconomy
11) Climate change
12) Cultivar/species mixtures
13) Decline of pollinators and biodiversity
14) Declining chemistry for pest control
15) Diet-related chronic diseases
16) Do-it-yourself
17) E-commerce
18) Economic pressure on farms
19) Electrification
20) Environmental concerns
21) Fair trade
22) Globalization
23) Healthy lifestyle
24) ICT on the rise
25) Increased mechanization
26) Intellectual property
27) Land-use pressure
28) NBTs and genetic modification
29) Offering of meat alternatives
30) Organic farming
31) Plant beneficial microbes
32) Population growth
33) Power of the online public
34) Product and research regulation
35) Public engagement in research
36) Renewable energy
37) Resource scarcity
38) Rising disposable income
39) Risk sensitivity
40) Robotics
41) Self-tracking/quantified self
42) Sustainability
43) Transparency
44) Urban farming/greenhouses
45) Urbanization

Uncertainties

Needs for adaptation	Limited impact	**Impact of environmental changes**[1]	Heavy negative impact
	Healthy, small population	**Development of demography**[2]	Large, unhealthy population
	Stable, prosperous economy	**Development of the economy**[3]	Poor, volatile economy
	Collaborative, open markets	**Development of the political environment**	Isolationism
Priorities in the value chain	Not important	**Importance of sustainability**[4]	Important and relevant
	Focus on food	**Role of the bioeconomy: food vs non-food**	Strong demand for non-food
Role of science	Breakthroughs and adoption	**Development of advanced biotech**	Ban of wide range of biotech
	Breakthroughs and adoption	**Development of nonbiological tech**[5]	Failures and abandonment
	Very high	**Influence and reputation of scientists**	Very low

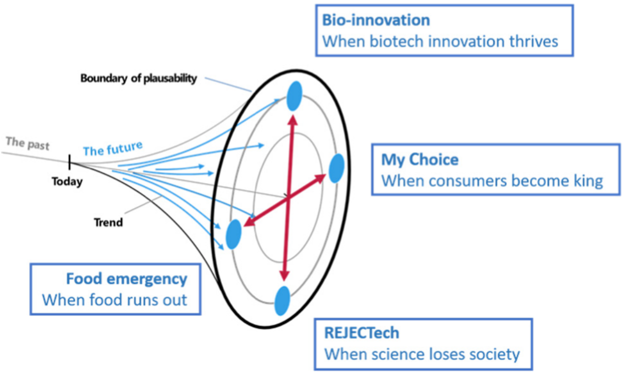
1 e.g., climate change, resources scarcity, development of pests, loss in biodiversity,...
2 e.g., size of population, age, chronic diseases,...
3 e.g., prices, income, equality,...
4 e.g., environmental concerns, animal welfare, organic farming,...
5 e.g., robots, AI, VR/AR, blockchain,...

Trends in Biotechnology

Figure 2. Trends and Uncertainties. Trends are considered developments going in a certain direction, while uncertainties can determine distinct outcomes with very different implications. Here the two most extreme ways that the uncertainties could play out are presented. Examples of specific uncertainties clustered around three more general themes are provided in the footnote. The exercise delivered four contrasting learning scenarios by detailing out specific aspects of possible future worlds and making them as concrete and vivid as possible (Figure 3). As the selected trends and uncertainties deal with society, environment, innovation, and policy, the learning scenarios helped to characterize implications not only for the future of agriculture in Europe, which was the initial scope of the scenario building, but they can also serve to aid decisions on future research and innovation (R&I) investments in other fields of biotechnology globally. Abbreviations: AI, artificial intelligence; AR, augmented reality; NBT, new breeding technique; VR, virtual reality.

developing climate change know–how, has a low risk of not being of relevance. The second, developing biotechnology innovation addressing climate change, is dependent on how policies develop across the globe, and therefore carries a higher risk [6]. For example, whereas it is conceivable in a bio-innovation world that society may see a broad replacement of fossil-based synthetic materials by bio-based alternatives, such a development is less likely to occur in a REJECTech setting, as although the know–how to do so would exist, the technical enablement would not be supported.

Another example relates to the exploitation of the microbiome. As microbes impact most, if not all, complex ecological systems, exploitation of biological know–how is expected to offer innovation options in a broad range of biotechnology fields and be at the core of new markets and business models. These may include medicine, health care, food systems, industrial and household processes and materials, resource recycling, and energy capture. For this to become reality, broad fundamental biotechnology discovery research on microbiomes needs to reach a tipping point, so that R&I for smaller and bigger opportunities across sectors becomes viable [7]. This necessitates a major public effort to advance precompetitive know–how and an enablement to a level sufficient for sector adoption within a reasonable risk perspective on a return of investment. A flagship approach in, for example, medicine building on



Trends in Biotechnology

Figure 3. Learning Scenarios. Four contrasting learning scenarios enable us to delineate the option space for the direction and context of future biotechnology. **Bio-innovation**: Biotechnology solutions are intensively used and sustainably provide sufficient high-quality food and large-volume feedstock for a thriving bioeconomy; **My Choice**: Health and sustainability concerns drive all sectors to be diverse and transparent; meeting the needs and preferences of individuals, personalized medicine, and nutrition are the norm; **REJECTech**: Consumers have little trust in politicians, scientists, and big industry. Society is highly polarized and rejects biotechnology-derived products and services, despite dissatisfaction about missed opportunities, such as a broad adoption of the bioeconomy due to limited agricultural production; **Food Emergency**: Due to severe environmental degradation, the world is struggling to fulfill basic food demand. In response to the crisis, global adoption of innovation, including biotechnology, occurs to mitigate impacts.

ongoing big data efforts, such as in the human ‘100K genomes project’[ii], may serve as a vehicle to reach, in a 5-year time span, the desired state of enablement and allow smaller initiatives to build on this cost-effectively. However, an entrepreneurial ecosystem is critical for this to happen, implying that such developments are more likely to occur under a Bio-innovation scenario or even in a Food Emergency scenario, once society starts prioritizing access to food and health.

A third example refers to diet shifts toward alternative protein sources. Consumer choice strongly depends on food properties such as taste, texture, palatability, color, convenience, and price. Making alternative protein products competitive to meat would require, among other improvements, major advances in biological insights to upgrade food sources [8]. The challenge is to get specific on the carriers, such as algae, insects, crops, fermentation, and so on, and the exact properties, so that the investments in biotechnology discovery have a practical effect. How to do this successfully is not obvious as it is currently not clear which products and product properties will match future market demands. This re-emphasizes the importance of contrasting learning scenarios and the need to identify scenario-specific indicators to get insights early in time about how particular trends are panning out. These indicators may relate to yes/no decision points in policy development, or the timely establishment of critical enabling technologies or of sizeable consumer demands. Tracking progress of multiple, scenario-specific indicators thus helps to steer focus in discovery research and to emphasize or de-emphasize timely manner to maximize the chance for successful innovation.

A current real-life example is the COVID-19 (coronavirus disease 2019) pandemic, an occurrence that was not foreseen because of which only relatively small and scattered efforts of research have been conducted prior to the pandemic. The current R&I race to develop a cure and vaccine against COVID-19 would have greatly benefitted from an advanced knowledge on coronaviruses, obtained through biotechnology discovery research [9,10]. Of course, in hindsight it is easy to highlight what should have been done. In practice, there are several million viruses in the world, over 200 of which are known to infect humans. Conducting extensive research on all these viruses in parallel would be too labor-intensive and unsustainable from an economical point of view. However, the current crisis reveals the advantage in time the use of scenario indicators can offer to international and local organizations dealing with public health. Such indicators might have flagged previous smaller outbreaks of other coronaviruses such as SARS (severe acute respiratory syndrome) and MERS (Middle East respiratory syndrome) in the past two decades. These outbreaks could then have been predictive for scenarios in which coronaviruses would become a major threat to human health, and could have triggered dedicated funding to advance specific biotechnological know–how, as well as to develop strategies to minimize the spread of this type of disease. Major funding is currently being gathered to mitigate the consequences of the COVID-19 crisis, including $8 billion pledged by world leaders to support dedicated R&I[iii]. However, today's continuing need to conduct significant biotechnology discovery research means that time, not necessarily funding *per se*, is a bottleneck. Along the same lines, developing scenarios today to understand how the future may unfold in the context of the COVID-19 pandemic could help anticipate the long-term consequences of the actions that are being taken and could allow countries, states, and communities to react to the crisis more effectively. In the context of the scenarios presented in Figure 3, the current pandemic emerges as a relevant indicator for the Food Emergency scenario. A global economic crisis may put critical agricultural supply chains at risk, such that food security becomes an even greater issue in certain world regions.

Concluding Remarks

The aforementioned biotechnology examples demonstrate the risk of a low innovation output when the founding know–how obtained from discovery research is not readily available and accessible in a usable format. The timely availability of founding know–how may greatly improve by adopting the use of learning scenarios and the tracking of progress against indicators for these scenarios. To make such an approach effective, several outstanding issues need to be addressed first (see Outstanding Questions).

We strongly believe that to improve the innovation output, the discussion should go beyond financial instruments and creativity. Rather, we would recommend looking at how the innovation ecosystem functions [11]. To maximize the utility of advances in know–how, the current working principles between academia, value chain players, and society would benefit from extensive review. Biological science needs a continuous cross-stakeholder interaction to move more efficiently from discovery to innovation. To steer biotechnological R&I more efficiently, an open innovation governance concept to deal with precompetitive and competitive big data information and activities is an absolute prerequisite.

We therefore propose to install virtual innovation workflows spanning academia and value chain players to address societal demands (Figure 4). The idea is to set up dedicated ecosystem knowledge bases that serve, for example, the medical, agricultural, or industrial biotechnology sectors or serve a broad innovation field such as the microbiome. These ecosystem knowledge bases should harbor harmonized and curated data in formats tailored to stakeholder use requirements. Such requirements can be defined for each of the biotechnology fields in a two-step process. First the generic workflow at handover points between academia and value chain players should be described, followed by the data and format requirements in this generic workflow, which would be necessary to start. These processes should ideally be described in both directions. In addition, users extracting information with their own software, if private, should commit to upload outcomes that are made anonymous, so that the next round of experimental questions can consider advanced information, and the knowledge base increases over time both in scope and in predictiveness.

To make this workable and sustainable, appropriate business models and governance concepts to deal with, among others, data ownership and intellectual property need to be developed, and

Outstanding Questions

How to motivate all relevant stakeholders to jointly develop a common understanding of learning scenarios and their impact?

How to ensure that scenarios are updated in a timely manner to address specific developments over time, including aspects that were not covered during earlier scenario exercises?

How to organize the tracking of indicators and the dissemination of weaker and stronger signals that may indicate direction of change before any of the scenarios fully materializes?

How to improve the quality of scenario development and its utilization by the latest developments in digitalization and artificial intelligence?

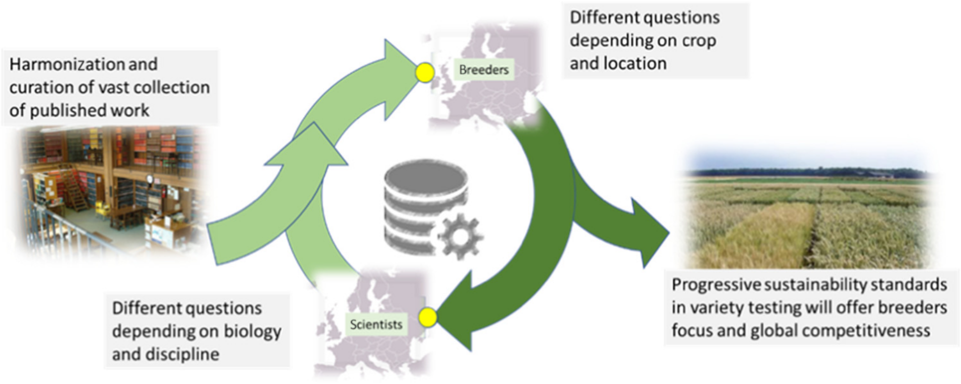


Figure 4. Outline of a Future 'Virtual Innovation Workflow' Driven by Biotechnology Big Data Governance. An example is given for agricultural innovation in Europe. To meaningfully contribute to the EU Green Deal, a rejuvenation of the agricultural ecosystem including academia, breeding and R&D companies, farm supply industry, and farmers is desirable. Required innovations should address environmental sustainability, impacts of increased weather volatility, climate change and associated pest and disease development, the European protein plan, development of more healthy and nutritious food, and an enablement of the bioeconomy. It should offer a lever to improve farm economics structurally through product branding and traceability. The novelty of the proposed 'virtual innovation workflow' is the bidirectional handover of outcomes and the holistic integration of data coming from plant, microbial, soil, agronomy, robotization, machine learning, modeling, and weather/climate disciplines. Critical success factors are, among others, the alignment of key performance indicators of stakeholders, incentives to participate, an open innovation attitude, a common benchmark to measure progress, smartly located research field stations, dedicated data centers with a user-oriented data curation, harmonization, storage and display approach, and an agreeable data governance concept. A pipeline of consecutive innovations can be primed by raising, over time, the requirements to successfully pass the formal variety testing and registration process. Customer demand (not shown) is in this example translated to requirements for official variety testing trials that, for example, meet progressively increasing levels of sustainability.

dedicated data stewardship teams need to be installed. Setting this up will likely need several rounds of optimization to reach the best compromise between stakeholder interests. Yet, it is well positioned to improve the overall flow of innovation to the market and to offer the desired flexibility to deal with upcoming trends in an ever-changing world.

Acknowledgments

The authors thank Dr Axel Sommer for his support and guidance on Scenario Analysis carried out under CropBooster-P. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 817690.

Disclaimer Statement

Responsibility for the information and views set out in this article lies entirely with the authors and do not necessarily reflect the official opinion of the European Commission.

Resources

[i] https://www.cropbooster-p.eu/

[ii] https://www.genomicsengland.co.uk/

[iii] https://www.reuters.com/article/us-health-coronavirus-eu-virus/world-leaders-pledge-8-billion-to-fight-covid-19-but-us-steers-clear-idUSKBN22G0RM

References

1. Schoemaker, P. (1995) Scenario planning: a tool for strategic thinking. In *Sloan Management Review* (Vol. 36), pp. 25–40, Massachusetts Institute of Technology
2. International Business (2012) *Chapter 8.5 Scenario Planning and Analysis*, Saylor Academy, pp. 442–448
3. Gillespie, I. *et al.* (2011) OECD outlook on prospects in industrial biotechnology. *Ind. Biotechnol.* 7, 267–268
4. European Commission (2018) *A Sustainable Bioeconomy for Europe: Strengthening the Connection Between Economy, Society and the Environment*, Updated Bioeconomy Strategy, European Commission
5. Steinwand, M.A. and Ronald, P.C. (2020) Crop biotechnology and the future of food. *Nat. Food* 1, 273–283

6. McLaren, D. and Markusson, N. (2020) The co-evolution of technological promises, modelling, policies and climate change targets. *Nat. Clim. Chang.* 10, 392–397
7. Małyska, A. *et al.* (2019) The microbiome: a life science opportunity for our society and our planet. *Trends Biotechnol.* 37, 1269–1272
8. European Commission (2018) *Report from the Commission to the Council and the European Parliament on the development of plant proteins in the European Union, COM/2018/757*, European Commission
9. The race against COVID-19 (2020). *Nat. Nanotechnol.* 15, 239–240
10. Graham, B.S. (2020) Rapid COVID-19 vaccine development. *Science* 368, 945–946
11. Anadon, L.D. *et al.* (2016) Making technological innovation work for sustainable development. *Proc. Natl. Acad. Sci. U. S. A.* 113, 9682–9690