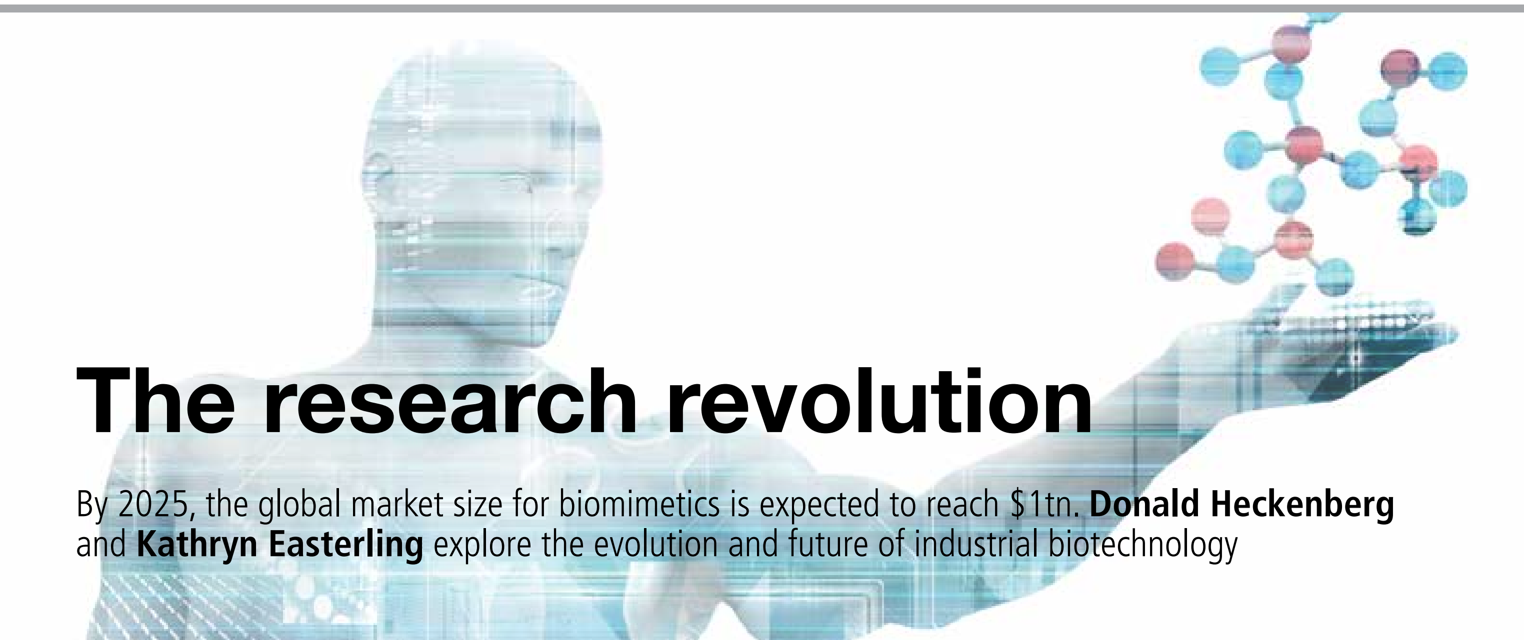

The research revolution

By 2025, the global market size for biomimetics is expected to reach $1tn. **Donald Heckenberg** and **Kathryn Easterling** explore the evolution and future of industrial biotechnology

Industrial biotechnology applies modern biotechnology to produce a wide variety of industrial goods and processes, ranging from fuel to food to textiles to energy to pharmaceutical products. These biotechnological outputs are more environmentally conscious, efficient, and sustainable than traditional outputs. While different forms of biotechnology have been practised for centuries, recent advances have moved the field light-years beyond what was once possible; for example, enzyme technology has evolved from basic use in baking and brewing to being tailor-made for use in items such as detergents, starches, biofuels, textiles, and food.

The following four sectors of industrial biotechnology are particularly representative of both current progress in and the future of the field. The last 15 years of innovation and change in these sectors is indicative of both where industrial biotechnology is headed, and the roles it will play in service of scientific discovery and global conservation.

Food biotechnology

Food biotechnology works to develop food sources with desired traits, and has seen considerable evolution from its early days of crossbreeding related species. In agricultural crops, food biotechnology has sought to increase tolerance and protection traits, increase valued output traits such as improved levels of beneficial nutrients, and potentially modify crops for use in other fields, such as medicine. Planting biotechnologically engineered crops can reduce the use of pesticides, increases soil conservation, and decreases greenhouse gas emissions. In animal food sources, genetics, genetic engineering, and cloning are being used to optimise the health and productivity of livestock and their outputs, both for breeding and for future consumption.

In order to provide a more secure future for our global food supply, scientists are creating new transgenic crops with greater tolerance to abiotic stressors such as temperature, drought, and salinity, to increase the range of potential environments in which farmers can plant these crops. Researchers are also working to reduce pollution in postharvest crop production, as well as engineer plants to remove or detoxify pollutants from the soil in a process known as phytoremediation.

While there are still those who worry about consuming genetically engineered organisms, consumers are becoming more aware of the health, environmental, and practical benefits of food biotechnology.

Synthetic biology

Synthetic biology uses biological and genetic engineering techniques to create new biological systems and commercial products often not found in nature. These discoveries can lessen production time and decrease costs of creating materials such as biofuels, food products, and pharmaceutical components. Synthetic biology is a newer field of study, but gained significant attention in 2010 when the first "synthetic cell", an organism controlled by a laboratory- and computer-generated genome, was created.

Since then, synthetic biologists have published several exciting breakthroughs. In early 2018, Synthetic Genomics and ExxonMobil discovered a way to engineer an oil-producing algae strain that would double the strain's production without compromising its growth, leading to more efficient biofuel production and potentially producing 10,000 barrels of algae biofuel a day by 2025.[1]

Manus Bio has engineered a bacterium that produces a synthetic version of "Reb M", a compound found in the stevia plant and used in zero-calorie sweeteners, with greater than 95% purity. Goodyear and DuPont Industrial Biosciences are working on reducing the environmental impact of making rubber through a biological process of creating isoprene, an important component of synthetic rubber that is normally only found in plants.

Much of the future of synthetic biology lies in medicine. Aforementioned Manus Bio has received a grant from the Bill & Melinda Gates Foundation for the development of advanced fermentation processes for artemisinin, a key component in malaria treatment.[2] Another recent recipient of a Gates Foundation grant, Lumen Bioscience, is researching the use of spirulina, an algae strain used to produce antibodies for infants that mimic those found in breast milk. The goal is to use spirulina to help protect infants in developing nations from intestinal diseases.[3] And Codexis is working with the University of California, Los Angeles to engineer a new form of the LovD enzyme (LovD9) that produces simvastatin, a cholesterol-lowering drug, one thousand times more efficiently than natural LovD.

An intriguing subfield of synthetic biology with great promise is bioengineered metamaterials. A metamaterial is an engineered material that uses its internal structural geometry to manipulate light waves, causing these waves to exhibit properties not found in nature. Constructing a metamaterial involves creating a series of macro- to nano-scale geometric structures, connected in a repeating pattern, that cause the resulting material to display unique characteristics. By controlling a metamaterial's optical properties through its design, researchers can alter characteristics of light beams such as direction, intensity, and colour. For example, researchers in the UK have created a non-metal, "all-dielectric" metamaterial that can phase-switch between an amorphous structure and a crystalline state, which causes it to become transparent at certain wavelengths.[4] The applications of bioengineered metamaterials extend into the biological realm, as they have the potential to be effective miniature sensors in the diagnosis and treatment of diseases through use of miniature optical devices to monitor patient conditions. There is also the possibility of using biomaterials in concert with abiotic materials to create hybrid metamaterials – for example, integrating the proteins of a virus capsid with metallic nanoparticles for increased structural integrity and symmetry of metamaterials.

Biomimetics

Biomimetics imitates nature through scientific innovation, taking advantage of centuries of evolution by using naturally-occurring phenomena to develop more efficient, more convenient man-made products. In 2008, the global market size for biomimetics was estimated at above $1.5bn, and an industry analysis predicted that, by 2025, the market size would be $1tn.[5]

There are numerous recent innovations in biomimetics. In 2005, WhalePower began developing wind turbine products and blades based on the anatomy of humpback whales. The whales have "tubercles" on their fins that help increase their lift while swimming, and research of these tubercles has led to the creation of more efficient fan blades. In 2006, through study of the Namib Desert beetle, the Massachusetts Institute of Technology managed to create a material with the ability to capture and control miniscule amounts of water, which has potential applications in cooling systems, water harvesting systems, and as a self-decontaminating surface. A 2011 study reported that, through investigation of mussels' byssi, which have high durability and an adsorptive power greater than any found in nature, scientists are creating high-strength cultured carbon nanotube fibres. And recent research into bacteria that generate calcium carbonate through natural metabolic and calcification processes is yielding self-healing concrete with the ability to fill gaps in damaged concrete.[6]

The future of biomimetics will have a strong focus on medicine and biomedicine. In nanotechnology, researchers are working to engineer nanoparticles with protein, carbohydrate, and peptide functionalities to speed development of protein secondary structures. Biomedical engineers are studying mosquitos' proboscises to develop needles made of a biodegradable polymer which makes the needles safer and less painful. Composite fibrous biomaterials based on sponge and mollusc anatomy are being tested as scaffolding for bone and tissue repair and regeneration. And researchers are using gecko foot hair as inspiration for a medical bandage that is biocompatible with human tissue, resulting in less irritation and potentially integrating with the body to monitor vital signs.

Bioenergy

Bioenergy turns 'biomass', or biodegradable products and residues, into energy and power. Bioenergy end products include "traditional" outputs such as outdoor cooking and heating fuel, as well as 'modern' outputs including heat, electricity, and transportation fuel. Bioenergy has long been a steady contributor to global energy production, accounting for 9% of the world's total primary energy supply in 2017.[7] Modern bioenergy is currently the most used form of renewable energy, with demand five times higher than wind and solar power combined.

However, the outlook for bioenergy differs greatly between the European Union and the US. On one hand, the EU's bioenergy production doubled between 2007 and 2017, and its member states have comprehensive bioenergy policies in place and a well-maintained production system. On the other hand, in the US, there is little financial incentive for the government to continue to back bioenergy. The Renewable Fuel Standard, enacted by Congress in 2005 to expand the renewable biofuel sector by setting a target goal for gallons of advanced biofuels in use by 2022, is being reconsidered by the current administration. There are concerns over US land use limitations restricting the biomass that can be sourced directly from the land. Moreover, wind and solar power are experiencing increased popularity and decreased costs, are backed by US lawmakers and policy, and have expansive potential as alternative renewable resources over bioenergy. Because of these and other factors, few new bioenergy plants are being built in the US.

With the future fraught with concern over global warming and climate change, renewable resources are more important than ever, but it remains to be seen what role bioenergy will play.

What's next for industrial biotechnology?

The future of industrial biotechnology will see the practical and the extraordinary meet and bring about exciting new innovations. Topics covered at the 2018 BIO World Congress on Industrial Biotechnology (hosted in July) provided insight into what the industry leaders are focusing on. These topics included synthetic biology, genetic editing, biofuels, renewable chemicals, agricultural crop technology, and algae application, indicating an emphasis on medicine, energy, and food supply. Moreover, industrial biotechnology's use of discoveries and methods from other scientific fields will lead it to be shaped by the evolution of nanotechnology, bioengineering, genetics, and other such disciplines as well. 15 years ago, we could not have predicted what is possible with industrial biotechnology today; we can only imagine what may be possible in 15 years more.

Footnotes

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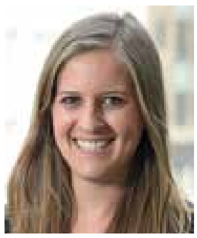

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