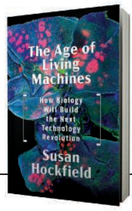
BIOENGINEERING

Leveraging nature's tool kit

Blending biology and engineering, researchers seek to tackle our biggest existential threats

By **Adrian Woolfson**

The Age of Living Machines
How Biology Will Build the Next Technology Revolution
Susan Hockfield
Norton, 2019. 244 pp.



Two to three million years after the first stone flakes were assembled into a rudimentary tool kit by a hominid, *Homo sapiens* stumbled across a new suite of tools that would fundamentally affect humankind. Initially known as "corpuscles" and then as "electrons," the technology had its basis in the particles carrying "negative electricity" discovered in 1897.

In her entertaining and prescient *The Age of Living Machines*, Susan Hockfield argues that the resulting "parts list" of the physical world facilitated the development of electronic tools, including the telegraph, television, computers, satellites, and the internet. Catalyzed by the interdisciplinary efforts of the Second World War, the technologies forged in this convergence of physics and engineering fueled a period of unprecedented industrial and economic growth that placed the United States in a global leadership position.

In the 1950s, a new generation of interdisciplinary researchers set out to break down the biological world into parts and rules. Building on the 1944 discovery that DNA was the "transforming principle" and chemical substance of genes, these pioneers formulated a new digital age, based not on the binary code script of computing machines but on the sequences of nucleotide bases. Hockfield asserts that the elucidation of this biological parts list, along with an unprecedented ability to manipulate it, has taken humankind to the cusp of a second convergence at the interface of biology and engineering.

That the idiosyncrasies of organismal biology should offer a trove of molecular innovation is not surprising. Indeed, we are surrounded at every scale by the blind ingenuity, creativity, and raw intensity of Darwinian evolution. As Hockfield writes, even humble sea snails are engineering virtuosos. These erudite alchemists have conjured up an ingenious method for transforming calcium and carbonate into a lightweight shell of remarkable dynamic strength through the judicious interleaving of protein filaments.

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By detailing examples of multidisciplinary projects that combine biology and engineering, Hockfield demonstrates how nature's molecular riches may be leveraged to provide potential solutions to some of humanity's existential challenges.

Hockfield meets with Jim Carrington, president of the Danforth Plant Science Center in St. Louis, who estimates that unless substantial improvements are made to current agricultural practices, additional farmland—equivalent in size to Africa and South America combined—will be required to feed the world's predicted 9.5 billion inhabitants by 2050. To help generate the next generation of resilient, high-yield crops, researchers at the Danforth Center have coupled sophisticated engineering technologies with bioinformatics and high-throughput analysis to allow the comprehensive characterization of individual plant "phenomes." Each phenome comprises a map linking a plant's physical traits to its genomic structure that facilitates the selection of variants.

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The need for clean water is an equally compelling problem being tackled by bioengineers. Biophysicist Morten Østergaard Jensen speculated that aquaporin, a naturally occurring protein that transports water across cell membranes, could form the basis of a biological water filter. Together with entrepreneur Peter Holme Jensen, he formed a company in 2005 that aimed to scale up aquaporin-based water filtration. In 2015, Danish astronauts used Aquaporin A/S membranes to filter the water they drank in space.

Other innovators use biologically inspired engineering approaches to derive previously unidentified energy sources. Chemist and material scientist Angela Belcher has shown, for example, that viral coat proteins may be engineered to bind metal particles and carbon nanotubules that self-assemble into biological batteries. Unlike traditional batteries, Belcher's batteries require little energy to make and produce no toxic byproducts.

In 1933, Ernest Rutherford famously stated that the transformation of atoms would never result in a source of power. As we contemplate the inevitable transition from an age defined by electron-based tools to one informed by biological tools, we too will be hard pressed to predict the ultimate outcomes, risks, and benefits that this new biological tool kit will bring to humankind. But as Hockfield cautions, the maintenance of a pole position in this new frontier of human accomplishment will require an infrastructure that fosters interdisciplinary projects, encourages curiosity-driven science, cultivates a diverse scientific workforce, and encourages financial instruments that facilitate long-term returns. ■

10.1126/science.aaw9433

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PODCAST

Nightingales in Berlin
Searching for the Perfect Sound
David Rothenberg
MIT Press, 2019. 184 pp.

"[O]ne easy way to make nature matter. Listen to it," writes philosopher David Rothenberg in his new book, *Nightingales in Berlin*, which chronicles his efforts to forge musical collaborations with nonhuman musicians: namely, the eponymous nightingale. This week on the *Science* podcast, Rothenberg reflects on the aesthetics of birdsong, a feature often overlooked by scientists, and explains how making music with other species has changed the way he thinks about our place in the world. sciencemag.org/podcasts

10.1126/science.aax5548

Science

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Science **364** (6438), 340.
DOI: 10.1126/science.aaw9433