ANDREW W. LO AND DENNIS G. WHYTE

What Can Fusion Energy Learn From Biotechnology?

Fusion energy faces many hurdles. The history of the biotech industry offers lessons for how to build public trust and create a robust investment ecosystem to help fusion achieve its potential.

Recent advances in fusion energy research have renewed excitement around this potentially transformative way to produce electricity and replace fossil fuel energy sources. Although fusion appears to face barriers that are unique to this nuclear technology, we believe that its progress could be accelerated by examining the history of another world-altering technology from a very different sector and time: biotechnology.

Five decades ago, emerging insights in biology, particularly in genetics, suggested the possibility of new technology that could address diverse challenges in health care, agriculture, industry, and the environment. But, like fusion today, many obstacles had to be overcome before biotechnology could be applied in ways that were useful or profitable. Unresolved scientific and technological questions would cost billions to answer, and profits were still decades off. Whole new regulatory and investment environments needed to evolve. And powerful cultural resistance to the very idea of genetic manipulation would have to be overcome.

Of course, there are many differences between biotech's history and fusion's present. But advocates for fusion can find several key lessons from the last half-century of biotech that could propel fusion forward and help it to navigate around hazards on its way to deployment.

Fusion energy and biotech share the stark financial realities facing all "deep technologies"—that is, early-stage technologies with tough scientific challenges that will require significant upfront capital, have low or unknown probabilities of success, and require long gestation periods before revenues start to flow (if they ever do). Conventional wisdom is that traditional finance methods such as venture capital and private equity are inadequate to sustain such long-shot investments. These methods are not equipped to carry long shots over financial "valleys of death," for example, where projects can languish or perish due to lack of support.

At their earliest stages of development, when the need for funding is greatest, deep technologies have unattractive risk-reward ratios. Investors are naturally drawn to high-yield, low-risk propositions, a relationship that financial economists have described mathematically as the Sharpe ratio: the excess expected investment return above the risk-free rate, divided by the risk. By their nature, deep-tech investments tend to have very low Sharpe ratios at the outset, discouraging all but the most confident and risk-tolerant investors. The situation is worse for the most speculative and transformative technologies, such as fusion energy, because their many "unknown unknowns" put risk quantification out of reach. Economists define *risk* as randomness one can measure, and *uncertainty* as randomness one cannot. Investors dislike risk, but they loathe uncertainty.

High risk and uncertainty carve out deep tech's valleys of death. Although they can't be eliminated, these valleys can be made less deep and less lethal by increasing a technology's potential profit, decreasing risk and uncertainty, or both. Successes in biotech can be attributed in part to the dynamic, constantly fermenting public-private funding ecosystem that has kept it moving over hills and dales and even across what could have been lethal valleys. Fusion energy's challenge today is to create a similar ecosystem.

With lessons from biotech in mind, we propose four initiatives that could accelerate fusion's progress. Our proposal is ambitious, but we feel it is well justified by the game-changing benefits a limitless source of carbon-free energy would bestow.

Standardize milestones

In the United States, to determine a drug candidate's safety and efficacy in humans, researchers must conduct randomized controlled trials. These studies are divided into three distinct phases, each involving more human subjects than the previous one. This staged approach was imposed because it minimized exposure to the health risks inherent in taking experimental drugs. But it had another, incidental advantage. It divided the prolonged investment timeline for drugs—often 10 or more years from the beginning of human trials to regulatory approval—into three shorter stages. As a drug candidate graduates from one phase to the next, its risk declines, and its market value grows. These milestones allow biotech companies to periodically demonstrate positive returns to their investors, which attracts additional capital to pay for each next phase of development. And the milestones lead to new financial markets—especially large public equity and debt markets—creating liquidity for company founders, capital funds, and investors and attracting even more money to the sector. From this staging, a fecund biotech ecosystem emerged and coevolved with financial markets, creating safer pathways through potential valleys of death.

Along the same lines, a set of milestones for achieving commercially relevant fusion energy should be identified and published by a consortium of stakeholders. Milestones could include, for example, the sustained generation of high-temperature plasma producing more energy than it consumes, or identifying and developing materials that can withstand the extreme conditions inside a fusion reactor and form the "first wall" between the plasma and the rest of the reactor.

For milestones to be effective in creating a market, all stakeholders—including regulators, researchers, and fusion companies—must agree that, taken together, the milestones are both necessary and sufficient to achieve commercially relevant fusion energy production. They must also be easy for nonexperts to grasp, and their achievement must be verifiable by an unbiased third party at reasonable cost.

Get universities in on the action

Scientific and engineering expertise is as essential for fusion research and development as it was to biotech—and developing strong ties between industry and academic institutions is key to fusion's progress. Since the Bayh-Dole Act passed in 1980, universities receiving federal funding have had the right to pursue ownership of their researchers' inventions, rather than giving their intellectual property (IP) to the federal government. This has rewarded universities for investing in research to advance biotechnologies with commercial potential, creating a virtuous cycle of progress as the profits universities received were plowed back into labs doing cutting-edge research. Fusion R&D could also be accelerated if universities begin to attend to and streamline similar IP commercialization. Today such legal frameworks exist, but universities need to start taking advantage of the opportunities they present.

Three distinct steps could help. First, universities and national laboratories should standardize sponsored research agreements, term sheets, and technology licenses to expedite the process for spinning companies out of academia. Second, universities should mentor academics in fusion-related fields who are unfamiliar with startups and the business world. And third, financial institutions should create investment funds focused on startups among a consortium of universities and research labs. These would appeal to a broad set of investors due to their diversified "multiple-shots-on-goal" structure.

Support a commercialization ecosystem

There is one salient difference between biotech and fusion that cannot be ignored. Unlike the diversity of diseases and other application targets that support various niches in the biotech industry, all fusion companies aim to do one thing: generate safe, clean power.

Nevertheless, the parallels between biotech and fusion are still instructive: fusion energy startups are analogous to early biotech companies, engaging in breakthrough science and engineering programs that in many cases are selling proof of the viability of concepts rather than products themselves. In the fusion ecosystem, the equivalent of "Big Pharma" will be "Big Energy"—oil and gas companies with the financial resources to partner with startups. They can pay to complete the testing of promising fusion technologies, then in-license those technologies or acquire the companies once they have been de-risked. With the emergence of small modular fission reactors and fusion microplants, an even more complex and diversified dynamic between firms is likely to develop.

One key component will be US government-led programs positioned to finance growth. These should provide more scientific support for fusion research as well as support for small businesses; for example, with new government subsidies, loan guarantees, and tax incentives for fusion-related investments.

Parallel private-sector initiatives should include creating a robust ecosystem in which all fusion, fusion-supporting, and Big Energy companies can collaborate via in- and out-licensing, joint ventures, and mergers and acquisitions to diversify risk and increase the chance of achieving net energy production and financial gains. To further push this process forward, fusion impact funds—pools of investment capital with an explicit mandate from investors to reduce carbon emissions via fusion energy—could be created as part of a suite of climate-related "green" financial products, including fusion rating-agency metrics that could be used to construct such products.

Finally, in much the same way that fossil-fuel companies created oil and gas futures contracts to manage risk and gather information about supply and demand, financial exchanges should be created for trading standardized financial contracts on key fusion-related inputs and outputs, such as future delivery of tritium, helium-3, and fusion-generated electricity.

Foster two-way engagement

Biotech learned early on that public opinion would influence its trajectory and that the industry had as much to learn from public discussion as it had to contribute to it. Indeed, ethical and safety concerns were raised by the very scientists who pioneered the field, and public discourse regarding these concerns led to a coherent regulatory framework that assists in safely guiding scientific hypotheses toward life-saving drugs and other biotech products. This sensitivity to public interests—and the outreach from government agencies, university researchers, and biopharma designed to build trust as well as improve public appreciation of the technology's potential benefits and explain and address its risks—have been key to biotech's advancement.

A similarly robust mixture of regulation, public engagement, and innovative energy companies is required for fusion. It is essential to address public perceptions, especially given the common misunderstandings of the state of progress in fusion research—captured in the quip, "Fusion is the energy of the future—and it always will be." Fusion is not the first nuclear power that the public has encountered, and grappling seriously with public fears, conceptions, and expectations will be a necessary part of fusion's path.

Generating informed enthusiasm and dispelling misinformation will require a systemwide approach to outreach and education, where communication goes both ways. The fusion community must listen as well as inform. As new fusion technologies emerge and as some of them flounder, the industry must be open, direct, and transparent. Only by actively listening to community concerns, and addressing them systematically and comprehensively, can the industry earn the public's confidence. Public feelings of distrust or betrayal would pose major impediments to fusion energy's timely progress.

The public at large also needs to understand how the technology is progressing, which should not be left entirely to the promotional efforts of startup companies. Instead, a trade organization like the Fusion Industry Association should actively coordinate communication with media outlets, government representatives, and financial analysts, as well as university and industry public information and news centers. When scientific and engineering milestones are met, they should get the public attention they deserve.

Another crucial step is integrating fusion education into curricula for all levels of students. Middle schoolers should learn the basics, high schoolers should go more in-depth on the technology in physics and environmental science classes, and courses in fusion technology and governance should be accessible to all college and graduate students.

Fusion energy stands today where biotech was several decades ago—on the cusp of revealing potentially transformative insights into one of the most fundamental properties of our world. For biotech, it was understanding the blueprint of life itself. In fusion's case, it is commanding the power source of stars, the very force that makes life viable in the universe—which, if harnessed here on Earth, could help correct society's carbon-emissions trajectory. By learning from biotech's setbacks and triumphs, we believe fusion energy production can become a practical reality too, and that it need not take five decades to do so.

Andrew W. Lo *is the Charles E. and Susan T. Harris Professor at the Massachusetts Institute of Technology Sloan School of Management, director of the MIT Laboratory for Financial Engineering, principal investigator at the MIT Computer Science and Artificial Intelligence Laboratory, and an external faculty member at Santa Fe Institute.* ***Dennis G. Whyte*** *is the Hitachi Professor of Engineering in the MIT Department of Nuclear Science and Engineering and former director of the MIT Plasma Science and Fusion Center. Both authors are affiliated with Rutherford Energy Ventures LLC, a fusion-energy-related consulting and investment advisory company.*