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STRANGE COMPETITION

A Statement of Evidence Written in 2025

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Hearing on "Made in China 2025—Who Is Winning?"

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[2]The views expressed herein are solely those of the author and do not necessarily reflect the opinions of any organization or institution they may be affiliated with.

STRATEGIC CONTEXT

Biology allows near-boundless possibilities. The composition and control that software provides the digital world is realized by biology in the physical world. Natural living systems operate and manufacture materials with atomic precision on a planetary scale, powered by ~130 terawatts of energy self-harvested via photosynthesis.[3]

Biotechnology enables people to change biology. Domestication and breeding of plants and animals for food, service, and companionship began millennia ago. Gene editing, from recombinant DNA to CRISPR, is used to make medicines and foods, and is itself half-a-century old. Synthetic biology is working to routinize composition of bioengineered systems of ever-greater complexity.[4,5] Biotechnology goods and services already account for ~5% of the United States' economy; foods, fuels, materials, and medicines are the major product categories.[6]

Up to "60% of the physical inputs to the global economy"[7] could be made via biotechnology by mid-century, generating ~$30 trillion annually in mostly-new economic activity.[8] Emerging product categories include consumer biologics (e.g., bioluminescent petunias,[9] purple tomatoes,[10] and hangover probiotics[11]), military hard power (e.g., brewing energetics[12]), mycological manufacturing (e.g., mushroom 'leather'[13]), and biotechnology for technology (e.g., DNA for archival data storage[14]). Accessing future product categories will depend on unlocking biology as a general purpose technology[15] (e.g., growing computers[16]), deploying pervasive and embedded biotechnologies within, on, and around us (e.g. smart blood,[17] skin vaccines,[18] and surveillance mucus[19]), and life-beyond lineage (e.g., biosecurity at birth,[20] species de-extinction[21]).

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[3]For context human civilization consumes "only" ~20 terawatts excluding the energy embedded in food and other biomaterials sourced directly from the land and oceans.
[4]https://doi.org/10.1038/s41467-023-40199-9
[5]https://doi.org/10.1038/s41586-020-2650-9
[6]https://www.nationalacademies.org/our-work/safeguarding-the-bioeconomy-finding-strategies-for-understanding-evaluating-and-protecting-the-bioeconomy-while-sustaining-innovation-and-growth
[7]https://www.mckinsey.com/industries/life-sciences/our-insights/the-bio-revolution-innovations-transforming-economies-societies-and-our-lives
[8]https://web.archive.org/web/20250116082806/https:/www.whitehouse.gov/wp-content/uploads/2024/11/BUILDING-A-VIBRANT-DOMESTIC-BIOMANUFACTURING-ECOSYSTEM.pdf
[9]https://light.bio/
[10]https://www.norfolkhealthyproduce.com/
[11]https://zbiotics.com/
[12]https://serdp-estcp.mil/focusareas/3b64545d-6761-4084-a198-ad2103880194
[13]https://www.mycoworks.com/
[14]https://dnastoragealliance.org/
[15]https://www.scsp.ai/2023/04/scsps-platform-panel-releases-national-action-plan-for-u-s-leadership-in-biotechnology/
[16]https://www.src.org/program/grc/semisynbio/semisynbio-consortium-roadmap/
[17]https://www.darpa.mil/news/2024/rbc-factory
[18]https://med.stanford.edu/news/all-news/2024/12/skin-bacteria-vaccine.html
[19]https://2020.igem.org/Team:Stanford
[20]https://dspace.mit.edu/handle/1721.1/34914
[21]https://colossal.com/

For President Xi Jinping, biotechnology is arriving on time and in ways that are directly responsive to China's highest-level needs and goals including: (i) "complete domestic circulation" of China's economy, (ii) "improve and stabilize" supply chains, (iii) "improve the mix of scientific and technological inputs and outputs," (iv) "ensure harmony between humans and nature," and (v) "develop a bottom-up (public health) system that ensures early detection, warning, and response so as to control diseases as they arise."[22] When Xi wrote during a pandemic, "we need to attach greater importance to basic research in life sciences, including genetics, genomics, virology, epidemiology, and immunology; accelerate R&D and innovations in relevant medicines and vaccines; and put more emphasis on the use of IT and big data in these fields,"[22] he meant it. Behind Xi's statement, "China must be basically self-sufficient in food production and industrial development. We must never forget this,"[22] is a primal driver; compared to the United States, China must secure food for ~4-fold more people with ~25% less farmland.[23]

CHINA AND BIOTECHNOLOGY LEADERSHIP

There is ongoing debate whether China is already the world leader in biotechnology.[24,25,26] From a policy-maker perspective this debate risks missing the point. The progress of students, scientists, engineers, entrepreneurs, policy makers, and leaders in transforming China into a biotechnology powerhouse over the past twenty years has been extraordinary.[27] Through hard work, ambition, and an all-of-nation effort, China is at-least matching the United States in key elements of biotechnology's "strategic stack" (education, research, entrepreneurship, and manufacturing), is now better organized and supported by Beijing and beyond, and has tremendous momentum. What do these accomplishments look and feel like from a competitive perspective?

Let's start with education. In 2003 I helped launch what became the iGEM competition. Just 16 undergraduates with four instructors at MIT,[28] modeled after Lynn Conway's 1978 VLSI System Design Course that helped launch a revolution in computer chip design.[29] iGEM is now the world-leading synthetic biology "olympics," held in Paris each fall. Teams of students compete to design, build, and test bioengineered systems for useful purposes that they define. Last year's champion from Germany sought to reprogram dandelions to produce carrot-shaped roots in support of sustainable latex production.[30] ~100,000 students have participated so far.[31]

[22]http://en.qstheory.cn/2021-01/14/c_604551.htm
[23]https://www.cia.gov/the-world-factbook/
[24]https://www.labiotech.eu/in-depth/china-biotech-industry/
[25]https://cen.acs.org/business/economy/Chinese-biotech-attracting-global-attention/102/web/2024/12
[26]https://www.biopharmadive.com/news/biotech-us-china-competition-drug-deals/737543/
[27]https://itif.org/publications/2024/07/30/how-innovative-is-china-in-biotechnology/
[28]https://news.mit.edu/2003/blinkers-0226
[29]https://ai.eecs.umich.edu/people/conway/VLSI/MIT78/MIT78.html
[30]https://2024.igem.wiki/marburg/
[31]https://igem.org/

US-based iGEM participation plateaued in 2012 at ~50 teams. It is a lot of work to compete. That same year, potential concerns associated with public perception (i.e., "fear of the fear" of synthetic biology[32]) caused US funding agencies to narrow their focus to "engineering biology." The result was confusion and a "mini ice age" domestically in terms of support for education and research in synthetic biology. The 2015 William & Mary iGEM team was the last champion from the United States. Meanwhile, starting in 2012 China adopted and went all-in on a 20-year roadmap for synthetic biology that was developed in partnership with the UK and US.[33] Ever since, students in China have benefited from all-of-government tailwinds. Last year ~50% of the 400-plus iGEM teams were China-based. Incredibly, some students in California found it easier to participate in iGEM by traveling to China and joining a team there.[34] China has also made significant progress in scaling biotechnology and biomanufacturing education, more broadly.[35]

What about research? The United States remains a world-leader in life science and biotechnology research, broadly defined, but China is overtaking via a focus on emerging biotechnologies. This trend is most noticeable in synthetic biology. From 2003 to 2013 the United States was the undisputed world leader in synthetic biology research. By 2017 researchers in China were reportedly matching their US-colleagues in publishing high-impact synthetic biology research.[36] The trend has apparently continued; researchers in China publish most (>60%) high-impact synthetic biology papers today. What sort of research? The first mirror-image RNA polymerase and ribosome components, as needed to make mirror-life,[37] the first synthetic plant chromosome,[38] and so on. Of note, many of the advances reported by Chinese scientists involve foundational breakthroughs that result in leverage across many aspects of biotechnology (e.g., research towards mirror-life is now a safety and security concern[39]).

How did China's emerging biotechnology research engine get built so quickly and set in high gear? First, China benefited from starting fresh, with most institutional investments and programs launching at or after the dawn of the genomics era. For example, the Beijing Genomics Institute (now BGI Group) was launched in 1999 to help complete sequencing the first draft of the human genome.[40] By comparison, the United States remains burdened with legacy biotechnology research infrastructure and portfolios. Second, China, from President Xi down,

[32]https://doi.org/10.1080/09505431.2014.986320
[33]https://nap.nationalacademies.org/catalog/13316/positioning-synthetic-biology-to-meet-the-challenges-of-the-21st-century; disclosure: I led the US delegation in this trilateral effort.
[34]https://www.linkedin.com/posts/drew-endy-69ba17_last-month-5000-students-met-in-paris-to-activity-7262819887272636416-dVey
[35]https://x.com/NikoMcCarty/status/1774047214081552838
[36]https://techtracker.aspi.org.au/tech/synthetic-biology/historical-performance/
[37]https://www.science.org/doi/10.1126/science.abm0646
[38]https://www.nature.com/articles/s41477-023-01595-7
[39]https://www.science.org/doi/10.1126/science.ads9158
[40]https://en.wikipedia.org/wiki/BGI_Group

has prioritized biotechnology via an "all-of-nation" approach.[41] What does "all-of-nation" look like? All-of-nation involves things like, since 2013, President Xi's portrait hanging proudly in the lobbies of biotechnology centers in Guanming with direct quotes like "artificial life is not only of great significance… but also shows great potential and application." All-of-nation means that the world's-largest genome center can rapidly expand in Shenzhen because Hong Kong real-estate families can afford to quickly forgive a US$1 billion dollar note used to underwrite construction, expansion, and research.[42]

Taken together, China has been building new campuses, institutes, and centers in pursuit of emerging biotechnology. Some of these facilities are now the envy of the world,[43,44] rivaling what the U.S. developed in pursuit of high-energy physics during the mid 20th century. The United States operates nothing like China's emerging biotechnology foundational research platforms. As a result, global coordination of biotechnology's future grand-challenge research projects (e.g., building cells from scratch) now happens in Shenzhen.[45]

Biotechnology entrepreneurship in China is similarly impressive. JP Morgan's Healthcare Conference takes place in San Francisco each January and is one of the most influential events in the industry. Reporting on last month's event STAT noted: "Are we entering a world in which all of the exciting new therapeutics come from China?," and "More than a third of the therapeutic molecules bought by pharma companies came from China last year... That number was zero four years ago," and "Not only were there research parks that dwarfed biotech hubs like Kendall Square in Cambridge, Mass., but the businesspeople and scientists he was reaching out to on the ground were dogged."[46] Similar reports from last month's event are easy to find.[21] Dr. Sandra Barbosu anticipated such reporting, writing in her thoughtful and understated July 2024 report, "China used to be considered a laggard in biotech. But with a comprehensive national strategy and extensive resources now supporting the industry, it is becoming more innovative."[22]

China is also a leader in biomanufacturing at full scale.[47] For example, China is reported to have a majority global share of fermentation capacity for some amino acids, organic acids, and especially vitamins. 90% of the raw ingredients for antibiotics are reportedly manufactured in China. Meanwhile, bio-entrepreneurs in the United States bemoan, "the lack of sufficient US

[41]"All of nation" is a better description for how China approaches biology as a strategic domain compared to "military-civil fusion" (MCF), which is itself impressive (please see the excellent work from State Department on MCF here: https://www.state.gov/wp-content/uploads/2024/11/ISAB-Report-on-Biotechnology-in-the-PRC-MCF-Strategy_Final.pdf)
[42]The families may have recovered more money when the surrounding property values increased.
[43]https://x.com/NikoMcCarty/status/1773685194765250586
[44]https://x.com/NikoMcCarty/status/1774772972999659767
[45]https://isynbio.siat.ac.cn/en/view.php?id=317
[46]https://www.statnews.com/2025/01/15/jpm-conference-biotech-industry-excited-anxious-chinese-biotech-deals/
[47]https://www.daofoods.com/news/l2r8uohyho2vldn15hxqfb8z3gj2f4

manufacturing capacity (full-scale) is causing a backlog of promising innovations that cannot be commercialized."[48]

BIOTECHNOLOGY R&D DEPENDENCIES

The US and global biotechnology research community benefits significantly from ingredients, products, and services provided by China or China-owned firms. For example, phosphoramidites are the chemical ingredients used to synthesize DNA. It used to be that phosphoramidites were sourced starting from salmon milt,[49] typically obtained from the Pacific Northwest or Japan. ~30 years ago new routes to phosphoramidites starting from sugarcane were developed. While the United States maintains on-shore phosphoramidite synthesis capacity,[50] China is likely the cheapest global supplier.

As a US-based academic researcher, my lab routinely contracts with service providers in China. For example, although we primarily order DNA and genes from US-based companies like Twist (California) and IDT (Iowa), for difficult-to-construct genes we find that Genscript (Shanghai) has been our most reliable supplier. Last year, when we sought to understand how the genes of a microbe that lives on the human skin might turn on and off in response to changes in blood glucose levels we used Novogene (Beijing) to carry out rRNA depletion, cDNA library preparation, and sequencing as part of Novogene's Prokaryotic RNA Sequencing service.[51] Why? Novogene's service offering was the best available and allowed one more Stanford bioengineering student to earn her Ph.D.

The Biosecure Act (H.R. 8333) highlighted many more dependencies permeating the U.S. and global biotechnology research ecosystem.[52] As one example, WuXi AppTec (WuXi) is a world-leading contract research, development, and manufacturing organization (CRDMO) serving various biotech markets.[53] Among other offerings, WuXi provides drug discovery, preclinical safety testing, analytical and manufacturing process development, cell line, viral vector, and monoclonal antibody development, cell and gene therapy development, and small molecule and clinical trial material manufacturing as a service.

One concern is that data generated in the course of contracting work with WuXi is or could be used within China for other purposes. For example, in January 2024 Rep. Auchincloss (D-MA 4th District) stated, "The Chinese Communist Party and its affiliated biomedical corporations are operating unethically in the collection of genetic information without consent, and U.S.

[48]https://agfundernews.com/synonym-bio-report-documents-global-gaps-in-fermentation-capacity
[49]https://dspace.mit.edu/handle/1721.1/39657
[50]https://www.thermofisher.com/us/en/home/life-science/oligonucleotides-primers-probes-genes/phosphoramidites/amidite-learning-resources/phosphoramidite-considerations.html
[51]https://doi.org/10.3389/fmicb.2024.1408796
[52]https://en.wikipedia.org/wiki/Biosecure_Act
[53]https://www.wuxiapptec.com/

taxpayers should not be helping to fund those or other nefarious practices."[54] However, the frank reality is that US biotech R&D has become so dependent on CRDMO's like WuXi that strong domestic industry push back helped stall the Biosecure Act in the Senate.[55] Soon after, in December 2024, the Worcester Business Journal reported that WuXi resumed construction of its $300 million facility outside Boston.[56] Imagine if the information technology sector in the US became utterly dependent on cloud servers and services operated or owned by Chinese firms.

CONCERNS OR POTENTIAL CONCERNS

Regarding bio-manufacturing competitiveness, China already has a diverse and robust set of commercial actors who are skilled at making money while making low-value bioproducts; making money by making higher-value products will be easier. China has and continues to invest in state-of-the-art biomanufacturing capacity via an all-of-nation approach. US innovators who prototype novel bio-based processes struggle to access existing domestic manufacturing capacity or the capital needed to build new facilities; the resulting situation creates the risk of an increasingly "brewed in China" future, analogous to what occurred with other technology sectors that failed to scale and sustain manufacturing domestically (e.g., solar panel, batteries, etc). Current USG focus on expanding pilot-scale biomanufacturing will be woefully inadequate if "downstream dollars" fail to flow at the scales needed to enable full-scale biomanufacturing[57].

But biomanufacturing competition is just the "snowflake on the tip of the iceberg." Economic prosperity, environmental health, and national security are all increasingly dependent on biotechnology. The foundational science and engineering practices underlying biotechnology are poised to break through the limitations of an Edisonian (i.e., "tinker and test") era. Biology as a fully-mature technology offers very different opportunities compared to the entrenched biotechnology practices of today. Recall the transition from industrial, to personal and networked computing that began ~50 years ago. Emerging biotechnology promises similar structural transformations today. Twenty-first century biotechnologies could fill a space of opportunity defined by "download (DNA code) and grow (locally)", pervasive and embedded biotechnologies, routinized bioengineering workflows (i.e., "design, build, work" replacing "design, build, test, learn"), life beyond lineage, AI-enabled biotechnology, and biotic citizenship[58] (e.g., biotechnology becomes cool).

Imagine such a world in which the United States is not the undisputed biotechnology leader. Imagine a world in which the "Silicon Valley" of twenty-first century biotechnology is in

[54]https://auchincloss.house.gov/media/press-releases/release-auchincloss-joins-bipartisan-group-of-select-committee-members-in-introducing-house-and-senate-bills-to-ban-foreign-adversary-biotech-companies-including-bgi-group
[55]https://www.jdsupra.com/legalnews/biosecure-stalls-will-not-become-law-in-9534650/
[56]https://www.wbjournal.com/article/wuxi-construction-resumes-at-delayed-300m-facility-as-biosecure-act-stalls
[57]For every dollar invested in pilot scale biomanufacturing we should expect, on average, twenty dollars will be needed to realize full scale biomanufacturing.
[58]https://bio4e.stanford.edu/report

Shenzhen not California. At best, we will experience increasing economic dependencies and security vulnerabilities. At worst, The United States will slip as a global power in a world in which conventional capacities are increasingly disadvantaged by rapidly changing contexts and needs.

COMPETITION AND COOPERATION

While competition can be used to frame US-China biotechnology relationships nowhere will cooperation become more important than with biological weapons. The Biological Weapons Convention entered into force almost fifty years ago.[59] Today, no nation admits to maintaining an offensive biological weapons program but distrust among nations, including the US and China, is at risk of increasing.[60] In 1970 Matt Meselson correctly declared that those who would seek to use biotechnology to cause harm should be considered "hostis humani generis," or enemies of all mankind.[61] It is vitally important that Washington D.C. and Beijing find common ground and creative approaches in cooperating to strengthen opposition to biological weapons at all levels.

Separately, what if the US is unwilling or unable to lead the maturation of biology as a general purpose technology while China succeeds in doing so? In this scenario should we consider a change of posture in which the US adopts a more cooperative "second place" stance? We would expect to experience significant potential leverage by China over the United States. Everything from access to climate-resilient seeds and essential medicines, to next-generation materials and force projection would become increasingly contingent on Beijing.

OTHER TRENDS TO TRACK

Technologies become true when people make them true.[62] Whichever nation learns to fall in love with biotechnology first will have a significant competitive advantage. How do the Chinese people feel about biotechnology and how does that compare to how Americians feel about biotechnology? Paying careful attention to the cultural context, support for, and engagement with biotechnologies will matter most in the long run. Paying careful attention to how such opinions are shaped and sculpted is important.

[59]https://en.wikipedia.org/wiki/Biological_Weapons_Convention
[60]https://www.defense.gov/News/News-Stories/Article/Article/2963280/russia-and-china-falsely-accusing-use-of-biological-weapons-against-russians-sa/
[61]https://www.scientificamerican.com/article/chemical-and-biological-weapons/
[62]https://vimeo.com/204559504?

POLICY RECOMMENDATIONS

Public funding for biotechnology research in the United States is grossly misallocated. We tend to spend most public treasure on the immediate applications of biotechnology.[63] We fail to sustain public investments in the foundational science and tool development needed to generate an evergreen transformation in how we partner with biology to solve problems. The private sector attempts to fill the gap (e.g., Codon, Gen9, Amyris, Zymergen, Gingko) but more often than not fails to mature new tool platforms soon enough to realize commercial success.

Consider how much money the NIH spends, directly and indirectly, supporting researchers building the DNA constructs they need to conduct NIH-sponsored research (over a billion dollars per year). Now ask how much money the NIH spends getting better at building DNA (at most a few percent of the cost to the taxpayer of building DNA). The situation is akin to if computer scientists could only receive funding for working on mobile phone applications that help patients in doctors' offices tomorrow. Proposals to create new compilers, programming languages, and operating systems – all seeking to make the process of solving problems with software, in general, easier – would be rejected. What disease does "making it easier to cure diseases" cure?

To lead in biotechnology in perpetuity the United States needs to smartly spend only a few billion dollars per year. But we must transpose how capital is allocated. Public capital must focus on extraordinarily high leverage and risky foundational research. Private capital should support entrepreneurs who can quickly and reliably translate scaled-solutions to market. The challenge for the USG will be to make such adjustments as needed to support foundational and high-leverage opportunities. For example, the forthcoming report from the National Security Commission on Emerging Biotechnology[64] has an important opportunity to support emerging, and not entrenched, biotechnologies. Here are some examples of high-leverage opportunities:

(1) Resource NIST to create a Bio-Measurement Laboratory (BML). The NIST BML should push the limits of measurement science in biology to establish and promulgate the standards that accelerate scaling of the US bioeconomy and guarantee that as much of the world as possible is operating on America's biotechnology stack. Leading in biometrology and standards setting will advantage all US activities globally, from biotechnology regulation to biosafety and biosecurity policy and beyond.

(2) Re-task DARPA BTO and ARPA-H to focus on the foundational science and technology opportunities and surprises that will fill in biology as a strategic domain (e.g., create and secure a "bionet" unlocking distributed manufacturing resilience). Dramatically dial back the focus on immediate utility to the warfighter and patient, respectively.

[63]The pressures to do so are justified (e.g., cure diseases and make biofuels now) but hinder progress overall.
[64]https://www.biotech.senate.gov/

(3) Repurpose or increase DOE funding to launch and support one or more National Biotechnology Accelerators whose primary mission is to relentlessly improve how researchers practice biotechnology and its underlying workflows (i.e., measuring, modeling, and making with biology). Public treasure gains the highest leverage when taxpayer money supports developing the tools that entrepreneurs later build upon for free.[65] World-leading biotechnology tools are an absolute requirement if the United States is to be the world leader in biotechnology.

(4) Repurpose or increase DOE funding to launch and support one or more Large Language Laboratories (LLLs) whose mission is to guarantee that the United States has the world leading foundation models in biology and biotechnology.

(5) Repurpose or increase DOD, DHS, HHS, and USDA funding to launch and sustain a joint National BioDefense Institute (NBDI) that convenes and supports the nation's best scientists and engineers in leveraging emerging biotechnologies to secure biology. To the greatest extent possible the NBDI should conduct its work in the open and in partnership with industry and international partners.

(6) Akin to GEOINT, task and support the Intelligence Community, DOD, Centers for Disease Control and Prevention (CDC), DHS, and the private sector in launching and sustaining a BIOINT consortium whose mission is to see behind the "molecular curtain" and help win a future free of biological catastrophe.[66]

(7) Increase support to the National Science Foundation for foundational science and engineering research in biology and biotechnology ten-fold. Make sure the support is used for foundational, blue-sky discovery and innovation. Adopt more effective models for allocating research funds.[67]

(8) The relevant Senate and House committees overseeing science and technology should make it obvious that America is "all in" on biotechnology by showcasing the nation's priorities, actions, successes, and opportunities via a central online resource, "bio.gov." This online resource must endure across administrations (e.g., where is ai.gov?).

In 1940 Marc Bloch wrote *Strange Defeat*. The choices we make, or fail to make over the next few years, will determine the architecture of a global biotechnology system. One path leads to multilateral flourishing within a human generation. Another leads to scarcity, stress, and worse.

[65]https://nap.nationalacademies.org/read/24656/chapter/1
[66]https://www.linkedin.com/posts/drew-endy-69ba17_winbywinning-biopartisanship-activity-7261753530116448256-qYzQ
[67]https://www.hypothesisfund.org/