Synthetic Biology
Leadership Excellence Accelerator Program

Perspectives on U.S. Military Synbio

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Some years ago I watched Arizona State University professor Daniel Sarewitz deliver an eye-opening lecture titled "How I Learned to Love the Military Industrial Complex," in which he isolated ten institutional features of the US Department of Defense that exercise tremendous long-term leverage over global energy economies. This leverage is a common source of consternation for activists and would-be reformers concerned with corporate greed and the on-going dysfunctions of regional world order. For Dr. Sarewitz, however, this leverage opens a profound opportunity. In short, anyone looking for an Archimedean pivot (so to speak) for global energy futures would do well to examine the DoD's role in shaping such futures, decade by decade.[1]

Since that lecture and its provocative Q&A session, I have thought a lot about what might happen if, over the next few decades, the Department of Defense were to develop and apply synthetic biology methods at scale for acquisition, procurement, and sustainment of propellants, purified water, food, lubricants, coatings, plastics, clothing, medical supplies, technologies for waste management and environmental remediation, et cetera.

On one hand, such futures entail the incremental (or abrupt) emergence of synbio-based industries linked in a global supply chain stable and reliable enough for the DoD to harness.[2] On the other hand, such futures may also entail the incremental (or abrupt) emergence of new forms of warfare and insurgency. I will discuss the DoD's anticipation of synbio-enabled warfare in a later section.

[1] For a cautious appraisal of the DoD's likely role in energy innovation futures, see Eugene Gholz. 2014. Military Innovation and the Prospects for Defense-Led Energy Innovation. *ISSUES in Science and Technology,* Vol 31, Issue 1.
[2] Considering how defense industrial firms are often major players in commercial industry, such futures also entail major impacts of synbio techniques on public services and economic sectors. For a short introduction to the defense industry's possible relation to "responsible innovation" in this regard, see Georgina Voss. Dec 24, 2014. "Beyond 'naughty or nice': defense research and responsible innovation." The Guardian.

Bottom Line Up Front

The US Department of Defense is a conspicuous force shaping the synthetic biology landscape today. Decisions made today, because they can be formative influences on such distant energy futures, have immense ethical significance.[3] DoD has a mandated preoccupation with ensuring strategic superiority to potential adversaries through investments in science and technology. Considering the impacts of this preoccupation on social and ecological dynamics historically, it seems appropriate that today's DoD synbio research programs might motivate exercises of ethical imagination to anticipate long-term impacts of alternative synbio development trajectories.

In what follows, I highlight some current initiatives that exemplify DoD's commitment to engineering biology. Examples of ethical perspectives to apply might include: how might we integrate discussions of diverse innovation pathways throughout the life cycle of DoD synbio initiatives? Who might be affected in the future if modifications to collaborative research partnerships, technology transfer practices, or foreign assistance programs emerged from combining synbio R&D management with conceptual frameworks such as "responsible innovation"? How might nurturing wide geographical access to the tools of synbio innovation today impact the likelihood of a stable global supply chain tomorrow? *More generally, what might ethical commitments to responsible innovation look like when constrained by national strategic priorities*? Moving forward, I hope that placing DoD synbio initiatives in conversation with conceptual frameworks from academia such as responsible innovation (or Transformational Sustainability Research) could motivate even military institutions to better translate critical ethical perspectives into experiments with institutional change.

DARPA

In February 2015, the DoD published its latest budget justification, or J-Book, providing (among other things) a program-level overview of Defense Advanced Research Projects Agency funds for current and upcoming fiscal years.

DARPA is a significant resource for young synthetic biology researchers, partly because the agency by law has to allocate 2.8% of its R&D budget to Small Business Innovation Research grants. DARPA's R&D budget request for FY2016 is $2.97 billion. In 2014, the agency consolidated much of its synthetic biology research under a new Biological Technologies Office. However, activities closely related to synthetic biology remain scattered throughout the agency's

[3] For example, four bioengineers sit with an entrepreneur sketching ideas on sticky notes. They want to help people practice biotech laboratory skillsets at the lowest possible cost. Decisions they make in an informal meeting may be actively shaping the geographical and socioeconomic distribution of access to the tools of synthetic biology innovation decades from now. How those decisions are made is ethically significant, and such decision-making can benefit from a strong ethical imagination.

official budget request using different names (e.g. "engineering biology"), making it difficult to place a composite dollar figure on investment magnitude. [4]

Among DARPA synbio programs, the Living Foundries and Biological Robustness in Complex Systems (BRICS) programs are most prominent, with requests of $30.9 million and $10.8 million for FY16, respectively. DARPA developed Living Foundries in 2012 to accelerate design, fabrication, testing, and evaluation of engineered biological materials. In 2013, program administrators added the 1000 Molecules program within Living Foundries with a mission to build a rapid prototyping infrastructure for synbio-based chemical synthesis. The logic of the 1000 Molecules program aligns with broader DoD research administration trends: rapid prototyping is used as a force multiplier capable of taking new research insights and applications quickly to advanced manufacture, test and evaluation. The goal is to continue outpacing enemy capabilities on present and future battlefields while shaping an emerging "organic industrial base" of domestic manufacturers.

To understand how DARPA currently perceives the ethical dimensions of synthetic biology research, consider the following caveat from the BRICS program administrator:

Proposals that include efforts to manipulate or study genetically modified organisms in open ecosystems or in any context not completely insulated from the natural environment will not be considered.

This caveat displays a complicated negotiation among societal actors, in which biosafety guidelines and internal processes of expert consensus among scientists actively anticipate and adapt to public perceptions of risk and congressional sensitivities to public perceptions of risk. A compelling recent example of this always-ongoing negotiation involves CRISPR/Cas9 gene drive technologies.[5] In May 2015 the Wyss Institute for Biologically-Inspired Engineering at Harvard University announced that biosafety guidelines for RNA-guided gene drive research are in place and will be updated periodically. Such guidelines are fascinating snapshots of dynamic negotiation not just among scientific communities, but regulatory agencies, industrial organizations, civil society groups, and concerned citizenries whose ethical responses have actually yet to be articulated. Documents like these provide practical examples of the importance

[4] Those familiar with the nebulous label of the "synthetic biology" will expect as much. Experience shows that "synthetic biology" entails participation from many communities of practices, such as: metabolic engineering, molecular biology, microbiology, systems biology, synthetic chemistry, chemical engineering, bioinformatics, systems integration, metrology, chemical manufacturing, law and bioethics.

[5] On one hand, an ethic of protection via containment or quarantine governs synbio innovation imaginaries. On the other, some innovators are openly devoted to the promise of beneficial transformation of wild populations through synbio innovation. These imaginaries are mutually reinforcing: they stabilize a present moment where an attitude of cautionary progress results from a realization of demonstrable power.

of ethical discourse as a component of R&D management.[6] Such ethical discourse is a management technique, and many thoughtful participants in engineering biology communities have noted how the manufacture of ethical discourse may forestall a more fundamental role for critical ethical imagination in shaping alternative futures for synbio innovation.[7]

ARMY

In January 2015 the Army Research Laboratory published its Technical Implementation Plan for 2015-2019. One of the core components of ARL's Materials Research Campaign is titled "Designed Microbial Consortia for Materials Synthesis and Sustainability." If we focus only on cases where the words "synthetic biology" are explicit in this Campaign, there are two mentions in the section on mid-term technical goals (2020-25):

c. Develop genetic engineering and synthetic biology tools to alter organisms in ecologies.

d. Manipulate ecologies through genetic modifications of individual species using newly developed synthetic biology tools. (27)

According to the Plan, aside from the usual list of synbio applications for water purification, fuel precursors and feedstocks, bioremediation, and waste management, the US Army is also targeting microbial ecologies in the stomachs of soldiers:

…[U]nderstanding microbial consortia and engineering them for biological processing / manufacture would provide the Army with...probiotics for enhanced Soldier health / performance.... (26)

A 2013 Defense Science Board report on Technology and Innovation Enablers for 2030 (p. 58) laments that over 90% of special forces soldiers currently experiment with nutritional performance enhancement without adequate guidance or personalized scientific formulations. It seems unlikely, therefore, that the Army will have trouble finding volunteers for synthetic microbial consortia test and evaluation, should such breakthroughs reach a stage of advanced technological development. Thus, we can begin to understand the US Army's evolving relationship to the tools of engineering biology: they are eager to develop and field new capabilities, and willing to consider very bold courses of action.

[6] Notably, some experts think techniques for designing synthetic gene drives should be classified as a matter of national security, due to the magnitude of potential negative consequences that might result from plausible open innovation trajectories. The administrative guidelines published by the Wyss Institute could be read as a political strategy driven by ethical perspectives designed to prevent excessive government restrictions on access to these nascent tools of synbio innovation. The US has a complicated history of assessing risk and declaring techniques of device manufacture classified; see Herbert N. Foerstel. 1993. *Secret science: federal control of American science and technology*. Praeger.
[7] See Paul Rabinow and Gaymon Bennett. 2012. Designing Human Practices: an experiment with synthetic biology. University of Chicago Press.

A successful line of research showing promise for synbio approaches to large-volume fuel production would trigger decades of accelerated prototyping, industrial partnerships, field testing, and fine-tuning in the Army and other agencies, especially in situations of dire energy demands or sudden reductions in energy supply. Historical research on DoD aviation programs shows that periods of fiscal austerity tend to increase reliance on experimental prototyping efforts. Since major Army vehicle modernization programs today entail increased fuel consumption compared to the systems they will replace, synbio-based fuels could find a sympathetic customer-base in a cost-conscious DoD moving forward. Internal policies mandating that large percentages of fuel come from renewable sources could also promote favorable attitudes toward synbio-based products. Currently, DoD policy mandates that 25% of its total energy use must come from renewable sources by 2025. Each Armed Service has unique energy policies that augment DoD policy, pushing toward more ambitious goals. Access to synbio-based solutions could motivate subsequent mandates that become sufficiently ambitious to yield the kind of infrastructure changes that would indicate global energy economy shifts. [8]

NAVY, Marine Corps, AIR FORCE

In addition to the Army Research Laboratory's biomaterials program, the Office of Naval Research's Warfighter Protection and Applications Division has synthetic biology, metabolic engineering, sensing, and bioprocessing thrusts. ONR maintains an in-house research capability, but leverages relationships with academia to fund much of this research through the MURI and DURIP programs. The Air Force Office of Scientific Research funds synthetic biology research internationally through various chemistry and biomaterials grants awarded by its overseas R&D agency, the Asian Office of Aerospace Research and Development (AOARD). Further documentary analysis is needed to uncover to what extent US military funds are impacting the synthetic biology landscape in countries like India, Japan, and Singapore. If anyone cares to join me in an effort to map the full extent of the reach of US military synthetic biology research, I welcome your collaboration, as many additional research programs with key synbio focus likely exist beyond my immediate attention.

SYNBIO & THE FUTURE OF WAR

I have focused thus far on the techno-scientific activity of producing, evaluating, and circulating funding and knowledge intended to increase US military advantage. Now, I will return to the impact that a move to synbio-based military acquisition and sustainment could have on the future of warfare.

[8] Of course, it is important to keep in mind that shifts in global energy economy may be achieved without any corresponding strides toward solution options for the world's most intractable problems. Synthetic biology, needless to say, is not a panacea. That is precisely why synbio innovation should be guided by strong ethical imagination that stresses the importance and urgency of solving "problems that matter." For DoD, the question is to what extent the primary constitutional mandate to secure the national defense entails "solving problems that matter."

On February 24-25, 2015 in Washington DC, the New America Foundation held a conference on the Future of War. One of the panel discussions considered the future of weaponized synbio. The organizing question was: "How Will the Digital Biology Revolution Transform Conflict?" Dr. Gary Marchant from Arizona State University emphasized a dilemma of *acceleration* that the defense community is aware of, but cannot resolve: DoD does not want to be surprised by adversary capabilities related to engineering biology, so it seeks to develop a visionary capacity to counter any efforts to deploy weaponized synthetic biology tools (e.g. poisoning water supplies, contaminating habitats, permanently altering human and animal genomes of a population); the problem, however, is that the quest to anticipate future enemy capabilities may actually *produce* enhanced enemy capabilities that intensify a perceived threat of weaponized synbio deployment and justify increased biodefense research. This is a complicated risk scenario, potentially involving a self-defeating logic, and a dilemma not amenable to risk-free solution.

Biodefense research can produce wide benefits to civil practitioners. For example, pathogenicity research can lead to innovations in laboratory techniques that benefit all practitioners and circulate widely through research communities. Those techniques may simultaneously broaden access to advanced techniques of weaponization that enhance adversary capabilities more rapidly than would have occurred in the absence of a dogged quest to outpace potential enemies[9]. Despite potential risks of co-producing enemy tactics, the DoD's practical responsibility of defending against unknown enemy capabilities compels each agency to develop biodefense research capabilities.

CONCLUSION

Taking a look at actual motivations driving US military investments in synbio research provides an important "reality check" that may be useful in discussions about designing advanced biotech applications for "the public benefit." The DoD's strategic preoccupation with national security will continue shaping applications of engineering biology. Changes in scientific knowledge, public perceptions of risk, international affairs, and domestic politics will each define the ethical dimensions of synthetic biology in unique geographical settings worldwide. Understanding some of the powerful incentives shaping status quo management of synbio innovation may indicate how immensely difficult it will be to "nudge" DoD toward integrating easily-marginalized critical ethical perspectives into the design of synbio R&D management and synbio innovation ecosystems. Nevertheless, making DoD into a testbed where such flexible ecosystems are desired and taken seriously is a worthy task for the next generation of synthetic biology leaders.

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[9] A polycentric governance approach to mitigating some risks of biosafety and biosecurity has emerged alongside the acceleration dilemma, combining formal and informal mechanisms at local, state, national, and international scales. For an overview of some relevant structures and issues see Cameron Keys. 2012. The Goldilocks Dilemma and Polycentric Governance: Risk and Regulation in Synthetic Biology. Arizona State University term paper. LAW 691.