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INDUSTRY STUDY: BIOTECHNOLOGY

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INTRODUCTION

With thousands of people dying each day from the pandemic outbreak of 2019 novel coronavirus (COVID-19), 2020 brought challenges previously unseen in the world. As the world reacts and tries to overcome this virus, biotechnology will be the industry to take the lead and forge the path forward. It will not be without difficulty though as the United States (US) must surge and mobilize against an unplanned enemy and must wade through ethical issues previously unrealized. In addition, the triple helix – the interaction between academia, industry, and government – must ensure enough resilience and adaptability to respond to unanticipated circumstances and emerging needs.[1] Collaboration within the US triple helix is essential to take advantage of opportunities and mitigate threats.

Biotechnology, defined by the seminar as "Leveraging technology to understand living processes, organisms, and systems to alter and/or enhance health and performance, prevent and cure illnesses and diseases,"[2] is often dual-use in nature with related risks and threats to public health and national security, as we are currently witnessing during the pandemic. In 2020 the possibilities and potential advantages of biotechnology have suddenly become extremely important as the world deals with a pandemic claiming hundreds of thousands of lives. The possibilities allowed with new technologies make biotechnology an exciting and fast-changing area of science.

BIOTECHNOLOGY INDUSTRY OVERVIEW

Industry Financials

The US biotechnology industry recently reported $112.4B in revenues with a profit margin of 12.1%.[3] In 2016, the biotechnology industry employed 1.74M workers in the US operating in almost 86K business establishments.[4] The economic output of these workers supports 8M jobs throughout the entire US both by indirect and induced effects.[5] Industry employment has consistently grown since 2001. In 2017, the average salary was $99K which is $45K greater than the nation's private sector.[6]

There is a high level of market share concentration in the US, where the top five industry players generate 74.4% of industry revenue.[7] These companies and their respective market shares are: Genentech ($24.2B, 21.6%), AbbVie Inc. ($23.7B, 21.1%), Amgen ($16.8B, 14.9%), Gilead Sciences Inc. ($12.0B, 10.7%), and Bayer AG ($6.9B, 6.1%).[8] These five companies employ more than 86,000 employees, while hundreds of smaller companies, usually counting less than 50 employees on their payrolls, fill the gaps in an otherwise fragmented industry.[9]

Industry Sectors – Focus on Human Health

The biotechnology industry is segmented into four major sectors which analysts represent by a corresponding color (see Appendix, Figure 1).[10] The top three US biotechnology sectors, by revenue, are Human Health, Agriculture & Aquaculture, and Industrial Technologies (see Appendix, Figure 3).[11] Each biotechnology sector is further specialized by application and is supported by a host of enabling industries such as research and development (R&D), industrial capabilities, finance and investment, analytics, suppliers, engineering, media and advocacy/policy (see Appendix, Figure 2).[12]

Human Health Technologies, by far the largest biotechnology sector, includes therapeutics and diagnostics which focus on the "application of biotechnology to the discovery and development of novel therapeutic compounds and probe molecules for applications in medicine."[13] Pharmaceutical companies are a major player here. They specialize in one or many areas of human health technologies to include antibodies, anti-infectives, biosimilars, cell therapy, drug delivery, gene therapy, generic drugs, immunotherapy, microbiome, molecular diagnostics, natural compounds, peptides, proteins, small molecules, stem cells, and vaccines.[14]

Medical technologies companies are involved in "research, development, production and marketing of systems, and devices for medical applications (i.e. to treat or diagnose diseases or medical conditions)."[15] This includes devices and materials such as active and non-active implantable devices, anesthetic and respiratory devices, biomaterials, coatings, delivery devices, dental devices, diagnostic and therapeutic radiation devices, hospital equipment, imaging, ophthalmic and optical devices, regenerative medicine, wound care and technical aids for disabled persons.[16]

HealthTech companies "provide healthcare services or products based on information and communications technologies."[17] These products and services include artificial intelligence, doctor network communications, electronic medical/health records, health and wellness, health services search, mobile healthcare communication, big data analytics, mobile fitness/health apps, online health communities, payments and insurance, population health management, remote monitoring, telehealth, and predictive analytics. These companies provide administrative and support technologies to sustain the broader complement of biotechnology companies and create their own products related to human health technologies.

Biotechnology R&D provides "support services such as product development services, analytical services, screening, contract manufacturing, and contract R&D to the biotechnology industry."[18] This includes companies devoted to analytical services, biochips, bioelectronics, bioinformatics, cell culture, contract manufacturing, contract research, diagnostic instrumentation and services, drug delivery, genomics, proteomics, screening, and synthesis services.[19]

Industry Sectors – Focus on Others

The next two major sectors are Agriculture & Aquaculture and Industrial Technologies where the companies "apply the concepts of biotechnology to areas other than drug development for medical use".[20] This includes agricultural biology (AgBio), cosmetics, food, industrial biotechnology, nutraceuticals and other industries not involved in developing therapeutic medicine or a provision of a service.[21] This sector includes suppliers and engineering services such as active pharmaceutical ingredients (APIs), chemicals, electronics, distributors, instrumentation, laboratory supplies/equipment/engineering, packaging & labeling, production engineering, synthetic materials, and software.[22] The remainder of biotechnology industry sectors are focused on environmental remediation and recovery technologies (such as wastewater treatment and biofuels) and veterinary technologies.[23]

There are many supporting services such as investor services (corporate, bank, institutional, and venture capital), professional services and consulting (business development, communication, public relations, event coordination, human resources, IT, legal, patents/trademarks, sales and marketing, and real estate), and media services (publications, trade journals, advertising, and others focused on gathering and distributing biotechnology information).[24] Infrastructure considerations are also included in this area accounting for public

institutions, non-profits, medical and research facilities, government organizations, hospitals (public and private) and academia.[25]

DRIVING FACTORS AND ECONOMIC OUTLOOK

Several factors drive the biotechnology industry, such as global R&D funding, investor confidence, demographics (aging populations), and the number of students in biotechnology disciplines.[26] These factors affect the supply and demand curves for each biotechnology sector, which drives critical investment and product development market characteristics. An overlay to these factors is overall global economic health, which not only helps finance individual demand for products and services in each market but also increases the availability of investment funds to companies across the biotechnology spectrum.

The knowledge-intensive nature of this industry requires substantial R&D investment. With extensive development lifecycles for many biotechnology products, there is substantial pressure on biotechnology companies to maintain revenues. This pressure can adversely influence global investor confidence, further restricting future biotechnology investments. This volatility in global investment directly affects biotechnology companies' ability to source funding and prioritize investments. Other considerations, such as regulation and intellectual property (IP) protection, can strengthen or weaken biotechnology business strategies. Cumbersome regulations or a lack of IP rights are non-conducive to recoupment of heavy initial investments.

Industry indicators show annualized revenues forecasted to grow at 2.9% through 2025.[27] Global R&D and total health expenditures also project steady growth. Demand for health-related products is increasing with a globally aging population, while consumer confidence in new biotechnology products and services is strengthening. New markets for agricultural products and

biofuels, along with advances in industrial technologies will improve labor costs and productivity, yielding new growth and profit opportunities for biotechnology companies. The culmination of these indicators reflects a mostly positive outlook for the biotechnology industry.

UNITED STATES GOVERMENT STRATEGY IN BIOTECHNOLOGY

The United States Government (USG) National Strategies that address national security and the biotechnology sector are the National Security Strategy (NSS), the National Defense Strategy (NDS), the National Biodefense Strategy (NBS), and the National Health Security Strategy (NHSS). The NSS calls for maintaining a "safe, prosperous, and free"[28] homeland and pursuit of our values abroad with like-minded partners. This requires maintaining a strong military able to participate in great power competition, especially against a rising economic powerhouse in China, while also reducing the threat of international terrorism. The NSS also addresses combatting biological threats and pandemics, protecting and supporting biomedical innovation, reducing regulations that impede R&D, improving the recruitment and retention of a STEM workforce, leveraging relationships with the private sector to align resources with national security applications, and reforming R&D to support rapid fielding and risk taking, and protecting IP rights (addressing foreign investments).[29]

Strategies that specifically relate to the potential of biotechnology to address national security issues are the 2018 National Biodefense Strategy (NBS) and the Department of Health and Human Services' (HHS) 2019-2022 National Health Security Strategy (NHSS). While the NBS aims to coordinate across the interagency and promote innovation in partnership with industry to achieve the goals of developing and manufacturing medical countermeasures,[30] it lacks a roadmap for specifically collaborating with industry across the scope of the plan.

The NHSS is more specific regarding developing and sustaining public-private partnerships for medical countermeasure development and production and fostering a resilient supply chain.[31] The differentiator may be clearer authorities granted to the Assistant Secretary for Preparedness and Response (ASPR) and the Biomedical Advanced Research and Development Authority (BARDA), along with specific funding for procurement.[32] HHS published the last Public Health Emergency Medical Countermeasures Enterprise (PHEMCE) Strategy in 2017 covering government-wide efforts to increase preparedness. PHEMCE at the time was a joint HHS-DoD-Veterans Affairs effort to coordinate investments in medical countermeasures.[33]

ROLE OF DEFENSE DEPARTMENT IN BIOTECHNOLOGY

Biotechnology is one of the DoD Under Secretary for Research and Engineering (OUSD(R&E)) ten Modernization Priorities. The DoD has a goal of writing a roadmap to address these priorities, however the timeline for completion is unclear.[34] Current DoD biotech research efforts include bacterially produced runways, yeast-produced novel composite materials, and 3-D printing of tissues to regenerate organs.[35] However, with no clarity on how to prioritize DoD's biotechnology investments and acquisitions, the development of a roadmap would be haphazard.

The DoD nests their basic science research portfolios under military Service laboratories, such as the Naval Research Laboratory's Center for BioMolecular Science and Engineering. Research, efforts here include engineering the gut microbiome for improved human resilience, harvesting energy under the ocean, and developing microfluidic platforms for miniaturized

biosensors. While still at the early stages, these projects could eventually yield innovative products.[36]

At the procurement level, the Defense Innovation Unit (DIU) is speeding up the integration of commercial solutions into the DoD. While not specifically in the biotechnology space, they look for technological solutions that could be rapidly acquired and adapted. They publish solicitations for the development of rapid prototypes. DIU staff reach across the DoD to conduct "problem curation" and identify potential commercial solutions, matching industry to relevant DoD programs.[37] This proactive DOD effort helps private companies navigate the often-challenging DoD funding, requirements, and contracting process. This method of DoD reaching out to the private sector serves as a bridge for the two to meet.

To augment the biotechnology industry, the DoD announced its intent to create the Synthetic Biology Manufacturing Innovation Institute.[38] This institute will be part of a network enhancing the adoption of innovations into the private sector by providing facilities and expertise in cutting edge technologies.[39] Also, Draper Labs, a non-profit founded to support national security problems with engineering solutions, has a biomedical solutions team that looks for innovations that can improve health care and the biotechnology/pharmaceutical industry.[40]

ROLE OF USG REGULATION

The Committee on Foreign Investment in the US (CFIUS) is a government mechanism used to control access to sensitive technologies. Primarily through a voluntary reporting system, this interagency committee seeks to identify investment by foreign individuals or countries with ulterior motives to gain access to critical technologies, sensitive information, or real estate near critical infrastructure. CFIUS was updated in 2018 with the Foreign Investment Risk Review

Modernization Act to address heightened concerns over certain technologies and "substantial interest" investments in US companies. These updated regulations expand CFIUS authority to review for noncontrolling investments in US critical technology firms in 27 different sectors, including biotechnology R&D.[41]

The US government's priorities, as communicated though national strategies, generally remain opaque to those outside the government. In off-the-record discussions during this biotechnology industry study course, several senior industry and government leaders noted that working with the government is challenging; it is hard to navigate, too bureaucratic, and too difficult to procure funding.

A DoD roadmap for biotechnology would clarify what the DoD seeks and how to better align its investments across multiple related agencies. This would help develop mechanisms to more easily share requirements, solicitation plans, grant opportunities, contracts, and acquisition information. It would also reduce overlap and maximize federal investments into more clearly targeted areas.

HUMAN CAPITAL IN BIOTECHNOLOGY

With heightened focus on biotechnology and its importance to national security, the USG will need to address human capital in order to maintain their edge in global competition. In 2018, TEConomy and the Biotechnology Innovation Organization (BIO), a world-renowned trade association, released a report focused on the economic progress and footprint of the US biotechnology industry.[42] The report details the economic value and impacts that benefit the bioscience industry throughout the country.

Earlier this year BIO issued its first annual report on race, ethnicity, and gender in the biotechnology industry.[43] The report provides a baseline for understanding diversity and inclusion within BIO member companies.[44] Based on responses from approximately 100 companies, women make up approximately 45% of employees, but only represent 30% at the C-suite level and 18% at the Board level.[45] Likewise, people of color made up 32% of employees, but only 15% of executives and 14% of board members.[46] Smaller, private companies appeared to have a more diverse representation than their larger, more profitable publicly-traded counterparts. The majority of the participating companies were based in the US, with 48% having multinational operations.[47] The report encourages companies in the biotech industry to assess their efforts and find ways to advance them when it comes to diversity and inclusion.[48]

INTERNATIONAL BIOTECHNOLOGY COMPETITION AND PARTNERSHIPS

Great Power Competition: China and Russia

President Xi Jinping intends China to be a world leader in biotechnology. Therefore, China funds most of the biotechnology industry through state sponsored programs. As part of the *Made in China 2025* master plan, China has set specific biomedicine goals in order to become an international development country[49] and to achieve more than just economic benefits. In fact, the Chinese military is transitioning toward a model that leverages science and technology as a core lever of combat power.[50] The US will need to monitor and try to manage any Chinese military application of biotechnology.

Russia also identified biotechnology as a key sector for economic growth, development, and national security. However, with a focus primarily on resource extraction, they do not appear

to have progressed in biotechnology innovation. While there is limited information in the public domain regarding potential clandestine biotechnology programs, remarks made by Russian President Vladimir Putin referring to the development of genetic weapons have generated grave concerns for the US and its allies.[51]

International Allies and Partners: Europe, Asia, Africa and the Americas

The European biotechnology industry is shaped heavily by the investment and regulatory policies of the European Union (EU), as well as national-level policies. The European Commission facilitates, coordinates, and funds R&D at the EU level. EU grants foster the development of Europe-wide networks by requiring cross-border, multi-member state collaboration. European policymakers have also promoted the bioeconomy as a transition away from fossil fuel-driven economies and towards more sustainable sources. This will help the EU to meet its climate goals and create green jobs.[52]

Northeast Asia's biotech scene is dominated by China, Japan, and South Korea. The Japanese market is mature, with larger companies investing heavily in R&D. This dynamic fosters innovation and the continued introduction of new products. While in Korea, President Moon Jae-in recently announced that "his government will foster the biotechnology and pharmaceutical sectors as the country's new economic growth driver, aiming to triple the export and the global market share of pharmaceutical products and medical instruments by 2030".[53]

Singapore has more than fifty top global biomedical science firms and thirty public research institutes. The government continues to provide heavy biotech R&D investment while also implementing strong Intellectual Property (IP) laws.[54] Biotech plays a significant role in the "Thailand 4.0" growth model. The country has IP protections, a well-educated technological

workforce, offers tax incentives for companies investing in biotech, and offers a network of organizations that support R&D in biotech.[55] Taiwan invests heavily in R&D and boasts the Argonne National Laboratory and the Industrial Technology Research Institute.[56] India is also growing its biotechnology industry and is the global leader in generic drug production, supplying over 50 percent of global vaccines.[57]

Australia is a global leader in biotechnology, ranking in the top 5 bioeconomies.[58] This ranking is due largely to heavy government R&D support ($10.1B invested in 2015-2016), significant tax incentives,[59] strong IP protections, enterprise support, workforce/education, productivity (ranked 2nd globally), and policy.[60] The US should continue its strong relationship with Australia to help them hone their regulatory environment in step with US policies and to dampen China's influence in the region.

Israel possesses the most dynamic biotech sector in the Middle East. Its strength in information technology complements a high-quality human capital pool and life sciences R&D base. These factors make the Israeli biotech sector globally competitive.

South Africa has pursued a coordinated biotechnology sector strategy for nearly 20 years. While their overall biotech industry remains nascent, it has shown strength in the number of scientific articles published and cited, attesting to globally relevant research. This dichotomy highlights the difficulties of successfully transitioning from research discovery to commercialization.[61]

Although South America has traditionally lagged in biotech due to low government R&D investment, the region is gaining traction.[62] Between 2012 and 2017, private investment in South America's pharmaceutical industry almost doubled. The use of genetically modified organisms (GMOs) has grown substantially in Brazil and Argentina, the leading agricultural economies in

the region. With 10 of the world's 26 genetically engineered crop-producing countries located in Latin America,[63] the US should focus its attention on agricultural biotech in South America and work to enact regional policies where strategic goals naturally align.

International Policies

The US needs to posture for Great Power Competition against Russia and China. It must also form strategic collaborations with international allies and partners that ensure continued global US leadership in biotechnology. Therefore, the US and its allies should push for international policies regarding the military application of biotechnology. This will require consensus on acceptable behaviors, agreements, and treaties. Working together, they should focus on improving their abilities to prevent, detect, and respond to biological security events in ways that mitigate overall global risk.

Given that a new multilateral instrument is unlikely (nor, perhaps, necessary), the role of the US and other like-minded nations in working to both establish and shore up international norms is of critical importance.[64] The US and its allies need to take a leading role in biotechnology agenda setting in order to ensure that we are leading and shaping, rather than responding to others who seek to create a rules-based order in their favor. Whether it is addressing the dual-use aspects of biotechnology, the shaping of internationally accepted norms of behavior, or the setting of the biotechnology agenda, expertise and focus are critical.

DISRUPTIVE TECHNOLOGY – HUMAN ENHANCEMENT

The potential for emerging disruptive technology is great within biotechnology and can be separated into the following areas: bio-storage, bio-manufacturing, bio-surfaces, bio-fuel, and

human performance. Each of these areas is vulnerable to exploitation by a US adversary and require oversight and leadership within the global community to ensure ethical boundaries are established and maintained. Due to its natural and direct relationship to the joint warfighter, the focus in this paper will be enhanced human performance.

Human enhancement is defined as "a field of research that involves the use of medicine or technologies to improve human productivity or capability by adding to the human body to enhance the things we can do."[65] A report provided by the Prescient & Strategic Intelligence Private Limited stated that the global human enhancement industry was approximately $64.8 billion in 2019, with projected growth of $271.6 billion by 2030.[66] The market segmentation within the industry has four specified areas: exoskeletons, smart devices, medical devices, and implants.[67] Each of these segments has application across three broad categories, Healthcare, Industrial, and Defense.

Critical to understanding the industry's view on the human enhancement space is their concern regarding ethical challenges. These controversial issues may lead to increased costs, innovation bottlenecks, and difficulty bringing products to market. This same concern exists within the DoD but is further shaped by how these applications impact national security.

Human performance standardization falls under OUSD(R&E)'s Human Systems Directorate. This same office also created the Biotechnologies for Health and Human Performance Council, which "assesses scientific advances for improved health and performance with a potential military application."[68] One of this organization's critical undertakings was the assessment they conducted under the direction of DoD, which developed vignettes to analyze "feasibility; military application; and ethical, legal, and social implication considerations."[69]

DARPA is critical to the development of human enhancement technologies. They focus on developing the application of biotechnologies before an adversary can develop and deploy them against the US.[70] This ultimately led to creation of the Biological Technologies Office, which specifically focuses on the biologic applications for human enhancement.

ETHICAL CONSIDERATIONS IN BIOTECHNOLOGY

The five ethical concerns foundational to biotechnology are genetics, stem cells, human testing, genetically modified organisms (GMOs), and the cost of drugs. Each of these areas has challenged the status quo in scientific development. While adding positive value and making modern-day advancements, they also raise serious ethical concerns for modern society. Of particular concern for the biotechnology industry are gene-editing technology, regulatory guidance, and international implications on maintaining a competitive edge.

In particular, the study of genetics and the endless possibilities to genetically engineer and manipulate a human's biological DNA through gene editing generates a multitude of ethical dilemmas. CRISPR is a tool that permits genomes to be edited like a Word document.[71] This technology allows researchers to easily alter DNA sequences and modify gene function capable of correcting genetic defects, treating and preventing the spread of diseases, and improving crops.[72] Although innovative, the many conceivable applications of CRISPR technology have justly provoked questions about the ethical merits and potential consequences of tampering with genomes.

Militaries around the world have become interested in CRISPR technology and its potential applications. Studies have already demonstrated how CRISPR could change warfighter

capabilities of tomorrow. One notable study found that "CRISPR-mediated gene editing of beagle embryos produced pups with twice the muscle mass…that could theoretically be genetically engineered to enhance humans ."[73] If this technique could be applied to humans, it is easy to see where the dual-use of this technology comes into play: the military could certainly benefit from stronger soldiers, yet the ethics of this technology will certainly cause apprehension.

One constant concern expressed by the public is whether scientists are "playing God." In 2018, Chinese scientist, Jian-kiu He, publicly announced he had successfully edited the genes of twin embryos, changing their DNA to be naturally immune to the human immunodeficiency virus (HIV).[74] These twins are the first successfully gene-edited humans.[75] Dr. He was ultimately sentenced to three years in prison and was shunned by the scientific community as many believe he disregarded the ethical principles by experimenting on humans without proving to be safe. Given the risk to human misuse, gene editing commands significant regulatory oversight and justifies a comprehensive approach to ethical considerations.

Regulatory governance is a core element to protect Americans against ethical misconduct. The US Food and Drug Administration (FDA) has a fundamental responsibility to protect the public health by assuring the safety and efficacy of drugs, biologics, and medical devices and advancing public health by promoting scientific research and medical innovation.[76] The FDA's ability to reject a pharmaceutical product gives firms and researchers compelling motivation to adhere to federal regulations and rigorous ethical standards.[77]

Global variation in ethics raises questions of whether the US can maintain a competitive edge and the ethical high ground in biotechnology. As long as China and like-minded countries behave unethically, the US risks losing its competitive advantage in biotechnology. This example "emphasizes the need for an urgent improvement of ethics governance at all levels, including, the

enforcement of technical and ethical guidelines, and the establishment of laws relating to such bioethical issues."[78]

BIOTECHNOLOGY SURGE AND MOBILIZATION

Disease outbreaks are among the most insidious threats facing the US and the international community as population size and density increases around the world.[79] Today's interconnected global markets and abundant international travel have made the rapid spread of potentially deadly diseases from even remote areas to other countries a near-certainty. The Severe Acute Respiratory Syndrome (SARS) outbreak in 2002 and the current COVID-19 pandemic – both of which originated in China – demonstrate that viruses will travel, affect other countries, and threaten international security.

Biological weapons also present risks to US national security. The Biological Weapons Convention (BWC), which entered into force in 1975, prohibits the development, production, and stockpiling of bioweapons. As of August 2019, 183 nations are party to the convention, though eight countries are currently suspected of having some form of offensive bioweapons program.[80] The ratification of the BWC may have reduced the biological threat from other states, but in the hands of non-state actors or terrorist organizations, bioweapons present unique challenges to US national security. Rapidly evolving technology, naturally occurring pathogens, and inadequate laboratory security controls make sourcing biological material and weaponizing a viral agent, bacteria, or toxin relatively easy.[81]

Whether the next devastating outbreak is natural or man-made, the national security of the US depends on its readiness to respond. Outbreaks can quickly overwhelm the day-to-day

capacity of medical systems, requiring additional capacity to mitigate the threat – first a surge within the healthcare industry, and then a partial or full mobilization of others (see Appendix, Figure 4). The US must build a prompt surge and complete mobilization capacity as well as supply chain security in response to any biological crisis. To do this, the USG must explore options to improve rapid drug development, expand R&D, and increase government partnerships that broaden the biotech industrial base.

Four components (known as the 4-Ss) comprise surge capacity: medical supplies and equipment (stuff), trained personnel (staff), care facilities (structures), and the policies and procedures that link them all (systems).[82] If surge capacity proves insufficient to treat a biological outbreak, larger-scale industrial base involvement, called mobilization, is necessary to provide additional resources. Mobilization involves the same 4-Ss as surge, but broadens the scope from which resources are pulled, necessitating the conversion of civil sector manufacturing to produce healthcare materials, while also sourcing workers outside normal channels.

During pandemic infectious disease outbreaks, surge and mobilization of therapeutics and vaccines are critically important. Effective public-private partnerships have expanded the number of vaccine manufacturersin the US from two in 2004–2005 to six in the 2016–2017 flu season.[83] Most recently, BARDA awarded Sanofi a $226 million contract in order to expand vaccine capacity in support of pandemic preparedness.[84] Moreover, BARDA established three manufacturing centers to develop medical countermeasures such as therapeutics and vaccines. Theses Advanced Development and Manufacturing sites retrofit capabilities to achieve full manufacturing levels essential for surging a vaccine or drug.

To improve surge and mobilization response, it is vital to improve developmental lead times for drugs and vaccines. The emergence of vaccine platform technologies have shown promise over recent years and can be an excellent opportunity for the government to partner with the biotechnology industry. The current paradigm can be characterized by a "one bug, one drug" approach where effective vaccines and therapeutics are developed, manufactured, and deployed against one disease organism.[85] Newer platform technologies make it possible for multiple vaccines to be more rapidly produced from a single system.[86]

However, pandemic infectious diseases, by their sporadic once in a generation nature, will never represent an attractive market for industry. It offers high risks for indeterminable financial rewards and minimal opportunity costs.[87] Therefore, in spite of the economies of scale achievable with these technological advances, vaccine platform technologies require deliberate and forward-thinking R&D funding considerations.

Artificial Intelligence (AI) is a powerful technological advancement that will enable the reduction in drug development lead times. By leveraging machine learning, AI can manage disparate clinical trial datasets, enable virtual screening, and analyze vast amounts of data. This will not only reduce developmental lead times, but will also save costs in clinical trials.[88]

Typically, diagnostic testing for a new or emerging infectious disease is developed based on an organism's unique genetic code, the proteins they express, or the presence of antibodies in the infected person.[89] The future of diagnostic testing is developing a single test that can detect hundreds of pathogens – viruses, fungi, bacteria, and parasites.[90]

Current plans on surge and mobilization capacity focus primarily on production. This primarily involves making more medicine, expediting equipment, or formulating vaccines.

However, three critical areas that receive less attention are personnel capacity, surveillance and communication, and supply chain security. To combat these issues, the USG must develop a consolidated, national database of health care workers of all kinds that tracks their training, certifications, and contact information for emergency recall; create just-in-time training opportunities and emergency credentialing to augment personnel; leverage technology and telemedicine as a force multiplier; increase multilateral cooperation in health care surveillance and reporting; and build a resilient, secure, and diverse supply chain, including domestic capacity.

CASE STUDY: COVID-19

The US is facing an enemy that will test its strategic partnerships, supply chains, and the entire biotech industry – the COVID-19 pandemic. At the end of December China informed the World Health Organization (WHO) of a potential pneumonia-like infection of unknown origin. Within a month, on January 30, 2020, the WHO declared a public health emergency of international concern. The White House stood up a COVID-19 Task Force the very next day. As of mid-April 2020, the US has the highest infection rate and deaths worldwide. The WHO stated COVID-19 is ten times more deadly than H1N1, the last major pandemic.[91]

The economic impacts of COVID-19 are devastating. The majority of US small businesses are shut down and unemployment claims exceeded 7 million for the week ending March 28, 2020.[92] The pandemic has also exposed the US's lack of preparedness for such a contingency, as well as dangerous supply chain dependencies on China and other countries. The US is now in a full mobilization of our healthcare and public health systems, as well supporting

industries such as automobile manufacturing. It is an all-out effort by government, universities, and commercial industry to increase testing, find or develop efficacious and safe therapeutics, manufacture medical equipment such as ventilators, and develop a vaccine.

Global forces are rapidly coalescing around the COVID-19 vaccine development and production race. This effort spans the continuum of basic science research, clinical evaluation and trials, manufacturing, and distribution. The biotechnology industry is leading this charge, accompanied by academic, institutional, and governmental researchers and regulators. Emerging from these multi-disciplinary collaborations are not just solutions to the current outbreak, but platform technologies that will forever change the human race's biological threat landscape.

The DoD must understand in real time how this vaccine race is unfolding so it can shape the result. Examining the competitive pressures, rapid innovation, and international multidisciplinary collaborations that are driving the COVID-19 vaccine race makes clear the challenges and opportunities facing the DoD, as well as the areas ripe for partnership and advancement.

In order to meet their future force protection requirements, the DoD needs to field rapid response platforms that can identify a pandemic infectious disease threat, develop a vaccine solution, and then manufacture and distribute that product to warfighters in real time. COVID-19 offers an unfolding case study of how that is possible now and in the future.

Specific near-term policy initiatives and recommendations include: 1) increase investment in military Service laboratories (transitioning to defense-wide laboratories in the longer term) focusing on platform technologies; 2) develop manufacturing partnerships that solidify DoD's position in the global vaccine supply and distribution chain; and 3) integrate

biotechnology-driven rapid vaccine response capability into the military's core strategic guidance and contingency planning.

In addition, the lessons learned on testing and therapeutics should be applied in the future to ensure our federal and state emergency response systems and hospitals are equipped for the next pandemic. Federal agencies should review pandemic preparedness, and update policies and procedures to ensure a more rapid response to the next pandemic. Furthermore, in a vaccine development and production system short on sustained financial incentives, the USG and the DoD should consider spending "war fighting" levels of money on this vaccine race.

As demonstrated in other countries who had initial success containing COVID-19, testing was a key component of their strategy. From a preparedness standpoint, the Centers for Disease Control and Prevention (CDC) and FDA must have policies and procedures in place to quickly produce, validate, and approve diagnostic tests through a streamlined process. The test validation and approval process must be clear to federal agencies, state labs, and industry.

The USG should consider using internationally approved tests until specific US tests are made. The US chose not to use the WHO coronavirus test because of accuracy concerns. However, using this test would have bridged the gap until US testing was fully operational. The delay in a US-approved test has proven fatal. The CDC can lead diagnostic test development, but they must leverage commercial production capabilities quickly.

Testing protocols are also key and must be reviewed and updated. The initial COVID-19 protocol focused solely on persons who traveled to China or were in close contact with someone who had relevant symptoms. However, this protocol missed many others who may have been contagious and in fact helped spread the virus.

The US response to COVID-19 has highlighted the importance of investing in basic science research. The ability to quickly evaluate existing therapeutics and develop new ones is built on prior US R&D on coronaviruses and infectious diseases. This investment has paid dividends in the ability to quickly spin up clinical trials leveraging existing antiviral treatments for SARS, Middle East Respiratory Syndrome MERS, Malaria, and Ebola. The federal infrastructure, talent, and work by the National Institute of Health (NIH), FDA, and DoD must be cultivated and funded in the future to ensure a robust capability to respond in the event of another pandemic.

COVID-19 has also highlighted the value of the academic, industry, and government (i.e., the "triple helix") construct to foster conditions of innovation and entrepreneurship. The federal government's partnership and investment with industry and academia must continue to grow, ensuring future innovation and preparedness for the next pandemic. University-level science and technology programs should also be expanded, with federal and state scholarships for students pursuing degrees in these areas.

In addition, it is and will continue to be, industry, not the DoD, that leads the fight to produce COVID-19 testing, therapeutics, and vaccines. Still, the DoD must find ways to integrate, shape, and incentivize the biotechnology industry to deliver platform technologies that benefit the national defense. Building partnerships at every level of the therapeutics and vaccine development and production pipeline is an urgent necessity that will position the DoD for success in this emerging landscape.

CONCLUSION

As the US and the world races to find a vaccine for COVID-19 biotechnology will lead the charge. It will not be without challenges however, and the US needs to ensure policy is in place to guide the country and the world. The US needs to strengthen R&D capacity to produce new knowledge, ideas, and foundational technologies required to develop products and services that support the biotechnology industry. While this may not have an immediate affect in the battle against COVID-19, it will ensure the US is better prepared for any future pandemics. In addition, the US must strategically collaborate with international allies to ensure US remains a leader and, along with its partners, must create policies regarding the military application of biotechnology, to include the ethics surrounding the industry. With regards to preparation for future pandemics, this must be prioritized within the NSS and then appropriately funded by Congress and state and local governments. Finally, the US must continue to invest in the triple helix construct to foster conditions of innovation and entrepreneurship.

Biotechnology is a fascinating and fast-changing industry that has the potential to change the world, either by eradicating diseases, or by pushing forward with genetically modified humans. Biotechnology has the potential to solve the most complex challenges facing life on earth including health, environmental, industrial and food production, fuels, and materials. The US needs to ensure they are at the front of the line to help shape how the world progresses and what the resultant world looks like.

Appendix

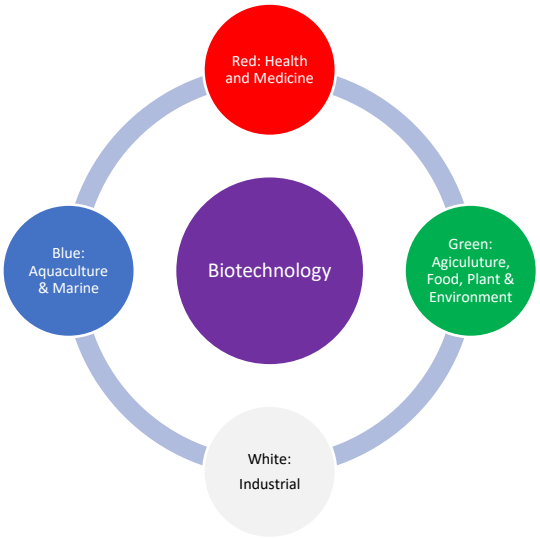

Figure 1: Colors of Biotechnology

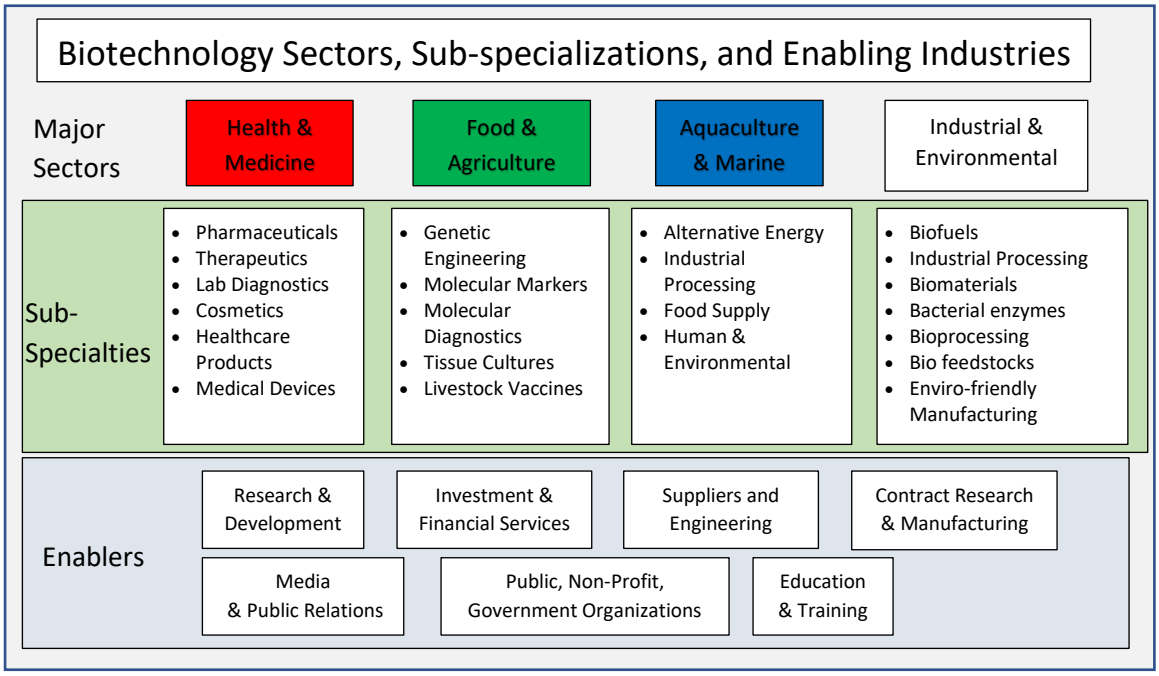

Figure 2: Biotechnology Industry Overview

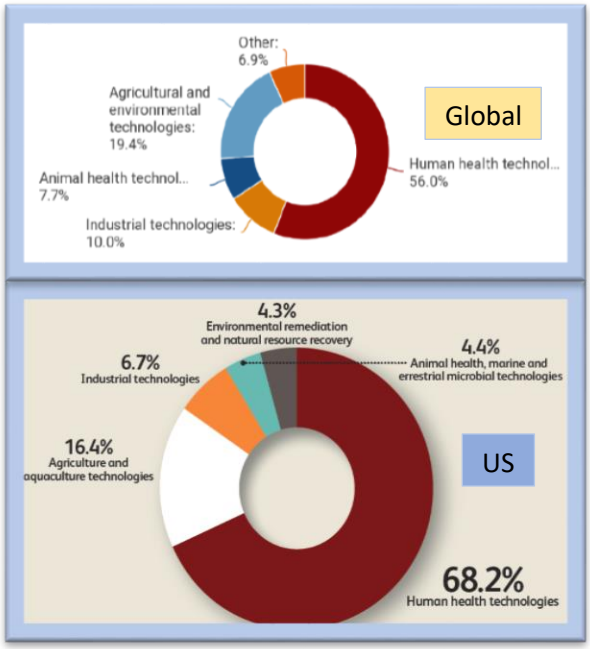

Figure 3: Global & US Market Segmentation

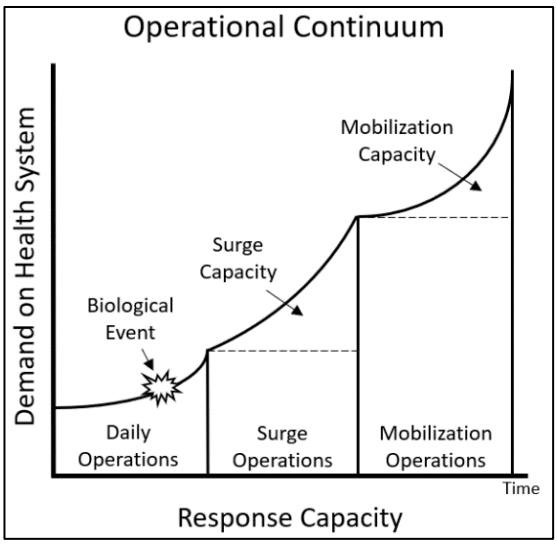

Figure 4: Continuum of Operations from Daily to Surge to Mobilization

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