

Members of the 2013 ASU iGEM Team recently had the privilege to enroll in a second-year law course at ASU's Sandra Day O' Connor School of Law through the Barrett Honors college Project Excellence program. Three undergraduate students attending Arizona State University were permitted to enroll in Dr. Gary Marchant's "LAW691: Biotechnology: Law, Science, and Policy" course, in which the legal, ethical, and societal implications of biotechnology were discussed in great deal with a strong focus on policy. Based on education from the course, members of ASU iGEM evaluated various safety and security points in both synthetic biology and the biotechnology movement as a whole.

### **Introduction:**

The rise of synthetic biology in universities also signals the advent of DIY Biology and with it, plausible security risks. The 2013 ASU iGEM Team took into account current trends in synthetic biology movements worldwide to evaluate the feasibility and likelihood of bioterrorism in the modern age of biotechnology.

### **The relationship between Synthetic Biology, DIY Bio, and Bioterrorism**

The Do-it-yourself biology movement was first publicized in 2005 from an article written by Rob Carlson, a scientist at the University of Washington, in *Wired Magazine*, telling readers to “take a moment to buy yourself a molecular biology lab on eBay.”<sup>1</sup> With the cost of equipping a small lab under \$5,000 and the continuously decreasing cost of gene synthesis and sequencing, it has become possible for ordinary people to take research formerly confined to well-funded university laboratories and begin doing the same work out of their kitchen, garage, or basement. Cheap materials have been assembled together to mock the function of expensive lab equipment,

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<sup>1</sup> Carlson, Rob. "Splice It Yourself." *Wired.com*. Conde Nast Digital, May 2005. Web. [http://www.wired.com/wired/archive/13.05/view.html?pg=2?tw=wn\\_tophead\\_5](http://www.wired.com/wired/archive/13.05/view.html?pg=2?tw=wn_tophead_5).

such as centrifuge machines and thermal cyclers, to make DIY biology a reality for anyone with a small space and the will to get started.

In the past, access to molecular biology based bioterrorism was limited due to sophisticated barriers of entry such as education, resources, and regulations<sup>2</sup>. Previous threats of biological weapons stemmed from research at the state level, where governments advocated the development of genetically engineered bioweapons. This threat was noted during the Cold War in particular, where the Soviet Union aggressively pursued development of bioweapons throughout the 70's and 80's.<sup>3</sup> However, while large scale bioengineering and weaponization required superpower backing in the past, new technologies have made genetic engineering more readily accessible.

#### *Barrier 1: Access to education*

The development of the Internet and its respective technologies have made scientific knowledge readily available to the public sphere. This is especially true for molecular biology, where the rise of open source information has made molecular biology knowledge and laboratory techniques accessible to all individuals.<sup>4</sup> This comes as a double edged sword. On one hand, open sourced information allows for researchers and other innovators to advance development of their work. Likewise, since open sourced information is accessible to everyone, it may also be used by those who intend on developing bioweapons.<sup>5</sup> This growth in both the official and

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<sup>2</sup> Kelle, Alexander. "Ensuring the Security of Synthetic Biology—towards a 5P Governance Strategy." *Systems and Synthetic Biology* 3.1-4 (2009): 85-90. Print.

<sup>3</sup> Hart J (2006) The Soviet biological weapons program. In: Wheelis M, Rozsa L, Dando M (eds) *Deadly cultures*. pp 132–156.

<sup>4</sup> Wolinsky, Howard. "Kitchen Biology. The Rise of Do-it-yourself Biology Democratizes Science, but Is It Dangerous to Public Health and the Environment?" *EMBO Reports* 10.7 (2009): 683-85.

<sup>5</sup> Kely, Christopher M. "Outlaw, Hackers, Victorian Amateurs: Diagnosing Public Participation in the Life Sciences Today." *Journal of Science Communication* 9.1 (2010): n. pag. *Jcom.sissa.it*. SISSA - International School for Advanced Studies. Web.

unofficial research population creates problems with regulations. Molecular biology research is no longer limited to universities or large corporations which can be easily identified and screened as a smaller pool of groups. The rise of “independent” synthetic biologists make regulations much more difficult to enforce because the state may not be aware of the participant, nevertheless the research associated with that individual.

Proponents of synthetic biology regulation may also cite the BioBricks Foundation and the iGEM Competition as sources of dangerous biomaterials. The BioBricks Foundation is a non-profit organization committed towards establishing a centralized databank of standardized and characterized biological parts<sup>6</sup>. This organization works closely with the iGEM Competition, where undergraduate students of various universities throughout the world design and create their own synthetic biological devices. iGEM is of particular interest because it requires the students publish all laboratory work and research to be readily available to the public. While some projects range from harmless cell circuitry, others may include the materials and methods for production of military grade spider silk<sup>7</sup>. This raises concerns as the DNA sequences and testing data are open to the public and could spur weapon development through synthetic biology. For applications such as spider silk, terrorists could illegally reconstruct the biological device to produce spider silk for weapons and equipment. This means that even if synthetic biology is not the direct producer of the bioweapon, it could be a means to developing and improving alternative terror weapons and equipment.

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<sup>6</sup> BioBricks Foundation. "About." *BioBricks Foundation About Comments*. N.p., n.d. Web. 09 May 2013.

<sup>7</sup> Utah State. "Team:Utah State/Project." *Main Page*. iGEM, n.d. Web. 09 May 2013.

### *Access to resources*

Technology advancements are typically characterized through cheaper, more effective hardware. The same is true for molecular and synthetic biology devices. Whereas in the past, a Polymerase Chain Reaction (PCR) Thermocycler would cost thousands of dollars, used PCR machines are now available for as low as \$59.<sup>8</sup> Decreasing costs result in an increased means of synthetic biology production, which in turn, results in higher risk assessment of misuse and bioterror. Combined with the aforementioned open source information on genetic engineering and parts, individuals now have the opportunity to conduct their own research. This increases room for both bioterrorism and liabilities, as individuals are now constructing potentially hazardous organisms without any oversight or preventative regulations.

Advancement in technology have also given rise to cheaper DNA synthesis techniques. Whereas in the past DNA synthesis required a postdoc-level of education, many of the synthesis processes are now automated, greatly decreasing cost and accessibility.<sup>9</sup> DNA synthesis is often used for producing designed primers. Primers are DNA sequences that bind to complementary strands of DNA and stimulate replication. In the context of synthetic biology, primers have numerous functions including mass replication of DNA, formation of new biological systems, and even mutations.<sup>10</sup> The decreasing barriers towards DNA sequencing appear to also have contributed to an increasing risk of bioterrorism. However, the production of primers is currently limited to large companies, and their accessibility for bioterror use will be discussed later.

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<sup>8</sup> Alper, Joe. "Biotech in the Basement." *Nature Biotechnology* 27.12 (2009): 1077-078.

<sup>9</sup> Carlson R (2003) The Pace and Proliferation of Biological Technologies. Biosecurity and Bioterrorism. *Biodefense Strategy Pract Sci* 1(3):1–12

<sup>10</sup> University of Michigan. "Design of Primers for Automated Sequencing." *Design of Primers for Automated Sequencing*. N.p., n.d. Web. 09 May 2013.

## *Limits of regulations*

DIY Biology and open source synthetic biology projects have made regulations much more difficult to enforce and far too dependent on intrinsic integrity. Despite the majority of hackers maintaining an informal, unspoken, and universal code of ethics<sup>11</sup> dedicated towards the safety of the general population, the past rise of computer viruses warranted that not all hackers act in the best interest of society.<sup>12</sup> Furthermore, there are no jurisdictional constraints on bioterrorist activity. Bioterrorists, beyond preserving themselves, would not follow legal or safety obligations designed to contain research disasters and concerns. This creates difficulty in limiting terrorist activity and requires preventive measures on a greater individual, yet nonintrusive scale. Rather than inefficiently attempting to regulate individuals, an effective counter-terror measure could attempt to limit opportunities for bioterrorists to acquire dangerous genetic constructs and key resources.

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<sup>11</sup> Massachusetts Institute of Technology. "The "Hacker Ethic"" *IHTFP Hack Gallery*:. N.p., n.d. Web. 09 May 2013.

<sup>12</sup> Schmidt, Markus. "Diffusion of Synthetic Biology: A Challenge to Biosafety." *System Synthetic Biology* (2008): n. pag.

## The Actual Risk of Bioterrorism

While the tremendous growth of the synthetic biology movement have given rise to speculative concerns, the actual risk of synthetic bioterrorism in the modern age must also be evaluated. Historically, only two biological attacks have successfully occurred in the United States. The first event occurred in late 1984, when a religious cult contaminated salad bars with *Salmonella*, causing about 750 cases of illnesses. The second event occurred in 2001, where various individuals in prominent government and media positions were targeted with anthrax laced mail, resulting in about five deaths.<sup>13</sup> It is worth noting that the aforementioned bioterror attacks that utilized bacteria commonly found as pathogens. There were no extensive alterations or insertions of cellular machinery that is characteristic of synthetic biology.<sup>14</sup> While the absence of alterations may be due to the limited genetic engineering knowledge of the past, the nature of engineering a bioweapon appears to act as a strong disincentive for terrorists compared to alternative disruptive agents.

### *Disincentive 1: The Nature of Infectious Diseases*

The nature of infectious pathogens is a strong disincentive for terrorist groups. Most biotechnology research regarding viruses uses either a cross-species incompatible virus—such as a plant virus—or very extensive biosafety equipment and space. This is due to the infectious nature of mammalian cell viruses, which have just as high a likelihood of exposure to the researchers as it is to the target of interest. Viruses of magnitude for a significant bioterror attack equivalent to 9/11 would be of BioSafety Level (BSL) 3 or 4, which requires a quarantined and

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<sup>13</sup>King, Nicholas B. "The Ethics Of Biodefense." *Bioethics* 19.4 (2005): 432-46.

<sup>14</sup>Danzig, Richard, Marc Sageman, Terrance Leighton, Lloyd Hough, Hidemi Yuki, Rui Kotani, and Zachary M. Hosford. "Aum Shinrikyo: Insights into How Terrorists Develop Biological and Chemical Weapons." *Center for New American Security* (2011): n. pag.

incredibly sterile lab space to prohibit exposure to the pathogen in question.<sup>15</sup> The pathogen then requires careful maintenance and handling throughout the entire process. One misstep during development, such as accidental inhalation of a single virus particle, could backfire and result in massive infections for the operators.

Beyond the dual-threat nature of a pathogenic virus, there must also be an effective delivery vector. Most biological organisms cannot survive varying conditions such as temperature and pressure. In fact, most organisms cannot handle temperature changes ranging by a few degrees.<sup>16</sup> This means that terrorist groups must either further engineer various thermophilic and barophilic properties into their virus to improve hardiness (which is time consuming, costly, and in many cases unsuccessful) or be very selective about their target site's geographical properties. Once that has been established, the illicit researchers must then find the most suitable vector for delivering the pathogenic virus into the population.

Vectors are of great importance towards bioterrorist groups because the pathogen must be hardy enough to withstand common elements yet delivered in a manner that will release the synthetic device effectively. One possible method is through the use of spores, which were used in the 2001 anthrax attacks. Spores are biological byproducts of certain stressed strains of bacteria. They are resilient to tougher environments and can be easily transported by public means such as mail. However, since 2001 screening technology has also improved. Cheaper spectroscopy techniques, such as Raman spectroscopy, can detect the presence of spores in mail

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<sup>15</sup> Center for Disease Control. "Criteria for Biosafety Levels 3 and 4." *Cdc.gov*. N.p., n.d. Web.

<sup>16</sup> Lopez-Caballero, M.E., J. Carballo, and R. Jimenez-Colmenero. "Microbial Inactivation in Meat Products by Pressure/Temperature Processing." *Journal of Food Science* 67.2 (2002): 797-801. Print.

without affecting the integrity of the package.<sup>17</sup> Improvements in counterbioterror measures means that terrorists must now consider more complex means of applying and activating bioterror weapons, which increases the possibility of error.

### *Disincentive 2: Opportunity Cost of Alternative Agents*

The narrative of bioterrorism's opportunity cost could be best summarized by the decision making surrounding the sarin gas attacks in Japan. In 1995, the Japanese cult Aum Shinrikyo conducted an act of terror on the Tokyo subway system releasing canisters of the nerve agent sarin. The attack killed thirteen people and was considered the most serious attack to occur in Japan since World War II.<sup>18</sup> While the damage inflicted by Aum Shinrikyo was considerable, sarin was not the original weapon of choice.<sup>19</sup> Leading up to the subway attack, the initial terror weapon of choice was actually reported to be a biological weapon, with which the group performed considerable tests but abandoned after trials yielded no significant injuries or deaths.<sup>20</sup>

What the Aum Shinrikyo bioweapons attempts demonstrated was a case study of terrorist decision-making. The opportunity cost of a developing a bioterror device—nevertheless a synthetic one—is minimal compared to chemical agents or explosives. While in theory, a bioterror device would be optimal due to its hypothetically uncontrolled rate of spread, panic,

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<sup>17</sup> Farquharson, Stuart, Lawrence Grigely, Victor Khitrov, Wayne Smith, Jay F. Sperry, and Gerard Fenerty. "Detecting Bacillus Cereus Spores on a Mail Sorting System Using Raman Spectroscopy." *Journal of Raman Spectroscopy* 35.1 (2004): 82-86. Print.

<sup>18</sup> Danzig, Richard, Marc Sageman, Terrance Leighton, Lloyd Hough, Hidemi Yuki, Rui Kotani, and Zachary M. Hosford. "Aum Shinrikyo: Insights into How Terrorists Develop Biological and Chemical Weapons." *Center for New American Security* (2011): n. pag.

<sup>19</sup> King, Nicholas B. "The Ethics Of Biodefense." *Bioethics* 19.4 (2005): 432-46.

<sup>20</sup> J.B. Tucker. 2000. *Toxic Terror: Assessing Terrorist Use of Chemical and Biological Weapons*. Cambridge. MIT Press.

and deadliness, it requires significant capital and labor to succeed.<sup>21</sup> Bioterror research would first require lab supplies and lab spaces, two necessities that could cost millions of dollars. Bioterrorists would then have to run countless recombinant DNA trials to produce their ideal construct. Synthetic bioterror would be particularly time consuming because it requires the recombination of several gene sequences, as opposed to simple insertion of a new gene. Beyond finances, ordering parts and kits to act upon various research procedures would also require these terrorist cells to surrender their location or be dependent on an externally regulated resource, which would not make sense for illicit activity. In large scale attacks, chemical or incendiary devices appear to be more effective for purposes of both time and money. This is a unique quality of synthetic biology that offers some mitigation of bioterrorism: the production of the device outweighs the intended destructive purpose.

### **Evaluations of Current Practices in Research, Governing Structure, and Business**

Current practices employed by synthetic biology researchers and businesses are designed to minimize risks while optimizing benefits. Whether or not these practices are effective is a different story. The evaluations research protocols, governing structure, and businesses, indicate that while current practices are somewhat effective, there are still some flaws that could be remedied.

#### *Research, Self-Governance, and Regulation*

Current research follows a two-step governance style: self-regulation and organizational regulation. Before admittance into any research programs or beginning labwork, individuals are

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<sup>21</sup> Zilinskas R. Technical Barriers to Successful Biological Attacks with Synthetic Organisms, Security and Regulation of Experiments of Concern. 2006.

often put through detailed safety and ethics training.<sup>22</sup> This training encourages individuals to understand the implications of working with genetic information and its accompanying responsibilities. Research institutes will often enforce the training through yearly inspections and training renewal. This helps limit and detect any growing security and safety concerns.

Unfortunately, these protocols are often difficult to enforce without proactive accountability measures, and in some cases, researchers may produce dangerous work on their own behalf. For example, recent controversy regarding the publication of the lethal H5N1—and how it could be made easier to spread—generated a huge outcry from both academics and the public, who argued that the nature of such a publication only supplements individuals with dangerous agendas.<sup>23</sup> Despite the uproar, the investigators argued that releasing this information to the public help characterize the nature of the disease and inspire greater developments towards vaccine development. This instance demonstrates how in some cases self-regulation and organizational regulation may be ineffective at preventing the release of potentially dangerous information. In the event that the accountable researcher (the principal investigator) finds that there are no qualms with the research at hand, both a glaring lack of oversight and weakness in local regulations are exposed.

Another point of interest in the synthetic biology movement is the development of various “bio-chassis”. Bio-chassis are modified biological platforms that researchers can use to produce their work in a reliable yet contained manner. These safety platforms could address growing security concerns and offer a solution in reducing both accidental and bioterror risks greatly. There are two such examples that have stemmed from the iGEM competition. The first is

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<sup>22</sup> Division of Occupational Health and Safety. "Training Requirements & Available Courses." *NIH Laboratory Safety Training Courses*. National Institute of Health, n.d. Web. 09 May 2013.

<sup>23</sup> McNeil, Donald G., Jr. "Bird Flu Paper Is Published After Debate." *New York Times*, 21 June 2012. Web.

a cumate sensitive chassis that deactivates and is destroyed when exposed to cumin<sup>24</sup> and the second is a safety platform developed by Paris-Bettencourt that has four different fail-safes that can hypothetically self-deactivate when primary fail-safes are unable to function.<sup>25</sup>

The two chassis offer insight into a new strategy of mitigating biosecurity risk by limiting personalized synthetic biology to publically available platforms. If all synthetic biology parts were required to be constructed on these chassis, then the government could better enforce regulation on an academic scale that requires tests of different host cells while individuals could safely create their own systems. Proponents would argue that by allowing for genes of interest to be properly introduced while offering a readily available failsafe activator, accidental risks or bioterror attacks can be quickly thwarted. The cumate chassis offers a proof-of-concept that demonstrates how even every day spices could be utilized as a failsafe activator, meaning that in the event of an attack, an ordinary diet could already warrant coverage and safety measures, greatly reducing public concerns and demand for emergency vaccines.

Opponents to standardized bio-chassis would argue that limiting synthetic biology has two concerns: the chassis cannot account for mutagenesis and restrictive measures against synthetic biology research stifles growth and harms innovation. In addressing mutagenesis, researchers require either primers, large machinery, or a consistent source of radioactive exposure in order to introduce mutations into the chassis.<sup>26</sup> These mutations must then allow for the chassis to still replicate and function by some means.

The aforementioned chassis designed by Paris-Bettencourt offers a potential answer to both mutagenesis and innovation concerns. The chassis utilizes a multilevel failsafe design that

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<sup>24</sup> Trieste University. "Team:Trieste." *Main Page*. IGEM, n.d. Web. 08 May 2013.

<sup>25</sup> University of Paris-Bettencourt. "Team:Paris Bettencourt." *Main Page*. IGEM, n.d. Web. 08 May 2013.

<sup>26</sup> Perbal, B. "A Practical Guide to Molecular Cloning." *Gene* 52.1 (1987): 114. Print.

accounts for errors in the plasmid's functionality. This means that in the event some preliminary stage of the device is mutated and deactivated, a different failsafe activates that will initiate the shut down response. The chassis' individual regulation and safety measures demonstrate how synthetic biology can be self-regulating on a molecular scale. In terms of limiting innovation, while there are certainly different organisms of interest, the Paris-Bettencourt chassis is a plasmid that can be readily incorporated into competent cells. Furthermore, the chassis has been proven to be modular, indicating that insertion of new genes and cellular functions is still possible, meaning a novel synthetic device can still be constructed on it.<sup>27</sup> While the product is not complete by any means, the device offers insight into a potential solution for the synthetic biology community to account for both bioterror and accidental risks.

### *Business Protocols and Barriers*

Current synthetic and molecular biology business practices in place operate on two levels: the client and the product. On the client level, for individuals interested in large and rapid mutagenesis machinery such as Multiplex Automated Genetic Engineering (MAGE) and biolistic gene guns, some businesses will screen individuals in advance regarding their intended research goals, qualifications, and past history to reduce the likelihood of an individual exploiting the technology to create dangerous biological devices, much like a gun permit. This allows for some form of regulation on a hardware level. Unfortunately, these protocols are not very thorough as no concrete agreements are in place amongst genetics companies regarding the distribution of hardware. This means that synthetic biology insurgents, with sufficient capital, could acquire these machines. Likewise, in the event that an individual is a potential domestic terrorist with no

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<sup>27</sup> University of Paris-Bettencourt. "Team:Paris Bettencourt." *Main Page*. IGEM, n.d. Web. 08 May 2013.

previous legal infractions, these measures would be ineffective as there would be no basis for rejection of his or her receipt.

The majority of gene synthesis businesses also mitigate the risk of synthetic bioterrorism through screening of designed primers.<sup>28</sup> As mentioned earlier, primers are valuable to any molecular biology research because they are essential for replicating, sequencing, and even mutating genetic information. Upon ordering a desired primer sequence from a company, the business will screen the sequence for homology with dangerous, characterized pathogens.<sup>29</sup> In the event that a suspicious sequence is noted, the companies will relay information to governing boards and reject the synthesis order. This practice is particularly effective because it prevents any suspicious preliminary research from continuing without federal clearance and investigation. These measures are particularly effective in resolving concerns arisen by the open source movement. Despite potentially dangerous sequences being publically available, primer screening prevents individuals from acquiring the resources needed to generate and further develop a bioweapon. Unfortunately, like the hardware regulations, there are still some gene synthesis companies that do not enforce adequate screening measures and present a potential threat that can be easily resolved. This contention will be discussed later in greater detail.

In a counterintuitive sense, another corporate bioterror barrier is the patent. As synthetic biology requires a vast databank of standardized and publically available biological parts to thrive, the industry is constantly at a crossroads with molecular biology patents.<sup>30</sup> Patents on

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<sup>28</sup> Pauwels E, Ifrim I. Trends in American and European Press Coverage of Synthetic Biology. 2008. [http://www.synbioproject.org/library/publications/archive/why\\_scientists\\_should\\_care/](http://www.synbioproject.org/library/publications/archive/why_scientists_should_care/) 31 March, 2010.

<sup>29</sup> International Gene Synthesis Consortium. "Harmonized Screening Protocol." *Genesynthesisconsortium.org*. IGSC, n.d. Web.

<sup>30</sup> "Why Are Gene Patents Controversial?" *The Economist*. The Economist Newspaper, 18 Apr. 2013. Web. 09 May 2013.

genes mean their respective sequences are private knowledge. For example, if an individual desired to mutate a popular therapeutic virus into a potentially dangerous one, there would be no effective means of acquiring the sequence accurately. It is possible that terrorist groups may consider sequencing the DNA of the virus themselves, but preexisting screening barriers and inadequate facilities would then discourage this course of action. In an ironic way, many of the obstacles that plague current synthetic biology research are also obstacles that bioterrorist must overcome numerous times to successfully create a weapon.

## **Future directions:**

After examining the rise of the synthetic bioterror fear, the possibility of attack, and current countermeasures in place, it is also important to evaluate areas to improve and future directions to take. The following points are priority areas of interest that would have an immediate impact in diminishing synthetic bioterror risks and opportunities.

### *Area 1: Uniform standards on business and international levels*

In the synthetic biology conferences SB2 and SB3, potential precautionary measures were advocated for gene synthesis companies. The first measure was to have a uniform policy on screening of primers, as described in the current business practices segment. A study found that during the process of completing orders, a minority of gene synthesis companies did not test for potential pathogens.<sup>31</sup> This is alarming because in the off chance that a gene synthesis company does not detect a pathogen primer, a dangerous new bioweapon can be created. Gene synthesis companies adopting a universal standard of screening would ensure that on some surface level, illegal primers are unpermitted.

In the event that gene synthesis machinery becomes cheap enough for personal use, these devices could be limited in distribution following a licensing and registration procedure. While some businesses have already adopted this policy, many others have yet to form an agreement on how machinery should be sold. A protocol that investigates researcher credibility would greatly improve the effectiveness of regulation and reduce room for abuse, as culprits could be identified easily in a smaller pool of candidates. These barriers, while simple, would help prevent terrorist groups from obtaining dangerous genetic constructs.

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<sup>31</sup> Maurer SM, Lucas KV, Terrell S. From Understanding to Action: Community-Based Options for Improving Safety and Security in Synthetic Biology. 2006. <http://gspp.berkeley.edu/iths/UC%20White%20Paper.pdf> 31 March, 2010.

Another necessary universal standard includes international agreements on synthetic biology regulation. There are currently no international standards in place in regard to synthetic biology research and development. In the interest of mitigating bioterrorism, there must be some form of policy that allows for global enforcement. While social, cultural, and perhaps even political differences often create complications in reaching unilateral agreements, a uniform international agreement prevents from potential terror threats from relocating to deregulated countries and operating. Encouraging a spirit of compromise and urgency could facilitate reaching an agreement on how bioterrorism—nevertheless synthetic bioterrorism—could be prevented, detected, and punished globally.

A more localized example of possessing uniform regulations would be through institutionalization of DIYbio by establishing more community labs similar to Genspace and Biocurious. This shift will provide the best environment for fostering growth in the movement while providing the proper education for biosafety procedures and new regulations to be followed accordingly by new amateur scientists<sup>32</sup>. Amateurs will also be more likely to work in a lab space with up-to-date equipment, supplies, and experts willing to answer questions over working in their own households. Moving citizen scientists away from their homes also makes it easier to centralize DIYbio labs to certain hubs, providing institutions analogous to university research centers for promoting the exchange of ideas and innovation.

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<sup>32</sup> Holloway, Dustin T. "The Scientist." *The Scientist*. The Scientist Magazine, 1 Mar. 2013. Web. <http://www.the-scientist.com/?articles.view/articleNo/34444/title/Regulating-Amateurs/>.

### *Area 2: Effective categorization of construct risks and movement*

A common characteristic of molecular biology in academia is the exchange of genetic parts. This is undoubtedly true in synthetic biology as the nature of the industry requires testing of various genes to create an optimally engineering biological device. Unfortunately, the transfer of these biological constructs is not effectively recorded.

While it is inefficient to record and regulate the movement of every gene construct, it may help to instead prioritize different parts by categorizing them on different safety levels. If a particular part is of low risk, then there is no essential need for regulation. However, if a part is labeled to be dangerous, then monitoring its movement would be an effective way to reduce the possibility of acquisition by bioterrorists. This would also provide a geographical lead in the event that a potentially dangerous construct goes missing.

This initiative relies particularly on the community as it requires active participation from various synthetic biology organizations and members. Community participation is important in maintaining uniform policy as a majority of the enforcement will stem from responsible individuals committed towards utilizing synthetic biology as a force for good. If the synthetic biology community is committed towards good research practices, then many risks and concerns are lowered through social engagement.

### *Area 3: Increase overall education and awareness*

As always, increased education is the most effective method for reducing both bioterrorism threats and accidents from occurring. The majority of media coverage thus far has

associated synthetic biology with bioterrorism.<sup>33</sup> This raises alarming concerns because the more detrimental the word associations, the greater resistance the population will have towards accepting the technology. Like the biotechnology industry today, growing concerns with the synthetic biology industry may result in increased regulations, which may stifle growth and innovation.<sup>34</sup> Changing the way that synthetic biology is presented and shared in the public sphere will go a long way towards fostering support and producing a market for the growing industry.

Education also encourages the public to be involved in the decision-making process. Engaging synthetic biologists directly would encourage consumers to make their own requests and understand the precautions that can be taken to prevent contamination and accidents. Education will also develop entrepreneurship and innovation in synthetic biology, as more individuals become engaged in the process of researching and developing their own biological devices. Regardless of whether or not certain products succeed, the synthetic biology industry would greatly benefit from more contributors towards the standardized parts registry.

The public has been exposed an over-dramatization of synthetic biology with the media throwing around phrases such as “extreme genetic engineering” and “playing God”. Already 111 organizations have called for a moratorium of lab-confined synthetic biology research<sup>35</sup>, which makes the prospect of similar research being conducted in a household even more unsettling. The nickname “biohacker” for citizen scientists has already injected a negative connotation into the

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<sup>33</sup> Pauwels E, Ifrim I. Trends in American and European Press Coverage of Synthetic Biology. 2008. [http://www.synbioproject.org/library/publications/archive/why\\_scientists\\_should\\_care/](http://www.synbioproject.org/library/publications/archive/why_scientists_should_care/) 31 March, 2010.

<sup>34</sup> Committee on Science, Space, and Technology. "Excessive Regulation and High Taxes Stifle Innovation, Job Creation." *Welcome to Committee on Science*. N.p., 27 Mar. 2012. Web. 09 May 2013.

<sup>35</sup> Pennisi, Elizabeth. "111 Organizations Call for Synthetic Biology Moratorium." *Science*. American Association for the Advancement of Science, 13 March 2012. Web. <http://news.sciencemag.org/scienceinsider/2012/03/111-organizations-call-for-synth.html>.

DIYbio community. Efforts to persuade the public about the safety of genetic engineering has been occurring since the 1970's, but little evidence shows that this has had an effect on the public perception of synthetic biology<sup>36</sup>. However, the transparency and the open-source nature of the DIYbio movement will allow scientists and citizens alike to see and understand what really is going on in the synthetic biology community. Given its ever-increasing presence in areas such as healthcare, it's important for everyone to understand that "it's not magic, it's biochemistry".<sup>23</sup>

## Conclusions

Synthetic biology is ultimately a new frontier of molecular biology and biotechnology that has tremendous potential. From creating light activated insulin producers to even self-attacking cancer cells, the engineering of microbes creates an uncertain yet fascinating sense of progress. As the industry continues to flourish, researchers and policy makers must become increasingly wary of the risk of bioterrorism, as the same barriers that are lowering for curious individuals are also lowering for hostile groups. Thankfully, in evaluating current practices and the opportunity costs of terrorist groups, there are currently strong disincentives for synthetic bioterrorism, ranging from logistical to research woes. For the time being, it would seem as though the risk of a synthetic bioterror attack is greatly diminished.

If science and technology creates a double-edged sword, then for as many problems that arise, there will be solutions. As more and more individuals become familiar with synthetic biology and construction of its devices, there may be a proliferation of homegrown innovation and individuals who understand the technology greater than anyone, much like Bill Gates and

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<sup>36</sup> Hart Research Associates. "Awareness & Impressions Of Synthetic Biology." *Synbioproject.org*. The Woodrow Wilson International Center For Scholars, 9 Sept. 2010. Web. [http://www.synbioproject.org/process/assets/files/6456/hart\\_revised\\_.pdf?](http://www.synbioproject.org/process/assets/files/6456/hart_revised_.pdf?)

Steve Jobs were for the personalized computer movement. Socially conscious and progressive individuals who aspire to be entrepreneurs and problem solvers represent a new and optimistic perspective of synthetic biology's growth and success. In the event that a synthetic bioterror attack is successful, these same individuals will help bolster a database of new vaccines, therapeutics, and containment.

Synthetic biology does not promise panaceas or comprehensive solutions for all of the world's problems. However, as the threat of bioterrorism becomes increasingly prevalent with individualized research laboratories and spaces, synthetic biology is a cure of itself. The common motif of technology is the same for all branches of innovation: the same sources that represent the potential for problems represent the potential for solutions.