U.S. TRENDS IN SYNTHETIC BIOLOGY RESEARCH FUNDING

September 2015

Synthetic BIOLOGY PROJECT

Wilson Center

KEY FINDINGS

- Between 2008 and 2014, the United States invested approximately $820 million dollars in synthetic biology research.[1]
- Defense is a major contributor. One of the biggest changes since 2010 has been the increase in Defense Advanced Research Projects Agency (DARPA) funding, from no spending in 2010 to more than $100 million in 2014.
- There is little focus on risk research. Less than one percent of the total U.S. funding is focused on risk research and approximately one percent addresses ethical, legal, and social issues.
- When the National Science Foundation's Synthetic Biology Engineering Research Center (SYNBERC) sunsets in 2016, it is unclear whether there will be any dedicated programs for synthetic biology outside of DARPA.
- Funding in other countries is increasing rapidly. In 2014, the United Kingdom and the European Commission investments in synthetic biology exceeded non-defense spending in the United States (see Fig 8).

STATE OF RESEARCH FUNDING

Synthetic biology is rapidly becoming a global research enterprise. The Synthetic Biology Project has identified more than 565 unique entities that are conducting some type of synthetic biology work across the globe,[2] more than a 200 percent increase since 2010. The International Genetically Engineered Machines Competition[3] (iGEM) has grown from five U.S. teams in 2004 to 280 teams from six continents in 2015.[4] In addition, there are more than 100 products/applications that are on the market or close to market entry.[5] This report is an attempt to understand the investments the United States is making in synthetic biology through its research agencies. When possible, comparisons are made with the United Kingdom and the European Union to contrast the investment of various governments. There are no reliable public funding numbers available for Chinese research into synthetic biology. But based on the number of Chinese International Genetically Engineered Machine competition teams, the 254 publications produced since 2010, and the rise of the Beijing Genomics Institute (BGI), this report assumes China is investing heavily in the field.

METHODOLOGY

This research brief is an update to the Wilson Center's 2010 brief *Trends in Synthetic Biology Research Funding in the United States and Europe*[6]. The 2010 report was a preliminary assessment of the funding resources provided by governments in the United States and Europe for synthetic biology research. Five years later, this update gives a new overview of the state of publicly funded synthetic biology projects. The Federal Reporter Database[7] was used to obtain research projects from the National Science Foundation (NSF), National Aeronautics and Space Administration, En-

Disclaimer: *Based on our methodology and search criteria, this report may not incorporate all research that might be considered synthetic biology. Not all agencies use the same terminology or definitions. Some projects that would be considered synthetic biology could be missing from this analysis. Agencies are encouraged to provide more accurate data as it relates to specific programs they may be funding in synthetic biology, as well as detailed budgets for individual projects and programs that incorporate synthetic biology research.*[8]

vironmental Protection Agency, Department of Agriculture, and Department of Health and Human Services. The term "synthetic biology" had to appear in either the project title or project abstract/description to be included in this data analysis, both to provide reasonable boundaries for the search and allow comparisons to data in the prior report. Individual agency research databases and budget documents were also searched. Additional detail on individual agency search criteria is provided in the accompanying sections. The funding levels per fiscal year were calculated based on the start date listed on the grant or program. For grants from which funding levels were absent, contact with the principal investigator cited on the grant of the supervisory office was attempted. Data were also gathered in discussion with representatives from individual agencies.

U.S. FUNDING

Between 2008 and 2014, the United States invested a total of $820 million dollars[1] in synthetic biology research. The data presented in Fig. 1 shows that annual federal funding for synthetic biology is increasing rapidly – from almost negligible amounts in 2008 to more than $200 million in 2014. Since 2012 the majority of synthetic biology funding is coming from DARPA. In 2014, nearly 60 percent of all funding in the United States came from DARPA (removing other Defense Department expenditures). If other Defense Department research is included, defense spending on synthetic biology makes up 67 percent of all U.S. investments.

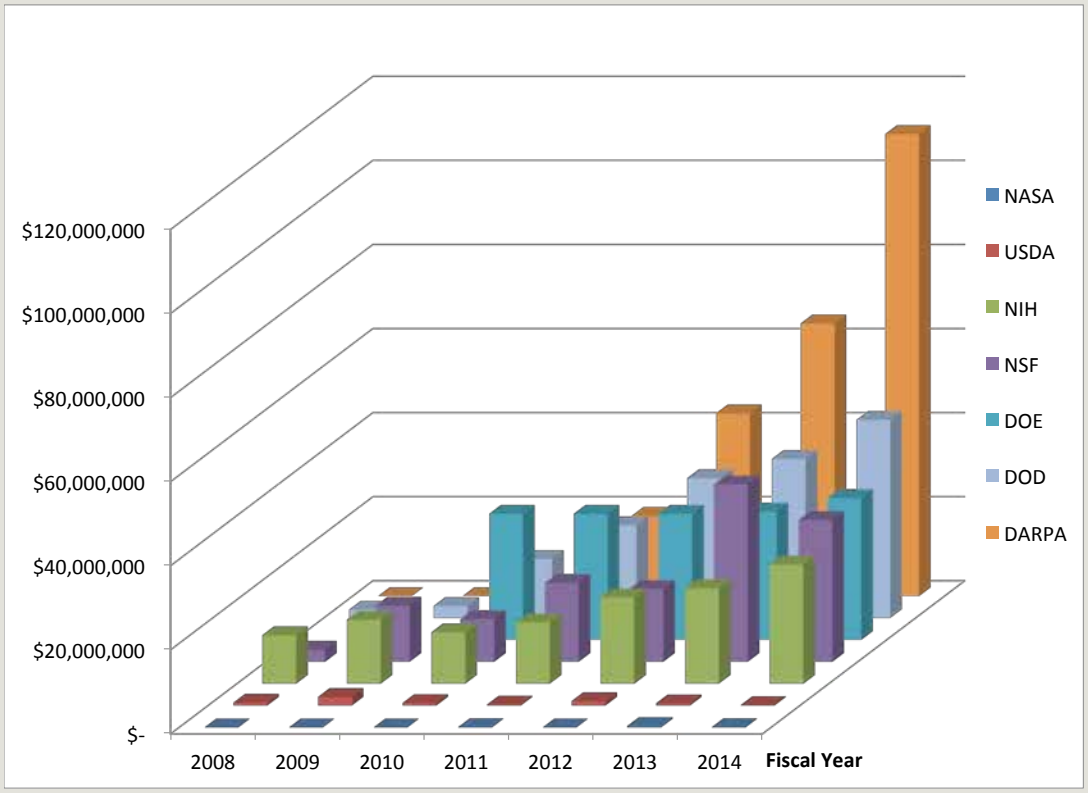

Fig. 1. Total U.S. Agency Funding by Fiscal Year

DEFENSE ADVANCED RESEARCH PROJECTS AGENCY (DARPA)

Today, DARPA is by far the most significant source of synthetic biology funding within the U.S. government, with nearly $110 million in funding for 2014. While the phrase "synthetic biology" does not show up until 2011, funding for "synthetic fuels," "synthetic cells," and "synthetic chromophores" began to appear in 2008 and continued through 2010 (see Fig. 2). A synthetic biology program began in 2011 and was incorporated into the Living Foundries program in 2013. In addition to the Living Foundries Program, synthetic biology projects are being funded through DARPA's Autonomous Diagnostics to Enable Prevention and Therapeutics (ADEPT) and Bio Design programs. In April 2014, DARPA created the Biological Technologies Office (BTO) to integrate all its biological research.[9]

Funding data for DARPA was estimated using the DARPA financial year budget estimates (www.darpa.mil/about-us/budget). Fiscal year estimates were chosen based on the data listed in the most recent budget estimate report which lists actual budgets from the previous two years. For example, for 2011 the amount was taken from what was listed in the 2013 budget estimate. Synthetic biology projects were found in these budget estimates by finding the key phrase "synthetic biology" in the title or project description.

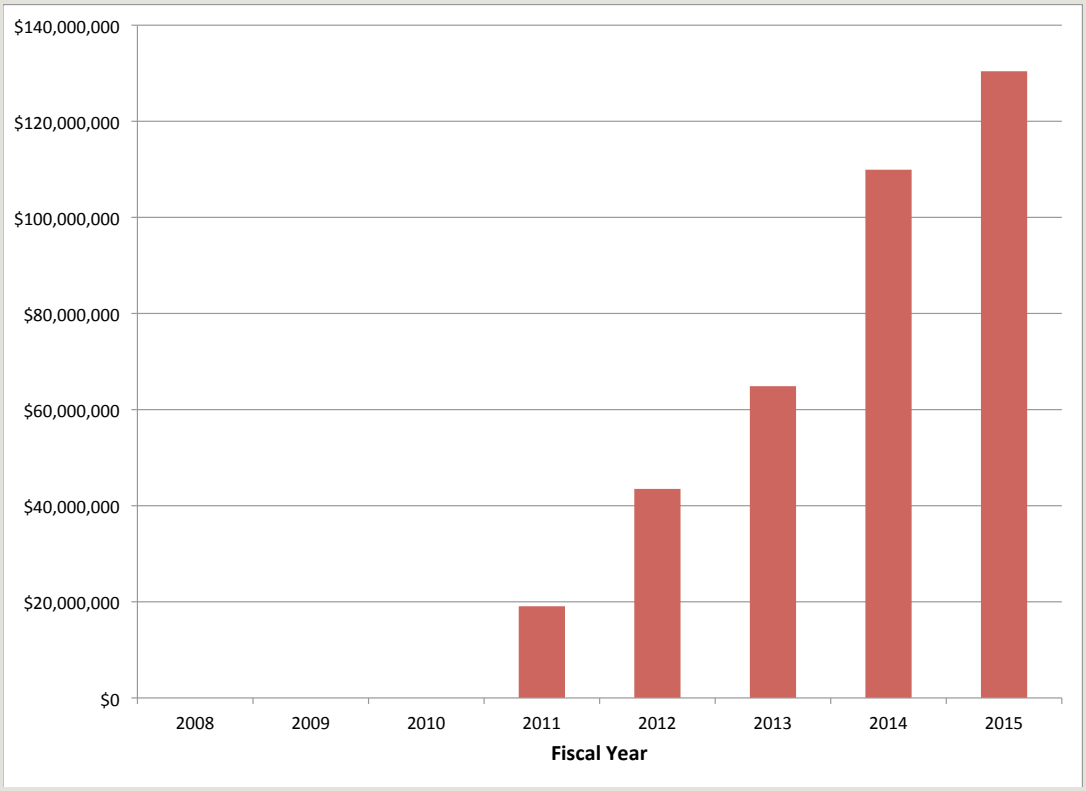

Fig. 2. Total DARPA Funding by Fiscal Year

DEPARTMENT OF DEFENSE (DOD)

Generally, award levels for DOD-funded research are classified. However, unclassified funding data was found for synthetic biology projects within five DOD programs using the RDTE/Procurement Search database.[10] DOD has significantly broadened and deepened its support for synthetic biology work, expanding from one branch of DOD prior to 2010 to five programs by 2014. Synthetic biology research has been conducted by the Army, Navy, Office of Secretary of Defense (via MIT Lincoln Labs), Chemical and Biological Defense Program, and DARPA.

Additionally, DOD confirmed support for 18 related projects in the Naval Biosciences program, but it did not provide funding amounts. Because the budgets for DOD projects are not publicly itemized, it is difficult to determine how much was allocated towards synthetic biology projects. To provide some context, the authors of this report approximated the total spending on synthetic biology-related projects to be 50 percent of the total budget listed (see Fig. 3). Therefore the DOD's non-DARPA activities should be used as a reference in terms of activity and not actual expenditures. The list of DOD projects is provided in the Appendix.

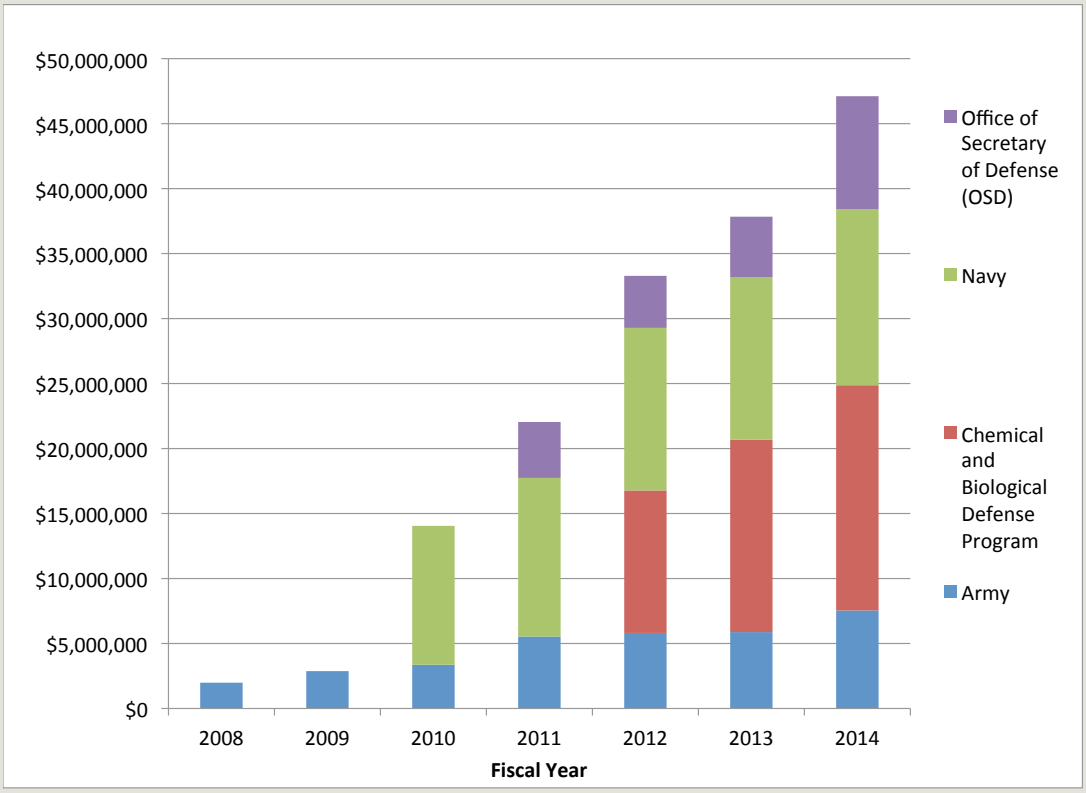

Fig. 3. Total DOD Funding by Fiscal Year

NATIONAL SCIENCE FOUNDATION (NSF)

Since 2008, NSF has invested approximately $138 million into synthetic biology-related research (see Fig. 4). NSF's engineering research center for synthetic biology, SYNBERC, is set to end in 2016 and this wind-down decreased spending from 2013 to 2014. It is unclear whether NSF will have a dedicated program centered on synthetic biology once the SYNBERC program concludes.

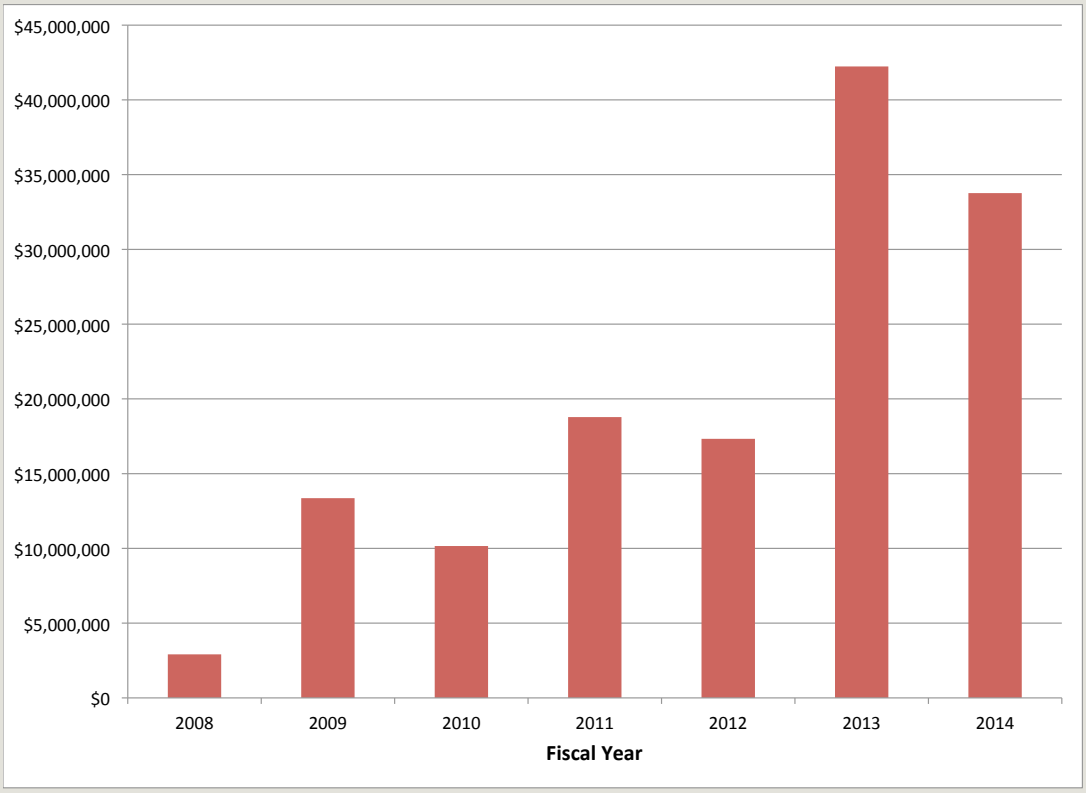

Fig. 4. Total NSF Funding by Fiscal Year

DEPARTMENT OF ENERGY (DOE)

According to a source within DOE,[11] the main activity focused on synthetic biology is the Biosystems Design program, which is part of DOE's Office of Biological and Environmental Research (BER). The Biosystems Design program budget is approximately $30 million per year. However, other activities within BER leverage the Biosystems Design program's work, including the Genomic Science program and DOE's Joint Genome Institute, a national scientific user facility that offers DNA synthesis and assembly among its capabilities. This is a significant difference compared to the 2010 report, when sources within BER suggested the entire budgets of the Genomic Sciences Program and the Joint Genome Institute could be classified as synthetic biology research, saying that it would not be "unreasonable" to consider all the work as related to synthetic biology.[12] At that time, DOE also benefited from 2009 Recovery Act investments. Four other related projects were identified within DOE's Advanced Research Projects Agency-Energy, or ARPA-E (see appendix).

DEPARTMENT OF HEALTH AND HUMAN SERVICES (HHS)

The National Institutes of Health (NIH), an agency within the Department of Health and Human Services (HHS), has awarded more than $120 million in synthetic biology-related grants since 2008 (see Fig. 5). It appears that the NIH does not use the term "synthetic biology" in the same context as other agencies; therefore, this number could be artificially low.

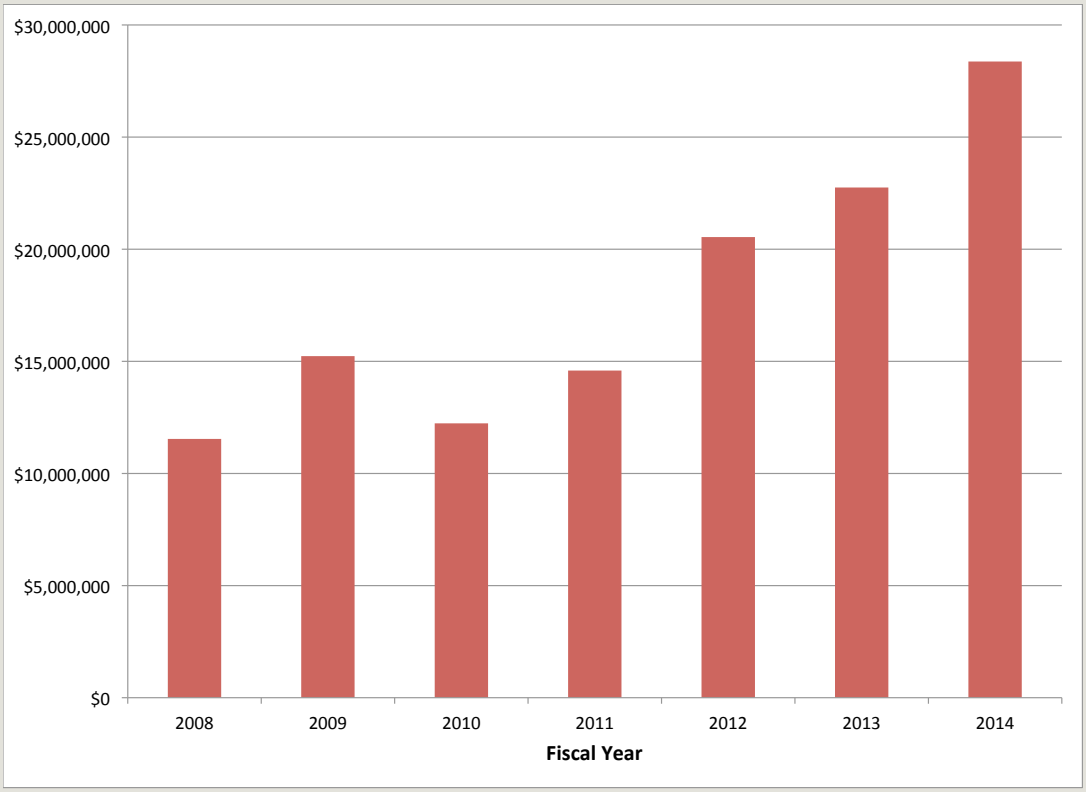

Fig. 5. Total NIH Funding by Fiscal Year

DEPARTMENT OF AGRICULTURE (USDA)

USDA has awarded more than $5 million in grants for synthetic biology since 2008 (see Fig. 6). In addition to the Federal Reporter Database, the USDA's Current Research Information System (CRIS)[13] was used to gather award data. The information-gathering process was complicated by the nature of the agency's funding database. CRIS does not routinely provide the dollar amount of each grant awarded. To obtain information on the funding levels, attempts were made to contact the principal investigator cited on the grant via the email address listed for them or contacting USDA directly.

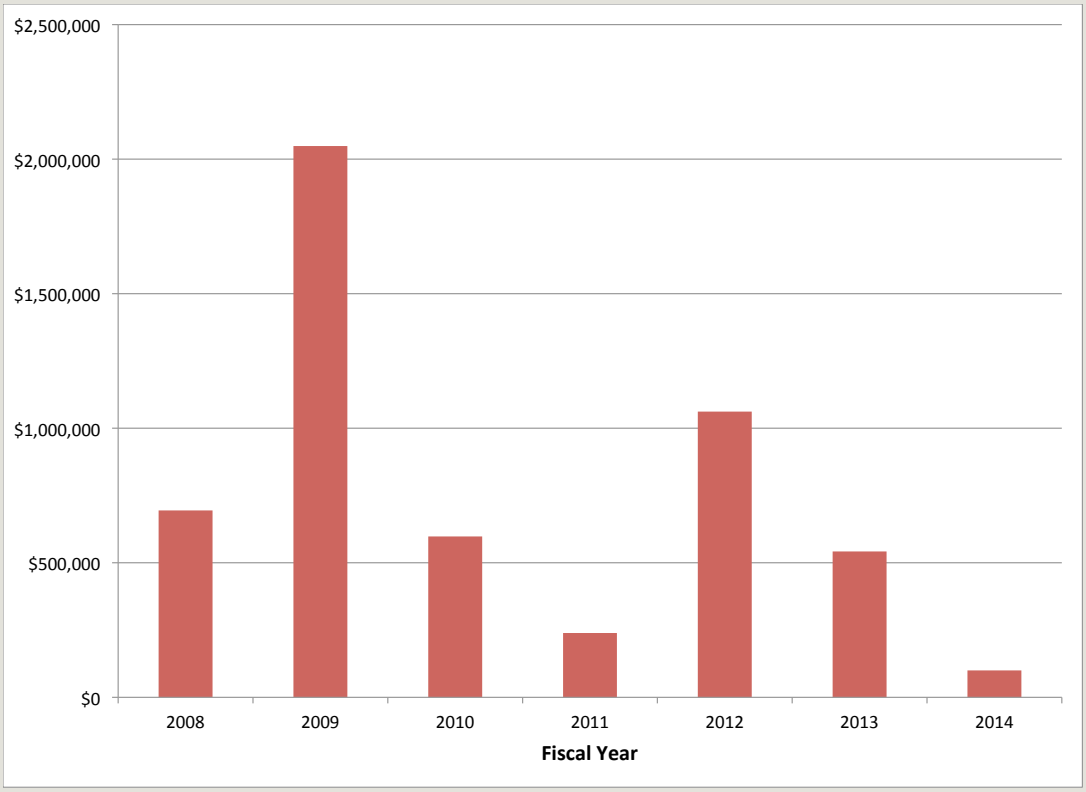

Fig. 6. Total USDA Funding by Fiscal Year

FUNDING FOR RISK RESEARCH

Four projects funded by NSF totaling $1.8 million were identified examining risk-related issues around synthetic biology (see appendix). Additional projects funded by DOE and DARPA have focused on risk; however, it is difficult to determine the amount spent. For instance, two papers that were published in 2015 dealing with biocontainment of synthetic organisms list multiple funding sources from both DARPA and DOE. *Biocontainment of genetically modified organisms by synthetic protein design*[14] lists multiple funding sources, including Grant #DE-FG02-02ER63445 ($3,000,000), awarded by DOE to Dr. George Church at Harvard University. *Recorded organisms engineered to depend on synthetic amino acids*[15] lists two DARPA awards along with funding from the DuPont chemical company and the Arnold and Mabel Beckman Foundation.

FUNDING FOR ETHICAL, LEGAL, AND SOCIAL IMPLICATIONS RESEARCH

Since 2006, 23 projects have been identified totaling about $8 million dollars (see Appendix). It should be noted that eight of these projects (representing around $3 million) are only partially focused on synthetic biology and/or ethical, legal, and social issues (ELSI), many of which mention ethics training for graduate students. It is difficult to determine exactly how much of each individual grant is going towards specific ELSI issues. NSF's SYNBERC has allocated approximately $3 million towards ELSI-related work. It is unclear whether NSF will continue to fund these types of projects when SYNBERC sunsets in 2016.

CROWDFUNDING

Recently, synthetic biology has begun to benefit from exposure in the crowdfunding community. In 2013, the project *Glowing Plants: Natural Lighting with No Electricity* raised nearly $500,000 on Kickstarter, greatly exceeding their $65,000 goal for crowdfunding support. This project raised a variety of ethical and safety concerns, debated publicly and among the academic community.[16,17] Ultimately, this led to a change in Kickstarter policy to prohibit projects that offer genetically modified organisms as a reward for contributions.[18,19] Other synthetic biology projects have raised more than $90,000 in support from various crowdfunding websites, including Kickstarter, Indiegogo, Rockethub, and Experiment, a crowdfunding site for supporting scientific research.

INTERNATIONAL FUNDING

European Union/European Commission (EC)

Many of the EC-funded projects are only partially funded by the commission, receiving additional contributions from research institutions. Although it is difficult to source these outside contributions, they are substantial and signify a broader European investment in synthetic biology (see Fig. 7).

United Kingdom (UK)

The UK has funded nearly $175 million in synthetic biology research since 2005, with the vast majority (more than $165 million) since 2010. Grant awards are divided between two programs, the Biotechnology and Biological Science Research Council (BBSRC)[20] and the Engineering and Physical Sciences Research Council (EPSRC).[21]

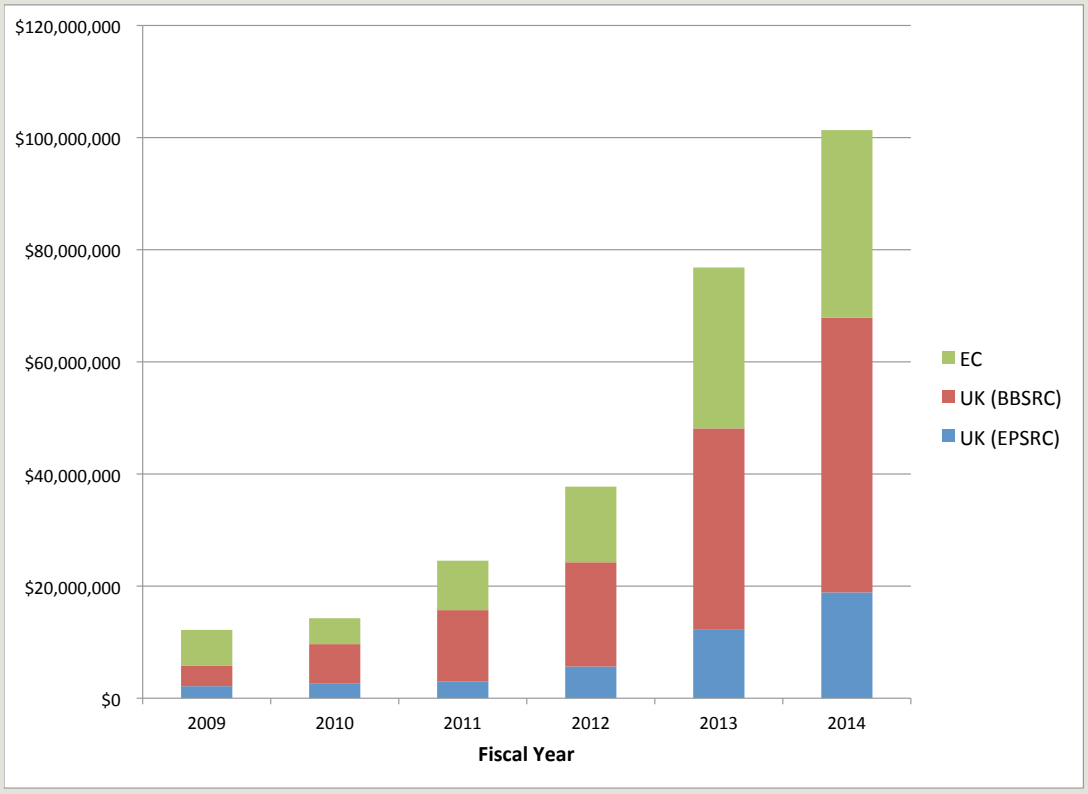

Fig. 7. Total European Commission and United Kingdom Funding by Fiscal Year

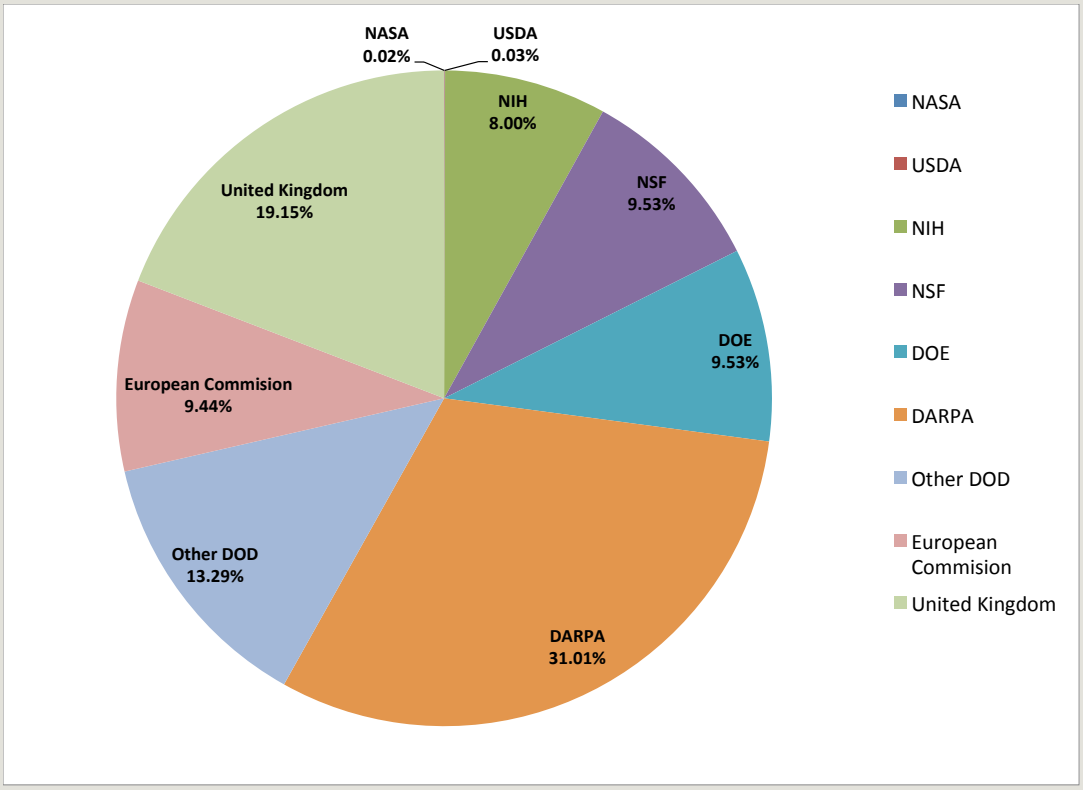

Fig. 8. Percent of Total Synthetic Biology Funding in 2014

CONCLUSION

With funding of more than a billion dollars from governments in the United States and Europe allocated to synthetic and more than 100 products/applications on the market or close to market, synthetic biology is no longer a basic research enterprise. Generally speaking, government agencies in the United States are funding synthetic biology research at a higher level than in 2010. DARPA and DOD have taken the lead in supporting this work and represent much of the federal government's investment in the field.

Despite the increased funding levels, risk research exploring the potential impacts of synthetic biology on human health and the environment is lagging far behind. For example federal ELSI research into synthetic biology is around 1 percent of total research funding, a lower level than other programs looking at emerging technologies. The Human Genome Project was mandated to fund ESLI research at 5 percent.[22] Between 2005 and 2012, the National Nanotechnology Initiative funded risk research at around 3.5 percent and ELSI at around 2 percent.[23] Both of these research initiatives also had coordinating bodies to help oversee federal research funding, something synthetic biology is currently lacking.

While it appears that the U.S. government is funding synthetic biology at a significant level, there is no easy way to determine the total amount of resources, both human and financial, that are being dedicated to the field. More transparency and better coordination are clearly needed, both within the U.S.

government and internationally. Data are needed, for example, from countries like China, which seems to be investing heavily in synthetic biology based on its growing number of scientific publications and teams it has entered in the International Genetically Engineered Machine competition.[3]

More accurate funding assessments from the private sector (both by industry and the venture capital community) and governments would provide better context for the more than 100 products/applications that are either on the market or close to market.[5]

Synthetic biology's race into the marketplace shows no sign of slowing down. The U.S. government's federal research program needs to keep up, both in terms of U.S. innovation in the field and in identifying and evaluating potential risks, as well as potential ethical, legal, and social issues.

Appendix: The appendix lists the individual research projects identified in this analysis. It can be found at: www.synbioproject.org/publications/u.s-trends-in-synthetic-biology-research-funding.

ENDNOTES

1 Because the budgets for DOD's non-DARPA projects are not publicly itemized, it is difficult to determine how much funding was allocated towards synthetic biology. In order to provide some context, this report approximates the total spending on synthetic biology-related projects to be 50 percent of the budget of the related program (listed in the appendix). This estimation brings total investments to $819 million. If you remove all non-DARPA, DOD-related expenditures, the total investment drops to $619 million. Therefore, the non-DARPA, DOD-related activities should be used as a reference in terms of activity and not actual expenditures.

2 http://www.synbioproject.org/inventories/maps-inventory/

3 http://igem.org/Main_Page

4 Map of 2015 iGEM teams: https://www.google.com/maps/d/u/0/viewer?mid=z_CMSHmDgyfc.kShytm5hSTEk

5 Synthetic Biology Products and Applications Inventory: http://www.synbioproject.org/cpi/

6 http://www.synbioproject.org/publications/researchfunding/

7 https://www.starmetrics.nih.gov/

8 To submit data, please email SYNBIO@wilsoncenter.org with FUNDING in the subject line.

9 http://www.darpa.mil/news-events/2014-04-01

10 http://dsearch.dtic.mil/search?site=rdds&client=rdds&output=xml_no_dtd&proxystylesheet=rdds&proxycustom=%3CADVANCED/%3E

11 Communication via email, December 22, 2014.

12 Communication via e-mail, December 18, 2009.

13 http://cris.nifa.usda.gov/cgi-bin/starfinder/0?path=crisassist.txt&id=anon&pass=&OK=OK

14 Mandell, DJ; Lajoie, MJ; Mee, MT; Takeuchi, R; Kuznetsov, G; Norville, JE; Gregg, CJ; Stoddard, BL; Church, GM. 2015. Biocontainment of genetically modified organisms by synthetic protein design. Nature. Vol. 518(7537).

15 Rovner, AJ; Haimovich, AD; Katz, SR; Li, Z; Grome, MW; Gassaway, BM; Amiram, M; Patel, JR; Gallagher, RR; Rinehart, J; Isaacs, FJ. Recoded organisms engineered to depend on synthetic amino acids. 2015. Nature. Vol. 518(7537).

16 http://www.nature.com/news/glowing-plants-spark-debate-1.13131

17 http://www.washingtonpost.com/national/health-science/glowing-plant-project-on-kickstarter-sparks-debate-about-regulation-of-dna-modification/2013/10/03/e01db276-1c78-11e3-82ef-a059e54c49d0_story.html

18 https://www.kickstarter.com/rules/prohibited

19 http://www.theverge.com/2013/8/2/4583562/kickstarter-bans-project-creators-from-giving-GMO-rewards

20 http://www.bbsrc.ac.uk/PA/grants/AdvancedSearch.aspx

21 http://gow.epsrc.ac.uk/Search.aspx

22 https://www.genome.gov/10002329

23 http://www.nano.gov/sites/default/files/pub_resource/2011_ehs_strategy_fact_sheet_locked.pdf

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