Woodrow Wilson International Center for Scholars

Synthetic BIOLOGY PROJECT

TRENDS IN SYNTHETIC BIOLOGY RESEARCH FUNDING IN THE UNITED STATES AND EUROPE

June 2010

RESEARCH BRIEF 1

The Synthetic Biology Project was established in August 2008 at the Woodrow Wilson International Center for Scholars. The Project aims to foster informed public and policy discourse concerning the advancement of synthetic biology – an emerging interdisciplinary field that uses advanced science and engineering to make or re-design living organisms, such as bacteria, so that they can carry out specific functions. Synthetic biology involves making new genetic code, also known as DNA, which does not already exist in nature.

KEY FINDINGS

Since 2005, the U.S. government has spent approximately $430 million (Figure 1) on research related to synthetic biology, with the Department of Energy (DOE) funding a majority of this research.[1] Approximately 4% of the total has been allocated to examine the ethical, legal and social implications of synthetic biology and is funded through DOE, the National Science Foundation and the Department of Agriculture. By comparison, the European Union and three European countries – the Netherlands, the United Kingdom and Germany – have spent approximately $160 million (Figure 1) on synthetic biology research with around 2% going toward implications research. **These figures are <u>preliminary</u> and based on best-effort attempts to gather data from multiple government sources in the United States and Europe. It is hoped that this report will stimulate a broad discussion of funding levels that will lead to better estimates over time. Figures will be updated as better information becomes available.**

Figure 1. Total U.S. and European Funding

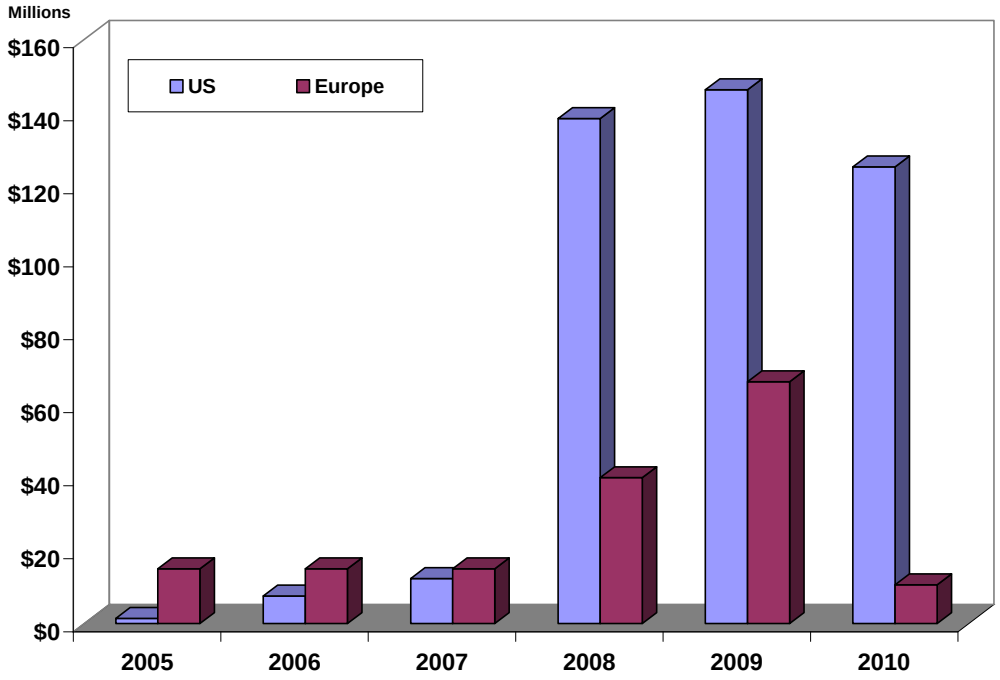
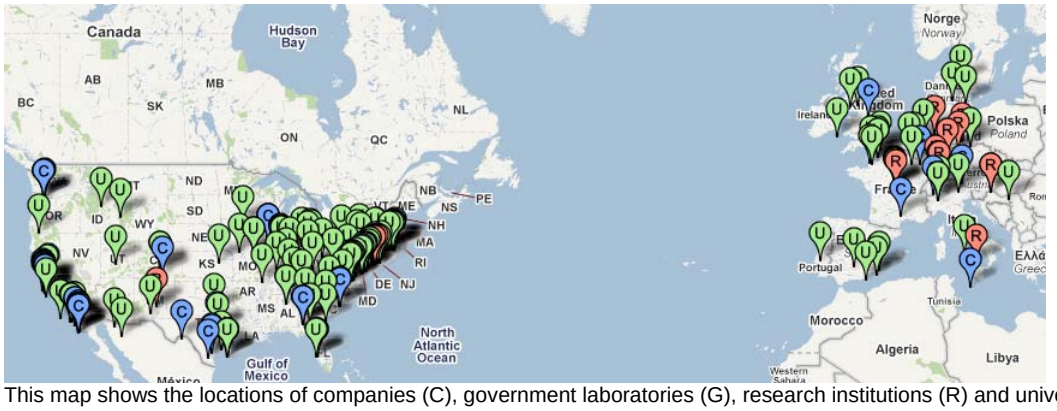


Figure 1 depicts the annual spending of the U.S. government agencies, the European Commission and individual European countries described in this report.

[1] See the section on DOE below for a detailed explanation of funding levels.

BACKGROUND

As Harvard biologist George Church recently observed, "The door to synthetic biology is already wide open and people are pouring through it." An analysis by the Synthetic Biology Project indicates that more than 180 entities in the United States and 50 in Europe are involved in synthetic biology research, development and commercialization (see map below), and the first products (in the areas of vaccines and biofuels) are poised to enter the marketplace.[i] Estimates have placed the current annual synthetic biology research market at $600 million, and that sum has the potential to exceed $3.5 billion over the next decade.[2] Other forecasts indicate that one-fifth of the chemical industry (currently worth $1.8 trillion) could be dependent on synthetic biology by 2015.[ii]



This map shows the locations of companies (C), government laboratories (G), research institutions (R) and universities (U) conducting synthetic biology research and policy centers (P) examining issues surrounding synthetic biology. Available at http://www.synbioproject.org/library/inventories/map/.

Why create synthetic biological parts or systems? Animals have long been selectively bred to provide improved sustenance, protection and labor for humanity. In recent years, genetically modified microorganisms have been employed in industrial applications. According to researchers, organisms engineered with new techniques could lead to more affordable, precise and sustainable industrial processes. In laboratories across the United States, microorganisms have already been developed to turn feedstocks into chemicals, drugs and biofuels. In the future, other microorganisms might sequester carbon or heavy metals, and still others might detect pathogens or monitor human health. The list of potential applications in energy, environment, health and other areas is long and growing.[iii] Currently, applications related to biofuels are drawing the most attention and funding.

> *"Synthetic biology is an emerging area of research that can broadly be described as the design and construction of novel artificial biological pathways, organisms or devices, or the redesign of existing natural biological systems."*
>
> *UK Royal Society*

Along with its potential benefits, synthetic biology has ethical, legal and social implications. For instance, the field

[2] http://www.researchandmarkets.com/reports/c31390; accessed March 3, 2010.

renews ethical debates about "playing God" by creating life in the lab, poses new challenges to intellectual property regimes and raises questions about how to address both biosafety and biosecurity. Biological systems are fantastically complex, and natural systems continue to surprise scientists, defying attempts to anticipate or predict aspects of their behavior. For this reason, organisms with synthetic parts, or totally synthetic organisms, could introduce new levels of uncertainty into assessments of health and environmental risks and necessitate greater support for risk assessment and management.

METHODOLOGY

This research brief is a preliminary and first-of-its-kind assessment of synthetic biology funding by governments in the United States and Europe. To obtain U.S. data, federal research grant databases were searched using the term "synthetic biology" to determine the amount of money the federal government is investing in synthetic biology. The search was limited to "synthetic biology" in order to obtain a narrow and focused picture of basic and applied synthetic biology research. Fiscal year funding levels were determined on the basis of the reported dollar amounts and then split evenly over the course of the individual grant. When funding levels were absent from the government databases, attempts were made to contact the principal investigator listed on the grant or the office in charge of the grant. Data also were gathered through discussions with agency representatives. Appendix A lists the individual research projects that were contained in this analysis. Appendix A is available here: http://www.synbioproject.org/researchfunding

U.S. FUNDING

DEPARTMENT OF ENERGY (DOE): Since 2006, the Department of Energy has spent more than $700 million on synthetic biology research. Data on DOE funding levels were obtained from the Office of Biological and Environmental Research (BER) budget. 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 they "wouldn't consider it unreasonable to mark all of that as synthetic biology-related spending."[iv] The budgets of these two programs alone total more than $230 million a year for fiscal years 2008, 2009 and 2010. Almost half of the Genomic Sciences Program budget is allocated to three bioenergy research centers located at Oak Ridge National Laboratory, Lawrence Berkeley National Laboratory and the University of Wisconsin at Madison, each of which was slated to receive $25 million a year for five years starting in 2008. These funds, as well as the remaining money, are spread among a range of recipients at national laboratories, universities and other private institutions. While it is doubtful whether the entire budget from the

Genomic Sciences Program and the Joint Genome Institute goes toward synthetic biology, the field does seem to receive priority in the DOE research budget.

Because the DOE has not released project-by-project data on what it is funding in synthetic biology, we chose a conservative approach and cut its overall numbers in half. This included cutting in half the budgets of the three bioenergy centers mentioned above. We added new funding from DOE's recently announced Advanced Research Projects Agency-Energy (ARPA-E) for synthetic biology projects (Figure 2). ARPA-E's mission is to fund projects that will develop transformational technologies that reduce America's dependence on foreign energy imports; reduce U.S. energy-related emissions (including greenhouse gases); improve energy efficiency across all sectors of the U.S. economy; and ensure that the United States maintains its leadership in developing and deploying advanced energy technologies. ARPA-E is funded by the American Recovery and Reinvestment Act. Even when its budget figures have been reduced by half, the DOE is still far outspending any other agency in terms of synthetic biology funding. This is not surprising, given the agency's recent push toward developing new biofuels.

Figure 2. DOE Funding

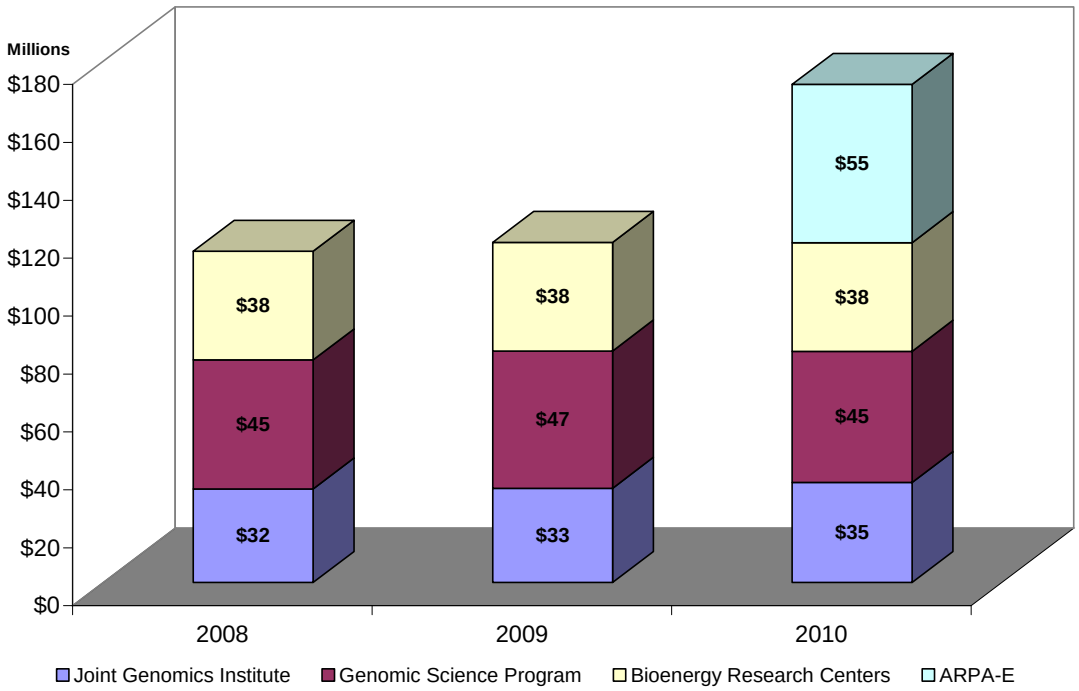


Figure 2 cuts in half the budget of DOE and also incorporates recently released funding from the ARPA-E program.

DEPARTMENT OF HEALTH AND HUMAN SERVICES (DHHS): Since 2005 the National Institutes of Health (NIH), an agency of the DHHS, has awarded approximately $48 million in grants in synthetic biology. The NIH Research Portfolio Online Reporting Tool was searched to obtain the projects funded in the field of synthetic biology (http://projectreporter.nih.gov/reporter.cfm, accessed December 2009).

NATIONAL SCIENCE FOUNDATION (NSF): As of January 2010, NSF had funded a total of approximately $40 million in research associated with synthetic biology.
NSF funding levels were obtained by searching the Foundation's awards database (http://www.nsf.gov/awardsearch/, accessed January 2010).

DEPARTMENT OF AGRICULTURE (DOA): Information gathered from the DOA suggests that it has awarded at least $2.3 million in grants in synthetic biology-related research since 2005. The DOA's Current Research Information System (CRIS) was used to search for grants funding synthetic biology (http://cris.nifa.usda.gov/cgi-bin/starfinder/0?path=crisassist.txt&id=anon&pass=&OK=OK; accessed December 2009). Unlike other databases CRIS does not always supply the amount of the grant. In order to obtain funding levels, attempts were made to contact the principal investigator (PI) listed on the grant proposal. In addition, the office in charge of the grant was contacted in an effort to obtain the funding level for grants listed in the CRIS database. In some instances neither the PI nor the office in charge of the grant would release the amount of the grant. A Freedom of Information Act request was submitted to obtain the funding level for these grants. Funding levels for one of the grants was provided; information for the remaining grants will not be available until mid-summer.

DEPARTMENT OF DEFENSE (DOD)/DEFENSE ADVANCED RESEARCH PROJECTS AGENCY (DARPA)

Research funding levels for the Department of Defense are primarily classified. However, DOD reported supporting nine projects within the Naval Biosciences and Biocentric Technology Program.

DARPA reports a budget of $20 million in synthetic biology for fiscal 2011 as part of a line item in its budget. Funding for previous years was unavailable. DARPA reports that its synthetic biology program "will develop and implement a revolutionary approach to the manufacture of bio-based materials that directly support a broad range of military capabilities, such as sensing of chemical/biological agents, production of bio-based fuels and chemicals, remediation of pollutants, and protection of the food supply chain. Synthetic Biology is based on a revolutionary framework for the algorithmic engineering of biological processes, enabling truly hierarchical biological systems with unbounded complexity. Research thrusts include automated process discovery,

tool-chain development, novel approaches to process measurement and validation, and development of application demonstrations."

DEPARTMENT OF HOMELAND SECURITY

Discussions with officials at the Department of Homeland Security suggested that the agency is spending millions of dollars to procure products based on synthetic biology. All of the Department's biological-detection programs, and some of its chemical-detection programs, are using synthetic nucleic acids and other synthetic systems (modified or engineered proteins and peptides primarily).

FUNDING FOR SOCIAL AND ETHICAL IMPLICATIONS RESEARCH

All databases were searched to identify funding directed at the study of the ethical, social or legal implications (ELSI) of synthetic biology. The U.S. government is spending approximately $15.9 million on ELSI-related studies (Table 1), or about 4% of its overall spending for synthetic biology. The DOE is investing approximately $15 million in ELSI research, as indicated in the budget of the Genomic Science Program. NSF has issued grants for nine projects totaling close to $1 million. The DOA lists one project looking into ELSI issues but does not provide the funding level.

Table 1. U.S. identified funding directed at the study of the ethical, social, or legal implications of synthetic biology

Agency	Project	FY Start	Amount
NSF	Synthetic Biology: Status, Outlook and Public Perception	2006	$60,000
NSF	Gordon Research Conference on Science and Technology Policy	2008	$60,000
NSF	Doctoral Dissertation Research: Crafting Life: A Sensory Ethnography of Constructive Biologies	2009	$14,929
NSF	"Sandpit" to address grand challenge topics in synthetic biology	2009	$28,800
NSF	ARS Synthetica - A Multimedia Forum Exploring the Artful Design of Living Things	2009	$74,902
NSF	Cultural Cognition of Synthetic Biology Risks	2009	$398,990
NSF	Synthetic Aesthetics: Connecting Synthetic Biology and Creative Design	2009	$244,560
NSF	Transatlantic Exploratory Workshop on the Implications of Cutting-Edge Biotechnologies for Sustainability Science and Policy	2009	$53,810
NSF	Prediction Markets - An Experimental Application to Synthetic Biology	2010	$25,000
DOA	Ethical Issues in Agriculture	2009	NA
DOE	Genomic Science Program-Ethical, Legal, and Societal Issues	2008	$5,000,000
DOE	Genomic Science Program-Ethical, Legal, and Societal Issues	2009	$5,000,000
DOE	Genomic Science Program-Ethical, Legal, and Societal Issues	2010	$5,000,000
		Total	**$15,960,991**

FUNDING FOR RISK RESEARCH

We searched all the relevant databases to identify any funds dedicated specifically to risk research (as separate from ethics). Of specific interest were risk assessments related to potential accidental releases of synthetic organisms from a lab or container, or risks associated with intentional non-contained use (for instance, biofuel production with synthetically modified algae in open ponds). We also searched the databases for studies that might explore extremely low-probability, but high-impact, events with large environmental and economic consequences.[v] No such projects were found.

EUROPEAN FUNDING

Since 2005, Europe has allocated around $160 million to synthetic biology research. This includes funding provided by the European Commision along with the individual country budgets of the United Kingdom, the Netherlands and Germany.

European Union/European Commission: The European Commission spent close to $45 million between 2005 and 2007 on synthetic biology as part of the Sixth Framework Program for Research and Technological Development. In 2003, synthetic biology was identified as one of several targeted research areas. The Seventh Framework Program, which runs from 2007 to 2013, has allocated approximately $8 million so far, including $2 million for implications research.

United Kingdom: Estimated funding of synthetic biology in the United Kingdom is estimated at between $30 million and $53 million since 2005. Research funding is divided among three programs: Biotechnology and Biological Sciences Research Council, Engineering and Physical Sciences Research Council and the Wellcome Trust.

Netherlands: In 2008, three Dutch universities announced that over the next five to ten years they would invest a total of $90 million in centers for synthetic biology research. The three universities are the Delft University of Technology (Department of Bionanoscience), University of Groningen (Centre for Synthetic Biology) and the Eindhoven University of Technology (Institute for Complex Molecular Systems).

Germany: On the basis of a joint 2009 position paper on the opportunities and risks of synthetic biology, the Deutsche Forschungsgemeinschaft (DFG, or German Research Foundation), acatech (the German Academy of Science and Engineering), the German Academy of Scientists Leopoldina and the National Academy of Sciences consider synthetic biology a funding priority. The DFG is planning to invest approximately $3.5 million in synthetic biology.

CONCLUSIONS

With well over half a billion dollars from governments in the United States and Europe allocated toward synthetic biology research and research under way in more than 200 locations worldwide, synthetic biology is no longer a hypothetical science dreamed up in the heads of science fiction writers. Although governments are already funding synthetic biology, there is no easy way to determine the total amount of resources, both human and financial, that are being dedicated to it. More transparency and better coordination are clearly needed, both within the U.S. government and internationally. Data are needed, for example, for countries such as Russia, Japan, China and Taiwan. Finally, better assessments of funding by the private sector (both by industry and the venture capital community) are essential.

Governments, individuals and private companies appear poised to increase their investment in synthetic biology research, but, as a recent poll suggests, almost 80% of Americans have heard little or nothing about synthetic biology.[vi] As investments ramp up, better mechanisms for public education and engagement will be needed.

REFERENCES

[i] Maps and data available at http://www.synbioproject.org/library/inventories/map/.

[ii] Lux Biosciences Intelligence. 2009. *Synthetic Biology's Commercial Roadmap.* State of the Market Reports. Lux Research. Available at http://www.luxresearchinc.com/info/smr. Accessed March 17, 2010.

[iii] See, for example, Royal Academy of Engineering. "Synthetic Biology: Scope, Applications, and Implications." May 2009, pp. 37–41.

[iv] Communication via e-mail, December 18, 2009.

[v] See Kent, Adrian. 2004. "A Critical Look at Risk Assessments for Global Catastrophes." *Risk Analysis* (24)1: 157-168.

[vi] Nanotechnology, Synthetic Biology, & Public Opinion. 2009. Peter D. Hart Research Associates, Inc. September. Available at http://www.synbioproject.org/library/publications/archive/6410/. Accessed March 4, 2010.