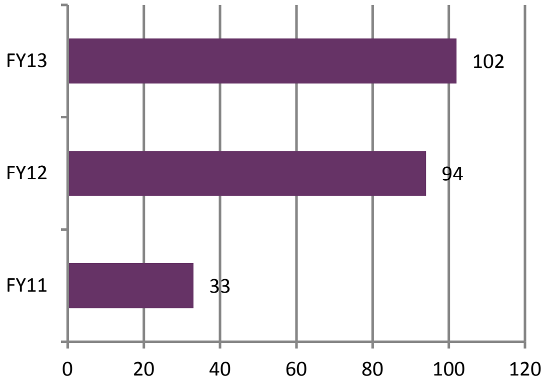
Outline

- BioMaPS
- Synthetic Biology Investments
- Synthetic Biology in Engineering
- Ecological and Evolutionary Implications
- Synthetic Biology and Society

BioMaPS

- Initiated in 2011 for fostering research at the intersection of life and physical sciences
- From 2012, engineering is included
- From 2011-13,
  - additional $66M invested in the research at the intersection
  - 229 projects were funded
- Areas at the intersection
  - Tools and resources
  - Predictive Biology
  - Synthetic Biology



Number of awards

	FY11 Actual	FY 12 Actual	FY13 Actual	FY14 Estimate	FY15 Request
BIO	$5.57M	$8.95M	$12.50M	$14.31M	$14.31M
MPS	$3.37M	$14.29M	$14.89M	$11.62M	$11.96M
ENG	-	$3.31M	$3.64M	$4.31M	$3M

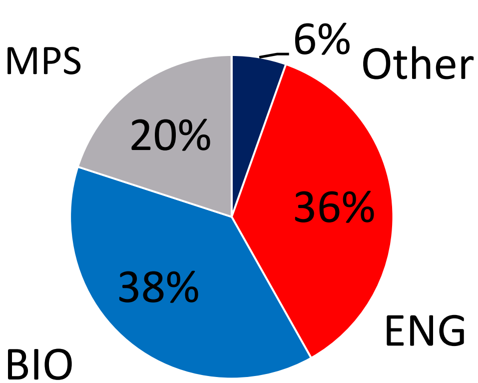
Synthetic Biology

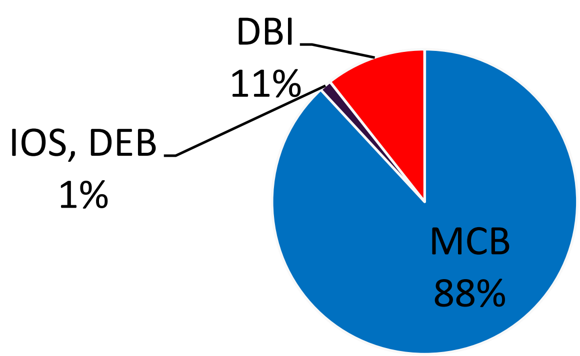
- What is synthetic biology?
  - The design and whole-sale construction of new biological parts and systems, and the redesign of existing, natural biological systems for tailored purposes, integrating engineering and computer assisted design approaches with biological research.
  - In the US, synthetic biology grew out of a convergence of ideas in metabolic engineering, electrical engineering, and molecular biology.
- Potential
  - Rapidly emerging technology for new applications
  - Disruptive technology for long-standing problems
  - Advancing frontiers of knowledge-base

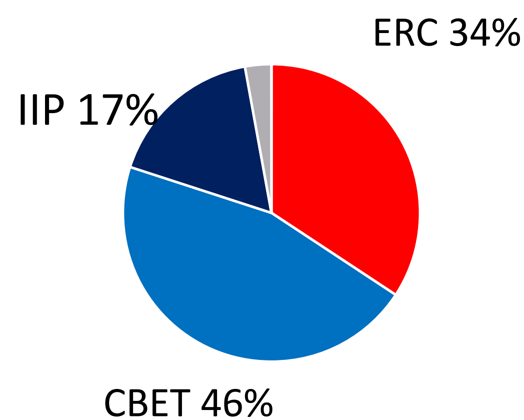
Synthetic Biology Funding at NSF

(~$50M /year)

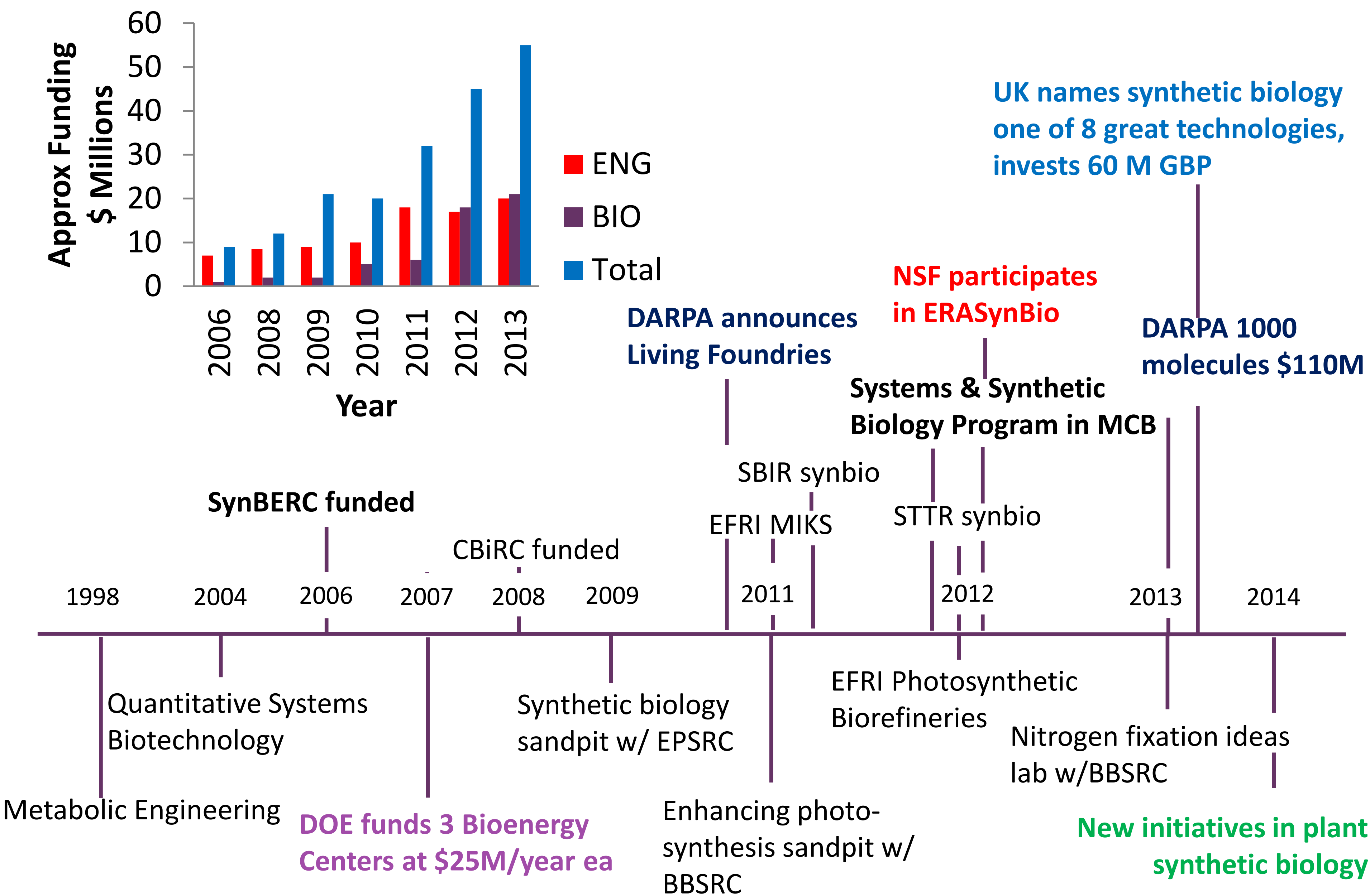
- BIO
  - MCB
    - Core
    - SAVI
  - DBI
    - Informatics
    - Education
  - IOS
  - DEB
- ENG
  - ERC
    - SynBERC, CBiRC
  - CBET
    - Core program
  - IIP-
    - SBIR, STTR
- CISE, SBE, MPS (CHE, PHY)





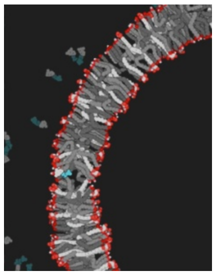


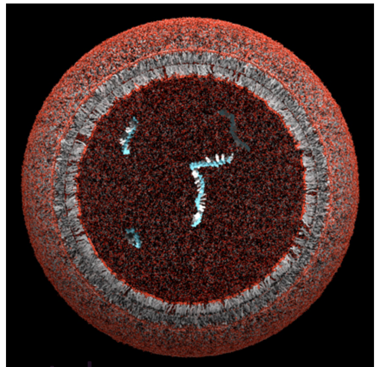
History of Synthetic Biology Funding



Examples: Foundational Knowledge

Origin of life



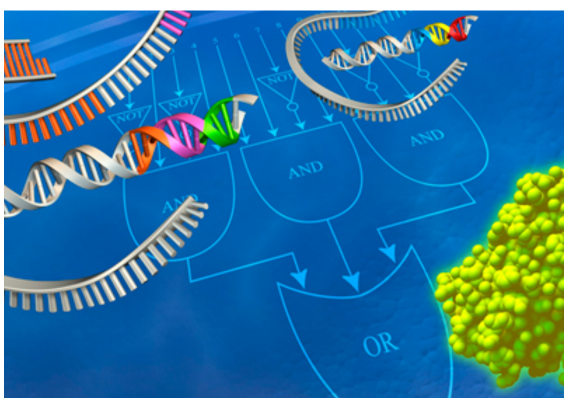


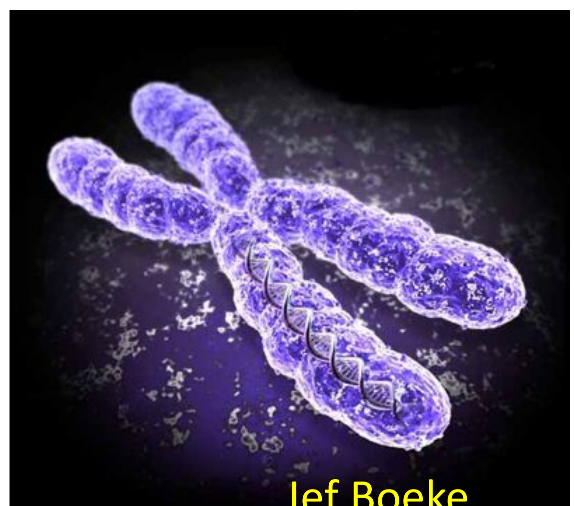
Jack W Szostak

Predictive Synthetic Biology

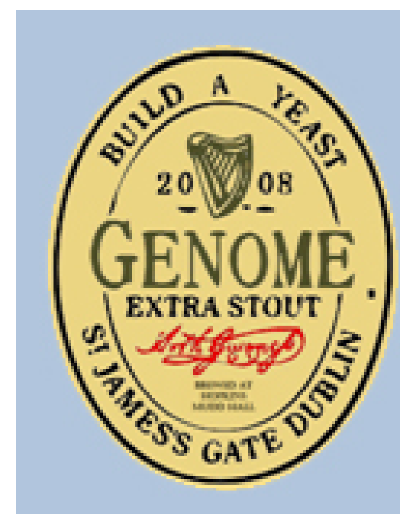
Joel Bader

Enabling Technologies





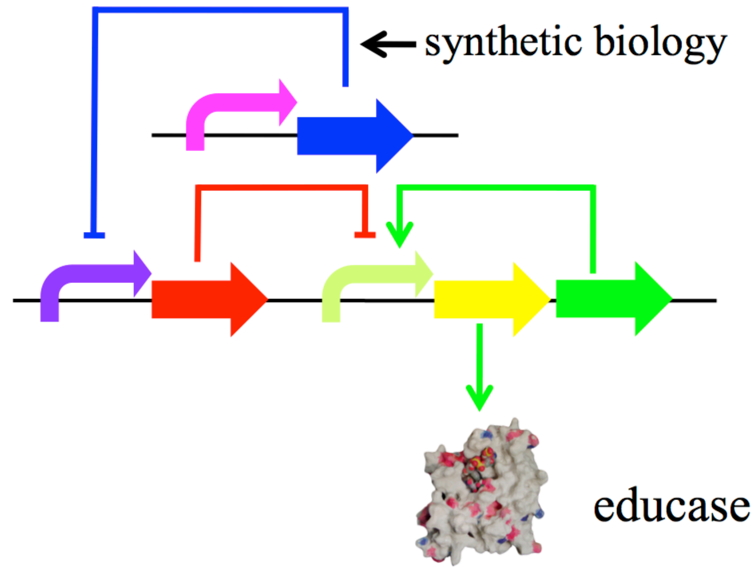
Jef Boeke



Examples: Education

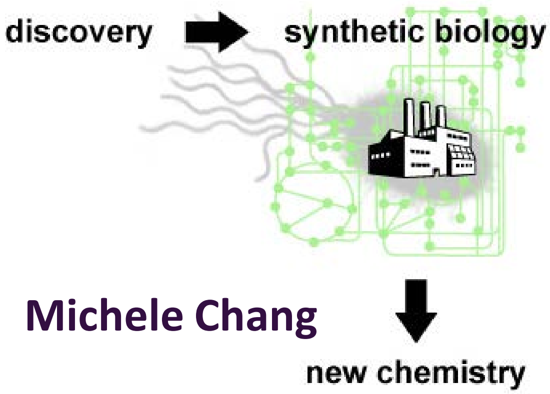
iGEM

GCAT



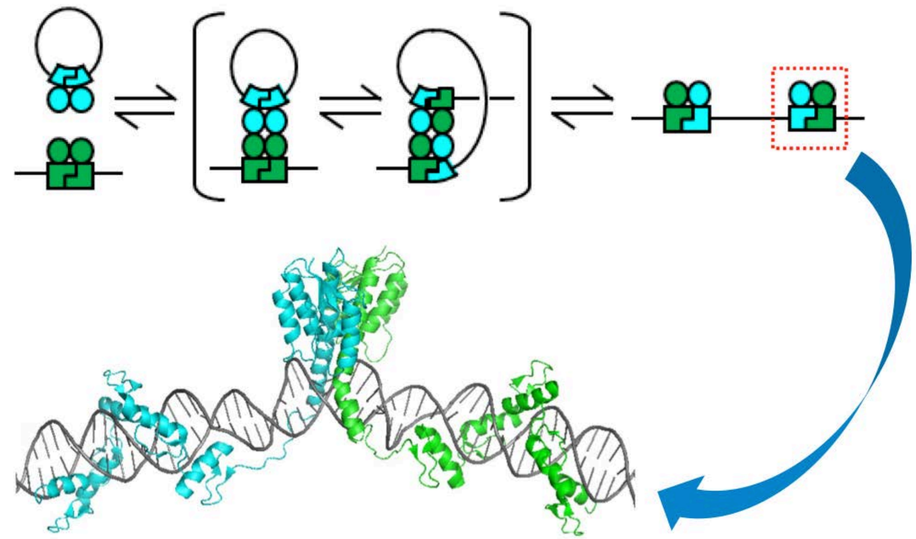
Examples: Applications

Biochemical Engineering



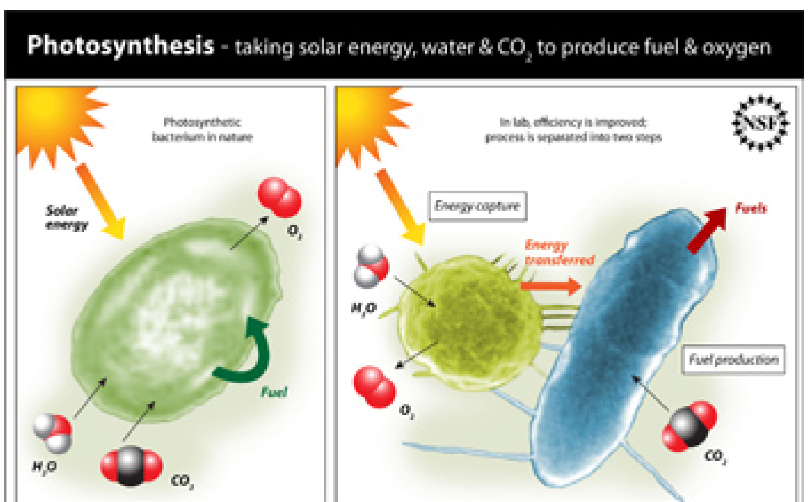
Michele Chang

Regenerative Medicine



Charles Gersbach – synthetic zinc finger proteins to control transcription

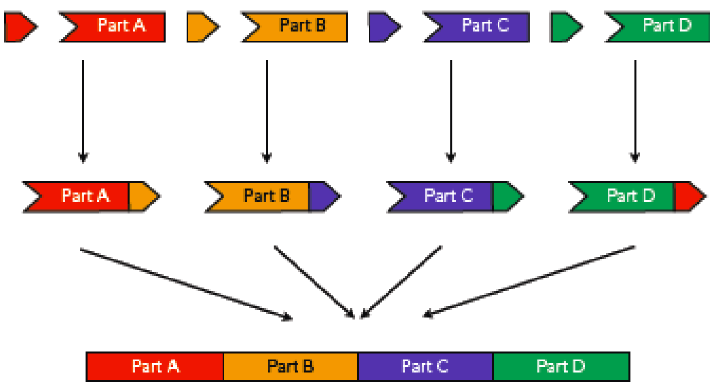
Disruptive solutions



Jones with US and UK Collaborators

Examples: Commercialization

Ginkgo BioWorks



REFACTORED MATERIALS

teselagen BIOTECHNOLOGY

Current Initiatives in Synthetic Biology

International Engagement

w/EU EraSyn Bio, EU-US Biotechnology task force SynBio WG
w/ UK BBSRC& EPSRC ideas labs, science & innovation workshops
w/ Germany DFG-NSF joint workshop
w/ India joint workshop (2014)
SAVI- yeast genome engineering (UK, China, India)

Interagency Engagement

NSTC working group (2012-2013)
Informal WG to share information

Applications & Industry Partnerships

SBIR and STTR programs
Exploring opportunities to reduce barriers to commercialization
National academies workshop – Industrialization of Biology

Environment

Wilson Center activities to examine risk/ environmental issues w/ practice of synthetic biology
New initiatives? In partnership with BIO (MCB, DEB, IOS), ENG (CBET, IIP)

Society (in partnership with SBE)

Workshop – participatory governance, public engagement & synbio
Synthetic Aesthetics workshop (EPSRC, SBE, MCB)
Other?

+

Overlapping BIO/ENG Interest

specifically MCB/CBET

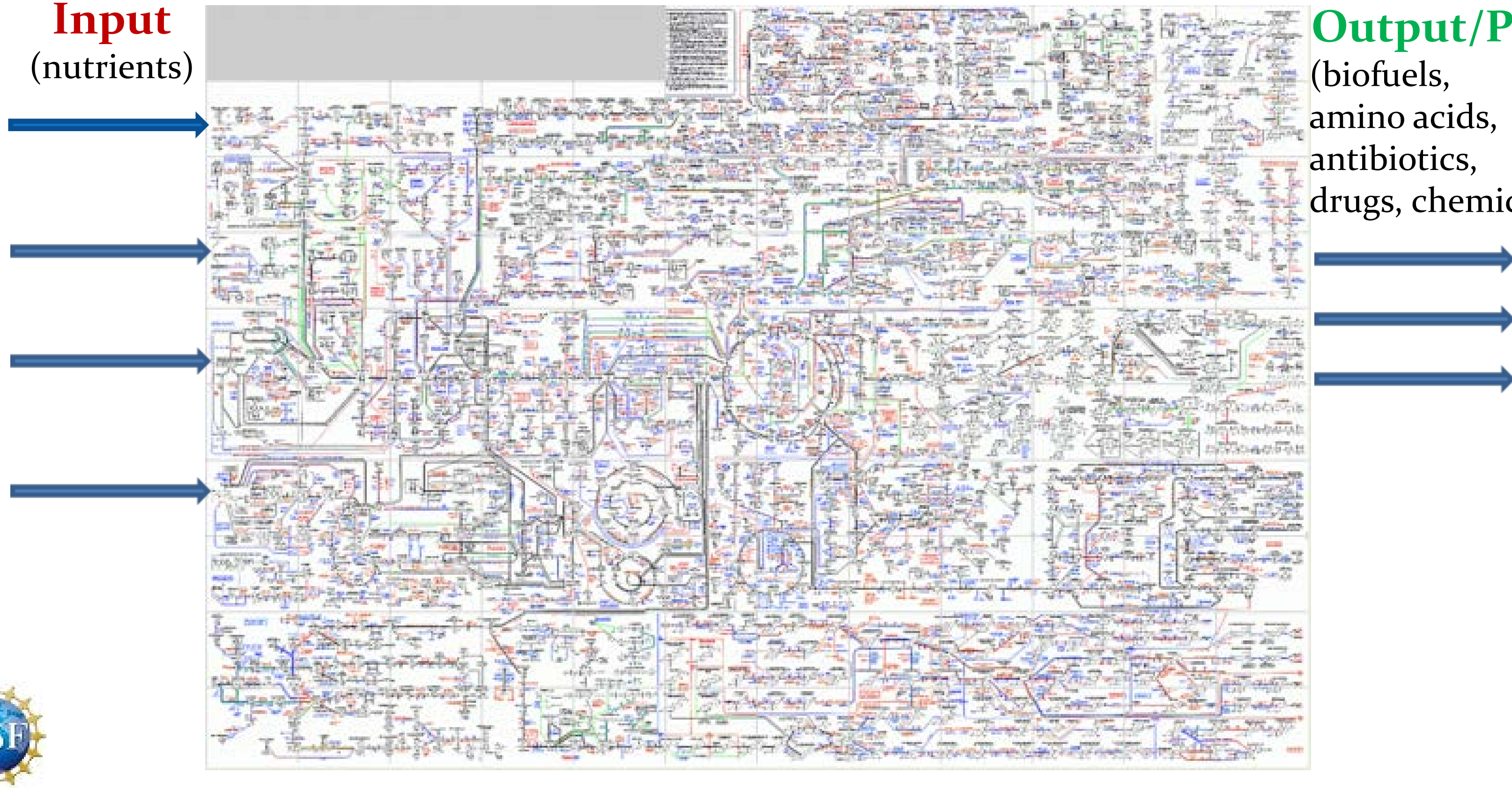
- Metabolic engineering and synthetic biology
- Tissue engineering and stem cell technologies
- Protein engineering and design
- Systems biology
- Development of novel molecular level and "omics" tools in support of biotechnology

ENG Approaches for BIO Systems

Re-design of natural biological systems for useful purposes

State-of-the-art for designing bio-production of chemicals: **Systems Metabolic Engineering**

Input
(nutrients)



Output/Products
(biofuels,
amino acids,
antibiotics,
drugs, chemicals, etc.)

ENG Design Objectives

(1) The highest selectivity/yield

- the highest yielding pathway can be identified from the set of elementary modes
- Knowledge of the set of elementary modes permits identification of elimination targets of reactions that forces cells to operate according to most efficient pathways

(2) High reaction rates

(3) Robust, stable systems

- Biological systems may change due to natural evolution

Realization of (1) – (3) will typically result in the smallest and most economical equipment needed for the process

Uncertainty, human behavior:

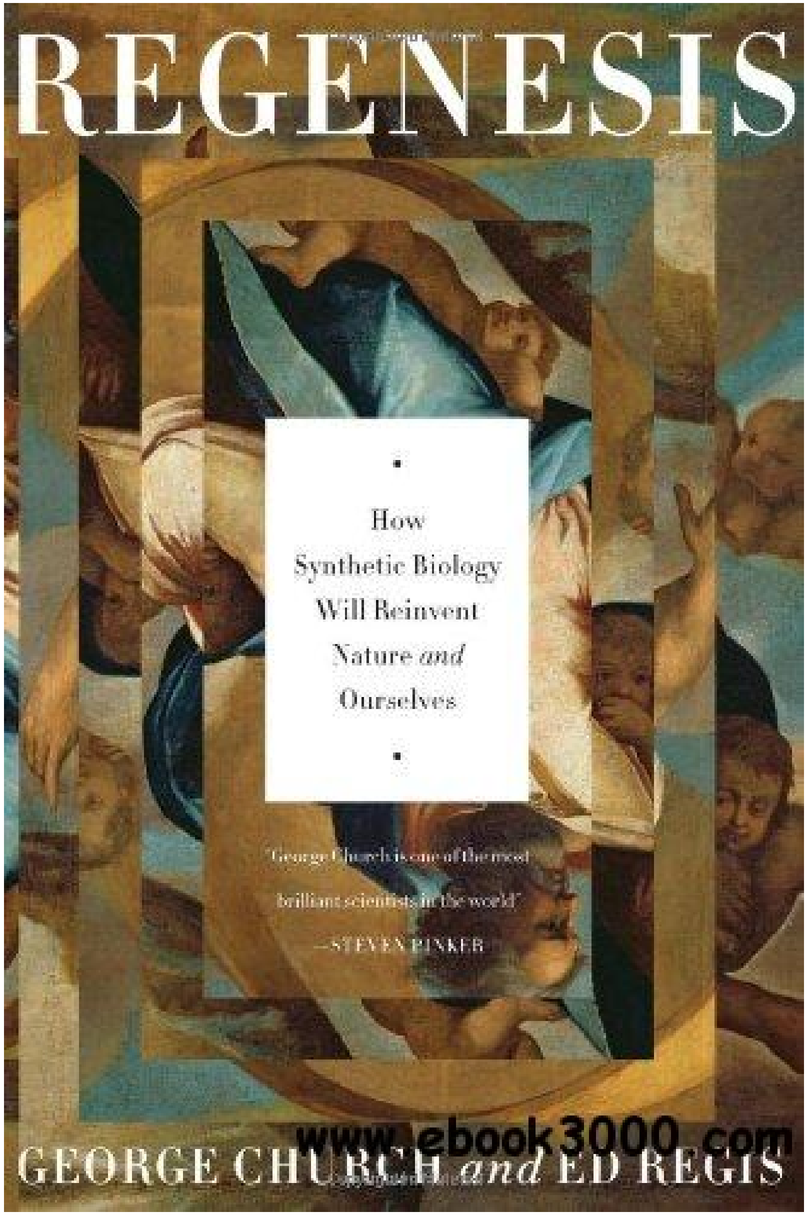
- the main uncertainty is related to the correctness of the model; this has to be validated by experiment and adjusted as needed
- The approach is not affected by human behavior as it is completely rational

The genomics revolution has dramatically impacted the study of evolution and ecology

- Increasing the ability to measure genetic variation
  - Among individuals of a population
  - Spatial within a species, temporal within & among clades
  - Whole assemblages of (microbial) taxa
- Enabling the study of non-model species in nature
- Linking genetic variation and expression to phenotypic variation

But as a tool for manipulative studies it has been more limited

Genetically modified (food) organisms have become common, but the time and costs of creating desired traits has been significant

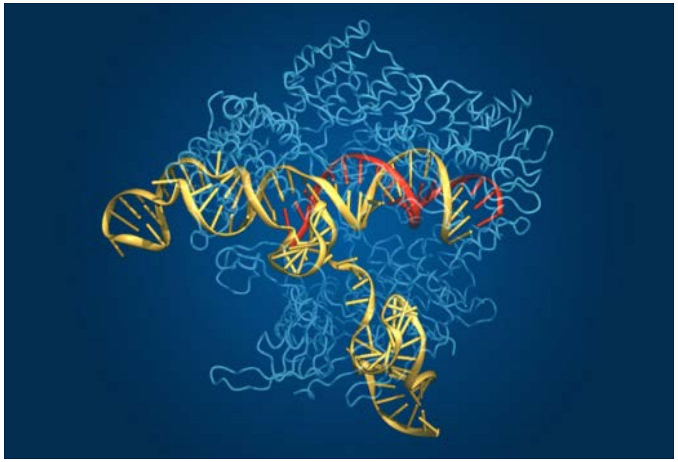


October 2012

Synthetic Biology

The control and manipulation of biological information at its most fundamental level

CRISPR-Cas9 – a new genome editing tool



This image of the Cas9 complex depicts the Cas9 protein (in light blue), along with its guide RNA (yellow), and target DNA (red). Image courtesy Bang Wong.

Discover
SCIENCE FOR THE CURIOUS

FROM THE OCTOBER 2013 ISSUE

Life as We Grow It: The Promises and Perils of Synthetic Biology

A *Discover* event highlights how scientists are engineering DNA that may one day eliminate malaria, solve the energy crisis and feed the world.

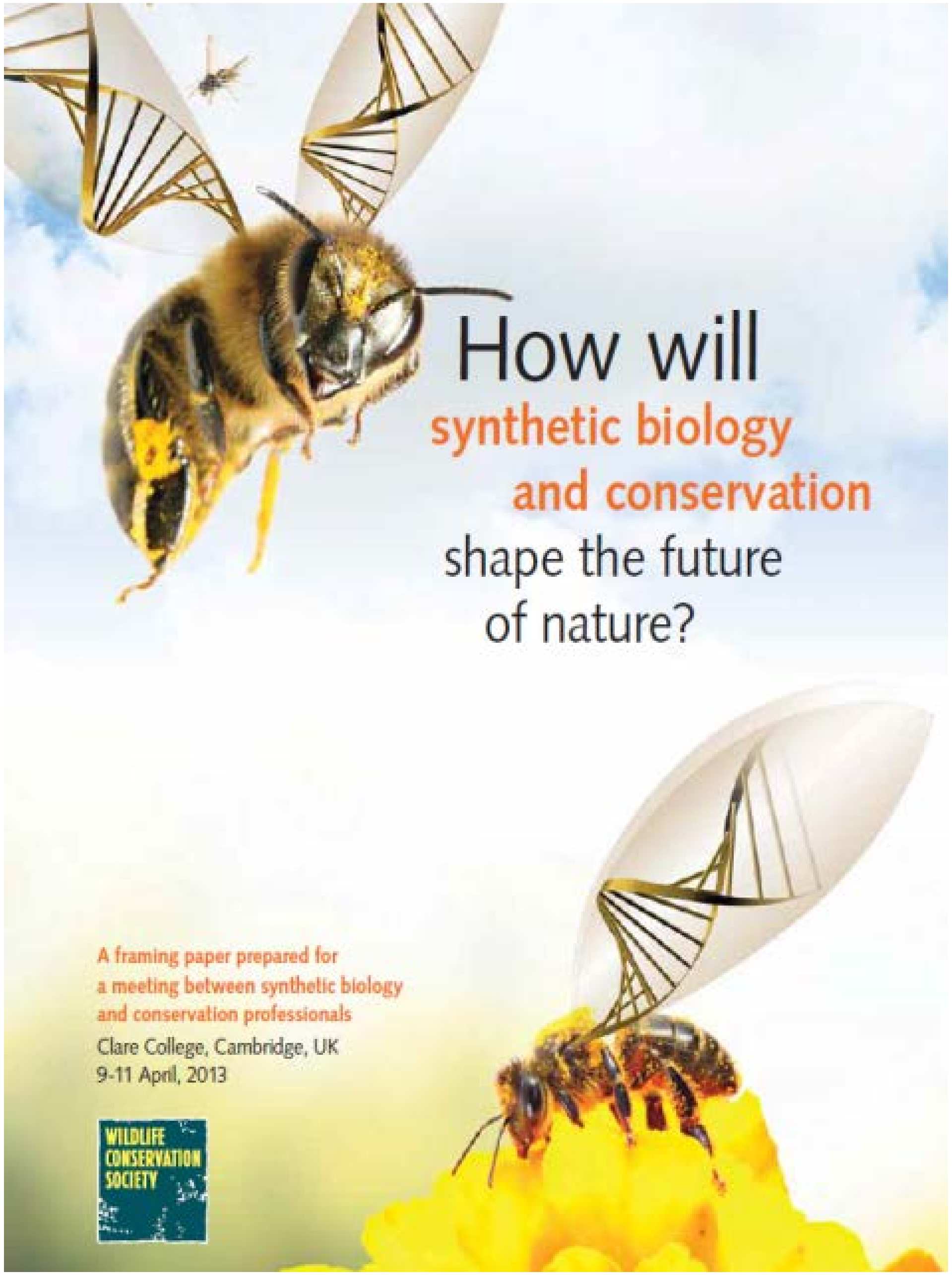
By Breanna Draxler | Wednesday, December 11, 2013

Ecology and Evolution

Review Sept. 2013

Release of genetically engineered insects: a framework to identify potential ecological effects

Aaron S. David*, Joe M. Kaser' Amy C. Morey' Alexander M. Roth' David A. Andow



Passenger pigeon workshop

Evolutionary and Ecological Perspectives on Synthetic Biology

Engineering Biodiversity

Ethical, Legal, and Social Implications (ELSI)

- ELSI concerns associated with synthetic biology include
  - Patenting and the Creation of Monopolies
  - Trade and Global Justice
  - Creating Artificial Life
- These issues are connected with cultural values that are very deep that concern notions of fairness and religious belief
  - There are multiple stakeholder groups with divergent cultural frameworks that underlie these notions and beliefs
  - Negotiating these differences requires ongoing stakeholder involvement that includes
    - public engagement, open access, and transparency
    - Socio-technical integrative collaboration

Socio-Technical Integrative Collaboration

- The scientific community must take, and be seen to be taking, a lead in debating the implications of their research and engaging with broader society around the issues raised by synthetic biology

- Partnership with social scientists and ethicists should be pursued as a highly effective way of understanding and addressing critical issues

- BIO/MCB and SBE/SES are encouraging the organization of a workshop that will involve scientists/engineers working in synthetic biology together with social-scientists/humanists to work together in an integrative manner

Public Engagement

- Experiments in upstream engagement and public consultation should be undertaken to provide a valuable channel for helping negotiate the boundaries of what is socially acceptable science
- It is vital to recognize the importance of maintaining public legitimacy and support
  - scientific research must not get too far ahead of public attitudes
  - potential applications should demonstrate clear social benefits
- Finally, the potential benefits of the technology must not be overhyped for this risks creating
  - excessive public anxiety
  - unrealistic hopes

Questions for BIO AC

- Which additional areas of synthetic biology should we catalyze?
- How can we communicate the potential of SynBio to the external community?
- Are there other areas at the intersection of life sciences with physical and engineering sciences that we should emphasize in our portfolio?

- Additional slides

Economic Considerations

- The global market for synthetic biology has been estimated (in 2012) to exceed $10bn in 2016
  - Some predictions are as high as $100bn
  - Growth rate of 45% per year
  - The US has around 70 products nearing market
- The market for GM foods (earlier but related technology) has seen substantial losses
  - Former Government Chief Scientific Advisor, Sir David King, estimated (in 2007) that the controversy over GM food crops cost the UK economy a billion pounds ($1.66bn) a year in lost revenue
  - There are harsh restrictions on GM crops in the EU, and substantial GM crop controversies in India and Africa

Environment, Health, and Safety

- Synthetic biology has tremendous potential to advance our knowledge of the biological realm as well as to bring about a number of new technologies including
  - Energy sources,
  - Biodegradable plastics,
  - Tools to clean up environments,
  - Ways of manufacturing medicines
- However, it could also result in technologies that adversely affect the health of persons or the environment
  - Environmental contamination through inadvertent or uncontrolled release of synthetic organisms
  - Health hazards such as new diseases, pathogens, and viruses
  - Safety/security threats due to bioterrorist exploitation of such hazards