

#Intro. to Bioengineering
include <biology.h>



Growing is Forever by Jesse Rosten

<https://vimeo.com/18305022>

Imagine a bioengineer...

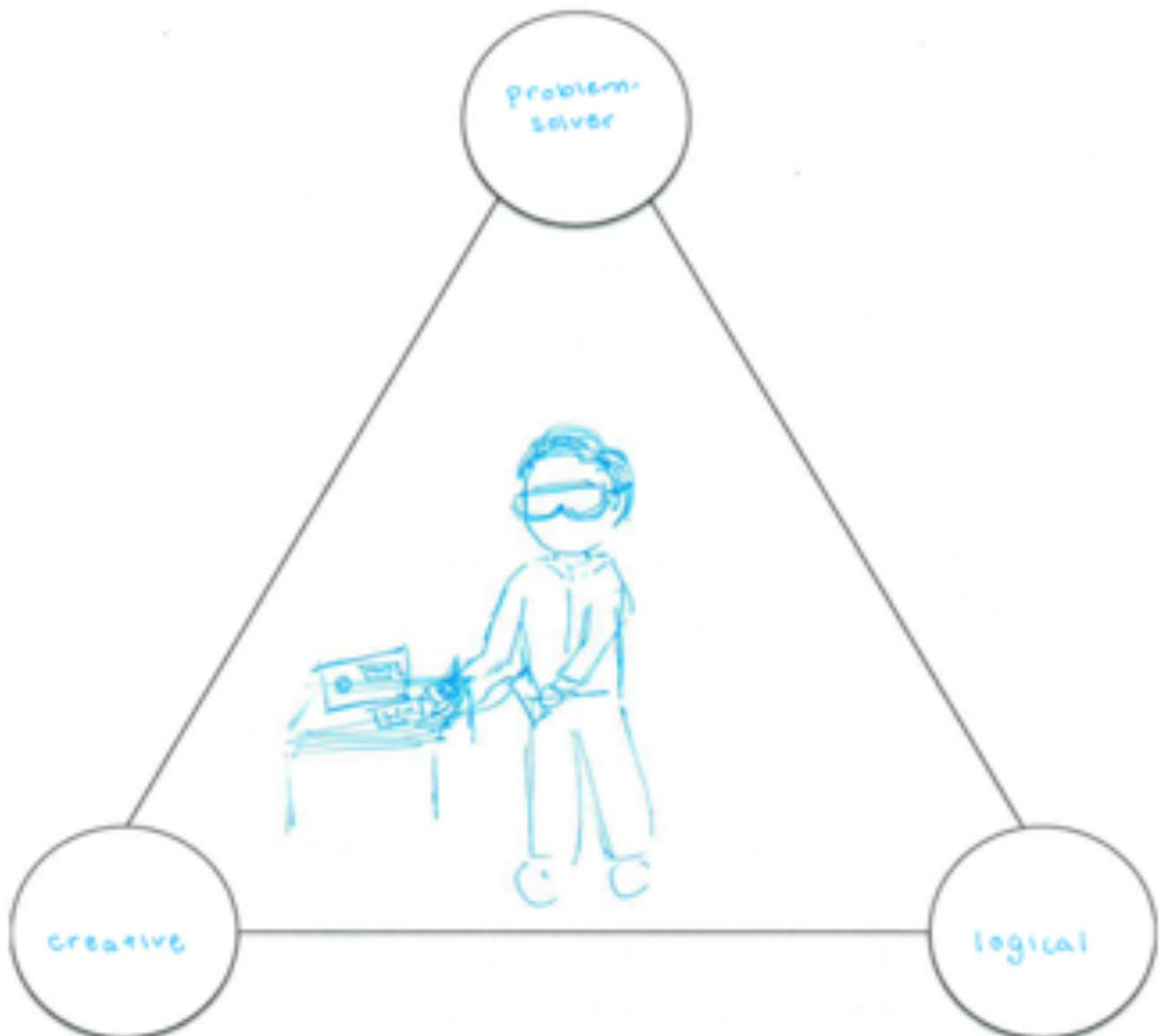
1. Draw a sketch of your bioengineer
2. Write down three words to describe your bioengineer

Imagine a bioengineer...

3. Find a neighbor, pair up.
4. Compare your bioengineers.
5. Note what is the same or different.
6. On a scale of 0 to 100 (totally different / same)
how different/alike are your bioengineers?

Imagine a bioengineer...

Imagine an Engineer:



What is a bioengineer?





Alexis Seymour



Marcos Torres



Brandon Walker
(Head TA)



Jonathan Calles
(Digital TA)



Kaisha Benjamin
(Quartermaster TA)



Alex Ferris



Siavash Ahrar



Veronica Brand



Micheal Specter



Jan Liphardt



Drew Endy

What is our class about?

Students successfully completing BIOE/ENGR.80 will have a working understanding for how to approach the systematic engineering of living systems to benefit all people and the planet.

Our main goals for the quarter are:

- (1) to help you learn ways of thinking about engineering living matter,
- (2) for you to become more capable of learning and explaining bioengineering to yourself and others,
- (3) for you to be capable of leading discussions of the broader ramifications of engineering the living world.

How does our class work?

There are two in-class sessions (Monday and Wednesday) and one lab or activity (Friday).

The in-class sessions are a mix of active learning and short lectures.

In a typical week, you will read the pre-class material, attend the in-class sessions and activity, and do a set set.

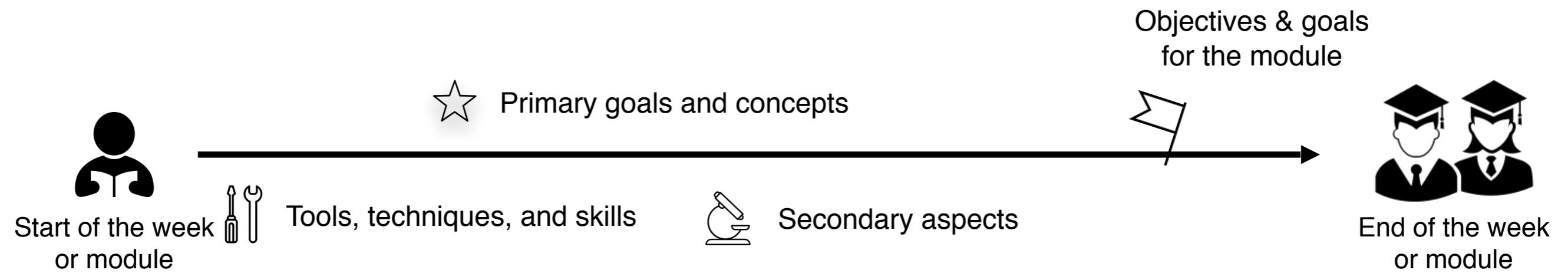
The course grade is based on your psets (70%), in-class puzzles (15%), and your final group project (15%).

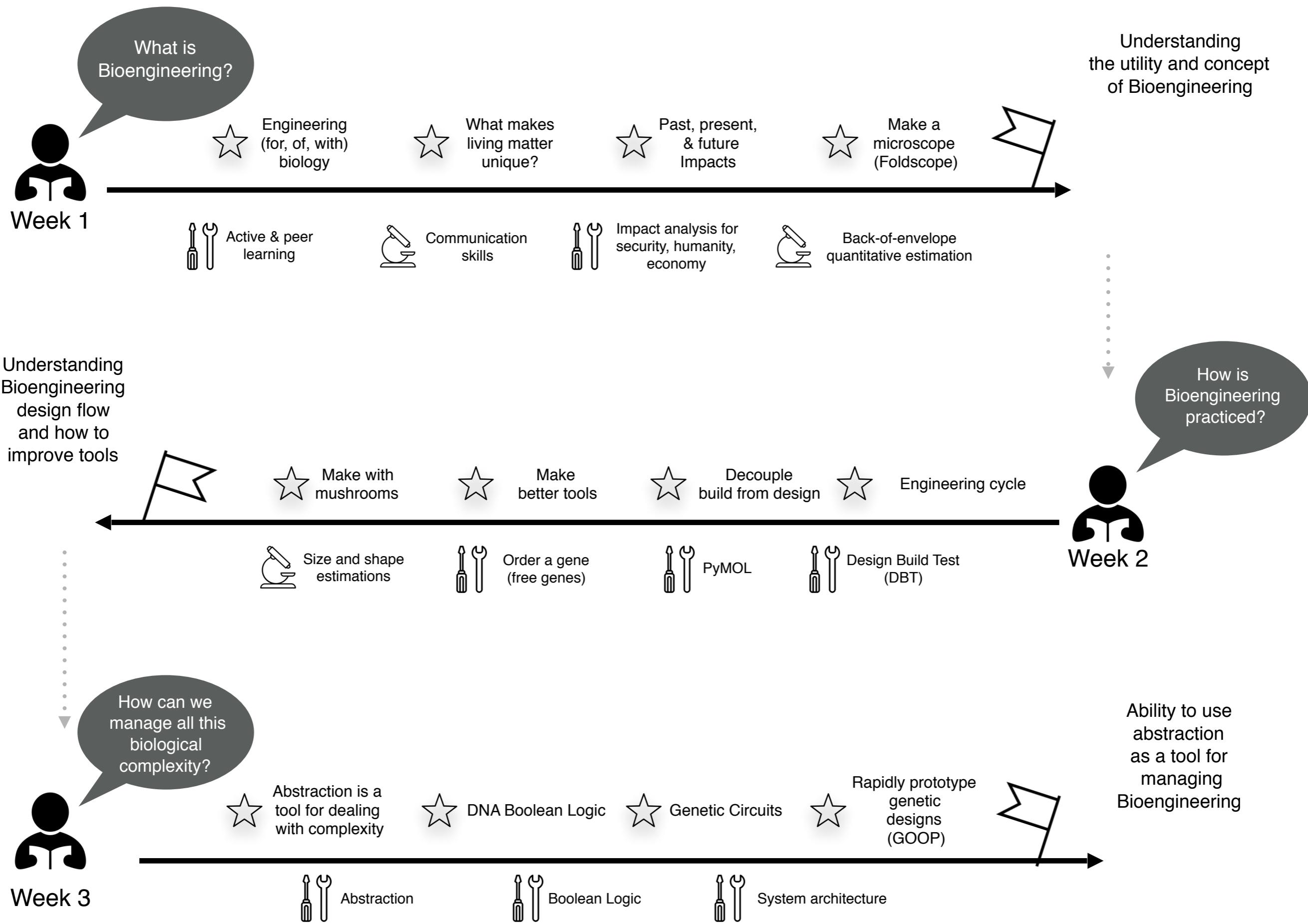
Bioengineering is a fast moving area, with big advances (and controversies) every few weeks, so keep your eyes open and let us all know when you learn about things outside of class.

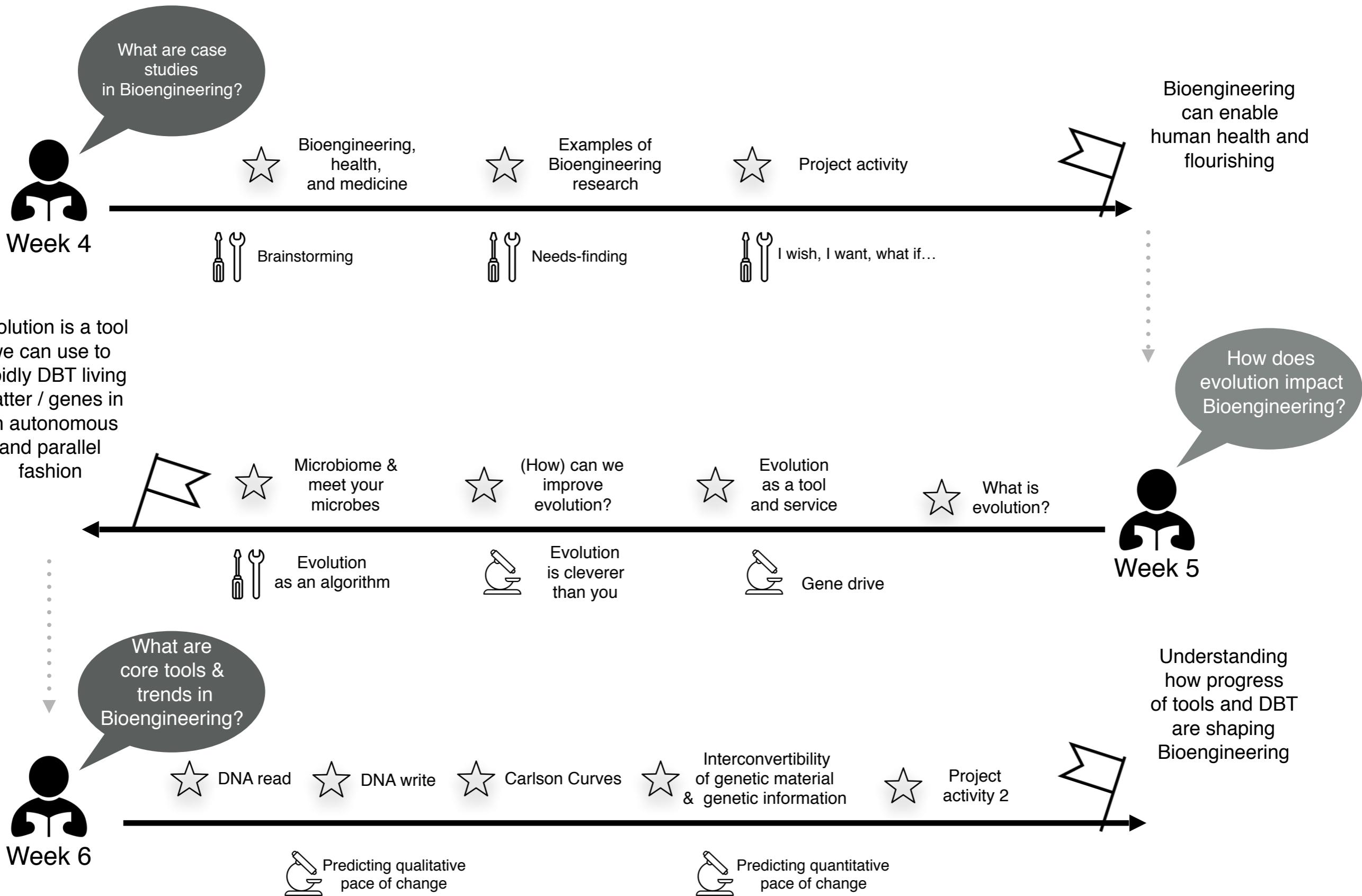
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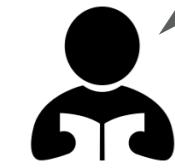
#include OAE

#include preclass & active learning & participate!









Week 7

What are priorities
in Bioengineering?



(How) can we escape
the halfpipe
of doom & salvation?



Hobbes vs
hobbyist



Political Theory
& bioengineering

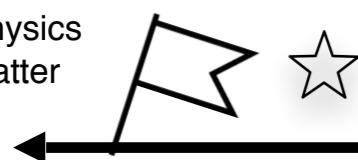


Gene Drives
activity



Apply Political
theory
to answer
Bioengineering
challenges

Understand
how to grow,
build, and control
patterns
using the physics
of living matter



Dancing
droplets
activity



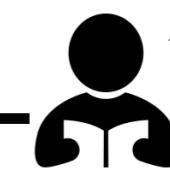
Implicit and explicit
storage of patterns



Gradients and
cellular operations
result in patterns



Diffusion happens!



Week 8

What physics
underlie cellular
biology?



Dancing droplets



Estimate
diffusion



Biased
random walks



Simple rules
can cause
complex patterns

There is more
to engineering
organisms
than just
building genes

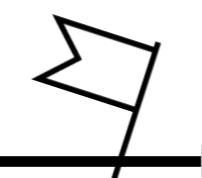


Week 9

Why is scaling
Bioengineering
hard?

The Humpty
Dumpty dilemma

Minimal
genome
mysteries



Read literature
at the frontier of
Bioengineering



Role of Bioengineering
in discovery
(149 genes)



Estimate
genome size

What future
do we wish
to realize with
Bioengineering?



Introduce others
to Bioengineering
(group project)

Can we enable
natural flourishing
with Bioengineering?

Why engineer biology? &
How much can we make
with biology?



Week 10

```
#include <domestication.h>
```



watermelon



eggplant



carrot



banana



corn



broccoli

```
#include <breeding.h>
```



HHMI

```
#include <landuse.h>
```



```
#include
<geneticengr.h>
```

- [54] PROCESS FOR PRODUCING BIOLOGICALLY FUNCTIONAL MOLECULAR CHIMERAS
 [75] Inventors: Stanley N. Cohen, Portola Valley; Herbert W. Boyer, Mill Valley, both of Calif.
 [73] Assignee: Board of Trustees of the Leland Stanford Jr. University, Stanford, Calif.
 [21] Appl. No.: 1,021
 [22] Filed: Jan. 4, 1979

Related U.S. Application Data

- [63] Continuation-in-part of Ser. No. 959,288, Nov. 9, 1978, which is a continuation-in-part of Ser. No. 687,430, May 17, 1976, abandoned, which is a continuation-in-part of Ser. No. 520,691, Nov. 4, 1974.
 [51] Int. Cl. C12P 21/00
 [52] U.S. Cl. 435/68; 435/172;
 435/231; 435/183; 435/317; 435/849; 435/820;
 435/91; 435/207; 260/112.5 S; 260/27R; 435/212
 [58] Field of Search 195/1, 28 N, 28 R, 112,
 195/78, 79; 435/68, 172, 231, 183

[56] References Cited

U.S. PATENT DOCUMENTS

- 3,813,316 5/1974 Chakraberty 195/28 R

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- Morrow et al., Proc. Nat. Acad. Sci. USA, vol. 69, pp. 3365-3369, Nov. 1972.
 Morrow et al., Proc. Nat. Acad. Sci. USA, vol. 71, pp. 1743-1747, May 1974.
 Hershfield et al., Proc. Nat. Acad. Sci. USA, vol. 71, pp. 3455 et seq. (1974).
 Jackson et al., Proc. Nat. Acad. Sci. USA, vol. 69, pp. 2904-2909, Oct. 1972.

Mertz et al., Proc. Nat. Acad. Sci. USA, vol. 69, pp. 3370-3374, Nov. 1972.

Cohen, et al., Proc. Nat. Acad. Sci. USA, vol. 70, pp. 1293-1297, May 1973.

Cohen et al., Proc. Nat. Acad. Sci. USA, vol. 70, pp. 3240-3244, Nov. 1973.

Chang et al., Proc. Nat. Acad. Sci. USA, vol. 71, pp. 1030-1034, Apr. 1974.

Ulrich et al., Science vol. 196, pp. 1313-1319, Jun. 1977.

Singer et al., Science vol. 181, p. 1114 (1973).

Itakura et al., Science vol. 198, pp. 1056-1063 Dec. 1977.

Komaroff et al., Proc. Nat. Acad. Sci. USA, vol. 75, pp. 3727-3731, Aug. 1978.

Chemical and Engineering News, p. 4, May 30, 1977.

Chemical and Engineering News, p. 6, Sep. 11, 1978.

Primary Examiner—Alvin E. Tanenholz

Attorney, Agent, or Firm—Bertram I. Rowland

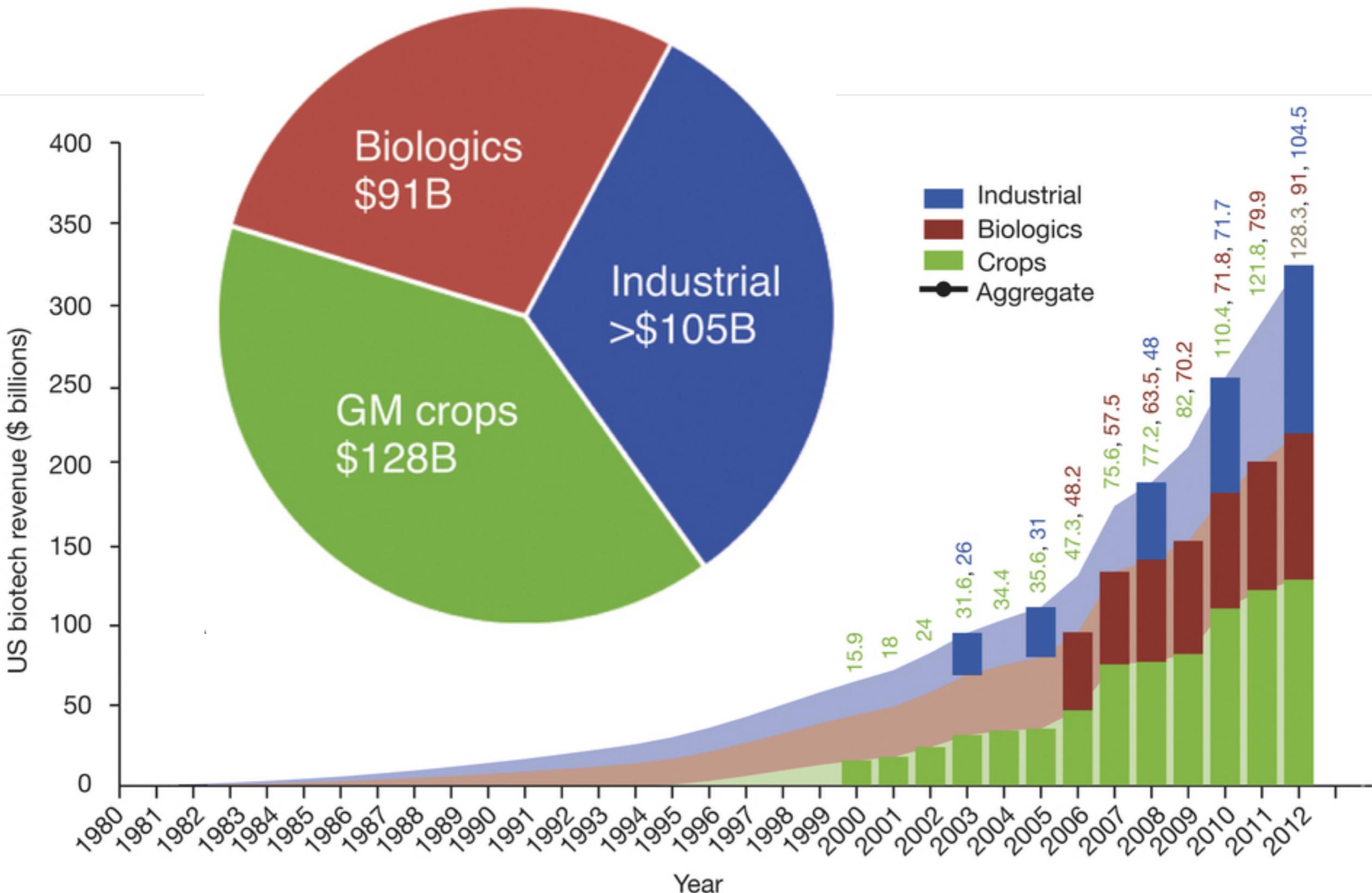
[57] ABSTRACT

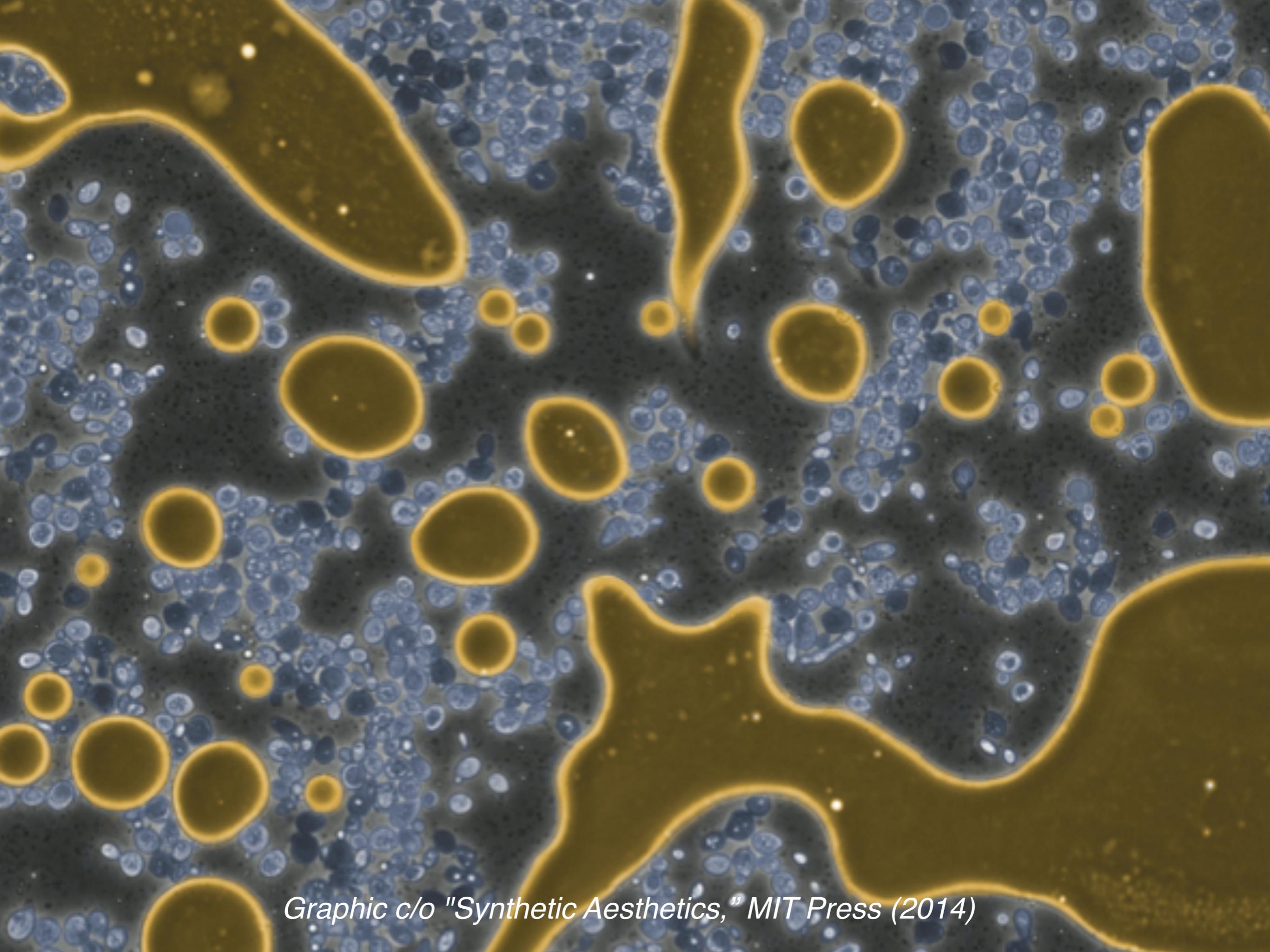
Method and compositions are provided for replication and expression of exogenous genes in microorganisms. Plasmids or virus DNA are cleaved to provide linear DNA having ligatable termini to which is inserted a gene having complementary termini, to provide a biologically functional replicon with a desired phenotypic property. The replicon is inserted into a microorganism cell by transformation. Isolation of the transformants provides cells for replication and expression of the DNA molecules present in the modified plasmid. The method provides a convenient and efficient way to introduce genetic capability into microorganisms for the production of nucleic acids and proteins, such as medically or commercially useful enzymes, which may have direct usefulness, or may find expression in the production of drugs, such as hormones, antibiotics, or the like, fixation of nitrogen, fermentation, utilization of specific feedstocks, or the like.

14 Claims, No Drawings

Best personal regards
Herb Boyer
Stan Cohen

Genetically Engineered U.S. Domestic Product (2012)



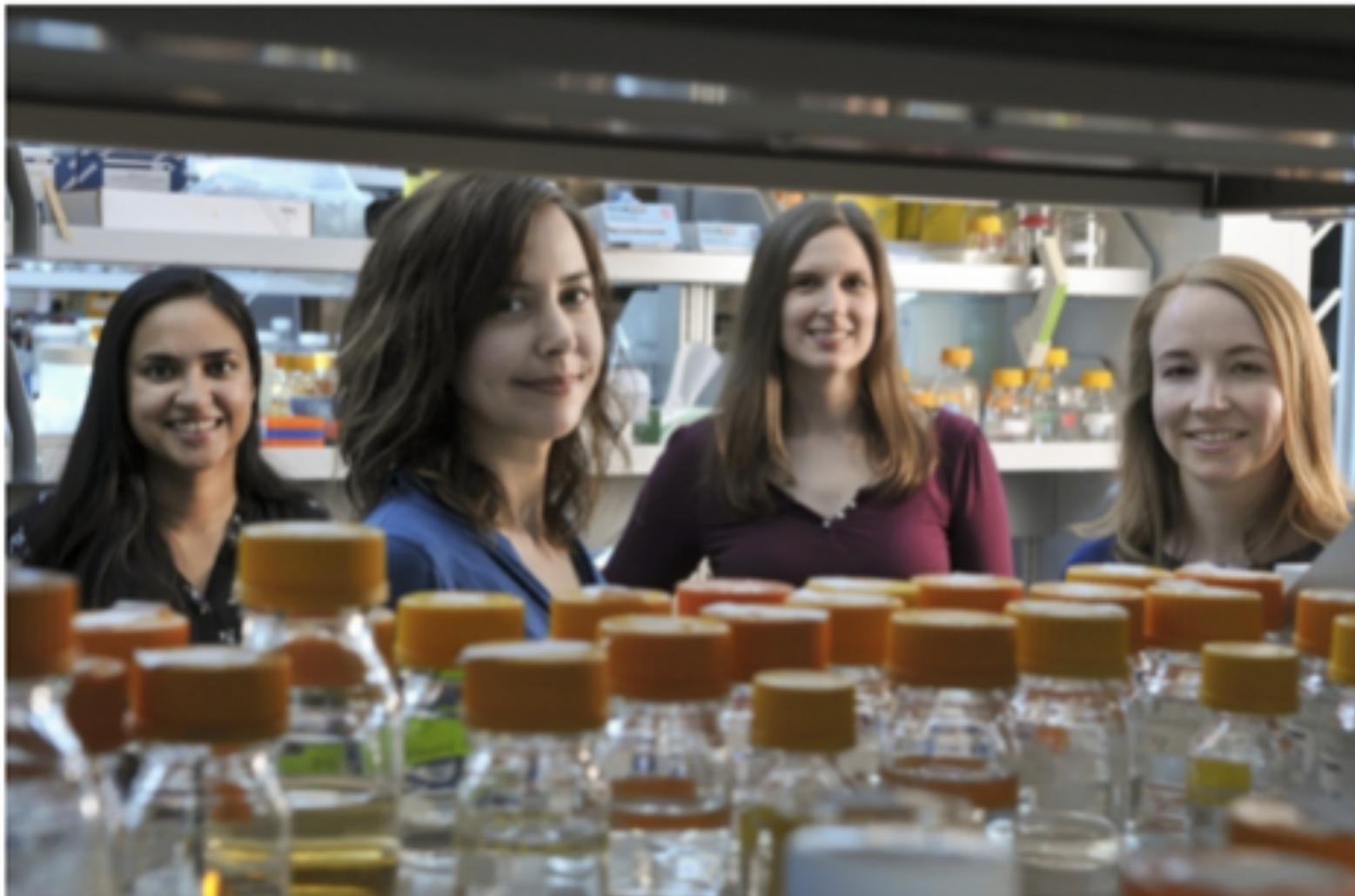


Graphic c/o "Synthetic Aesthetics," MIT Press (2014)

The Washington Post

Scientists engineer yeast to turn sugar into hydrocodone

By Rachel Feltman August 13 [✉](#) [Follow @rachelfeltman](#)



Now, for the first time, researchers at Stanford University have done it from start to finish. In a paper published Thursday in *Science*, they report the successful synthesis of hydrocodone from sugar, thanks to genetically engineered yeast.

ANTHEIA 

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OUR MISSION IS TO
MAKE AND FAIRLY
PROVIDE MEDICINES TO
ALL WHO NEED THEM

Stanford News, 08-13-15

STANFORD RESEARCHERS
GENETICALLY ENGINEER YEAST
TO PRODUCE OPIOIDS

It typically takes a year to produce hydrocodone from plants, but Christina Smolke and colleagues have genetically modified yeast to make it in just a few days.

The technique could improve access to medicines in impoverished nations, and later be used to develop treatments for other diseases.



<http://www.apsnet.org/edcenter/intropp/lessons/viruses/Pages/PapayaRingspotvirus.aspx>

Synthetic Biology

Drew Endy

Fellow of Biology & Biological Engineering, MIT

Patrick Lincoln

Director of Computer Science, SRI, Inc.

Richard Murray

Division Chair, Engineering & Applied Science, Caltech

October 8, 2003

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2003 Synthetic Biology Study

Study Participants

- October 8, 2003
- Drew Endy (chair)
 - Patrick Lincoln (co-chair)
 - Richard Murray (co-chair)
 - Frances Arnold (Caltech)
 - Ralph Baric (UNC)
 - Roger Brent (TMSI)
 - Rob Carlson (U.Washington)
 - Jim Collins (BU)
 - Lynn Conway (Michigan)
 - Ron Davis (Stanford)
 - Mita Desai (NSF)
 - Eric Eisenstadt (DARPA)
 - Stephanie Forrest (U.New Mexico)
 - Seth Goldstein (CMU)
 - Homme Hellinga (Duke)
 - Tom Kalil (UC Berkeley)
 - Jay Keasling (UC Berkeley)
 - Doug Kirkpatrick (DARPA)
 - Tom Knight (MIT)
 - Bill Mark (SRI)
 - John Mulligan (Blue Heron)
 - Radhika Nagpal (MIT/Harv)
 - Carl Pabo (Sangamo)
 - Randy Rettberg (MIT)
 - Pam Silver (Harvard)
 - Brad Smith (Johns Hopkins)
 - Christina Smolke (Caltech)
 - Gerry Sussman (MIT)
 - Jack Thorpe (ISAT)
 - Claire Tomlin (Stanford)
 - Jeff Way (Lexigen)
 - Chris Webb (Stanford)
 - Ron Weiss (Princeton)
 - Erik Winfree (Caltech)

Study participants included representatives from universities, industry, government. Participants provided expertise in basic biological research, biological systems modeling, DNA synthesis, device analysis & design, assembly, systems analysis & design, computer science, electrical engineering, engineering theory, and biological security. Rich Entlich and other staff provided expert organizational support throughout the study.

The study held three workshops and four executive meetings:

- October 23-24th (2002) at the Beckman Center in Irvine, CA
- March 3-4th (2003) at SRI, Inc. in San Mateo, CA (workshop)
- March 24-25th at Norton's Woods in Cambridge, MA (workshop)
- April 10-11th at IDA in Alexandria, VA
- May 29-30th at Caltech in Pasadena, CA (workshop)
- August 18-22nd at Johnson House in Woods Hole, MA
- October 8th in Alexandria, VA

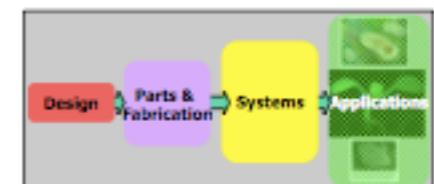
The following related events occurred while the study was underway:

- IBEA contracted by DOE to synthesize a bacterial genome (see <http://www.bioenergyals.org/news.html>)
- MIT conducts Synthetic Biology Lab (1/03) (see <http://web.mit.edu/newsoffice/nr/2003/blinkers.html>)
- Caltech announces Center for Biological Circuit Design (3/03) (see <http://www.eas.caltech.edu/ingenious/win03/cbcd.pdf>)
- EU NEST proposes Synthetic Biology research program (8/03) (see ftp://ftp.cordis.lu/pub/nest/docs/synthetic_biology.pdf)
- Lawrence Berkeley Lab creates Dept. of Synthetic Biology (see <http://www.lbl.gov/LBL-Programs/pbd/news/newsletter/>)

2003 Synthetic Biology Study

Executive Summary

- Biology is a powerful technology
 - Processing information
 - Fabricating materials
 - Converting energy
 - Maintaining & enhancing health
- Biological technology poses a danger on par with any past experience
 - Existing threats
 - Emerging threats
 - Engineered threats
- Synthetic biology advances science & technology while mitigating danger
 - General capability to engineer biological systems
 - Increased speed and scope of response to threats

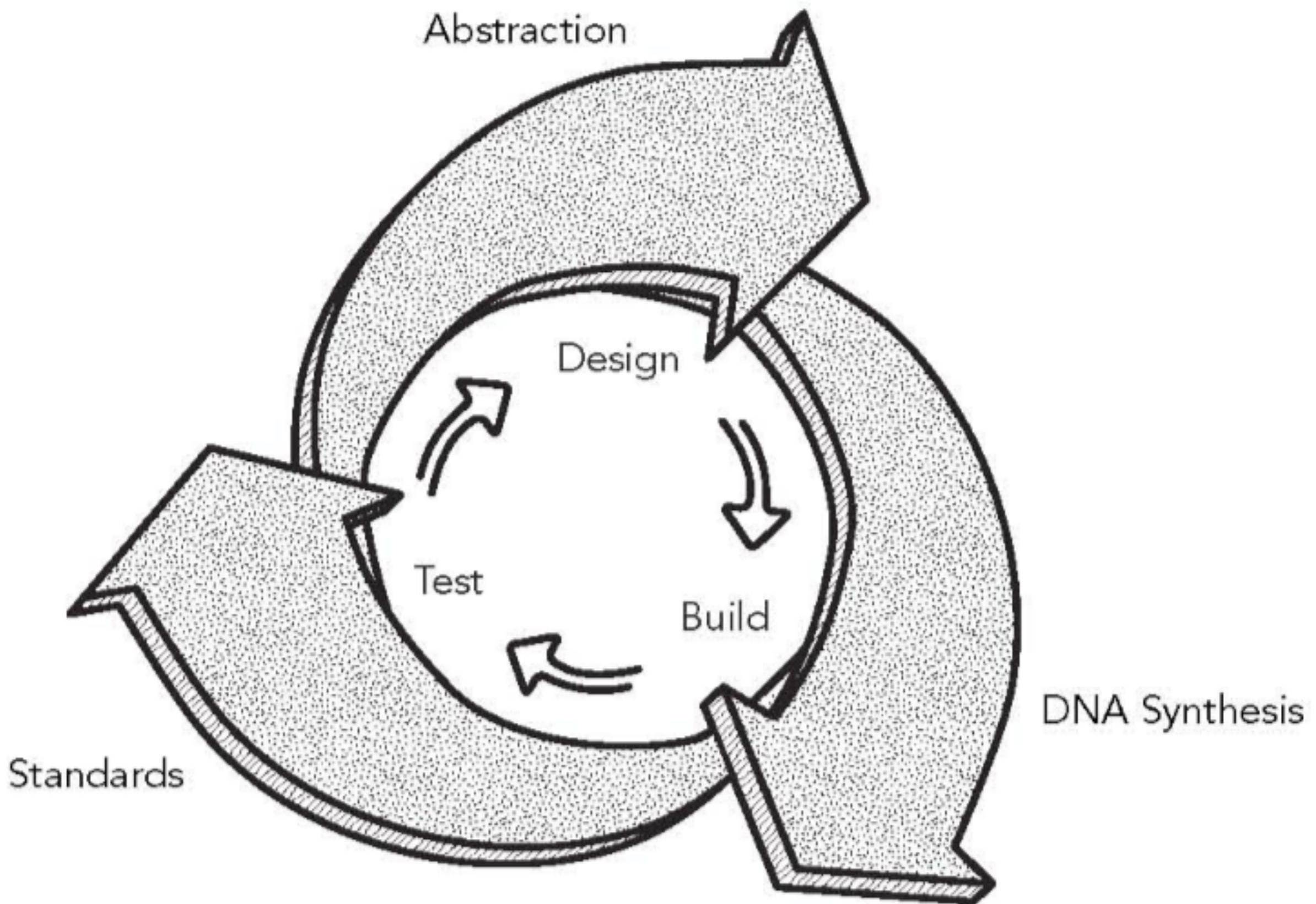


Biology is a technology for processing information, materials, and energy. As a technology platform, biological systems provide access to artifacts and processes across a range of scales (e.g., the ribosome is a programmable nanoassembler, a bamboo shoot can grow 12" per day). Biology also forms the basis for human welfare (e.g., modest amounts of memory and logic, implemented as genetically encoded systems, would directly impact biological research and medicine). However, our ability to deploy biology as a technology and to interact intentionally with the living world is now limited; the charge to our study was to begin to specify enabling technologies that, if developed, would provide a general foundation for the engineering of biology and make routine the creation of synthetic biological systems that behave as predicted.

We focused on improvements to the process of engineering biological systems. Three specific process improvements that should be pursued now are: (i) component standardization, (ii) substrate and component abstraction, and (iii) design and fabrication decoupling.

The development of technologies that enable the systematic engineering of biology must take place within the context of current and future risks due to natural and engineered biological agents. While the development of technologies for engineering biology appears inevitable, and their distribution uncontrollable, the net impact such technologies will have on the creation of biological risk is not known. However, any technology-based increase in risk creation seems likely to at least be offset by a concomitant increase in the speed and scope of response to risks. Consequently, any meaningful strategy for minimizing future biological risk requires that the development of technologies for engineering biology proceeds alongside the development of non-technical approaches to risk management; new training programs and professional societies will serve an important role in creating a cadre of engineers who can work in biology and who will serve as a strategic resource for responding to natural and engineered biological threats.

2003 Synthetic Biology Study



Graphic from "Synthetic Aesthetics" MIT Press (2014)

<http://soefuture.stanford.edu/impact>

How good can we get at engineering living matter?

Pushing the limits of engineered living systems

We can now foresee achieving exponential improvements in our capacity to engineer living systems and thereby more powerfully harnessing life's intrinsic capacity for organizing atoms. A greatly expanded capacity to engineer living matter would allow us to realize precision manufacturing on a global scale, using naturally distributed platforms that operate under normal environmental conditions. Such capacities could be used to:

- Remake our civilization's supply chains by enabling local and sustainable manufacture of high-value products.
- Open new frontiers in medicine wherein engineered cells sense, diagnose, prevent and treat diseases in place.

Bioengineering

#1	Johns Hopkins University (Whiting) Baltimore, MD	4.6
#2 Tie	Emory University-Georgia Tech University	4.6
#2 Tie	University of California—San Diego (Jacobs) La Jolla, CA	4.3
#4 Tie	Duke University (Pratt) Durham, NC	4.1
#4 Tie	Massachusetts Institute of Technology Cambridge, MA	4.0
#4 Tie	Stanford University Stanford, CA	4.0
#4 Tie	University of California—Berkeley Berkeley, CA	3.9
#4 Tie	University of Pennsylvania Philadelphia, PA	3.8
#9 Tie	Rice University (Brown) Houston, TX	3.8
#9 Tie	University of Michigan— Ann Arbor, MI	3.7

Biological Engr.

#1	Purdue University—West Lafayette	4.8
#2 Tie	University of Illinois—Urbana-Champaign Urbana, IL	4.6
#3 Tie	University of Florida Gainesville, FL	4.3
#5 Tie	Cornell University Ithaca, NY	4.0
#5 Tie	University of Illinois—Urbana-Champaign Urbana, IL	4.0
#6 Tie	University of California—Davis Davis, CA	3.9
#7 Tie	North Carolina State University Raleigh, NC	3.8
#8 Tie	Pennsylvania State University— University Park University Park, PA	3.8
#10	University of Nebraska—Lincoln Lincoln, NE	3.7

“Enough is known already of the diverse applications of computing for us to recognize the birth of a coherent body of technique, which I call computer science...Whether computers are used for engineering design, medical data processing, composing music, or other purposes, the structure of computing is much the same.

— George Forsythe, 1961

“Enough is known already of the diverse applications of biology for us to recognize the birth of a coherent body of technique, which we call bioengineering... Whether living matter is used for manufacturing, medicine, abiotic data storage, art, or other purposes, the structure of engineering life is much the same.

— Endy & Liphardt, 2017

Food

Energy

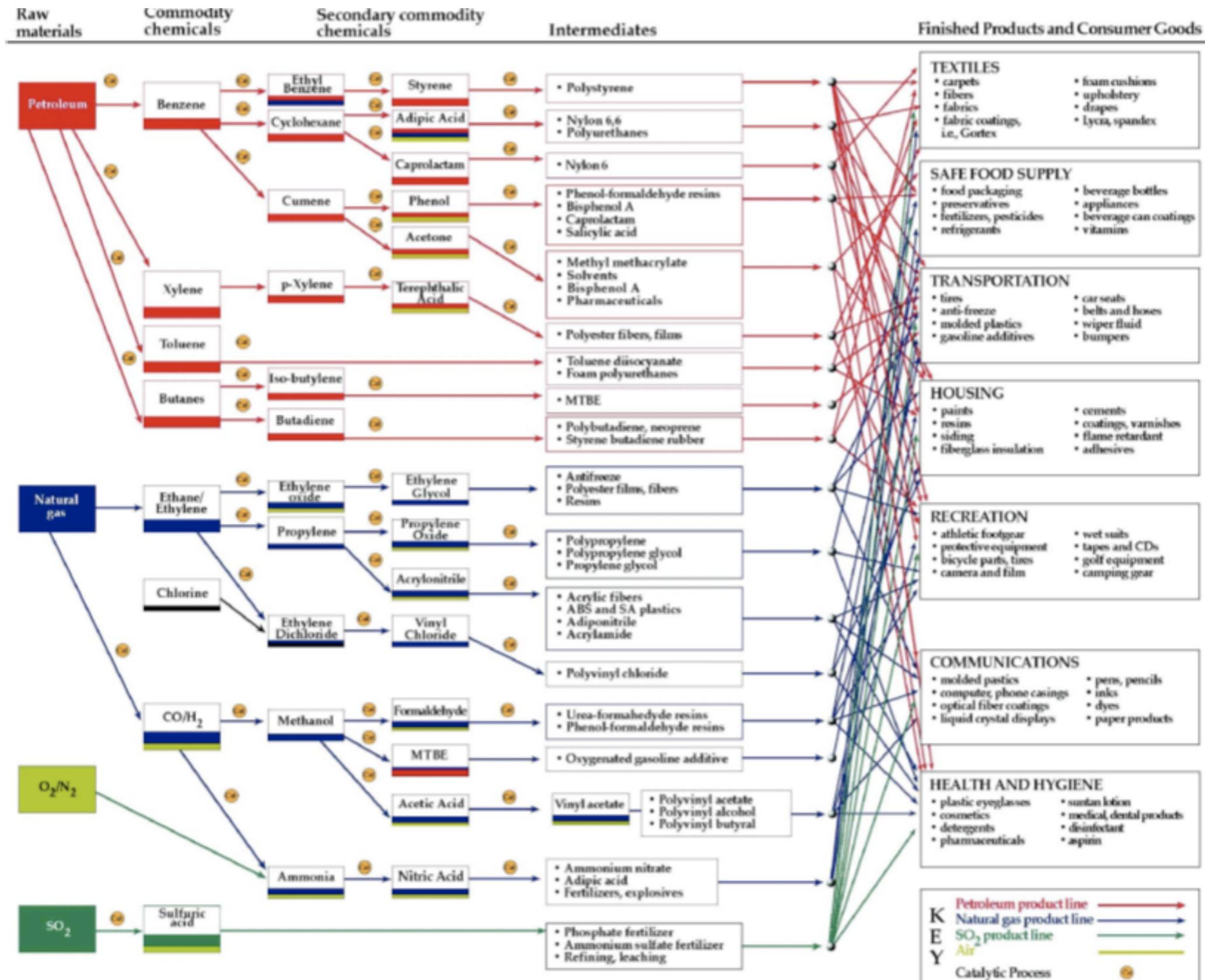
Environment

Agriculture

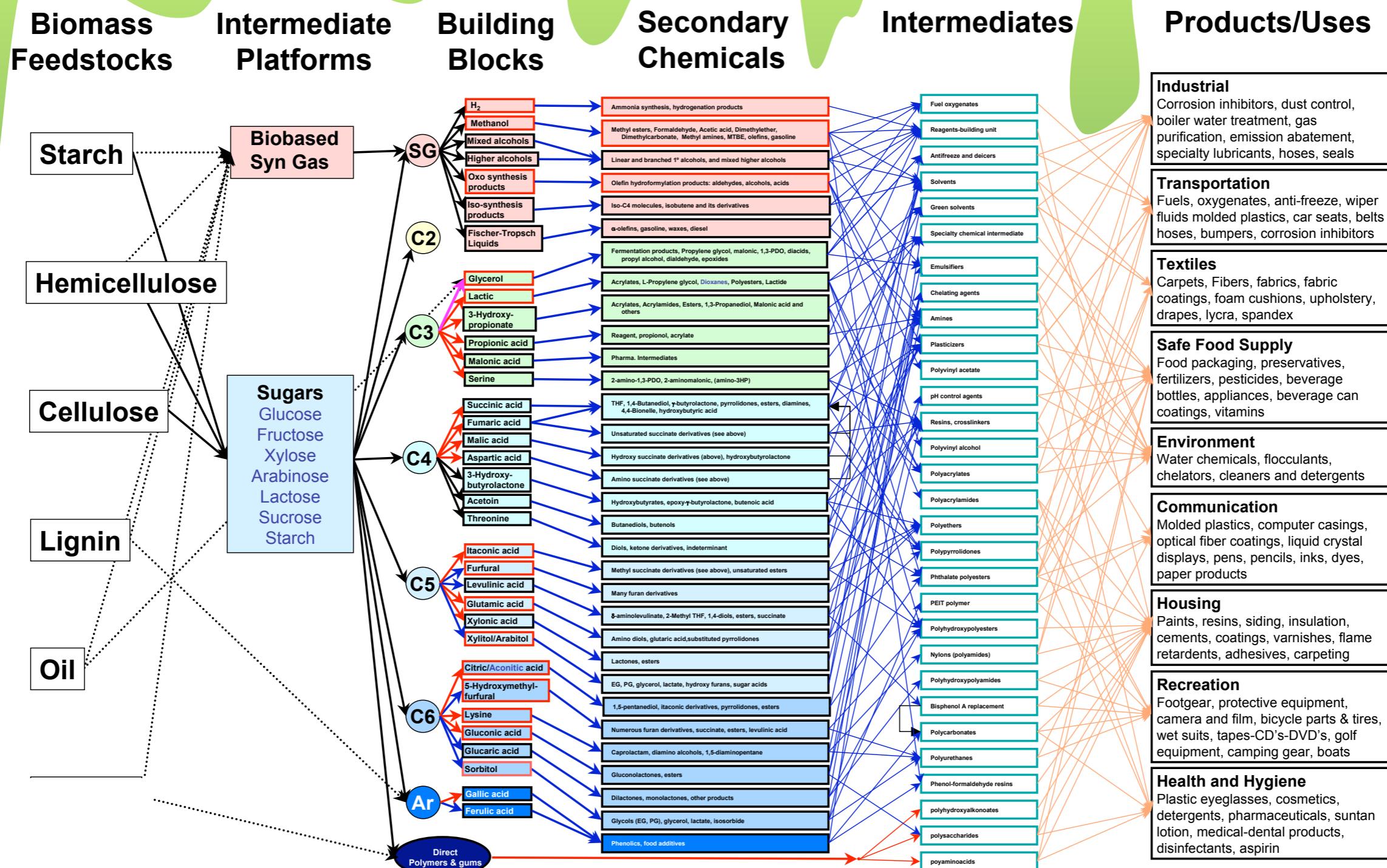
Health

Chemicals & Materials

Security



2004 DOE report lists 120 highvalue chemicals for biomanufacturing





Graphic c/o "Synthetic Aesthetics," MIT Press (2014)

What is our foundation & telos?

Biology is many places

~90 terawatts;
pre-distributed

Reproducing,
growing, &
healing materials

Massively functional

Living ramifications



Provide for all of humanity

Stabilize & recover natural biodiversity

Take infectious & other diseases off the table

Enable a culture of citizenship

Understand life via building



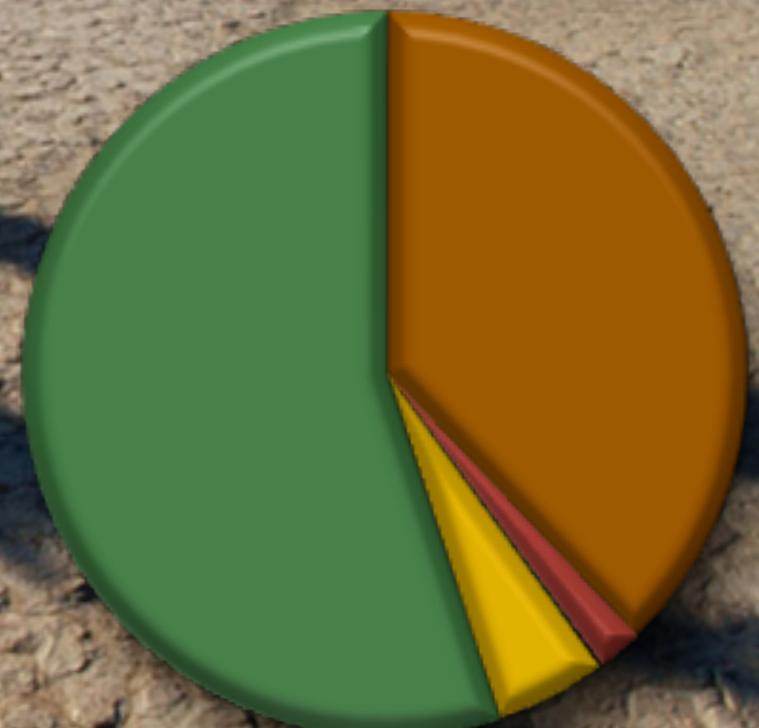
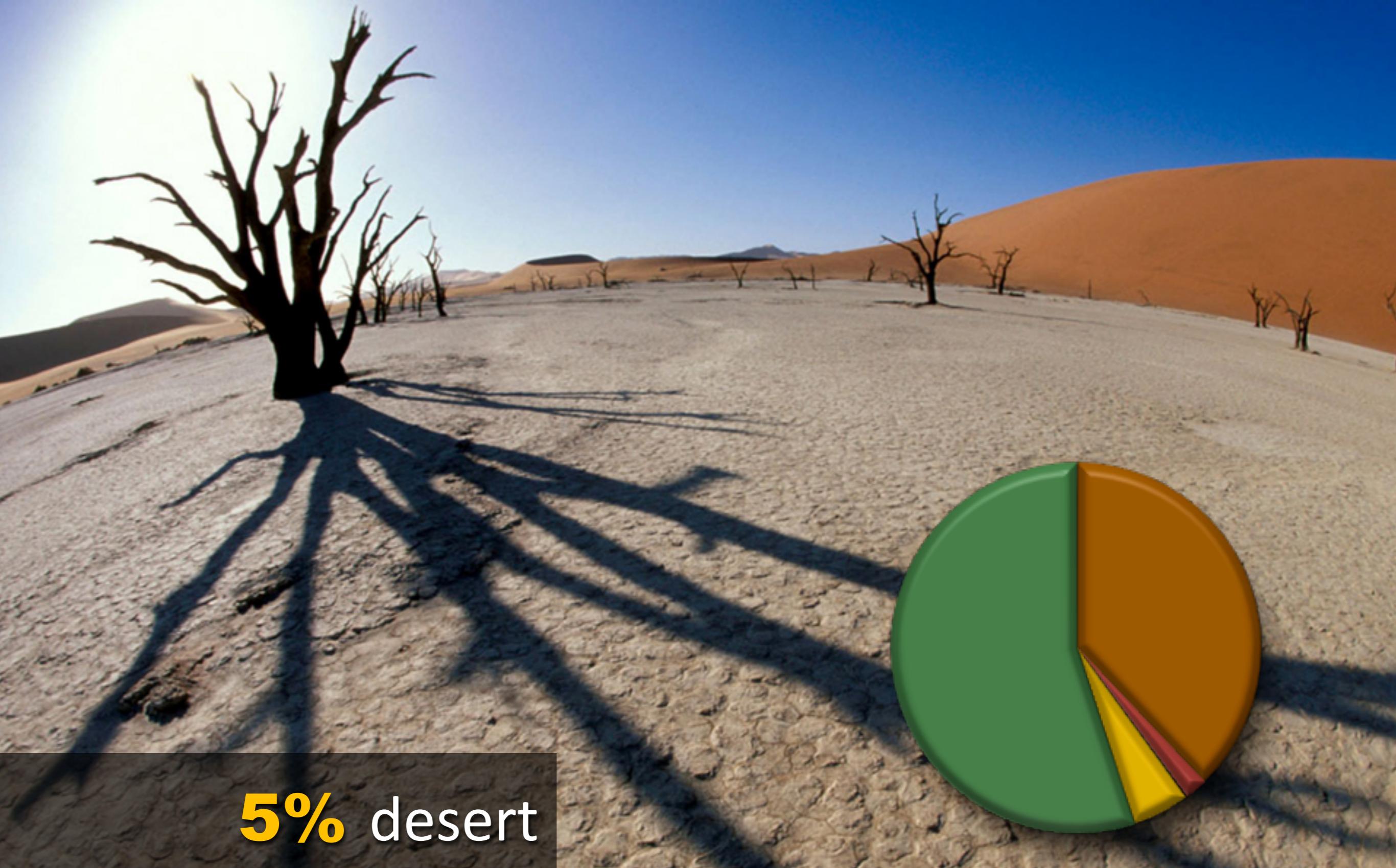
38% for food

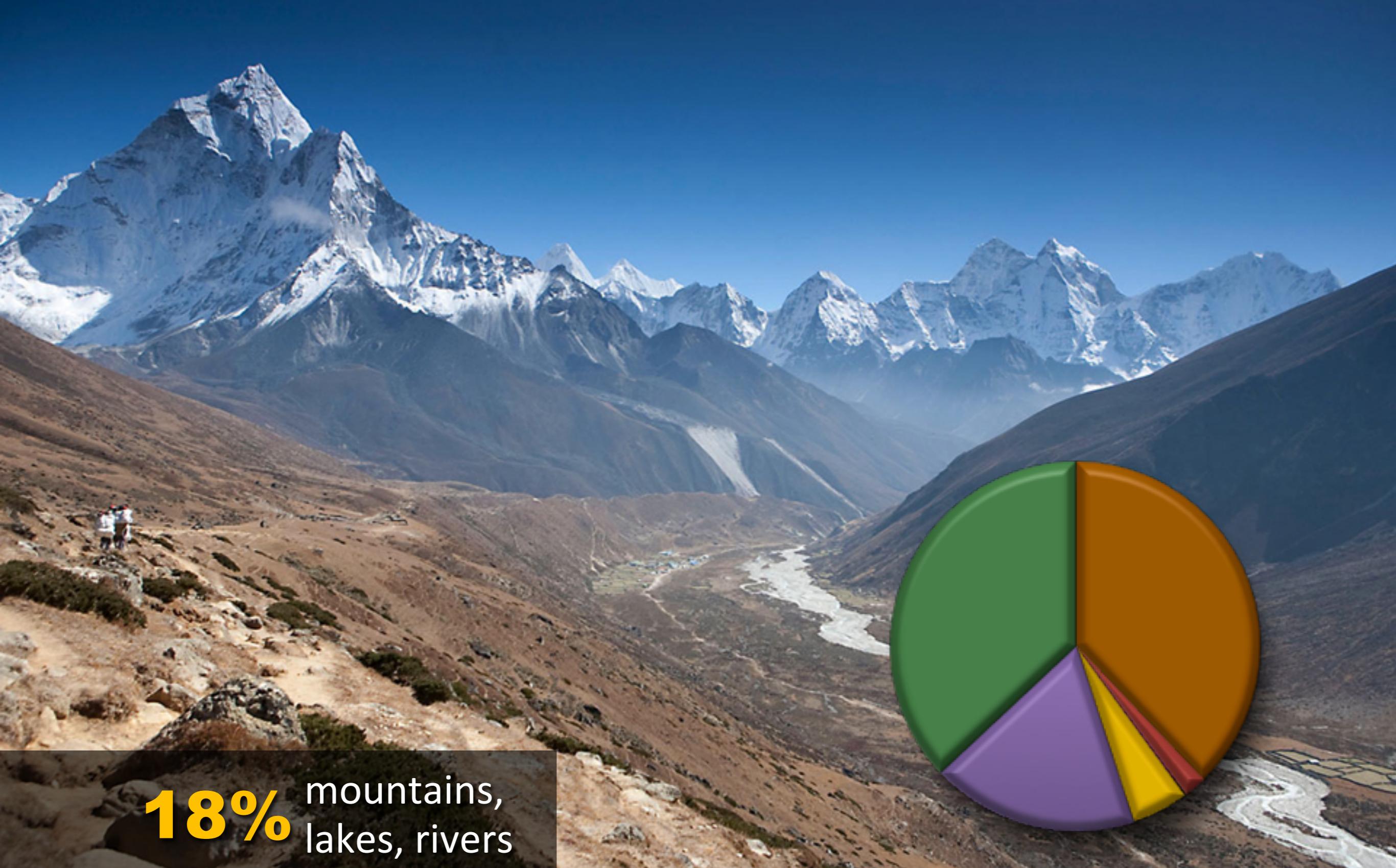
c/o Jon Hoekstra, Chief Scientist, World WildLife Fund





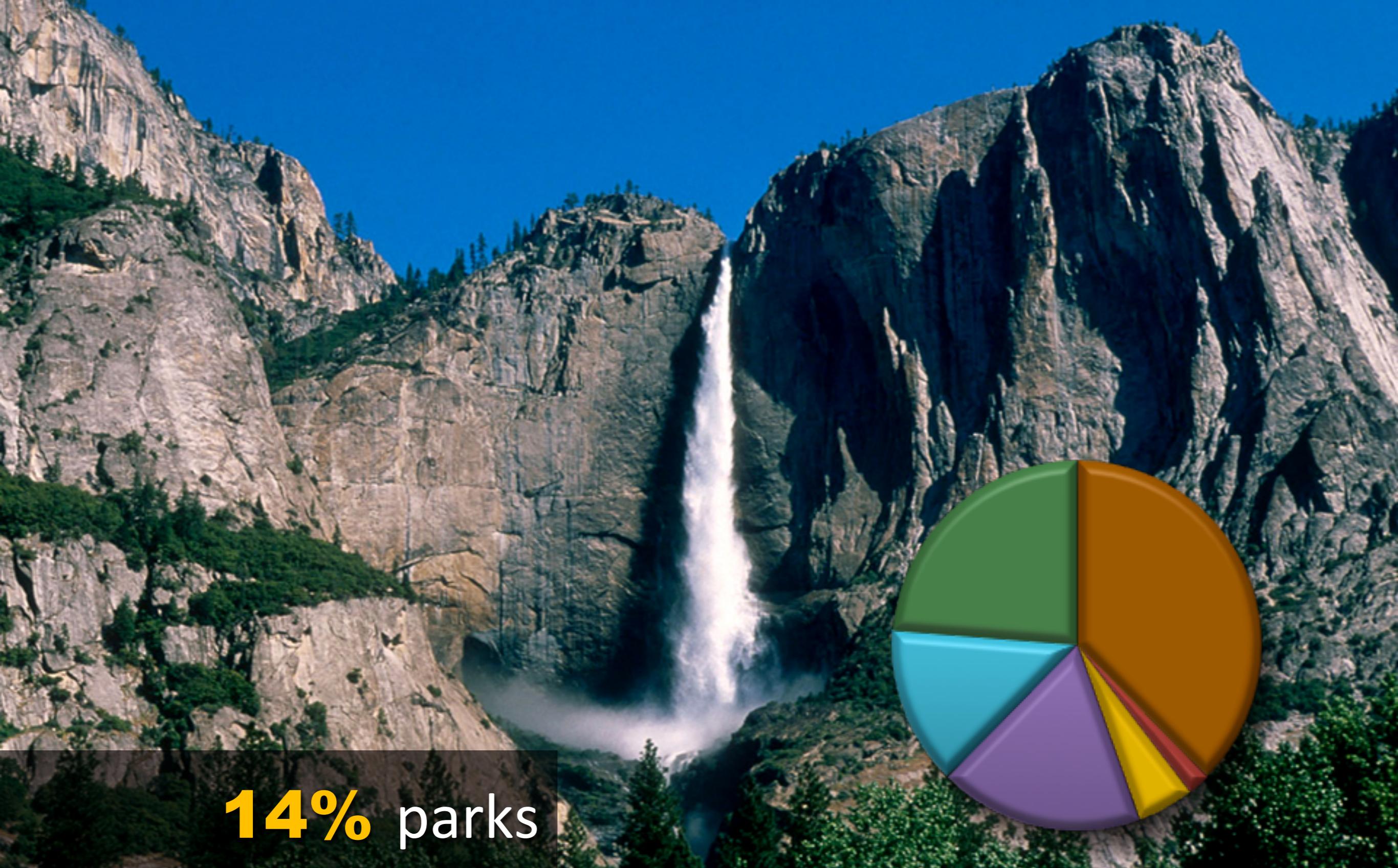
2% cities



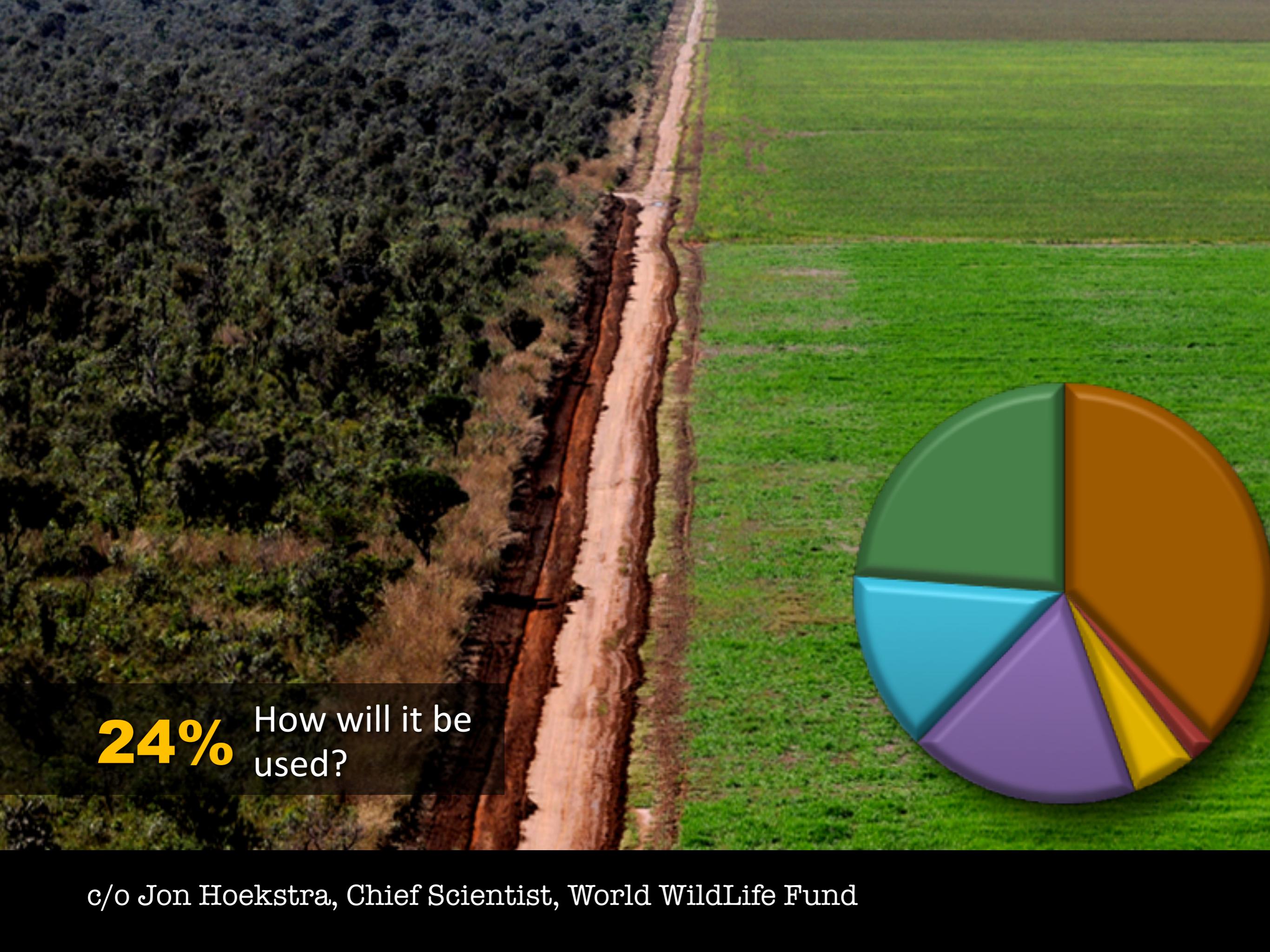


18% mountains,
lakes, rivers





14% parks



24% How will it be used?



What does it mean to engineer biology?

What might & should we wish for?

Can we realize a culture of bioengineering?

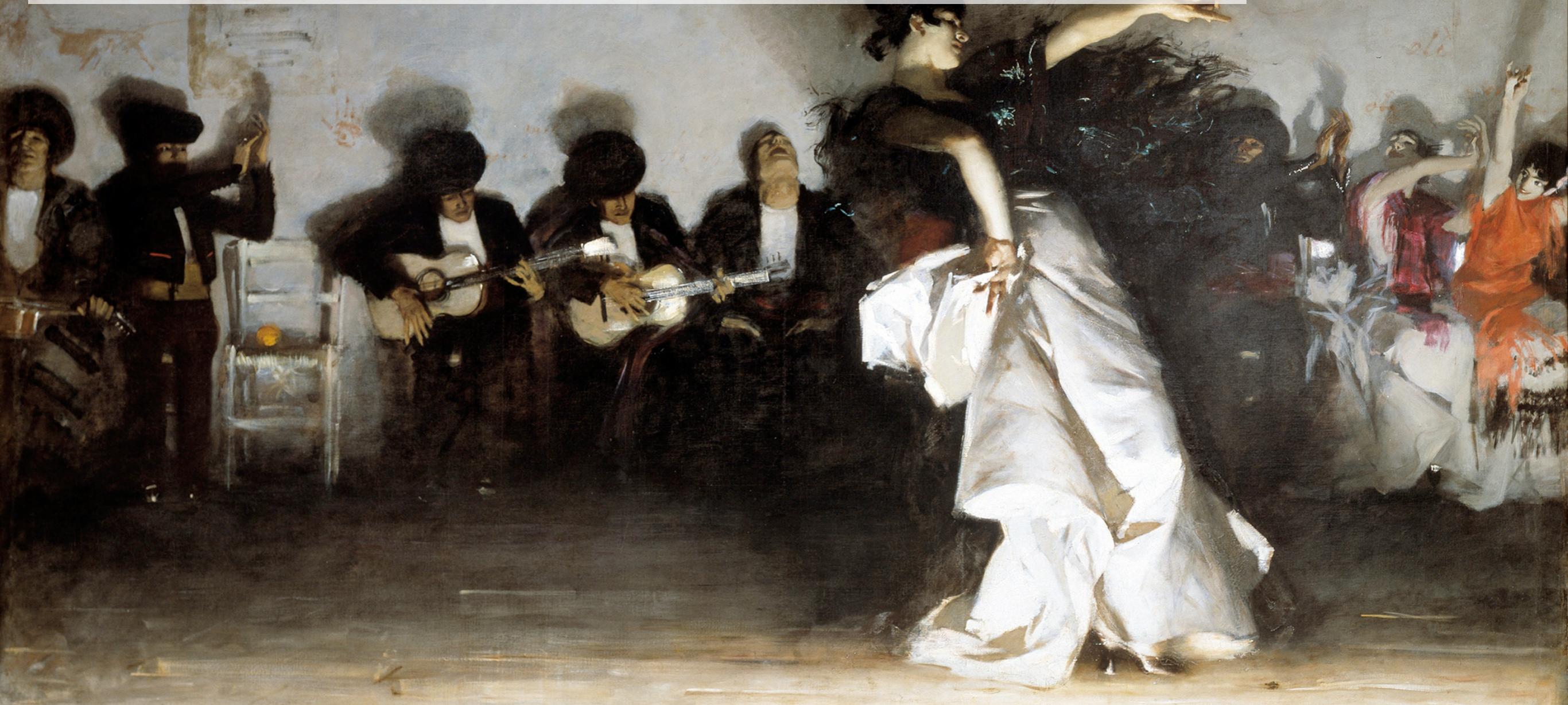




Photo by Roger Lancaster (<http://www.flickr.com/photos/rogeral/5813079061/>); educational fair use



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Welcome!

Introduction to Bioengineering (Engineering Living Matter)

Students successfully completing BIOE/ENGR.80 will have a working understanding for how to approach the systematic engineering of living systems to benefit all people and the planet. Our three main goals for the quarter are (1) to help you learn ways of thinking about engineering living matter, (2) to empower you to explore and do bioengineering starting from DNA, and (3) for you to become more capable of learning and explaining bioengineering to yourself and others, including discussing the broader ramifications of engineering the living world.

On this page[How does our class work?](#)

How does our class work?

There are two in-class sessions (Monday and Wednesday) and one lab or activity (Friday). The in-class sessions are a mix of active learning and short lectures. In a typical week, you will read the preclass material, attend the in-class sessions and activity, and do one problem set. The course grade is based on your problem sets, in-class puzzles (quizzes), and your final group project. Bioengineering is a fast moving area, with big advances (and controversies) every few weeks, so keep your eyes open and let us all know when you learn about things that relate to Bioengineering, genomics, or synthetic biology!