

Introduction to Bioengineering

BIOE/ENGR.80

Stanford University

Spring 2020 Class Slides

Day I
6 April 2020

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Imagine a bioengineer...

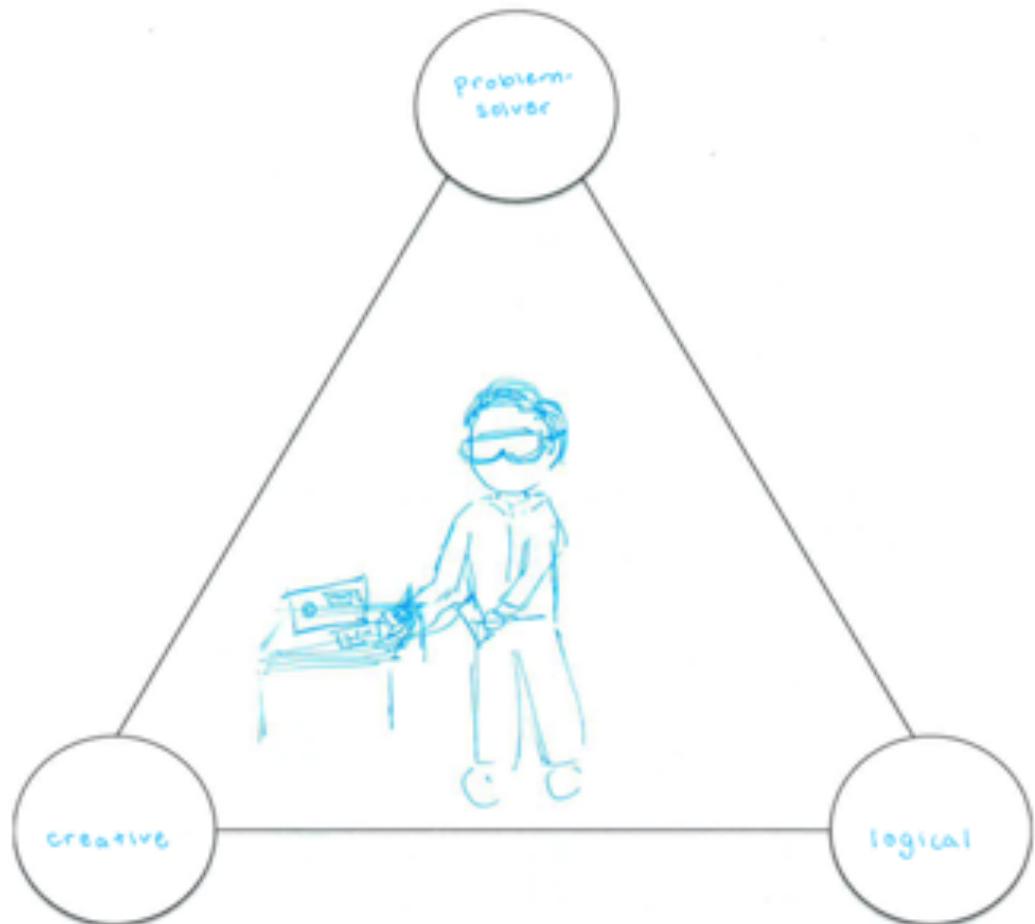
1. Draw a sketch of your bioengineer
2. Write down three words to describe your bioengineer

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
how different or alike are your bioengineers?

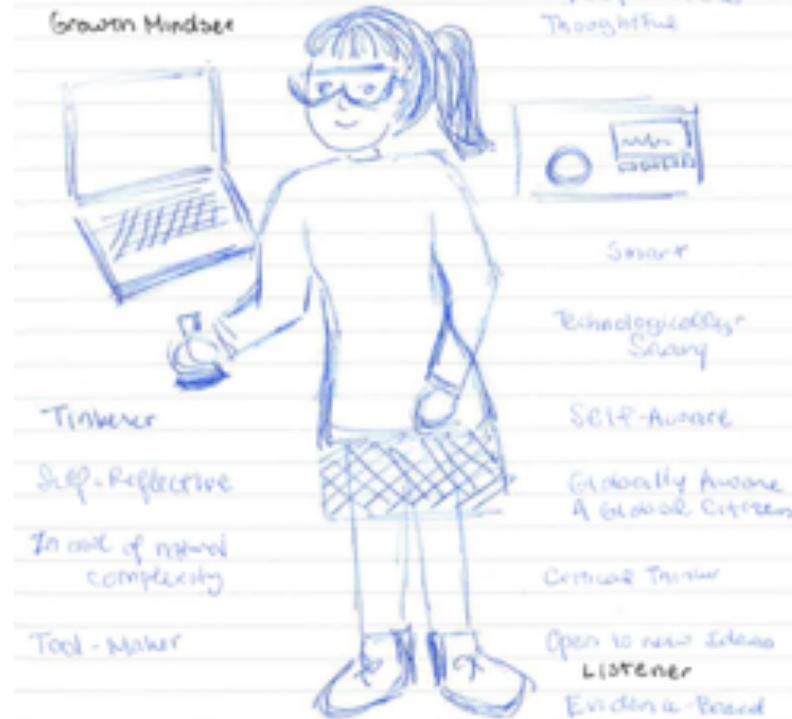
Imagine a bioengineer...

Imagine an Engineer:



What is a bioengineer?

Curious Diverse Problem-Solver
Creative Socially Aware Empathic
Alender Grown Mindset Ethical
Responsibile Thoughtful



Start of Quarter Self-Assessment

Range 0 = I don't know what these words means – zero or near zero knowledge

- 1 = Basic understanding / ability - words are familiar
- 2 = I have done this in class, problem sets, or activities
- 3 = I can confidently and independently accomplish this goal
- 4 = I can help other learners / can fully explain
- 5 = I can improve the approach (method) / can do better

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.
- (4) what do you wish to make true re: bioengr. by 2030?

Grading

The course is designed to operate on a S/NC basis. To earn a S grade a student must satisfy the following two conditions:

- (1) Earn an average grade of 70% or above on the PSETS.
- (2) Earn a cumulative grade of 70% or above on the Final Project (team-based).

Please note your lowest PSET grade will be dropped from your PSET average.

Please also note that we will offer quizzes throughout the quarter that will accrue points. You can apply your cumulative quiz points to reduce the threshold for (1) or (2) to as low as 60%, given sufficient quiz points.

Because of our S/NC grading basis please know that your teaching team is expecting and looking forward to writing very specific and detailed letters of reference, if and as useful to you.

Date

6 April
8 April
10 April

Topic

Why engineer biology?
What makes living matter unique?
How to read a bioengineering research paper

People health (what do people need of bioengineers?)
Planet health (what does everything else “need”?)
Political health (what does it mean to engineer biology at social scales)

Activity – Tools for seeing biology (Foldscope)
Analysis and design of molecules
Analysis and design a genetic systems

27 April	Engineering abstraction in living matter – synthetic genetic logic
29 April	Engineering abstraction in living matter – generic system architecture
1 May	Team Project – Framestorm/brainstorm plus teams rule(s)
4 May	DNA synthesis past, present, and future
6 May	Interconvertibility of genetic matter and information
8 May	Team Project – Story spine plus project priorities
11 May	Molecular diffusion and spontaneous behaviors
13 May	Activity – Dancing droplets
15 May	Programming morphogenesis (could you grow an arm?)

18 May
20 May
22 May

25 May
27 May
29 May

1 June
3 June
5 June

8 June
10 June

Team Project – Future thinking
Evolution as an algorithm
Evolution as a service

No class
Putting it all together – engineering with, of, & for biology
Team Project – Working session

Bioengineering futures related to planet health
Bioengineering futures related to human health
Team Project – Working session

Bioengineering futures related to political health
Closing discussion and charge

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



watermelon



eggplant



carrot



banana



corn



broccoli

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



HHMI

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



#include
<geneticengr.h>

United States Patent [19]

Cohen et al.

[11] 4,237,224

[45] Dec. 2, 1980

[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 Chakrabarty 195/28 R

OTHER PUBLICATIONS

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

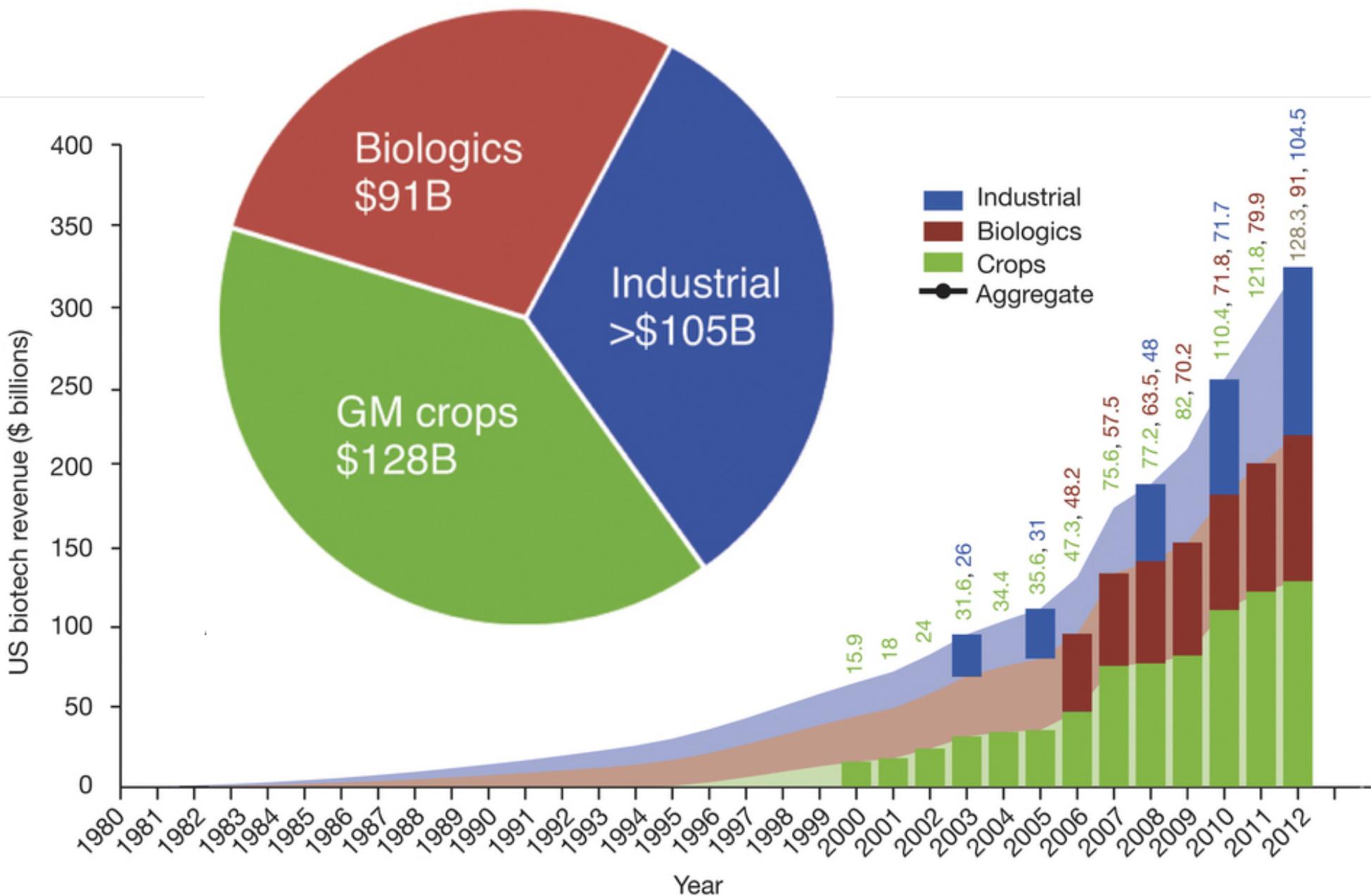
[57] ABSTRACT

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 bio-
logically functional replicon with a desired phenotypic
property. The replicon is inserted into a microor-
ganism cell by transformation. Isolation of the transfor-
mants 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.

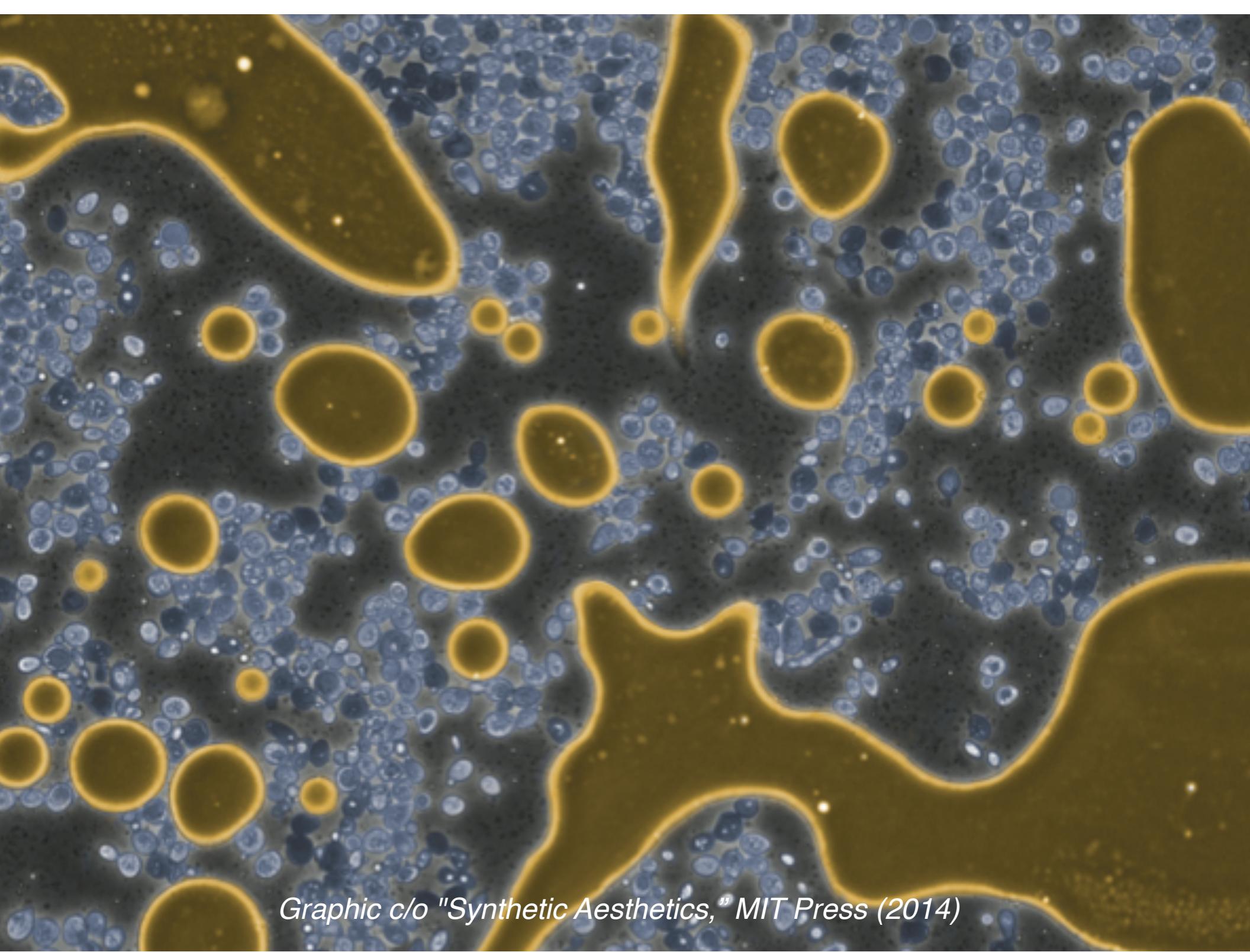
14 Claims, No Drawings

Best personal regards
Herb Boyer
Stan Cohen

Genetically Engineered U.S. Domestic Product (2012)



<http://www.nature.com/nbt/journal/v34/n3/abs/nbt.3491.html>

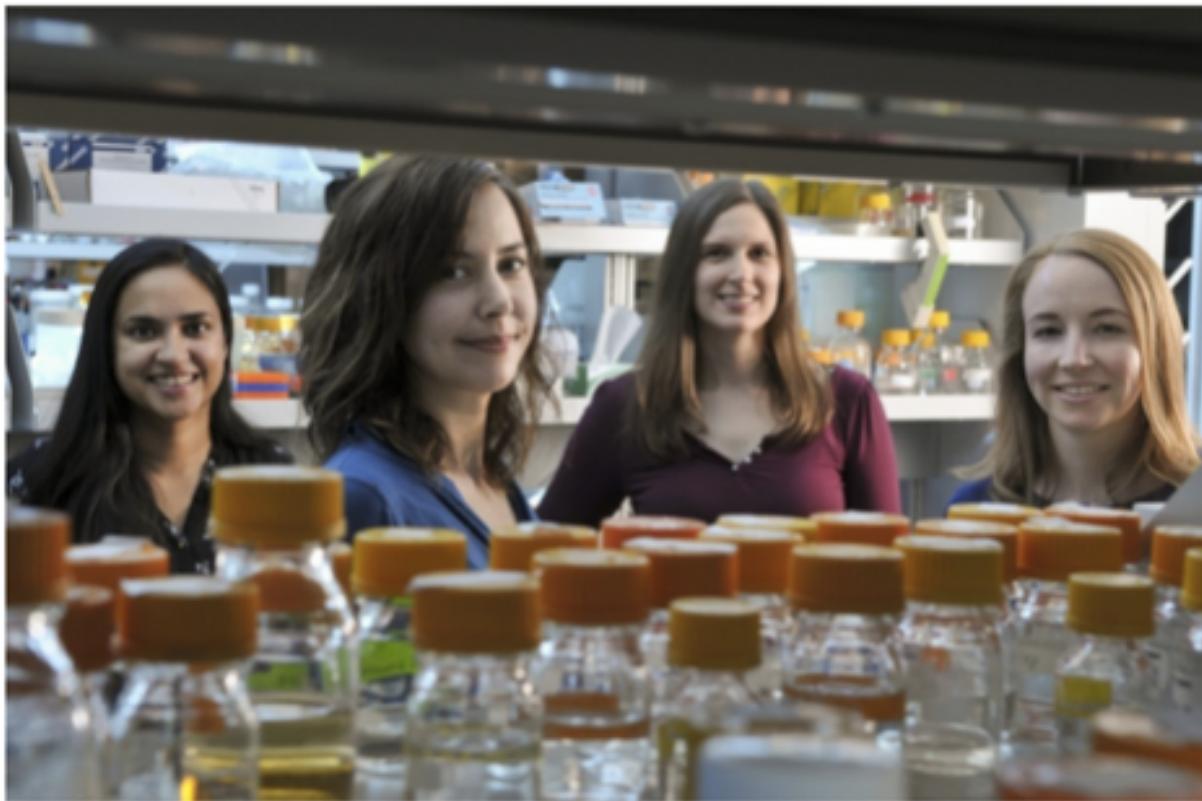


Graphic c/o "Synthetic Aesthetics," MIT Press (2014)

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



OUR TEAM

CONTACT US

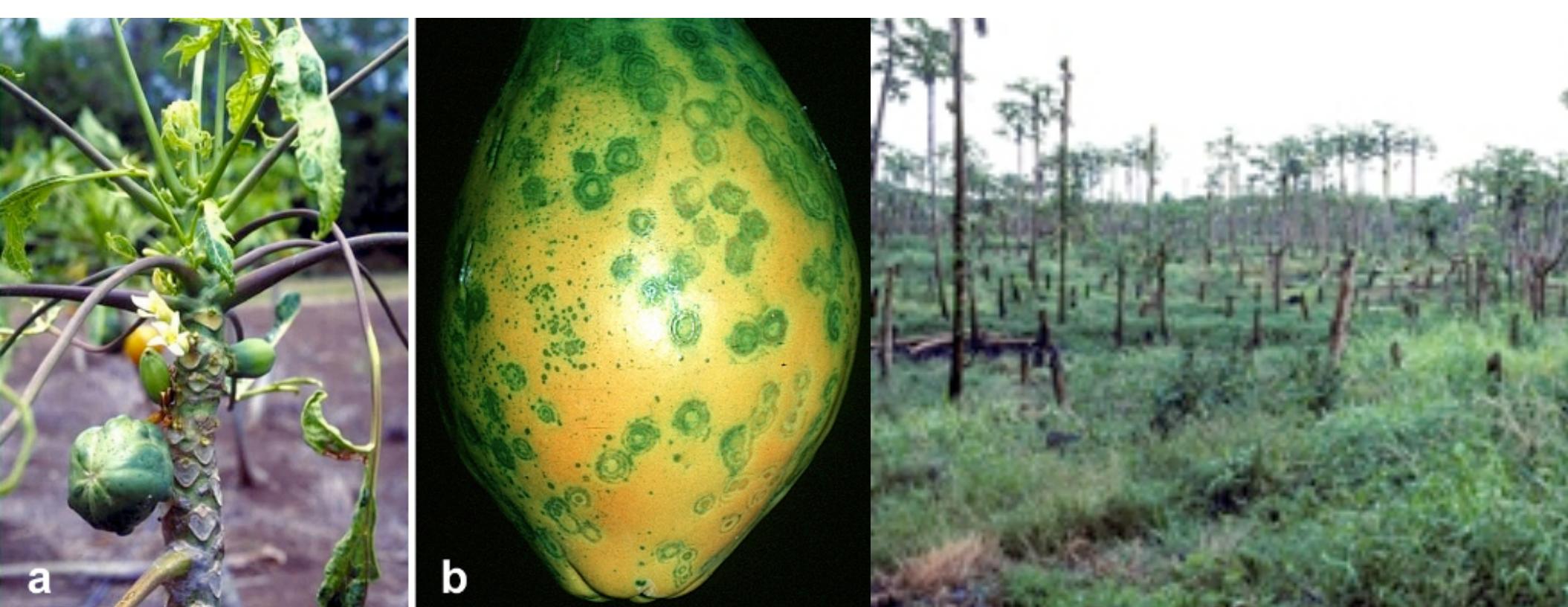
OUR MISSION IS TO
MAKE AND FAIRLY
PROVIDE MEDICINES TO
ALL WHO NEED THEM

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.



Dennis
Gonsalves

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



<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.

“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

DuPont INSIGHT SERIES

DuPont is a SCIENCE COMPANY!

- What are the ISSUES?
- What is our POSITION?
- What are the OPPORTUNITIES?
- LISTEN...
- LEARN...
- ENGAGE...
- CONTRIBUTE...
- ADDRESS intractable problems...
- DISCOVER...
- LEVERAGE...
- INQUIRE...
- UNDERSTAND...



We aren't seeking CONSENSUS!

We may not even need a DEFINITION...

...but are we talking about the

SAME THING?

DUPONT[®]

Synthetic Biology Roundtable
14-15 May 2014 • Palo Alto, CA USA

dpiict. Images by Anthony Weeks
www.dpiict.info

Discussion on
SYNTHETIC BIOLOGY

MAY 14-15, 2014
PALO ALTO
CA

UNDERSTANDING
COMPLEXITY!

THIS IS ONE OF THE
BIGGEST ISSUES OF
OUR TIME!

HOW
WHAT
WHERE

This is a SNOWFLAKE on
the TIP of the ICEBERG!

HUMANS

INTERACT with the
natural WORLD?

-IMPACT?
-RISK?

data

CREATIVITY

WHAT'S THE
PROOF?!

! WHAT IS IN
THE DEFINITION
and NOT IN THE
DEFINITION **BOTH**
matter!

Biodiversity

SYNTHESIS

CONSERVATION

Ethics

analysis

POLICY...
Science...
ethics...
TECHNOLOGY...
MARKETS...
religion...

Do we NEED to
DEFINE this?

How does
it HELP
us?

Food

Energy

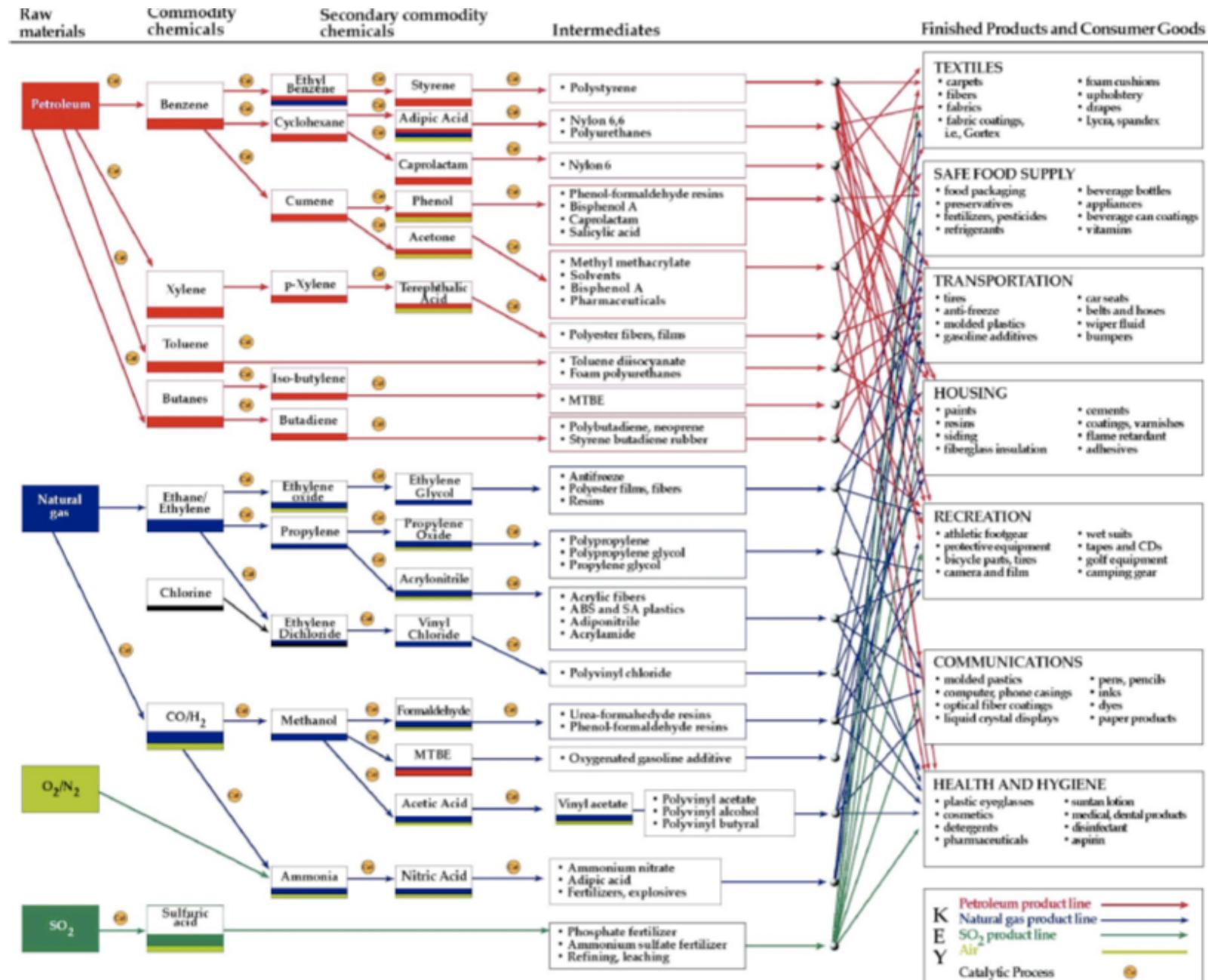
Environment

Agriculture

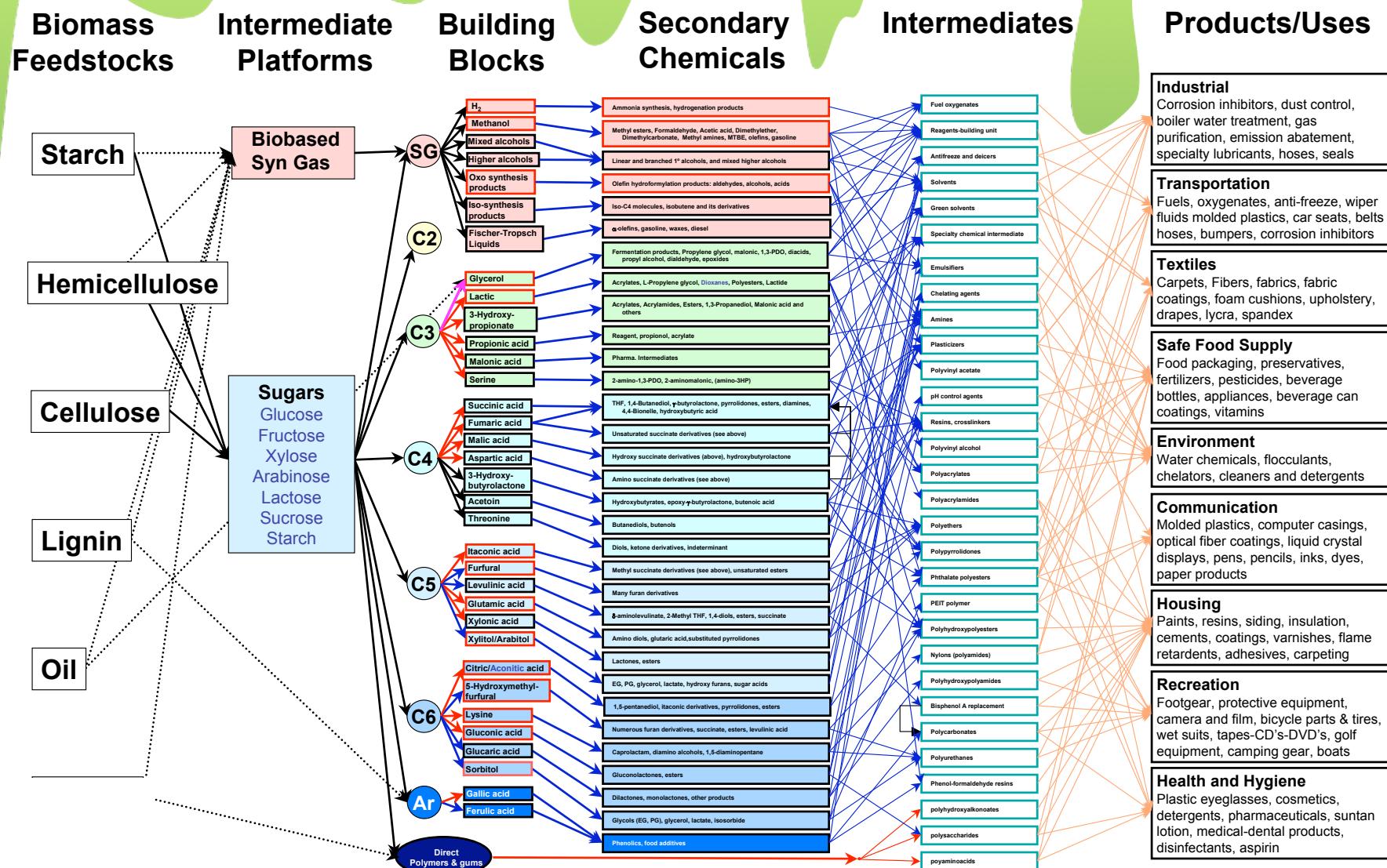
Health

Chemicals & Materials

Security



2004 DOE report lists 120 highvalue chemicals for biomanufacturing





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



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

© Roger Lancaster
2011



CALIFORNIA GROWN
ORGANIC MUSHROOMS



CALIFORNIA GROWN
ORGANIC MUSHROOMS



Redefining Leather with Mycelium

Creating materials with the power of organic technology.

We turn mycelium and
agricultural byproducts
into leather.

Photovoltaic ROE >> 1

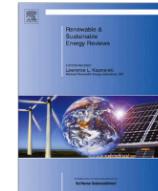
Renewable and Sustainable Energy Reviews 47 (2015) 133–141



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Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser



Energy payback time (EPBT) and energy return on energy invested (EROI) of solar photovoltaic systems: A systematic review and meta-analysis



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Energy return on energy invested

Embedded energy

ABSTRACT

There is a fast growing interest in better understanding the energy performance of PV technologies as evidenced by a large number of recent studies published on this topic. The goal of this study was to do a systematic review and a meta-analysis of the embedded energy, energy payback time (EPBT), and energy return on energy invested (EROI) metrics for the crystalline Si and thin film PV technologies published in 2000–2013. A total of 232 references were collected of which 11 and 23 passed our screening for EPBT/EROI and embedded energy analysis, respectively. Several parameters were harmonized to the following values: Performance ratio (0.75), system lifetime (30 years), insolation ($1700 \text{ kWh m}^{-2} \text{ yr}^{-1}$), module efficiency (13.0% mono-Si; 12.3% poly-Si; 6.3% a:Si; 10.9% CdTe; 11.5% CIGS). The embedded energy had a more than 10-fold variation due to the variation in BOS embedded energy, geographical location and LCA data sources. The harmonization narrowed the range of the published EPBT values. The mean harmonized EPBT varied from 1.0 to 4.1 years; from lowest to highest, the module types ranked in the following order: cadmium telluride (CdTe), copper indium gallium diselenide (CIGS), amorphous silicon (a:Si), poly-crystalline silicon (poly-Si), and mono-crystalline silicon (mono-Si). The mean harmonized EROI varied from 8.7 to 34.2. Across different types of PV, the variation in embedded energy was greater than the variation in efficiency and performance ratio suggesting that the relative ranking of the EPBT of different PV technology today and in the future depends primarily on their embedded energy and not their efficiency.

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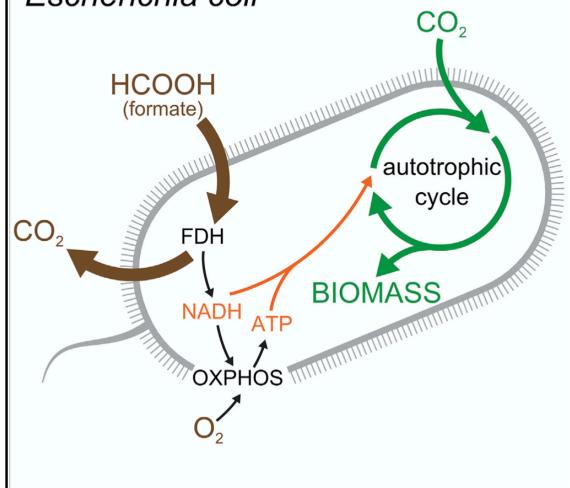
Transitioning to electricity abundant civilization

Electro-fermentation...

Conversion of *Escherichia coli* to Generate All Biomass Carbon from CO₂

Graphical Abstract

Engineered and evolved autotrophic *Escherichia coli*



Authors

Shmuel Gleizer, Roei Ben-Nissan, Yinon M. Bar-On, ..., Melina Shamshoum, Arren Bar-Even, Ron Milo

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In Brief

Metabolic rewiring and directed evolution led to the emergence of *E. coli* clones that use CO₂ as their sole carbon source, while formate is oxidized to provide all the reducing power and energy demands.

Original Paper | Published: 13 September 2008

Electro-reduction of carbon dioxide to formate on lead electrode in aqueous medium

B. Innocent, D. Liaigre, D. Pasquier, F. Ropital, J.-M. Léger & K. B. Kokoh

Journal of Applied Electrochemistry 39, Article number: 227 (2009) | [Cite this article](#)

1926 Accesses | 116 Citations | 15 Altmetric | [Metrics](#)

Abstract

The electrochemical reduction of carbon dioxide on a lead electrode was studied in aqueous medium. Preliminary investigations carried out by cyclic voltammetry were used to determine the optimized conditions of electrolysis. They revealed that the CO₂ reduction process was enhanced at a pH value of 8.6 for the cathodic solution i.e. when the predominant form of CO₂ was hydrogenocarbonate ion. Long-term electrolysis was carried out using both potentiometry and amperometry methods in a filter-press cell in which the two compartments were separated by a cation-exchange membrane (Nafion® 423). Formate was detected and quantified by chromatography as the exclusive organic compound produced with a high Faradaic yield (from 65% to 90%). This study also revealed that the operating temperature played a key role in the hydrogenation reaction of carbon dioxide into formate in aqueous medium.

Gleizer et al., 2019, Cell 179, 1255–1263

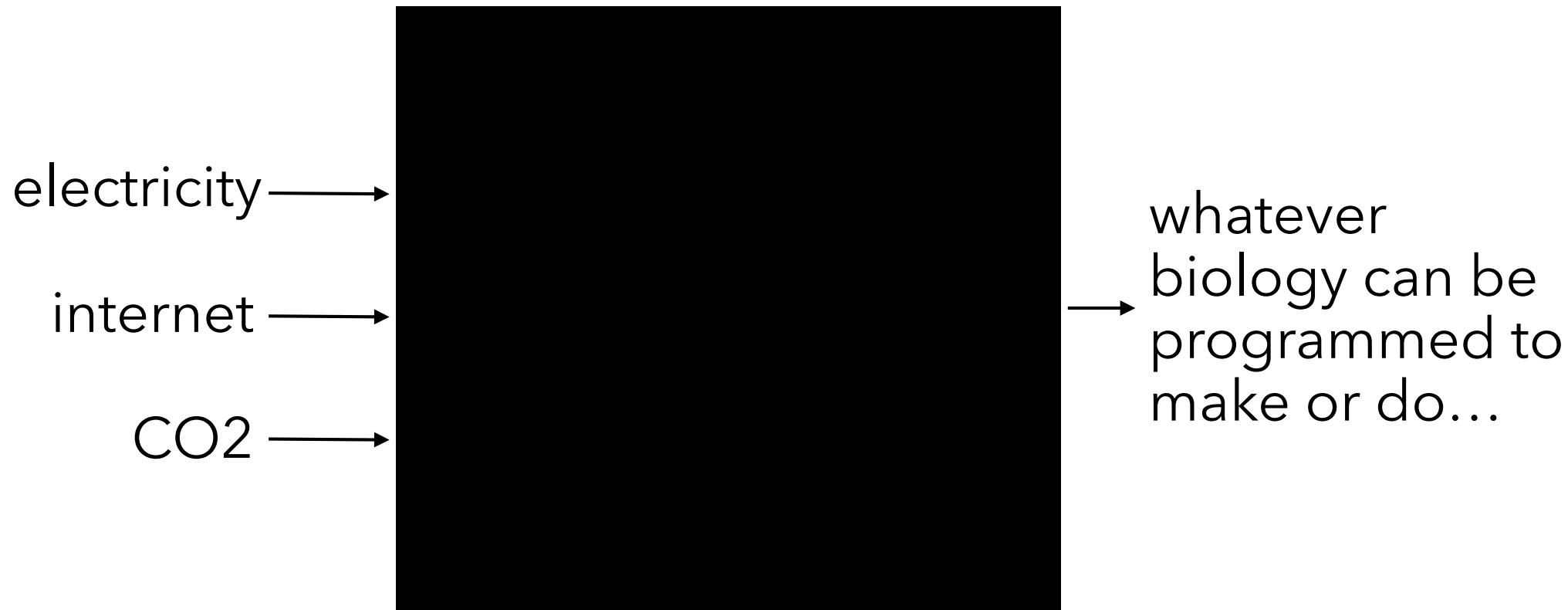
November 27, 2019 © 2019 The Authors. Published by Elsevier Inc.

<https://doi.org/10.1016/j.cell.2019.11.009>

~1 kWh electricity = ~ 1 gram new biomass

~\$0.11 = ~ 1 course of antibiotics

Q. How will this box change the world?



Q. What will the “PB” + the “bionet” lead to?

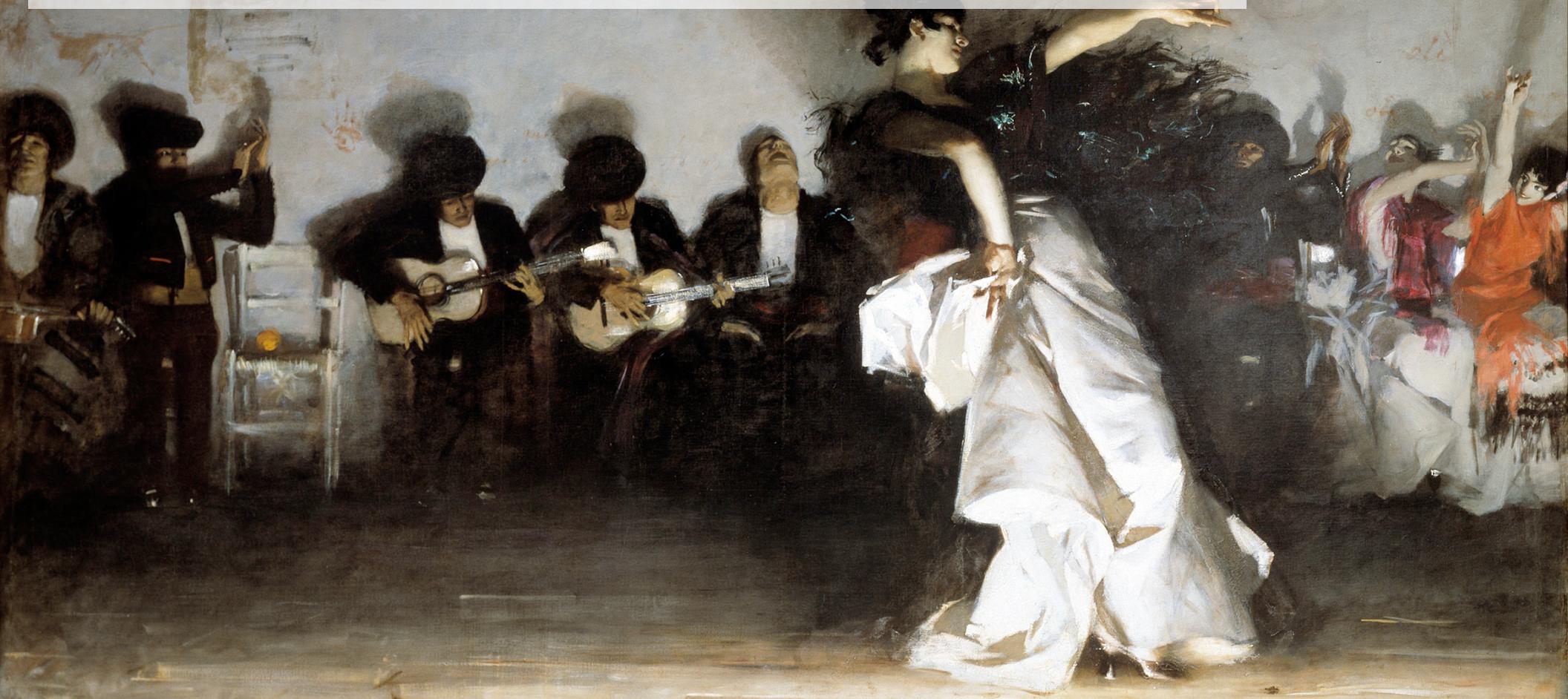
A. “design anywhere, grow everywhere”

John Sargent 1882

What does it mean to engineer biology?

What might & should we wish for?

Can we realize a culture of bioengineering?





How will synthetic biology and conservation shape the future of nature?

A framing paper prepared for
a meeting between synthetic biology
and conservation professionals

Clare College, Cambridge, UK
9-11 April, 2013



“The modern field of conservation was born as a crisis discipline and it really was focused on trying to stop extinction.

So what does conservation want? What it wants is to conserve nature. Particular biodiversity and species and ecosystems with less emphasis on the genetic component.

It is based on a set of foundational values that focus on the natural and the wilderness.

It wants a world that doesn't change except by its own agency.

It embraces change but natural change.” — Kent Redford

<https://vimeo.com/225308429>

[https://secure3.convio.net/wcs/pdf/
Synthetic_Biology_and_Conversation_
Framing_Paper.pdf](https://secure3.convio.net/wcs/pdf/Synthetic_Biology_and_Conversation_Framing_Paper.pdf)

What is our telos?

Biology is already
many places

~90 terawatts via
photosynthesis*

Reproducing,
growing, &
healing materials

Massively functional

Living ramifications



Enable humanity to
provide for itself

Stabilize & recover
natural biodiversity

Take infectious & other
diseases off the table

Enable a culture
of citizenship

Understand life
via building

*electrobiosynthesis will remove this cap