

# “Biohacking”

## The Promise and Challenges of Synthetic Biology

**Emerging Tech Forum**

Alexandria, VA

Feb 10 2009

**Andrew D. Maynard**

**Chief Science Advisor, Project on Emerging Nanotechnologies**

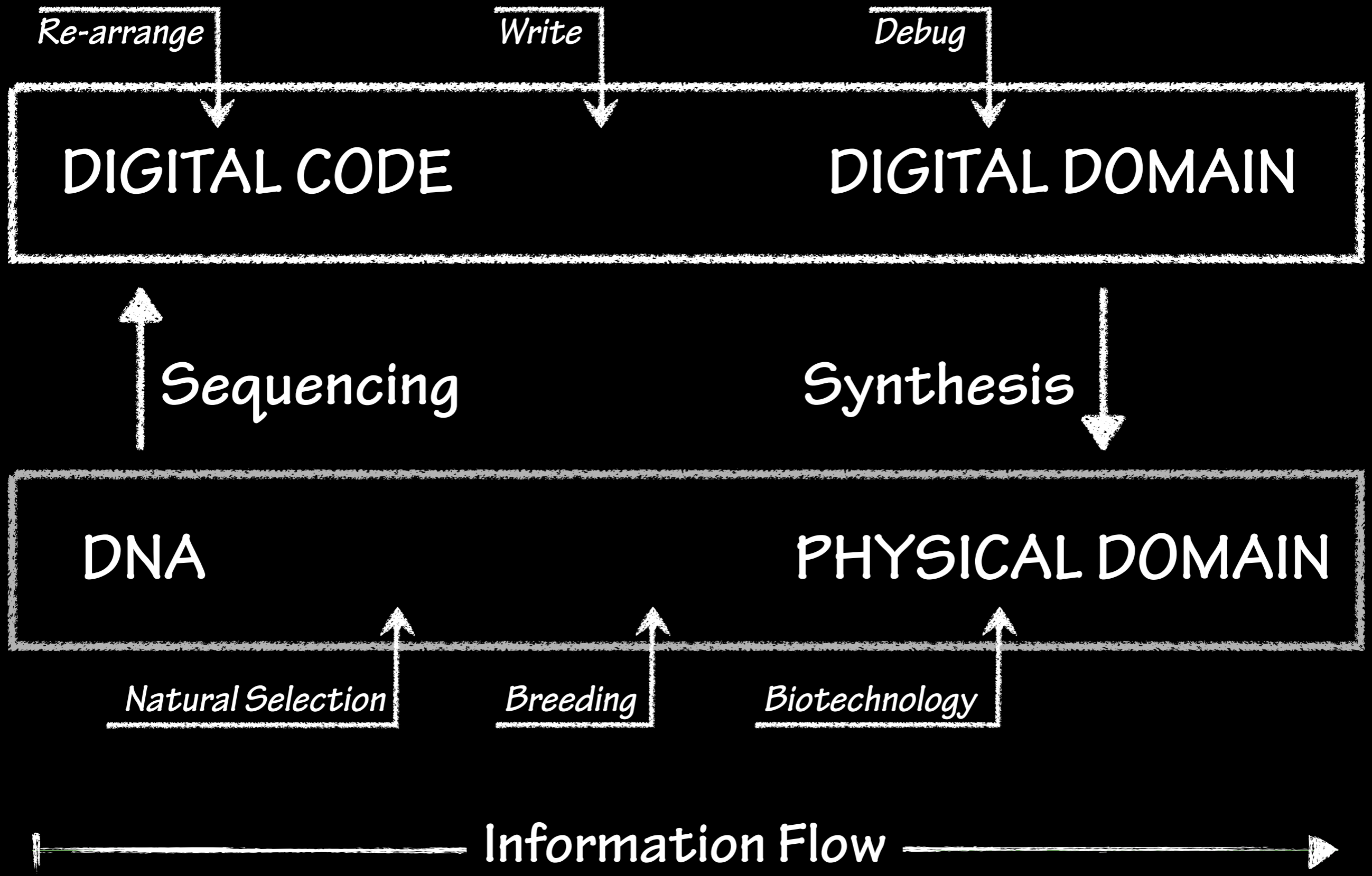
Woodrow Wilson International Center for Scholars (in partnership with the Pew Charitable Trusts)

# A quick note on this handout:

Some of these slides might not make much sense in the absence of the verbal presentation they were prepared for. In some cases, they could even be potentially misleading if taken out of context... you have been warned!

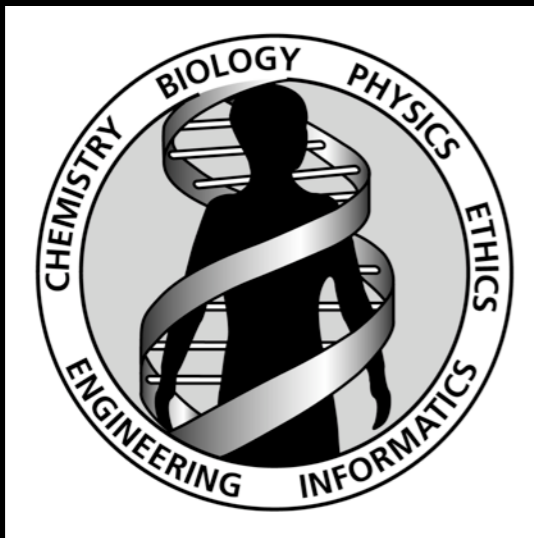
That said, please feel free to use them as a teaching resource - just remember to acknowledge me (Andrew Maynard), and any other relevant sources, if you do so.

Andrew Maynard  
andrew.maynard@wilsoncenter.org



# Sequencing the Human Genome

Human Genome Project



1988 - 2001

13 years

Science 291:5507, pp. 1304-1351,  
2001. doi: 10.1126/science.1058040

James Watson



2007

2 months

Nature, 1 June 2007.  
doi:10.1038/news070528-10

The near future?

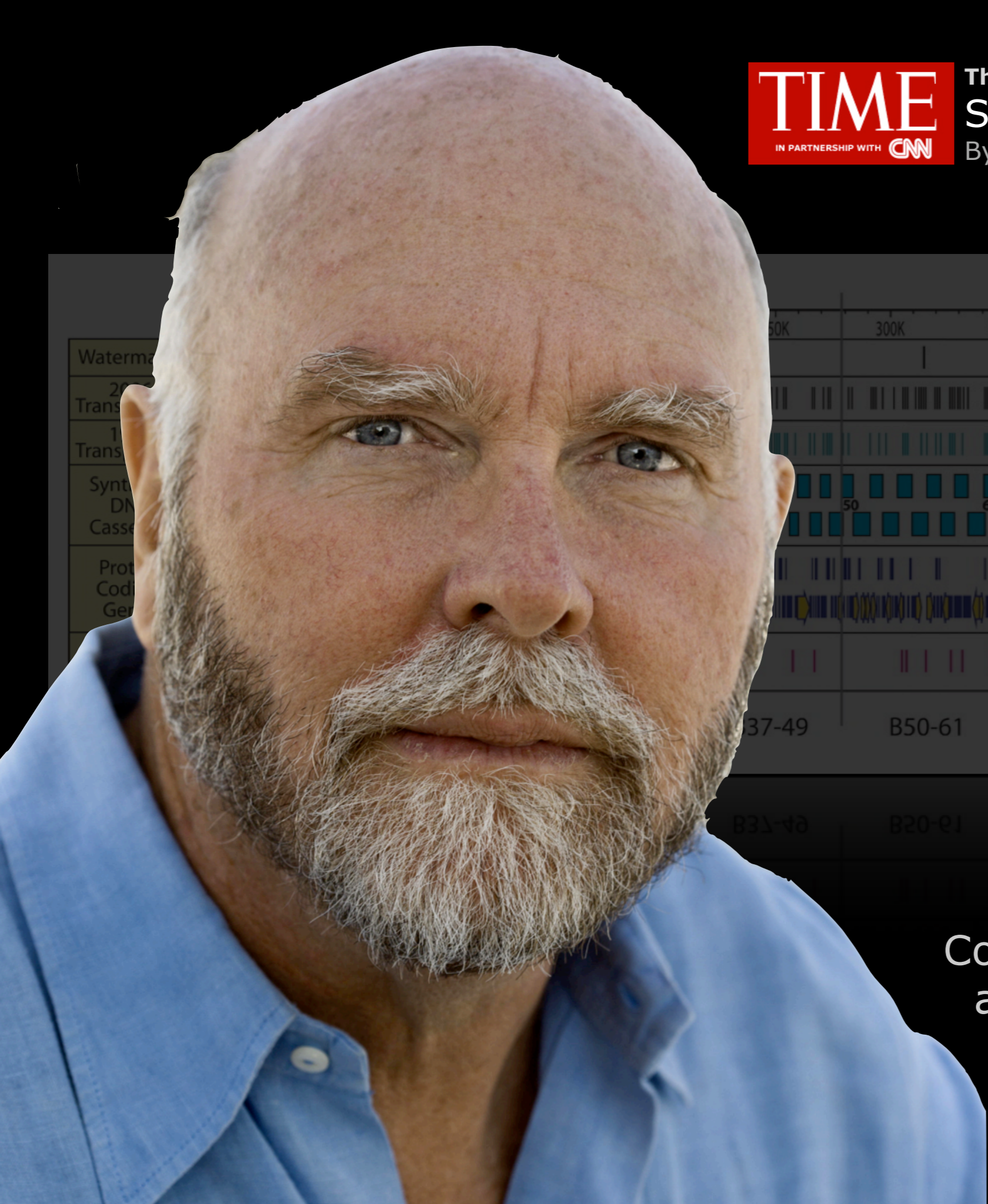


2013

3 minutes

Nature, 6 February 2009.  
doi:10.1038/news.2009.86

# The Minimal Genome



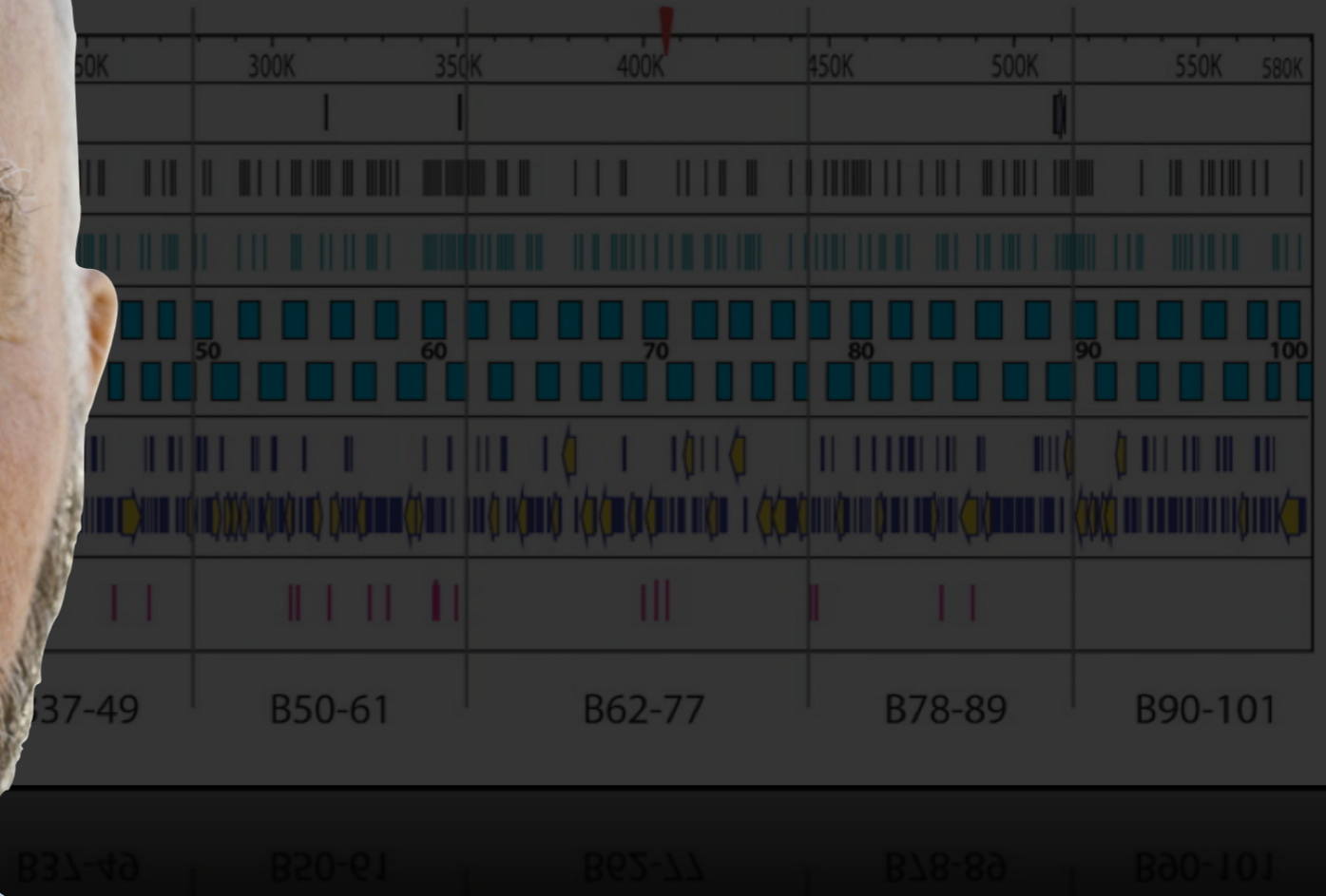
**TIME**  
IN PARTNERSHIP WITH **CNN**

Thursday, Jan. 24, 2008

# Scientist Creates Life — Almost

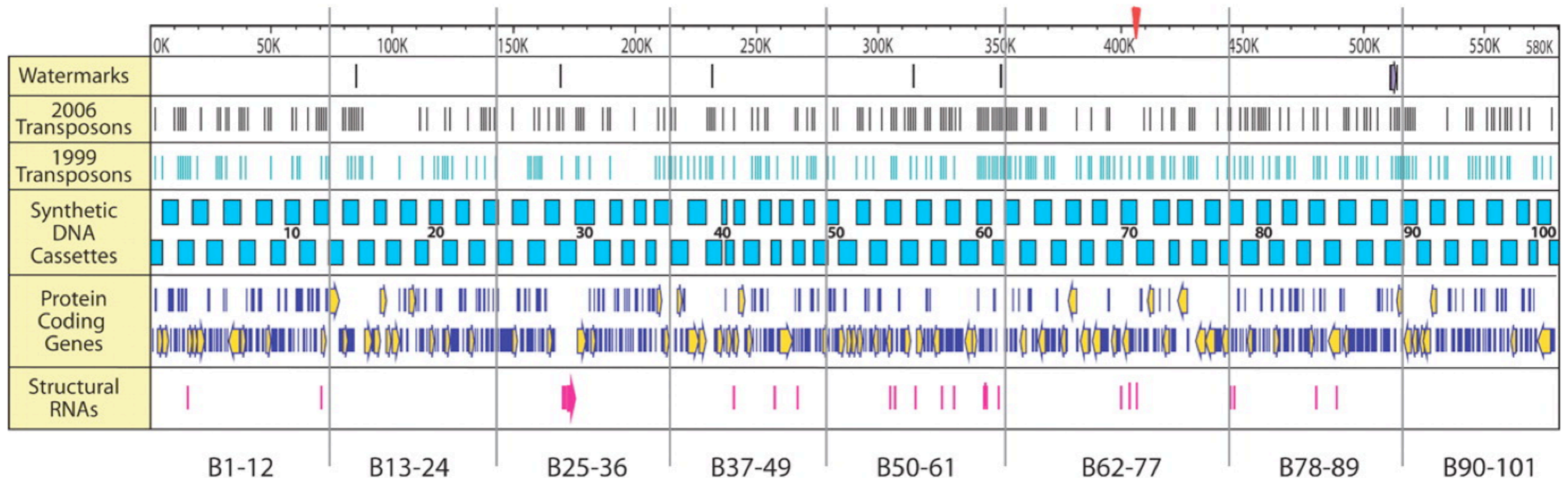
By Alice Park

Watermark  
2008  
Trans  
1  
Trans  
Synt  
DN  
Casse  
Prot  
Cod  
Gen



Complete chemical synthesis,  
assembly, and cloning of a  
*Mycoplasma genitalium*  
genome.

Gibson *et al.* *Science* 319(5867):  
1215-1220. 2008



Complete chemical synthesis,  
assembly, and cloning of a  
*Mycoplasma genitalium*  
genome.

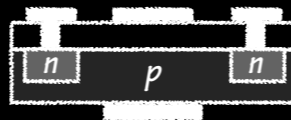
Gibson *et al.* Science 319(5867):  
1215-1220. 2008

# **Modular Biology**

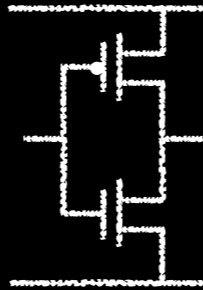


# Modular

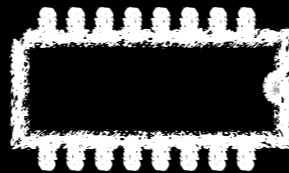
*MOSFET*



*CMOS*



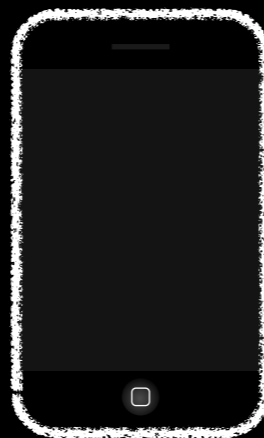
*Integrated  
Circuits*



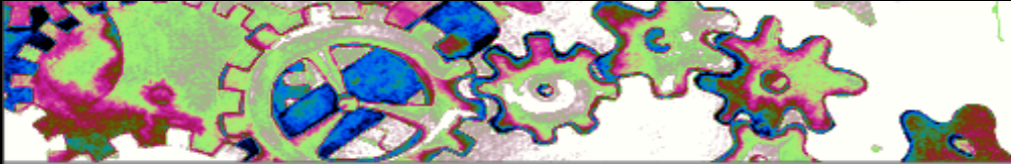
*Components*



*Devices*



# Systems



## Part Types

Browse parts by projects:

[iGEM 2008](#) | [iGEM 2007](#) | [iGEM 2006](#) | [iGEM 2005](#) | [Labs](#) | [Courses](#) | [Featured Parts](#)

Or browse parts by [part categories](#):

### Systems

- [Measurement ?](#)
- [Measurement \(Under Development\) ?](#)
- [Projects\(empty\)](#)

### Devices

- [Reporters ?](#)
- [Protein Generator ?](#)
- [Inverters ?](#)
- [Composite Devices ?](#)
- [Signalling ?](#)
- [Measurement ?](#)

### Parts

- [Ribosome Binding Sites ?](#)
- [Protein Coding ?](#)
- [Regulatory ?](#)
- [Terminators ?](#)
- [RNA ?](#)
- [Conjugation ?](#)
- [DNA ?](#)
- [BioScaffold ?](#)

### Chassis

- [E.coli Strains ?](#)
- [B.subtilis Strains ?](#)
- [Cell-Free Systems ?](#)

### Mammalian

### Vectors

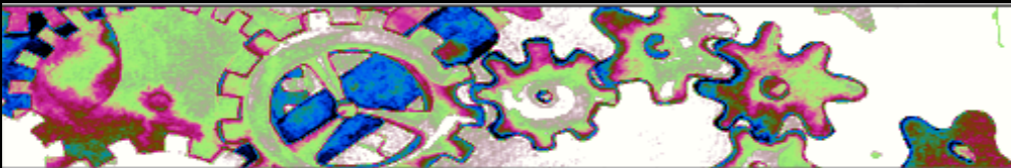
- [Plasmids ?](#)
- [Plasmid Backbones ?](#)

### Other

- [Yeast Parts ?](#)
- [A.B Construction Intermediate ?](#)
- [PCR Primer ?](#)
- [Tags ?](#)
- [Other](#)
- [Deleted](#)
- [Bacteriophage T7](#)

- For more information on each part type, click the [?](#) for [help documentation](#) next to the category name.
- To discuss how to measure the functions of these parts visit [Characterization of Parts](#)



  
Go Search

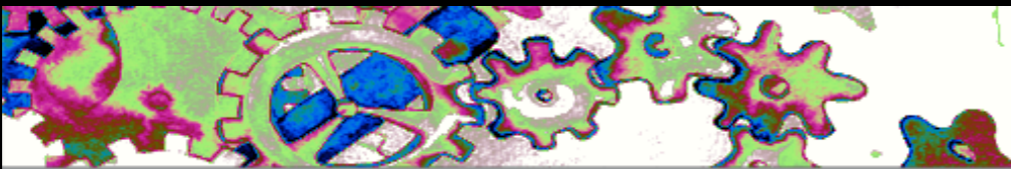
## Inverters and Logic Devices

Available Inverters and Logic Devices

[Show 43 more parts](#)[Edit](#)

-?-	Name	Input	Output	Protein	RBS	Tag -?-	Performance					Timing						
							I	L	H	O	L	O	H	T	L	H	T	H
A W	BBa J5516																	
A W	BBa Q04121	BBa P0412	BBa R0011	LacI	BBa B0034	LVA												
A W	BBa Q04400	BBa P0440	BBa R0040	TetR	BBa B0034	LVA												
A W	BBa Q04510	BBa P0451	BBa R0051	CI (Lambda)	BBa B0034	LVA												
A	BBa A340620																	
A	BBa I765005																	
A	BBa I765006																	
A	BBa I765012																	
A	BBa J06800		BBa R0011	LacI ts mutant	BBa B0034	LVA												
A	BBa J06801		BBa R0011	LacI ts mutant	BBa B0034	LVA												
A	BBa J5519																	
A	BBa J5520																	
A	BBa J5521																	
A	BBa J5522																	
S	BBa K098985																	
S	BBa K098986																	
A	BBa Q01121	BBa P0112	BBa R0011	LacI	BBa B0031	LVA												
A	BBa Q01400	BBa P0140	BBa R0040	TetR	BBa B0031	LVA												
A	BBa Q01510	BBa P0151	BBa R0051	CI (Lambda)	BBa B0031	LVA												
A	BBa Q01511	BBa P0151	BBa R0065	CI (Lambda)	BBa B0031	LVA												
A	BBa Q01530	BBa P0153	BBa R0053	C2 (p22)	BBa B0031	LVA												
A	BBa Q03121	BBa P0312	BBa R0011	LacI	BBa B0033	LVA												
A	BBa Q03400	BBa P0340	BBa R0040	TetR	BBa B0033	LVA												
A	BBa Q03530	BBa P0353	BBa R0053	C2 (p22)	BBa B0033	LVA												
A	BBa Q04511	BBa P0451	BBa R0065	CI (Lambda)	BBa B0034	LVA												
A ?	BBa Q04520	BBa P0452	BBa R0052	CI (434)	BBa B0034	LVA												
A X	BBa Q04530	BBa P0453	BBa R0053	C2 (p22)	BBa B0034	LVA												
A	BBa Q20050																	
A	BBa Q20060																	
A	BBa Q20061																	
A	BBa Q200614																	
A	BBa Q20070																	
A	BBa Q200714																	

[Recent changes](#)[What links here](#)[Related changes](#)[Upload file](#)[Special pages](#)[Recent part changes](#)[Printable version](#)[Permanent link](#)[Privacy policy](#)[Disclaimers](#)[Recent part changes](#)[Printable version](#)[Permanent link](#)[Privacy policy](#)[Disclaimers](#)

  
[Go](#) [Search](#)[page](#) [discussion](#) [view source](#) [history](#)[Log in / create account](#)[BBa Q04510 Main Page](#) [Part Design](#) [Physical DNA](#) [Hard Information](#) [Experience](#)

## Part:BBa\_Q04510

**DNA Available**  
**Experience: Works**

Designed by Caitlin Conboy and Jennifer Braff Group: Registry

Entered: 2003-12-02

### QPI (B0034.C0051.B0015.R0051)

Lambda cl [QPI](#) w/ strong RBS

### Usage and Biology

Preliminary data indicates that this inverter functions well. [jb, 5/24/04]

#### Sequence and Features

<b>Format:</b> <a href="#">Subparts</a>   <a href="#">Ruler</a>   <a href="#">SS</a>   <a href="#">DS</a>	<b>Search:</b>	<b>Length:</b> 987 bp	<b>Context:</b> Part only	<a href="#">Get selected sequence</a>
---	----------------	-----------------------	---------------------------	---------------------------------------

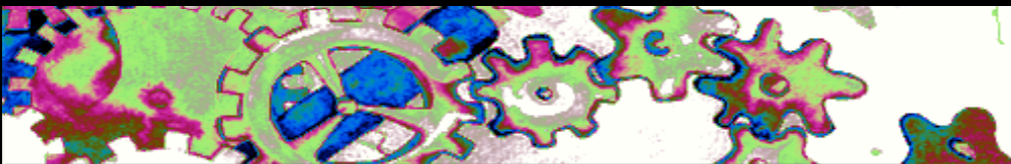


- [Recent changes](#)
- [What links here](#)
- [Related changes](#)
- [Upload file](#)
- [Special pages](#)
- [My preferences](#)
- [Recent part changes](#)
- [Printable version](#)
- [Permanent link](#)
- [Privacy policy](#)
- [Disclaimers](#)



- [Recent changes](#)
- [What links here](#)
- [Related changes](#)
- [Upload file](#)
- [Special pages](#)
- [My preferences](#)
- [Recent part changes](#)
- [Printable version](#)
- [Permanent link](#)
- [Privacy policy](#)
- [Disclaimers](#)



  
Go Search

page discussion view source history

Log in / create account

Ba Q04510 Main Page Part Design Physical DNA Hard Information Experience

## Part:BBa\_Q04510



DNA Available  
Experience: Works

Designed by Caitlin Conboy and Jennifer Braff Group: Registry

Entered: 2003-12-02

### QPI (B0034.C0051.B0015.R0051)

Lambda cl QPI w/ strong RBS

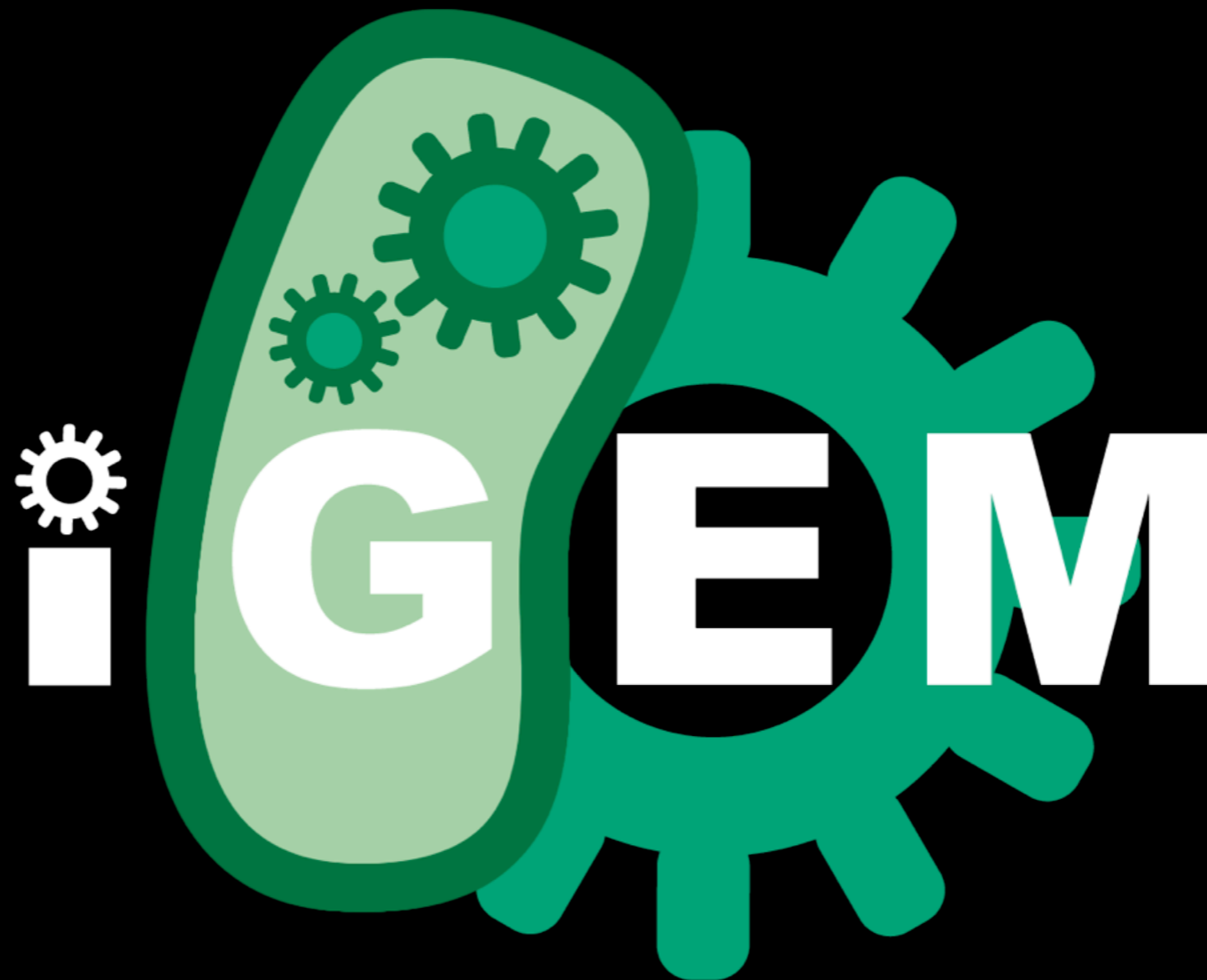
### Usage and Biology

Preliminary data indicates that this inverter functions well. [jb, 5/24/04]

#### Sequence and Features

Format: [Subparts](#) | [Ruler](#) | [SS](#) | [DS](#)      Search:      Length: 987 bp      Context: Part only      [Get selected sequence](#)

	1	11	21	31	41	51	61	71	81	91	
1	aaagaggaga	aatactagat	gagcacaaaa	aagaaacat	taacacaaga	gcagcttgag	gacgcacgtc	gccttaaagc	aatttatgaa	aaaaaagaaa	
	ttctcctct	ttatgatcta	ctcgtgtttt	ttcttttgta	attgtgttct	cgtcgaactc	ctgctgagc	cgaatttcg	ttaaatactt	tttttctttt	
											→
											→
101	atgaacttgg	cttatcccag	gaatctgtcg	cagacaagat	ggggatggg	cagtcaggcg	ttggtgcttt	atntaatggc	atcaatgcat	taaagtctta	
	tacttgaacc	gaatagggtc	cttagacagc	gtctgttcta	cccctacccc	gtcagtcocg	aaccacgaaa	taattaccg	tagttacgta	atttacgaat	
201	taacgcgcga	ttgcttgcaa	aaattctcaa	agttagcgtt	gaagaattta	goccttcaat	cgccagagaa	atctacgaga	tgtatgaagc	ggttagtatg	
	attgcccgt	aacgaacgtt	tttaagagtt	tcaatcgcaa	cttctttaat	cggaagttta	gcggtctctt	tagatgctct	acatacttcg	ccaatcatac	
301	cagccgtcac	ttagaagtga	gtatgagtac	cctgtttttt	ctcatgttca	ggcagggatg	ttctcacctg	agcttagaac	ctttaccaa	ggtgatgagg	
	gtcggcagtg	aatcttcaat	catactcatg	ggacaaaaaa	gagtacaagt	ccgtccctac	aagagtggac	tcgaatcttg	gaaatgggtt	ccactacgcc	
401	agagatgggt	aagcacaaac	aaaaaagoca	gtgattctgc	attctggott	gaggttgaag	gtaattccat	gaccgcacca	acaggctcca	agccaagctt	
407	ttctcctct	ttatgatcta	ctcgtgtttt	ttcttttgta	attgtgttct	cgtcgaactc	ctgctgagc	cgaatttcg	ttaaatactt	tttttctttt	



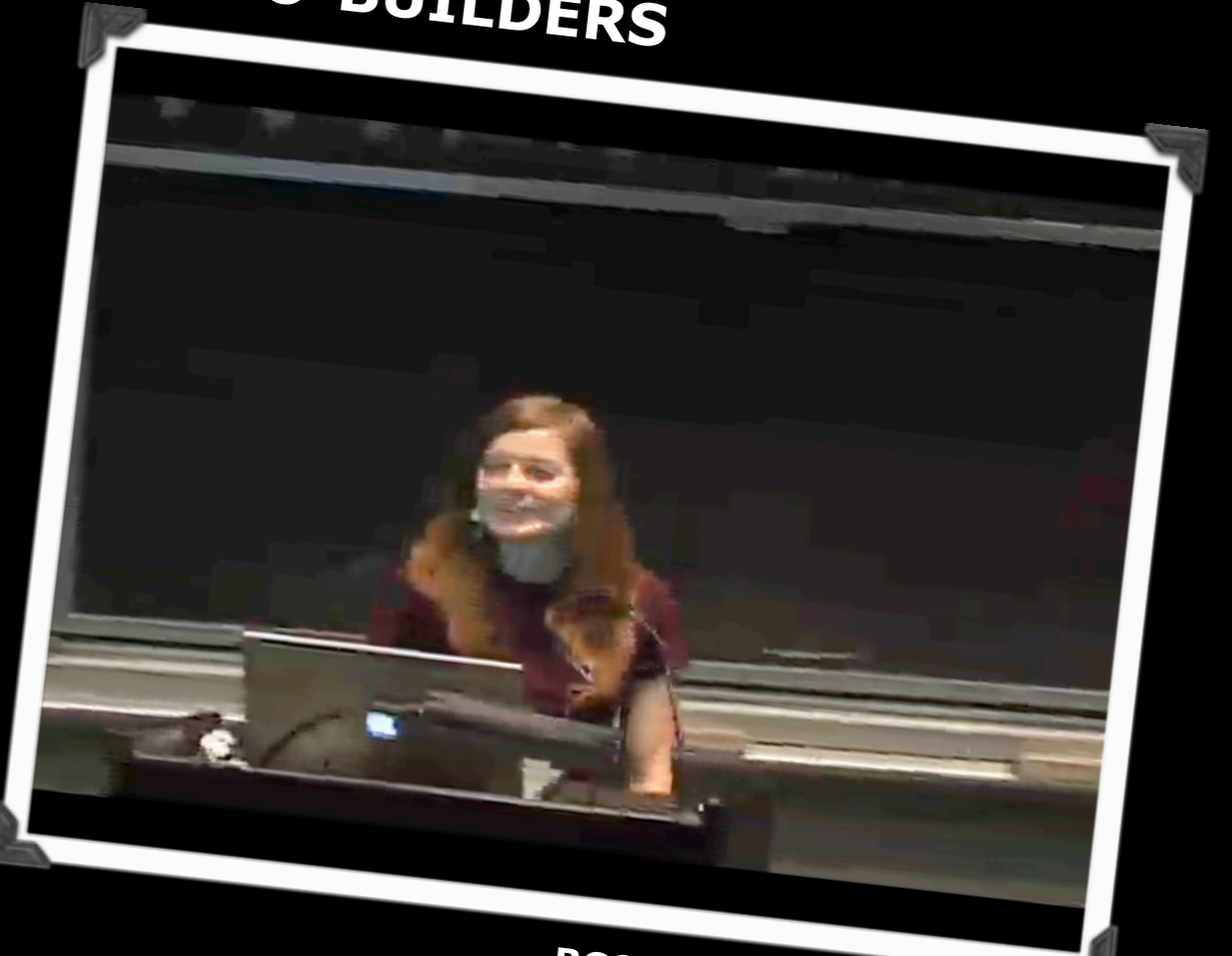
**International Genetically  
Engineered Machine Competition**

# iGEM 2008



21 Countries  
84 Teams  
1200 Participants

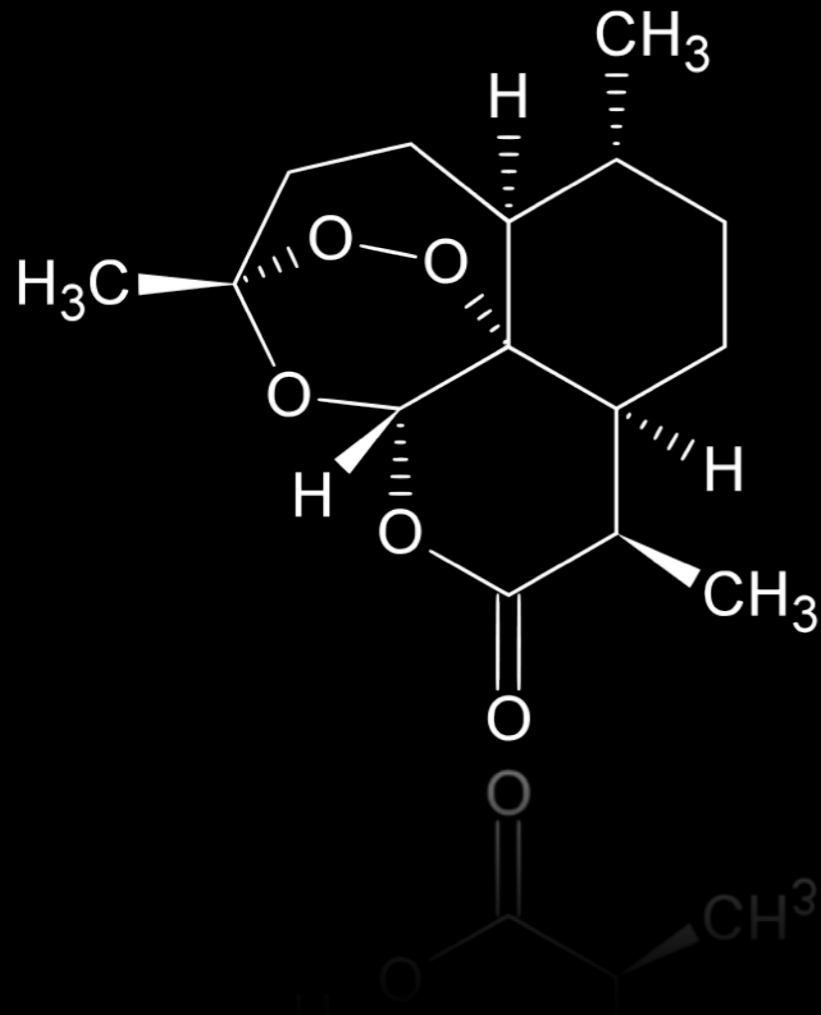
## BACTO-BUILDERS



BCCS-BRISTOL, iGEM 2008

# Treating Malaria

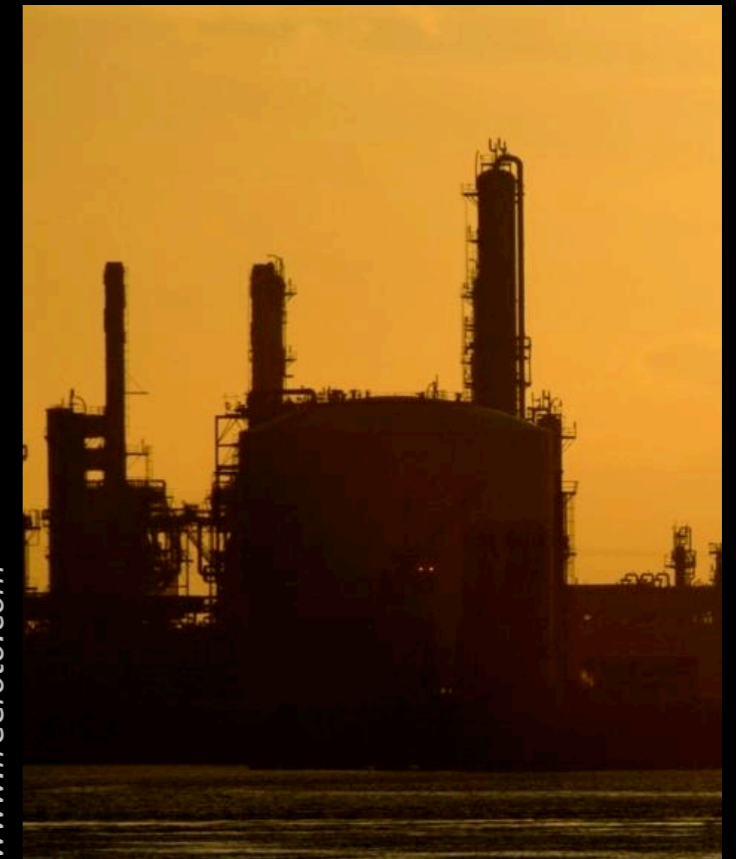
*Artemisinin*



*Artemisia annua*



*Chemical synthesis*

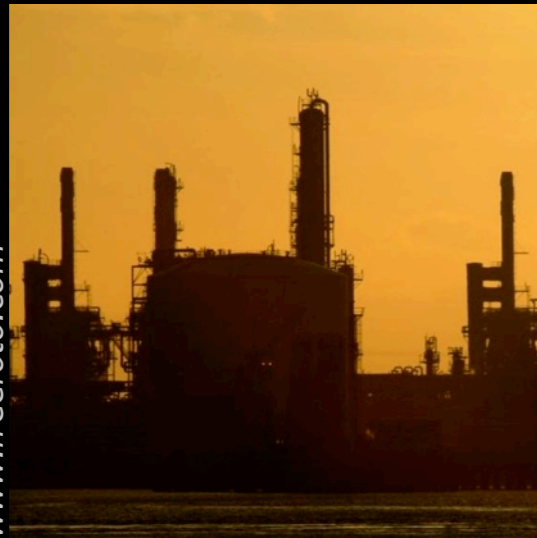


www.freefoto.com

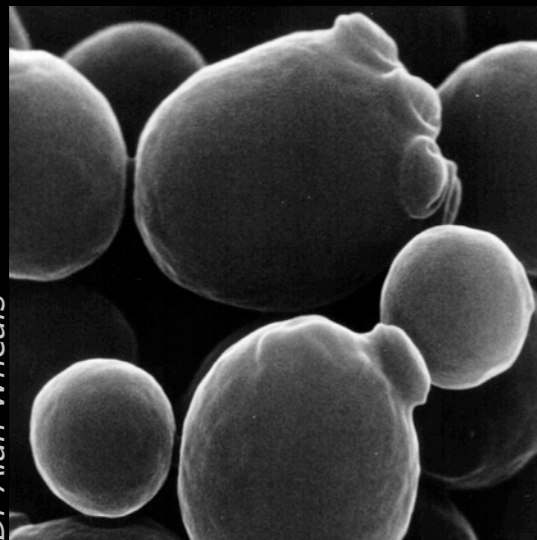


# Artemisinin

via a synthetic biology route



www.freefoto.com

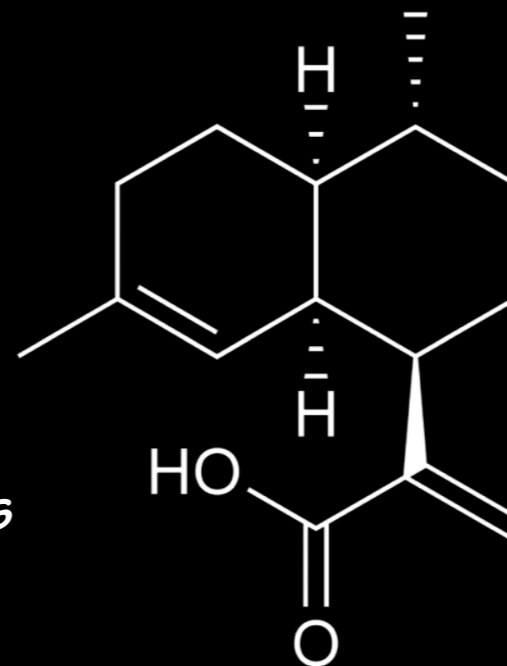


Dr Alan Wheals

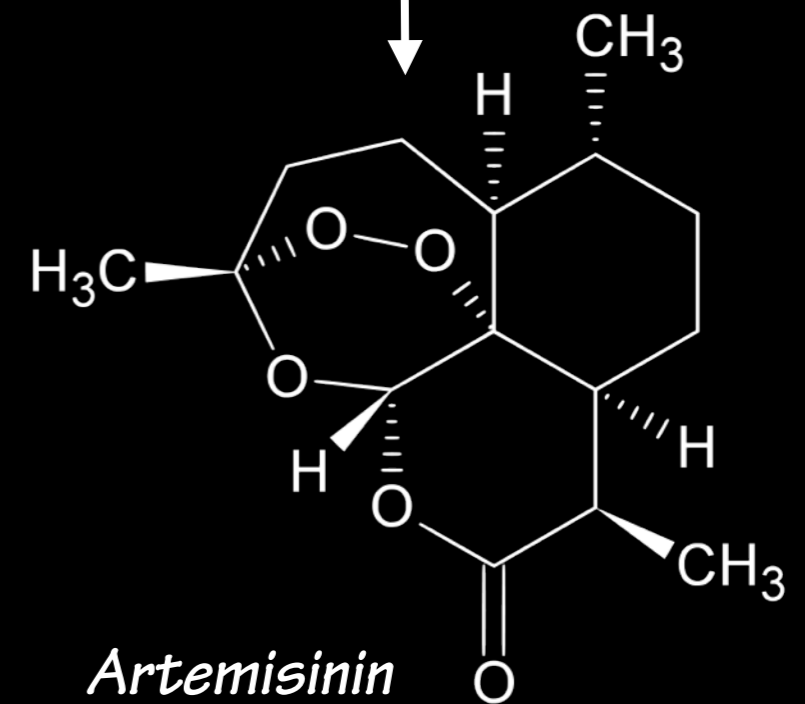


*Artemisia annua*

*Saccharomyces cerevisiae*



*Artemisinic acid*



*Artemisinin*

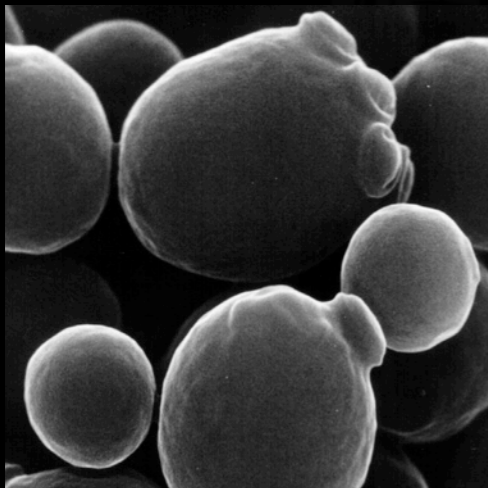
Production of the antimalarial drug precursor artemisinic acid in engineered yeast. Ro et al. Nature 440:940-943 (2006)

```
atcttgatgat catccaaga caaaaccaga gaaaagacc tgtctgtttt ttaagaagt
ctttatatta tttttttgt cggagaatct tataagcatg gcttcaggag gatcaaagtc
ggcagctttc atgcttctga tgctgaatct tggctcttat ttcgtcatca ccatcatcgc
ttcttgggct gttaatcacg gcatcgagag aactcgcgag tctggtaact aacaagata
acaactgatt aagtaacaat taatccaacg ttagaaaatg tcatcatcaa tcttcttttt
gtggtatfff gcagcgtcga cactgtcact tccggcgaag atattcccga tatacttccc
ggtggggaac atggcgaccg gttttttcgt aatattcacg ttaatcgccg gcgctcgcg
```



# Making a plant gene look like a microbial gene

```
atcttgatgat catccaaga caaaaccaga gaaaagacc tgtctgtttt ttaagaagt
ctttatatta tttttttgt cggagaatct tataagcatg gcttcaggag gatcaaagtc
ggcagctttc atgcttctga tgctgaatct tggctcttat ttcgtcatca ccatcatcgc
ttcttgggct gttaatcacg gcatcgagag aactcgcgag tctggtaact aacaagata
acaactgatt aagtaacaat taatccaacg ttagaaaatg tcatcatcaa tcttcttttt
gtggtatfff gcagcgtcga cactgtcact tccggcgaag atattcccga tatacttccc
ggtggggaac atggcgaccg gttttttcgt aatattcacg ttaatcgccg gcgctcgcg
```

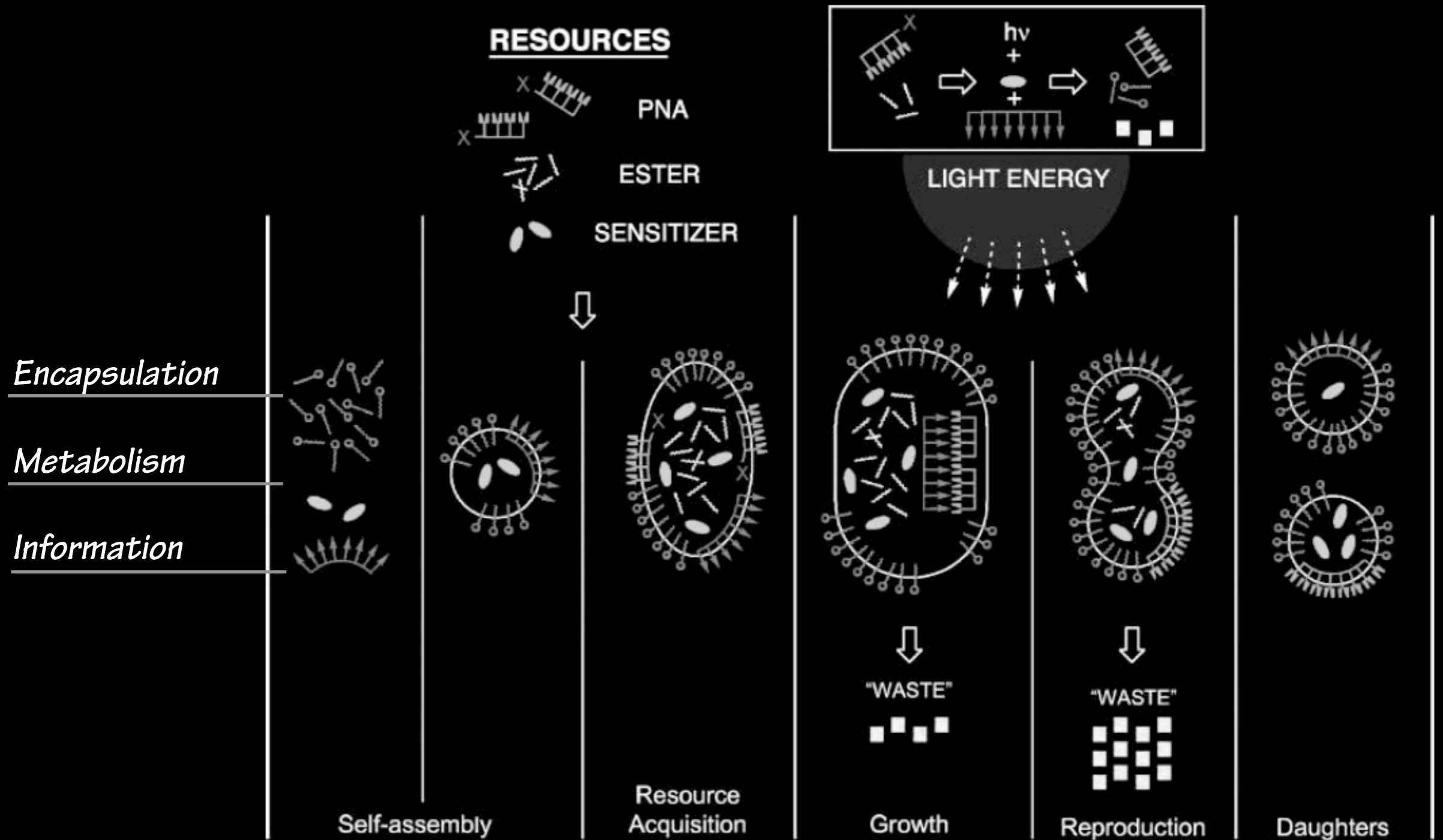


Dr Alan Wheals

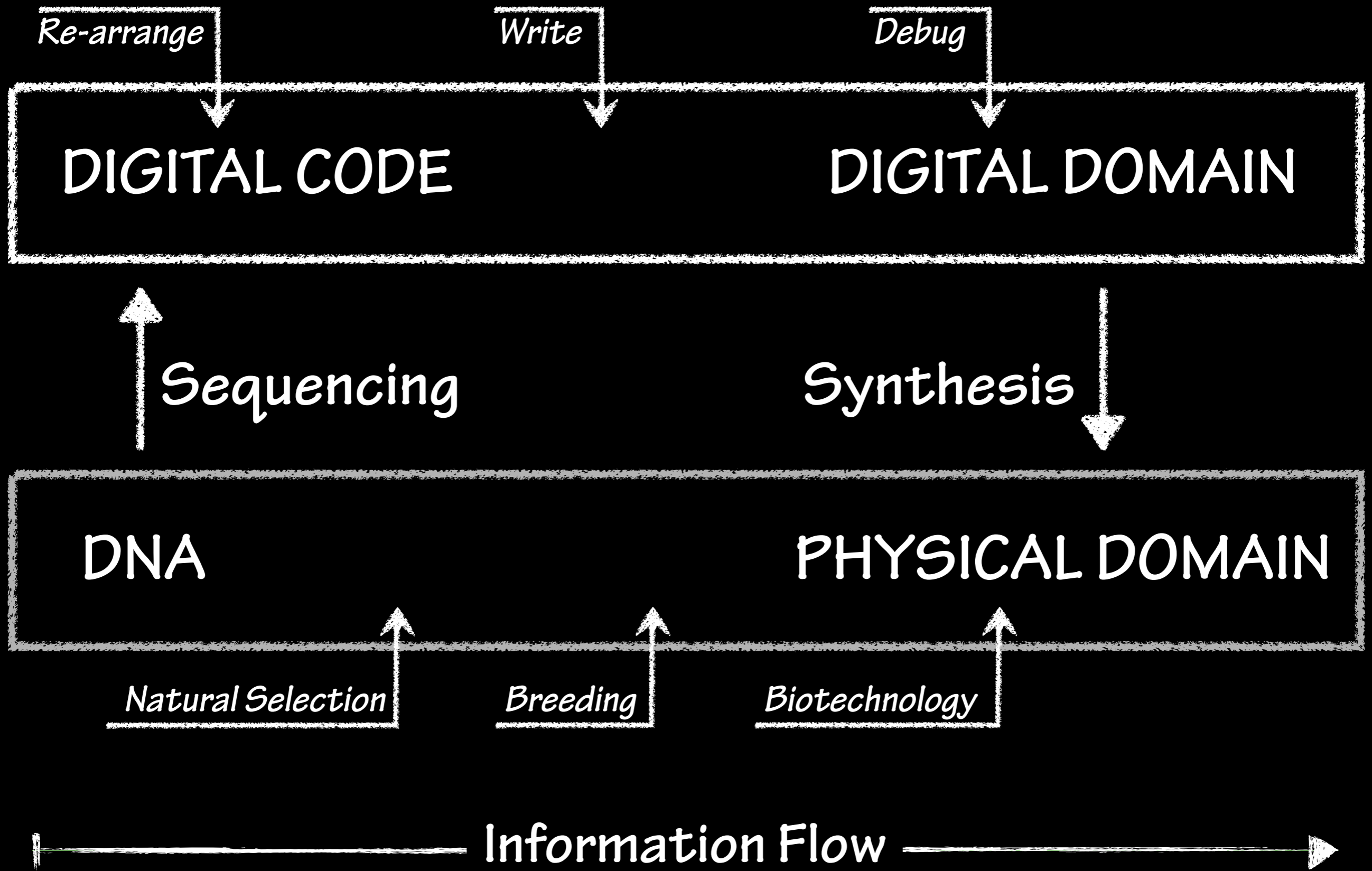
# **Artificial Biology**

# The "Los Alamos" bug

<http://protocells.lanl.gov/>



Fellermann, H., S. Rasmussen, H.-J. Zioch and R. V. Solé (2007). "Life cycle of a minimal protocell - A dissipative particle dynamic study." *Artificial Life* 13(4): 319-345.



**Challenges...**  
**Pitfalls...**  
**Opportunities...**

**Hubris**

*Biology is Complex!*



**Security**

SYNTHETIC GENOMICS | *Options for Governance*

**Michele S. Garfinkel**, The J. Craig Venter Institute, Rockville, Maryland, **Drew Endy**, Massachusetts Institute of Technology, Cambridge, Massachusetts, **Gerald L. Epstein**, Center for Strategic and International Studies, Washington, District of Columbia and **Robert M. Friedman**, The J. Craig Venter Institute, Rockville, Maryland

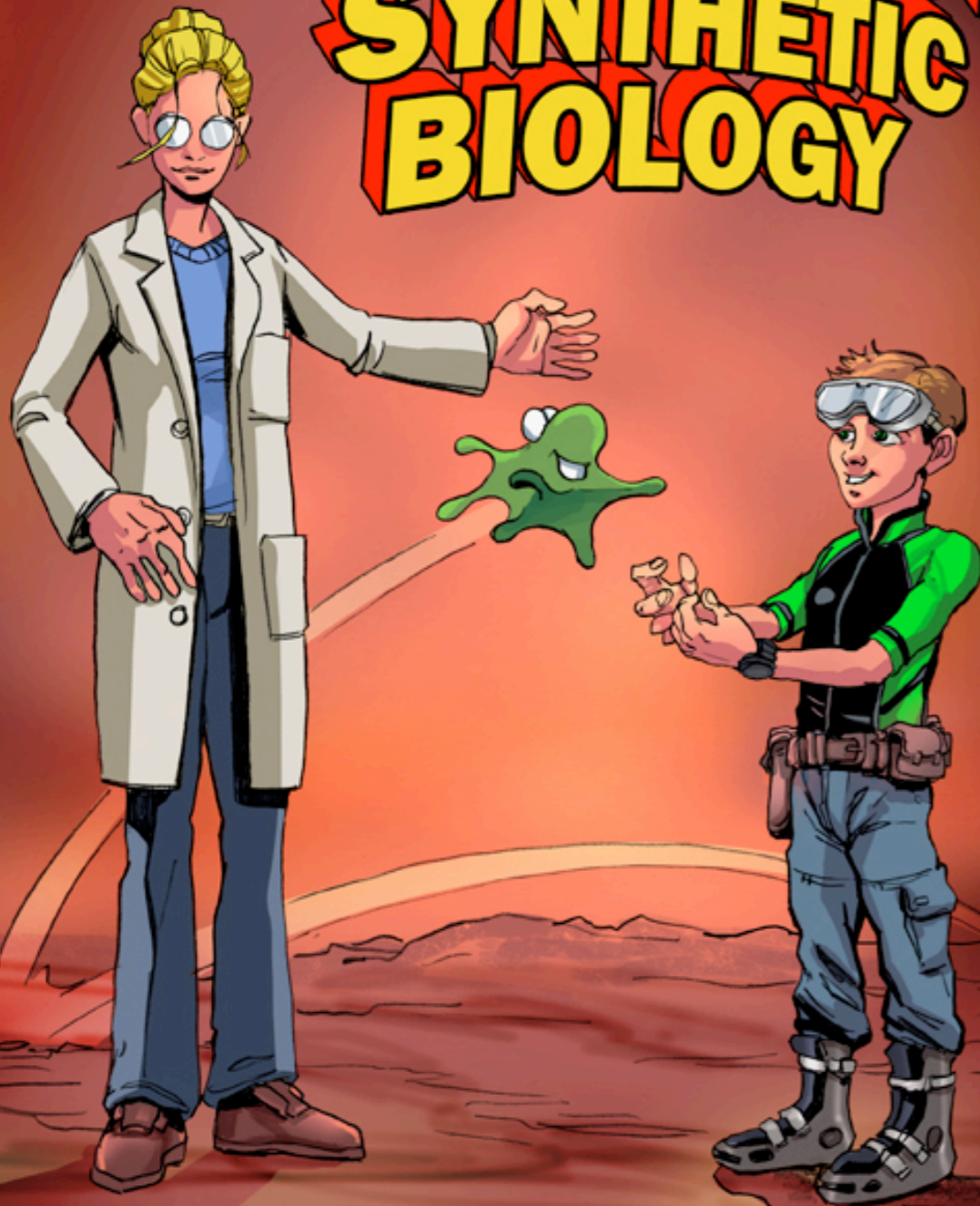
October 2007



... as in the case of many technologies, synthetic genomics may be “dual-use:” in addition to useful advances for society, it may provide those with nefarious intent new ways to harm. Although dual-use concerns exist for almost all technologies, the power and accessibility of modern biotechnology—with synthetic genomics being a prime example—makes these concerns particularly salient. Examination of the risks and benefits of this technology today has become entwined with the events of September 11, 2001 and the subsequent anthrax attacks.

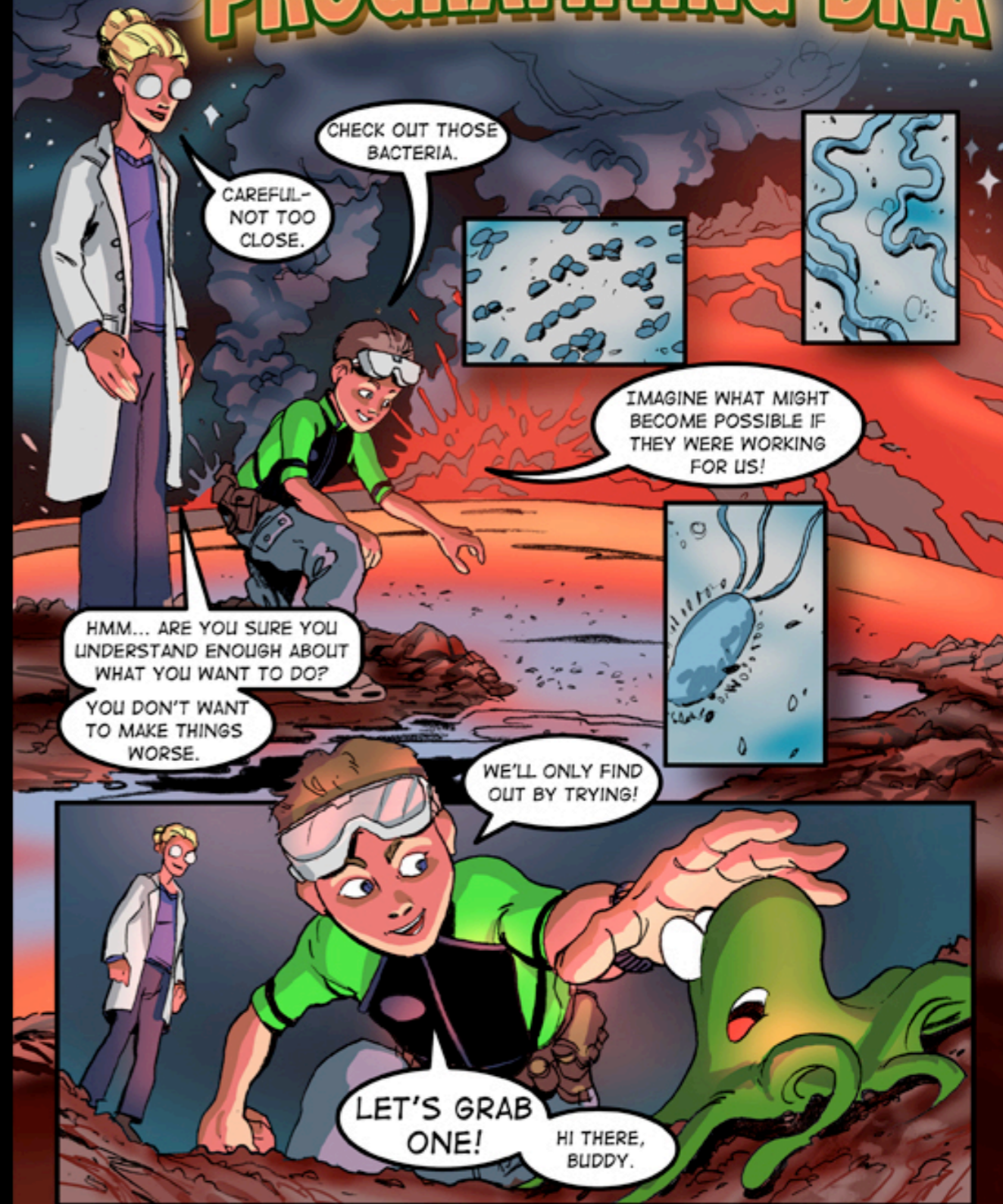
**Safety**

# ADVENTURES IN SYNTHETIC BIOLOGY



STORY: DREW ENDY ISADORA DEESE  
THE MIT SYNTHETIC BIOLOGY WORKING GROUP  
ART: CHUCK WADEY [www.chuckwadey.com](http://www.chuckwadey.com)

# PROGRAMMING DNA



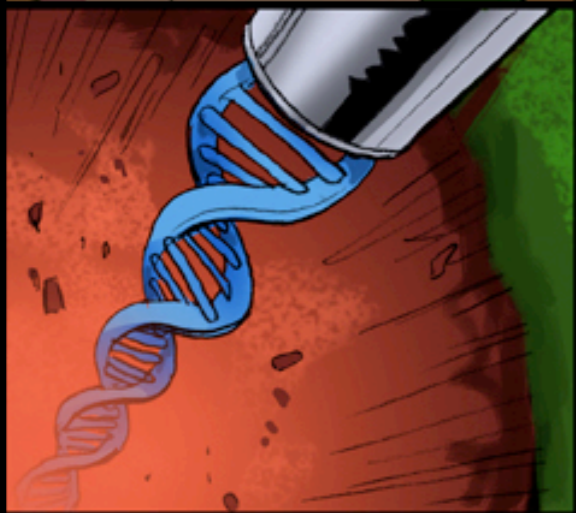


DNA'S READY TO GO.

HELP ME CATCH HIM!



MEEP!



-YOU MIGHT WANT TO STAND BACK.



HE'S CHANGING!



POP POP POP



CHECK IT OUT! IT'S WORKING!!!

SWEET!



HMM. THAT DOESN'T LOOK RIGHT



BANG!



WHAAT? WHAT WAS THAT?

YOU FORGOT TO TELL YOUR PROGRAM TO STOP!



BUDDY KEPT GOING UNTIL IT WAS TOO LATE.



HMM. I BETTER LEARN MORE ABOUT WHAT I'M DOING BEFORE I TRY ANYTHING ELSE.

GEE, YOU THINK?

TO BE CONTINUED...

CONTINUED TO BE

# **Accessible science Hackers aim to make biology household practice**

“CAMBRIDGE - In a third-floor loft where programmers build Internet start-ups, Mackenzie Cowell is talking about the tools he and like-minded young colleagues are using to fuel what they hope will be the next big thing in biology. The list includes a cut-up Charlie Card, ingredients bought on eBay to make a kind of scientific Jell-O, and a refrigerator, just scored on Craigslist.com, that chills to 80 degrees below zero.”

Boston Globe, Sept 15 2008

# Amateurs are trying genetic engineering at home

"[Patterson] learned about genetic engineering by reading scientific papers and getting tips from online forums. She ordered jellyfish DNA for a green fluorescent protein from a biological supply company for less than \$100. And she built her own lab equipment, including a gel electrophoresis chamber, or DNA analyzer, which she constructed for less than \$25, versus more than \$200 for a low-end off-the-shelf model."

Associated Press, Dec 25 2008

# Rise of the garage genome hackers

"KATHERINE AULL's laboratory in Cambridge, Massachusetts, lacks a few mod cons. "Down here I have a thermocycler I bought on eBay for 59 bucks," she says, pulling out a large, box-shaped device she uses to copy short strands of DNA. "The rest is just home brew," she adds, pointing to a centrifuge made out of a power drill and plastic food container, and a styrofoam incubator warmed with a heating pad normally used in terrariums."

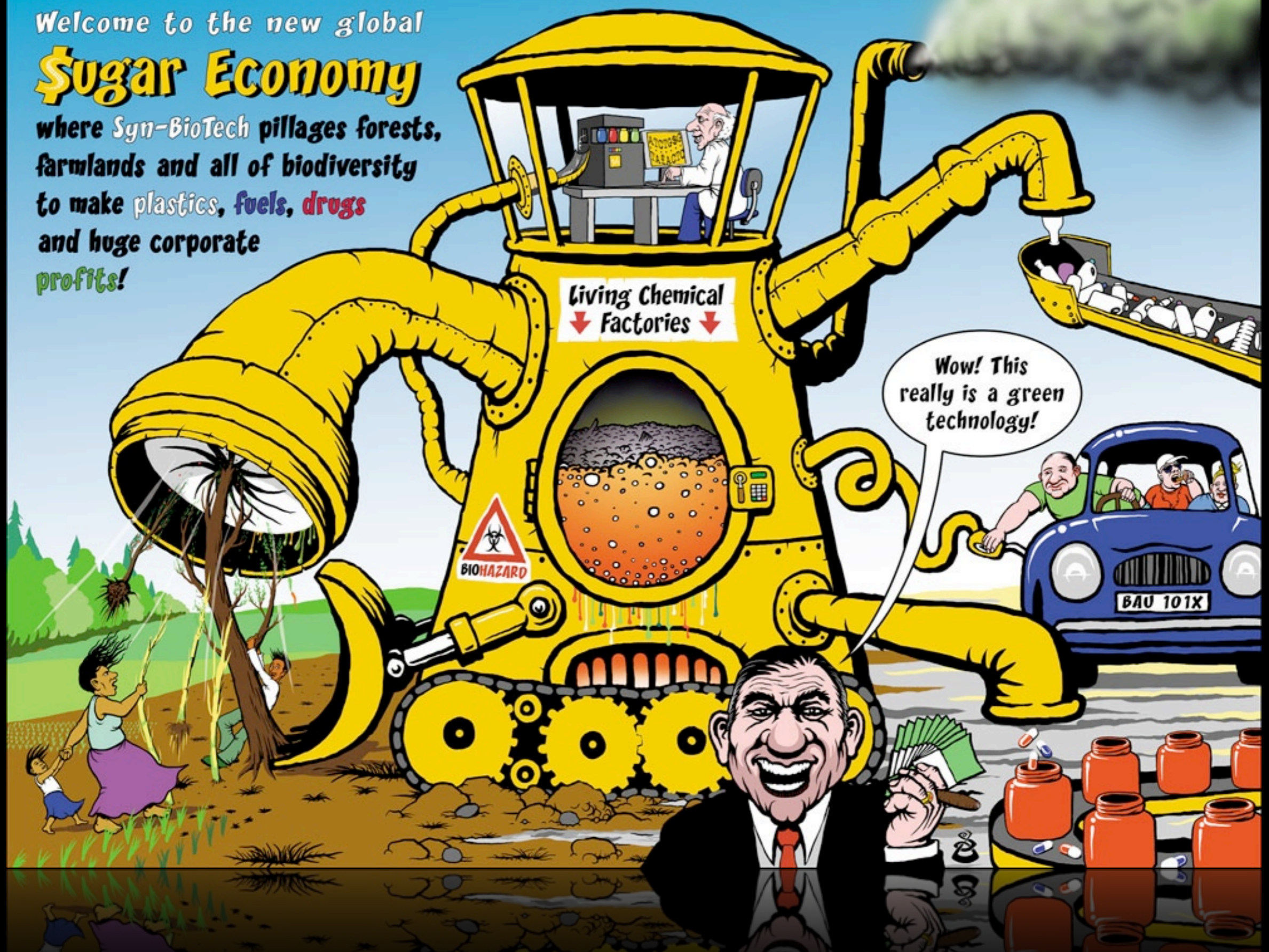
New Scientist, Jan 7 2009



**“Politics”**

Welcome to the new global  
**\$ugar Economy**

where *Syn-BioTech* pillages forests,  
farmlands and all of biodiversity  
to make **plastics, fuels, drugs**  
and huge corporate  
**profits!**



**Ethics**

# Arthur Caplan

Emanuel and Robert Hart Professor of Bioethics, University of Pennsylvania

## The Key Issues:

### Reductionism

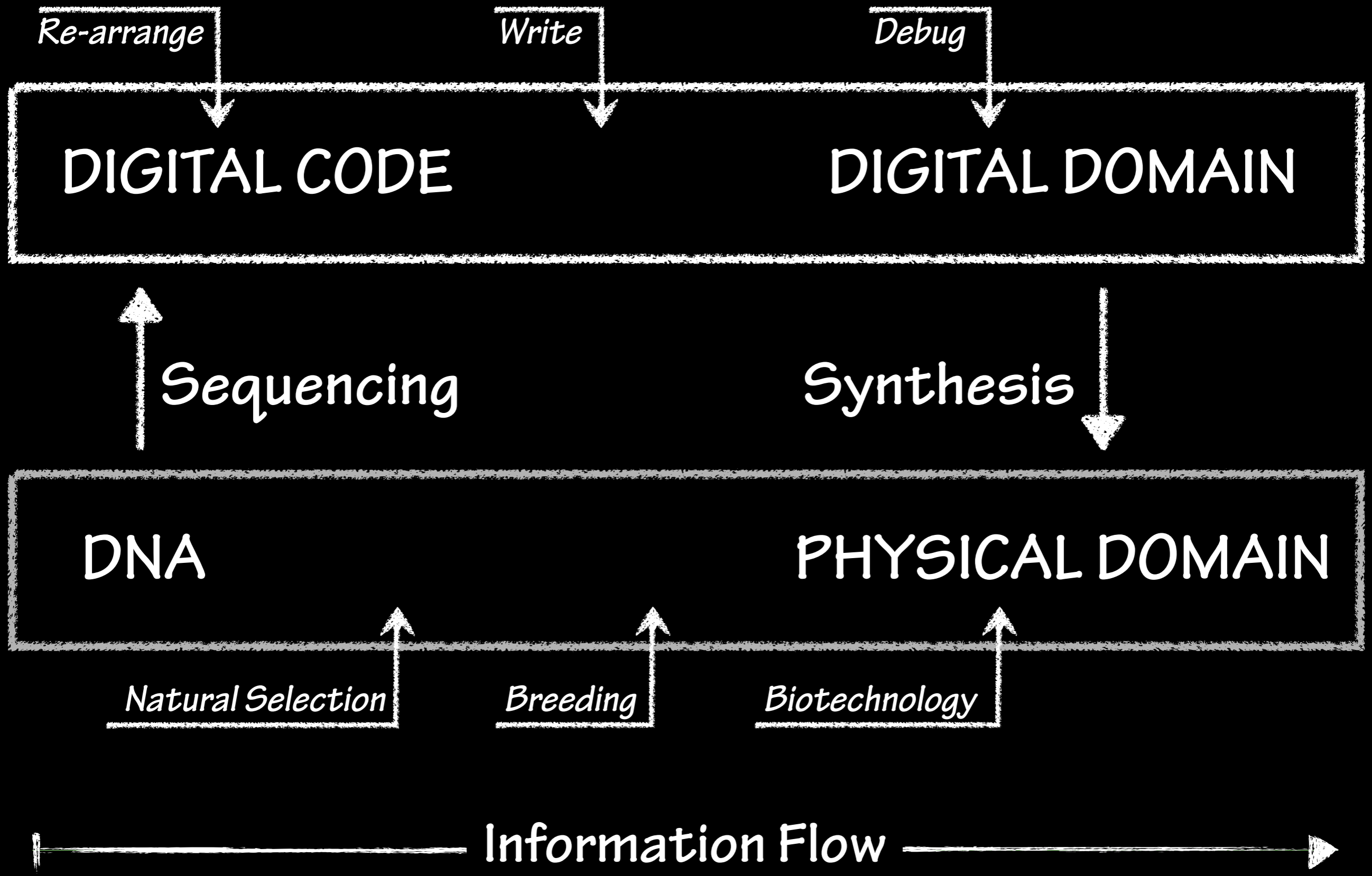
*Life reduced to genetics*

### Playing God

*Exemplifies human hubris*



<http://www.synbioproject.org/events/archive/caplan/>



# Additional Resources Synthetic Biology

## General Information

**2020 Science:** <http://2020science.org/category/synthetic-biology>

**Synthetic Biology Project:** <http://www.synbioproject.org>

**Select articles on synthetic biology:** [http://www.synbioproject.org/topics/synbio101/selected\\_synbio\\_readings/](http://www.synbioproject.org/topics/synbio101/selected_synbio_readings/)

**The Royal Society:** <http://royalsociety.org/landing.asp?id=1230>

## Research and Development

**Keasling Laboratory:** [http://keaslinglab.lbl.gov/wiki/index.php/Main\\_Page](http://keaslinglab.lbl.gov/wiki/index.php/Main_Page)

**SynBERC:** <http://www.synberc.org/>

**Haseloff Laboratory:** <http://www.plantsci.cam.ac.uk/Haseloff/>

**General synthetic biology resource:** <http://www.syntheticbiology.org/>

**The BioBricks Foundation:** <http://bbf.openwetware.org/>

**Registry of Standard Biological Parts:** [http://partsregistry.org/Main\\_Page](http://partsregistry.org/Main_Page)

**iGEM Competition:** <http://2008.igem.org/> and <http://2009.igem.org/>

## Policy, ethical and social issues

**Synthetic Biology Project:** <http://www.synbioproject.org>

**The Hastings Center:** <http://www.thehastingscenter.org/Issues/Default.aspx?v=2392>

**The Royal Society:** <http://royalsociety.org/landing.asp?id=1230>

**J. Craig Venter Institute:** <http://www.jcvi.org>

**Arthur Caplan on "Playing God":** <http://dsc.discovery.com/technology/my-take/synthetic-biology-caplan.html>

# **Andrew D. Maynard PhD**

Chief Science Advisor

Project on Emerging Nanotechnologies

Woodrow Wilson International Center for Scholars

Tel: +1 202 691 4311

Email: [andrew.maynard@wilsoncenter.org](mailto:andrew.maynard@wilsoncenter.org)

<http://2020science.org>