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ARIZONA STATE UNIVERSITY

Synthetic Biology and Sustainability

Presentation at 1st Interdisciplinary Symposium:

Global Sustainability – A Nobel Cause

Potsdam, FDR 10 October 2007

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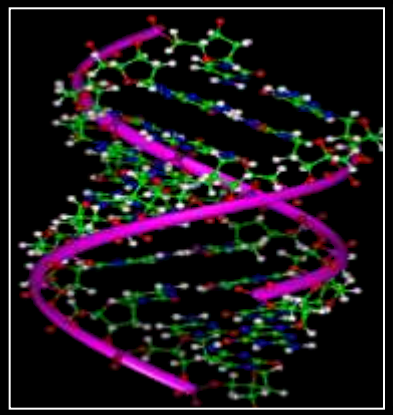
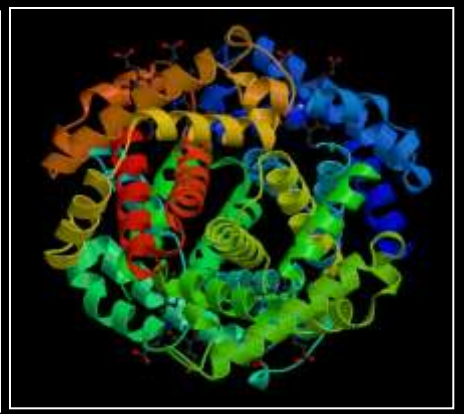
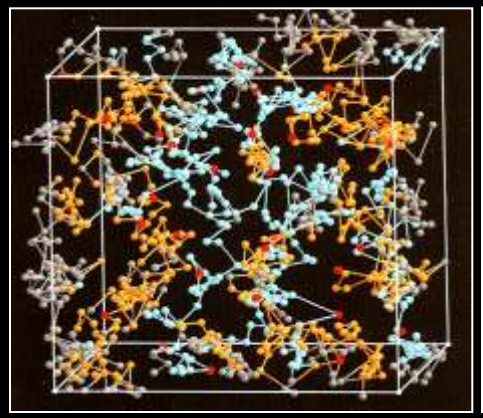
Synthetic Biology

- elucidation of the design principles and ‘rule sets’ of biological organization
- design and construction of novel biological functions and life forms


Synthetic Biology

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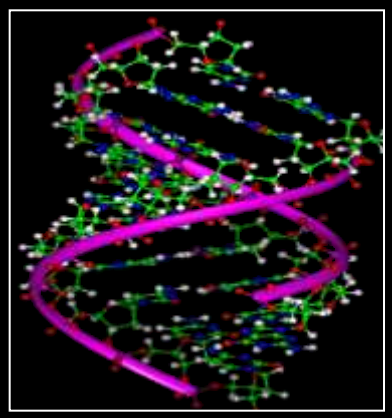
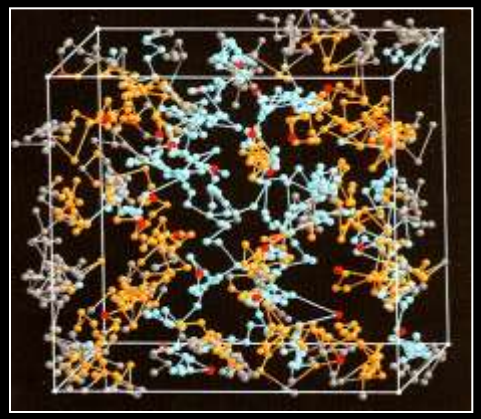





- understanding the encoded information content and information flow in biological systems

Biological Design: “Endless Forms Most Beautiful”: Limitless Diversity From Combinatorial Assemblies of Limited Building Blocks

Defining the Rule Sets for Biological Design, Assembly and Function

- common genetic (digital) code in all life forms
- genomes encode a limited series of structural building blocks (protein motifs and programmed assembly)
- combinatorial assembly of protein building blocks generates extravagant structural and functional diversity

Exploring Biospace
The Design Power of Combinatorial Interactions and Assemblies

- 30,000 genes
- two genes cooperate to create a function
  =(30,000 x 29,999)/2 = 449,985,000 potential combinations
- 100 genes generate a complex function
  $=10^{289}$ potential combinations
- if any combination of genes can generate a function
  $= 2 \times 10^{72,403}$ potential combinations
- number of theoretical possibilities for synthetic assembly (biospace) far exceed narrow molecular space sampled in evolutionary time

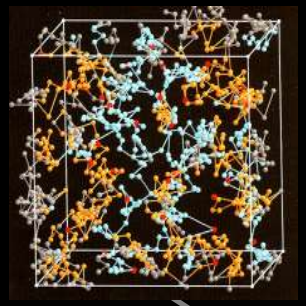
Synthetic Biology

- matching the versatility, elegance and inventiveness of natural systems
- expanding the dimension of explored biospace
- predictive biology: design, simulation and construction of novel functions/organisms

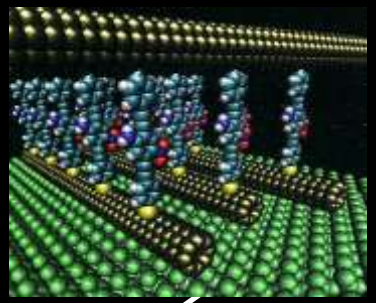
Synthetic Biology:
Inter-disciplinary Convergence and Complex Policy Issues

Systems Biology

Computational Biology

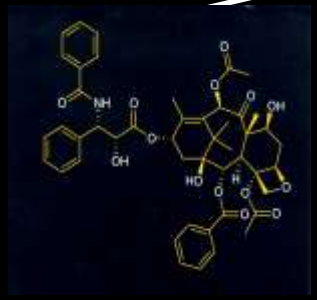


Materials and Nanobiotechnology



Industrial Bioprocess Engineering

Specific Applications



Occupational Safety

Dual-Use Applications

Public and Media Responses

Public Policy and Regulatory Oversight

Synthetic Biology:
An Emerging Technology with Diverse Industrial Applications

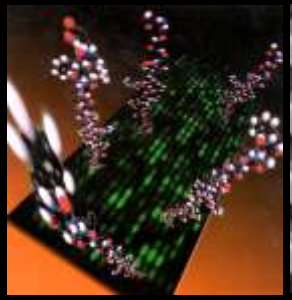
Healthcare

Public Health

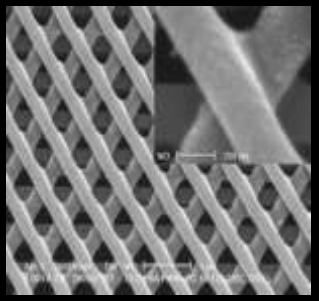
Agriculture

Functional Foods

Novel Materials



Textiles



Bioenergy and Biofuels

Industrial Enzymes

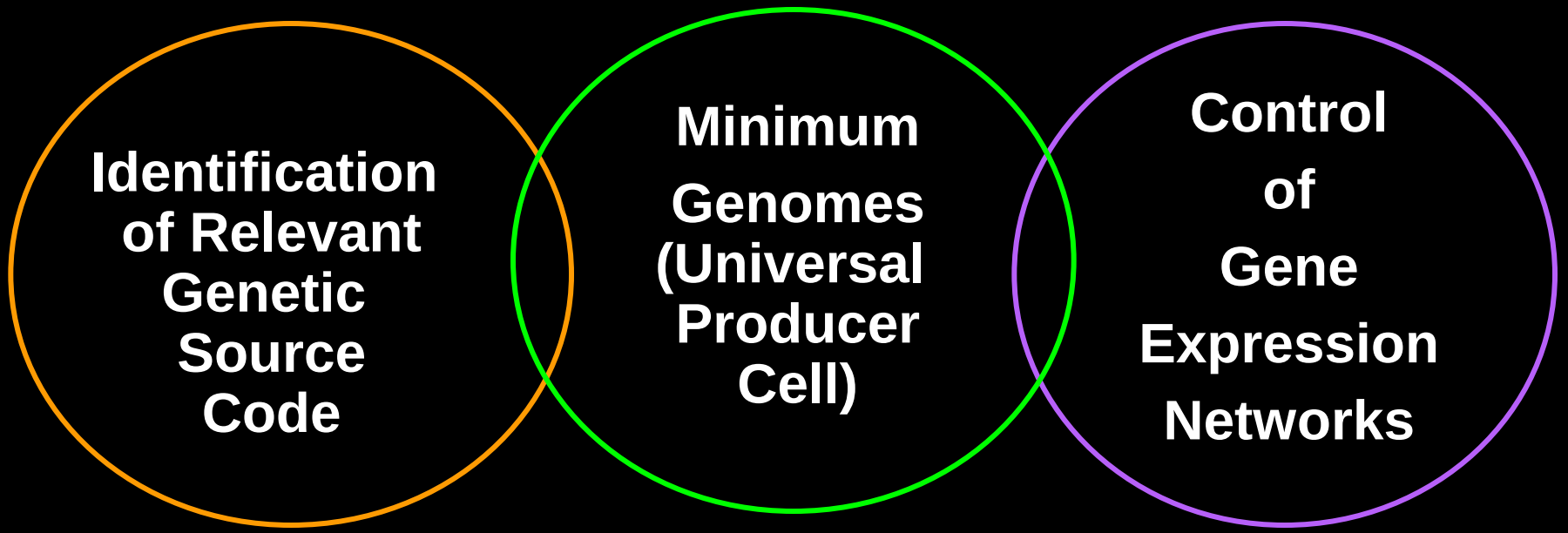
'Green' Mfg

Bio-remediation

Clean Water

Ubiquitous Sensors

Synthetic Biology

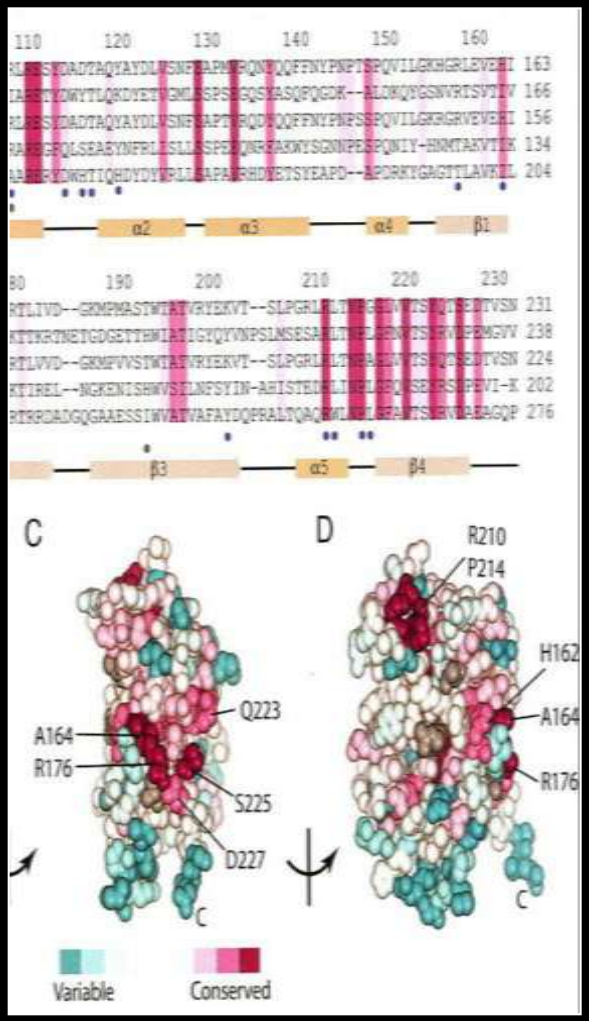


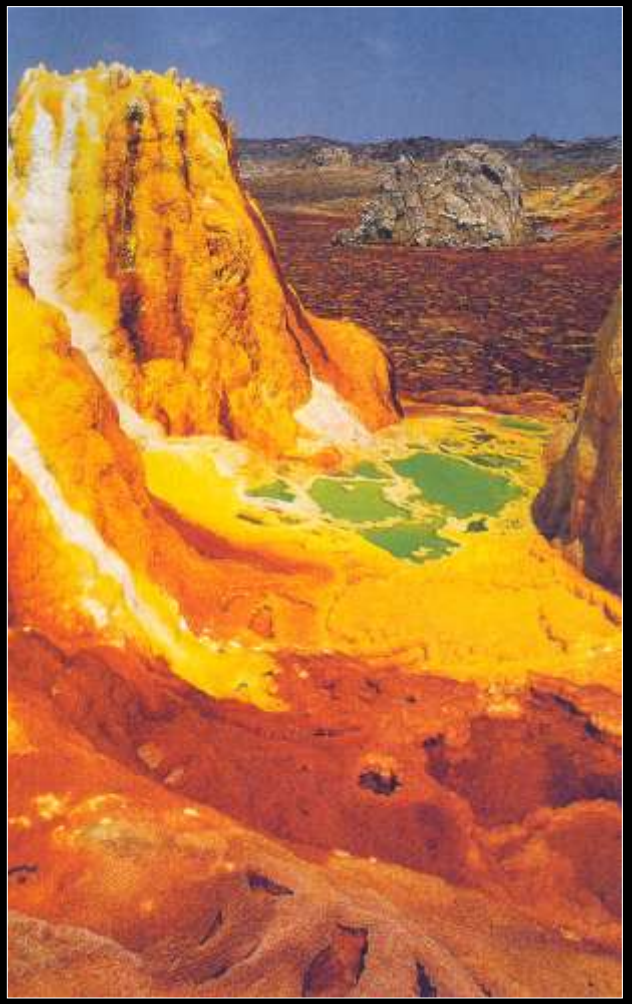
- metagenomic screening for desired trait(s)

- "plug and play" programmed expression of gene "cassettes"

- programmed biosynthesis
- induction of novel properties in specific cells/tissues/ organisms

Ecogenomics:
Mapping the Extraordinary Genomic Diversity and Biosynthetic Capabilities of Microbial Life





genomics

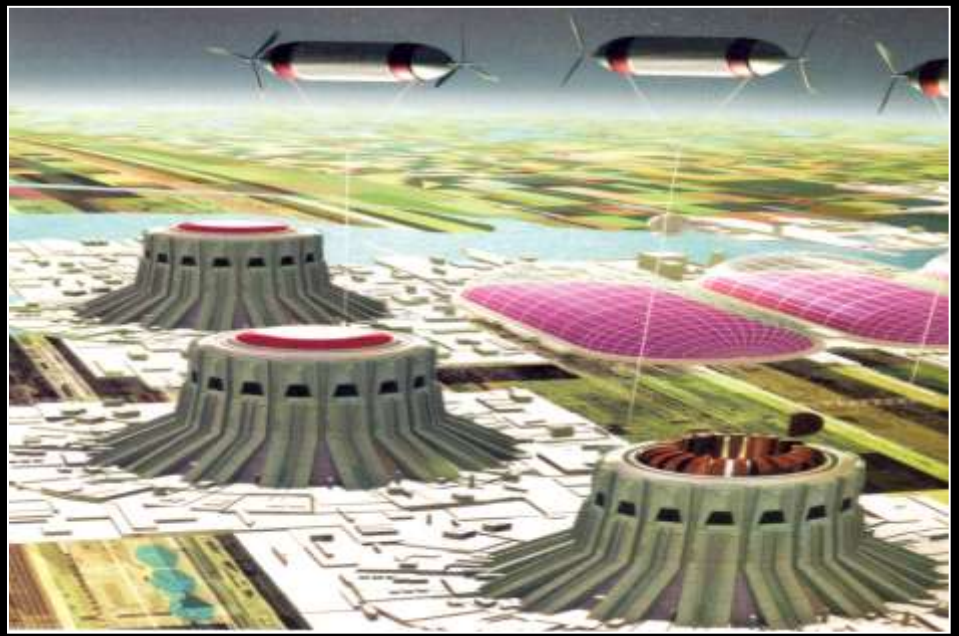
eco-niches

extremophiles

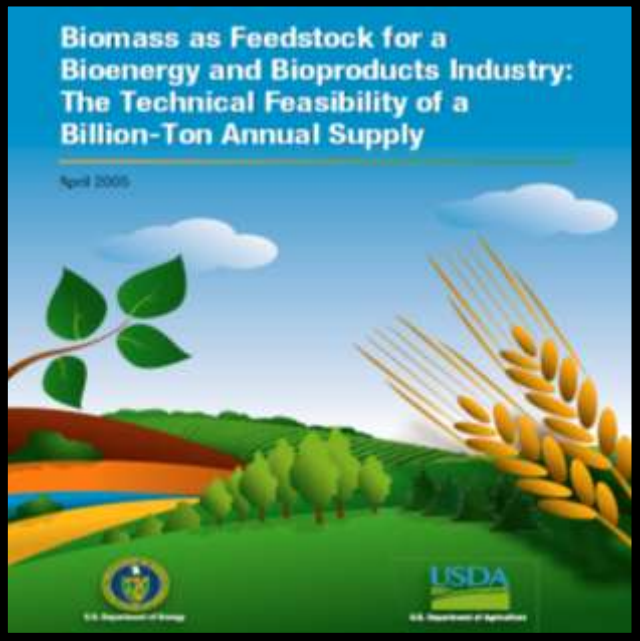
Metagenomics: Sampling the Extravagant Functional Diversity of Microorganisms

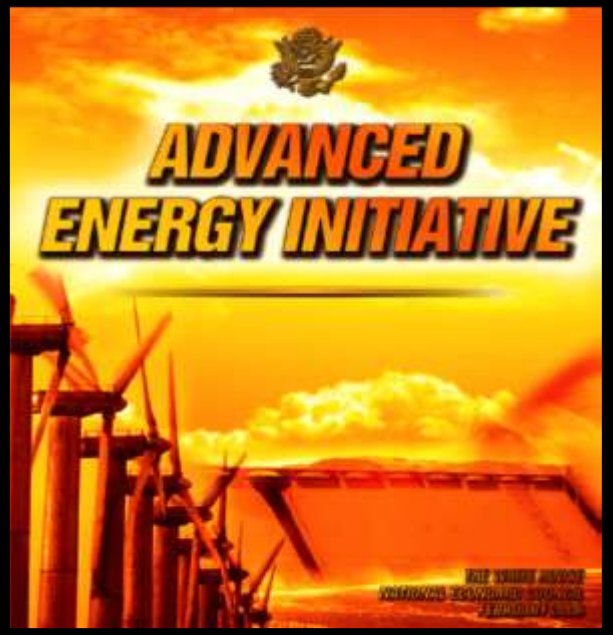
- estimated 100 billion microbial species
- only 6000 species cultivated and characterized
- massive repertoire of uncharacterized genes/proteins/metabolomes
- metagenomic sampling
  - mass screening of complete genomes of unknown/unculturable organisms
  - high throughput profiling to identify transfer of gene(s) with desired function into ‘universal acceptor’ organisms

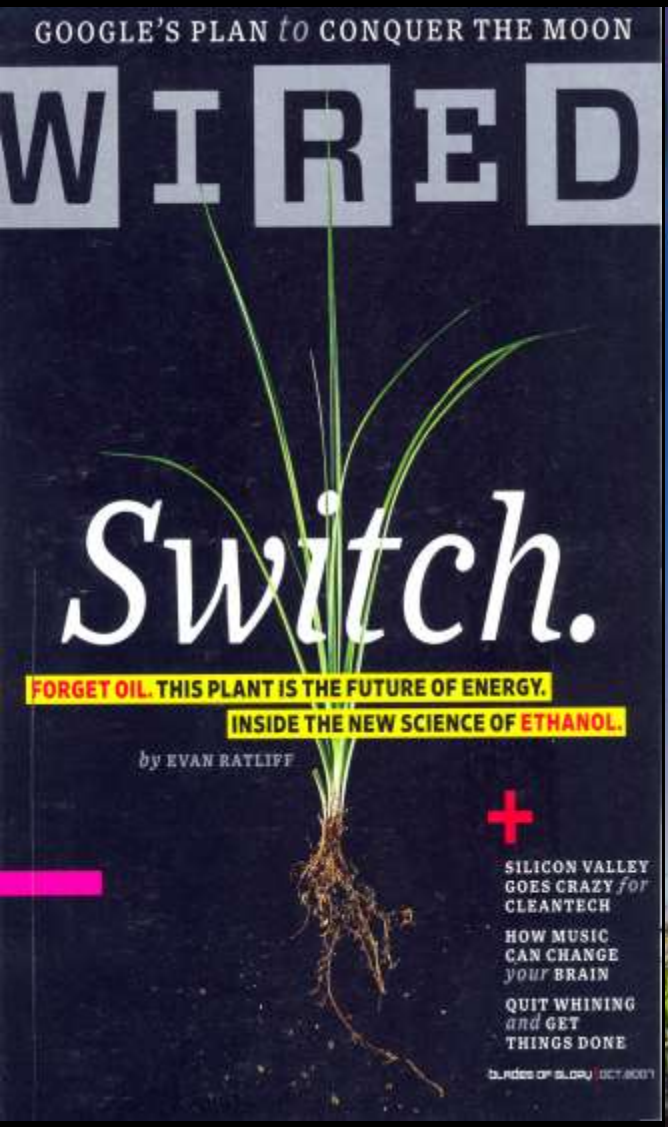
The Quest for Sustainable Energy Sources



Bio-Inspired Systems for Energy Production



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FORGET OIL. THIS PLANT IS THE FUTURE OF ENERGY.
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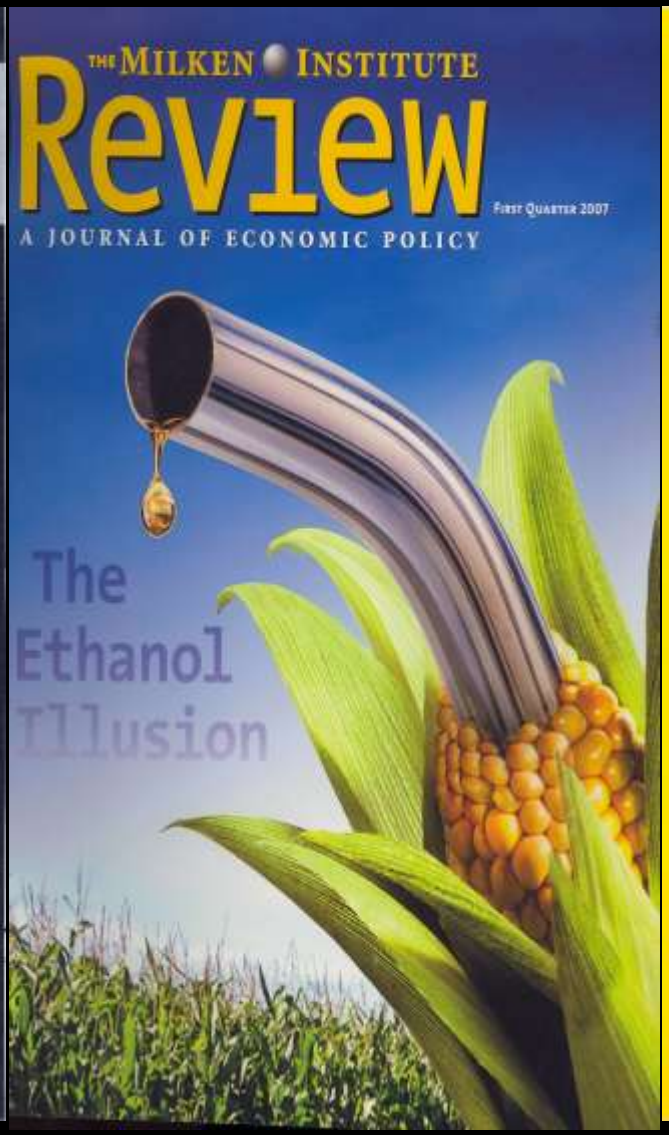
by EVAN RATLIFF
+
SILICON VALLEY GOES CRAZY for CLEANTECH
HOW MUSIC CAN CHANGE your BRAIN
QUIT WHINING and GET THINGS DONE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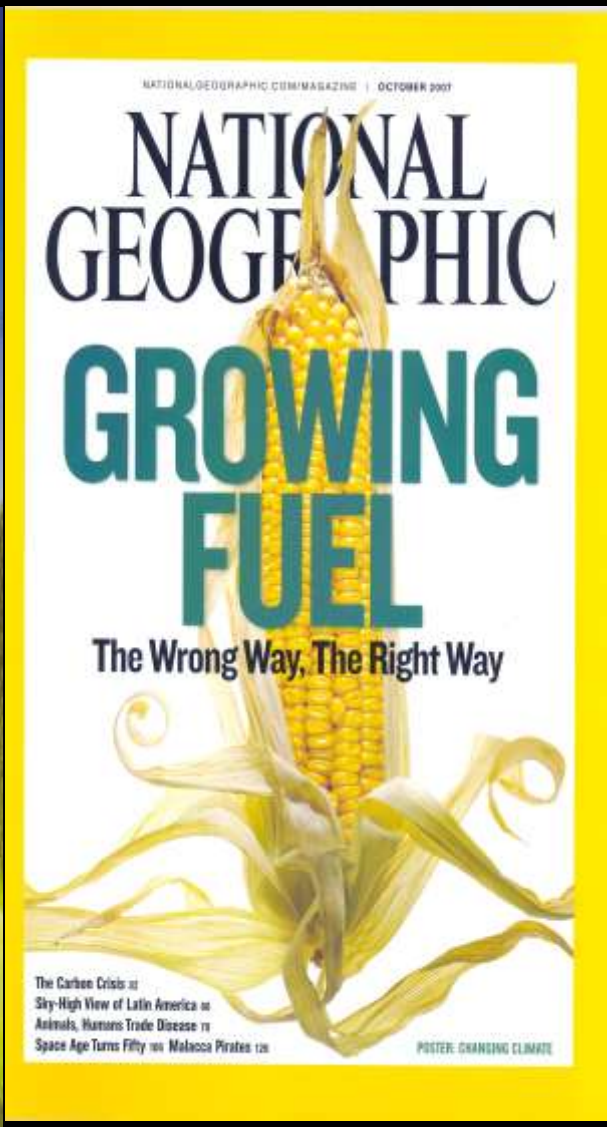
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GROWING FUEL
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The Carbon Crisis
Sky-High View of Latin America
Animals, Humans Trade Disease
Space Age Turns Fifty
Malacca Pirates
POSTER: CHANGING CLIMATE

Production of Biodiesel from Biomass: A Widely Differing Yield Spectrum*

Source	Yield US gal/acre	Yield L/Km^2
Soybean	40-50	35-45,000
Rapeseed	110-145	100-130,000
Mustard	140	130,000
Jatropha	175	160,000
Palm oil	650	580,000
Photosynthetic Microbes	10-20,000	9-18,000,000

* http://en.wikipedia.org/wiki/Biodiesel

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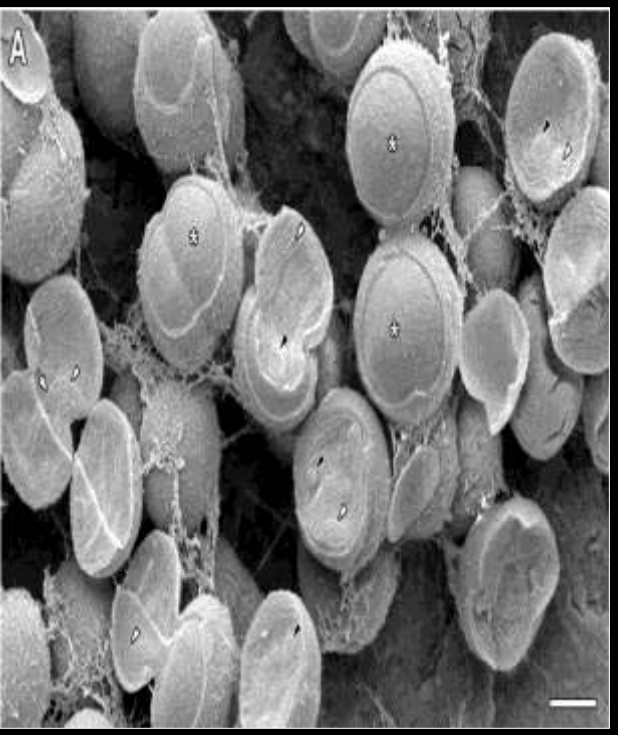
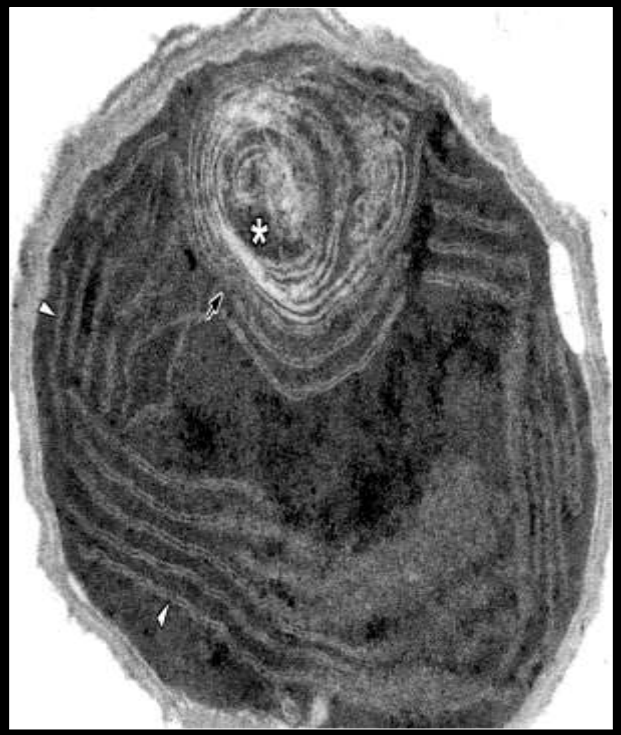
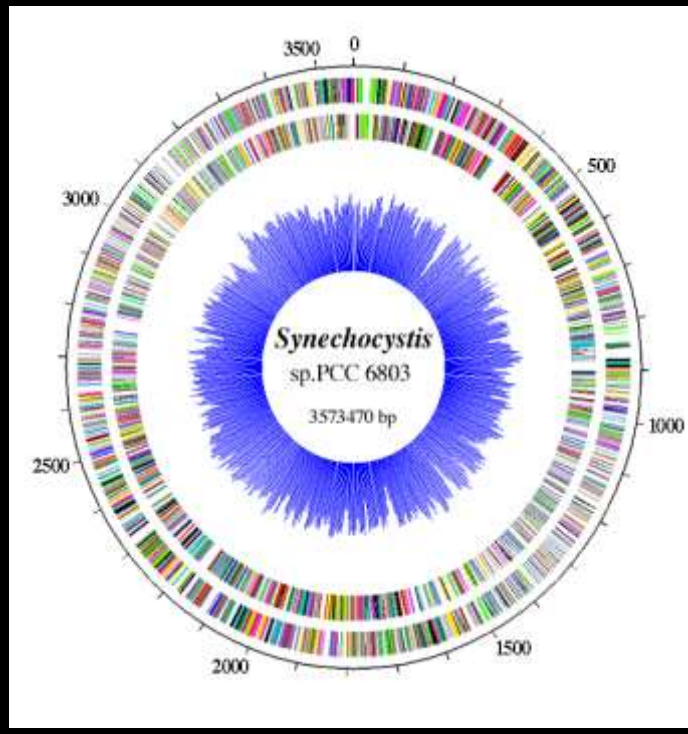
Biomass to Energy: The Merits of Cyanobacteria as a Feedstock







- well characterized, tractable genome for trait enhancement
- no celluose
- compositional homogeneity
- rapid assay of genetic modifications
- siting flexibility
- no or limited transport costs
- CO_2 fixation

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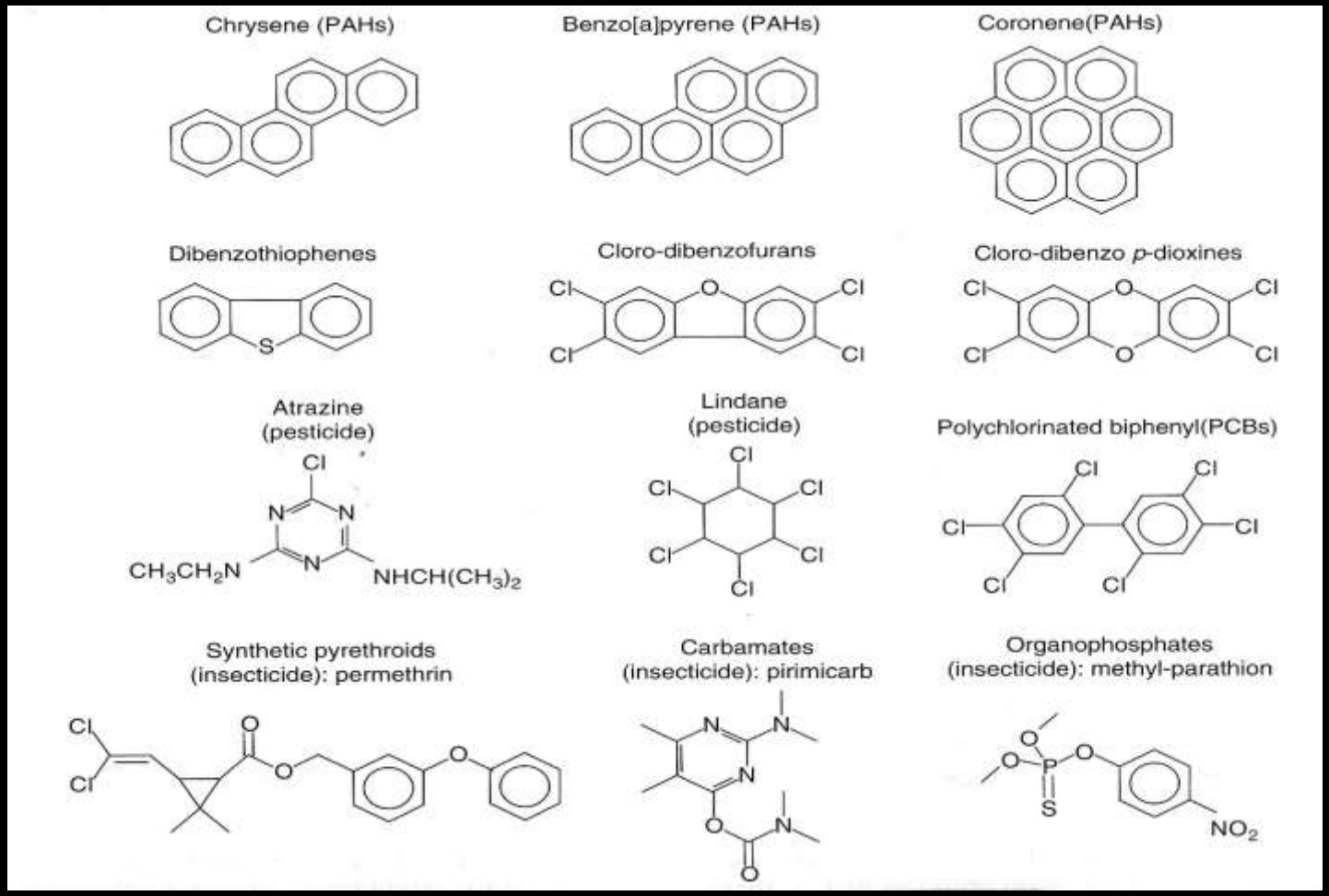
Water Supply and Safety
A Source of Future Geopolitical and Economic Instabilities






Microbial Genomics and Synthetic Biology: New Technology Platforms for Bioremediation and Improved Efficiency of Wastestream Management



Bio-Inspired Engineering: Removal of Perchlorate Contamination by Chemical Reduction by Biofilms of Hydrogen Producing Bacteria

- ✓ pilot scale project at La Puente, CA (400 L/min)
- ✓ influent: 25 mg/L of NO_3^- and 60 µg/L ClO_4^-
- ✓ ≈ 95% removal of ClO_4^-, from 60 µg/L to below the CA action level of 4 µg/L
- ✓ ≈ 98% NO_3^- removal of 25 mgN/L to ≈ 0.5mgNO_3^-/L
- ✓ essentially 100% H_2 usage

e.Waste

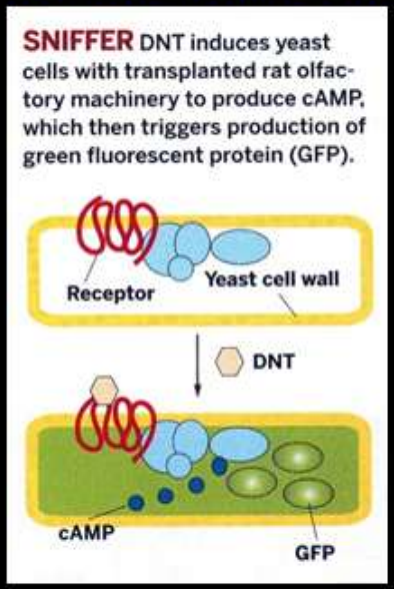
- US produces 2 million tons per year
- escalating toxicity in developing countries with out-sourced salvage activities
- lead, cadmium, mercury and flame retardants
- EC Restriction of Hazardous Substances Directive (ROHS)

Biological Sensor Systems for Environmental Monitoring and Ecosystem Status

Genetically-Engineered *Arabidopsis thaliana* Change-Color when Exposed to Landmine Degradation Products

Aresa Biotection, Demark

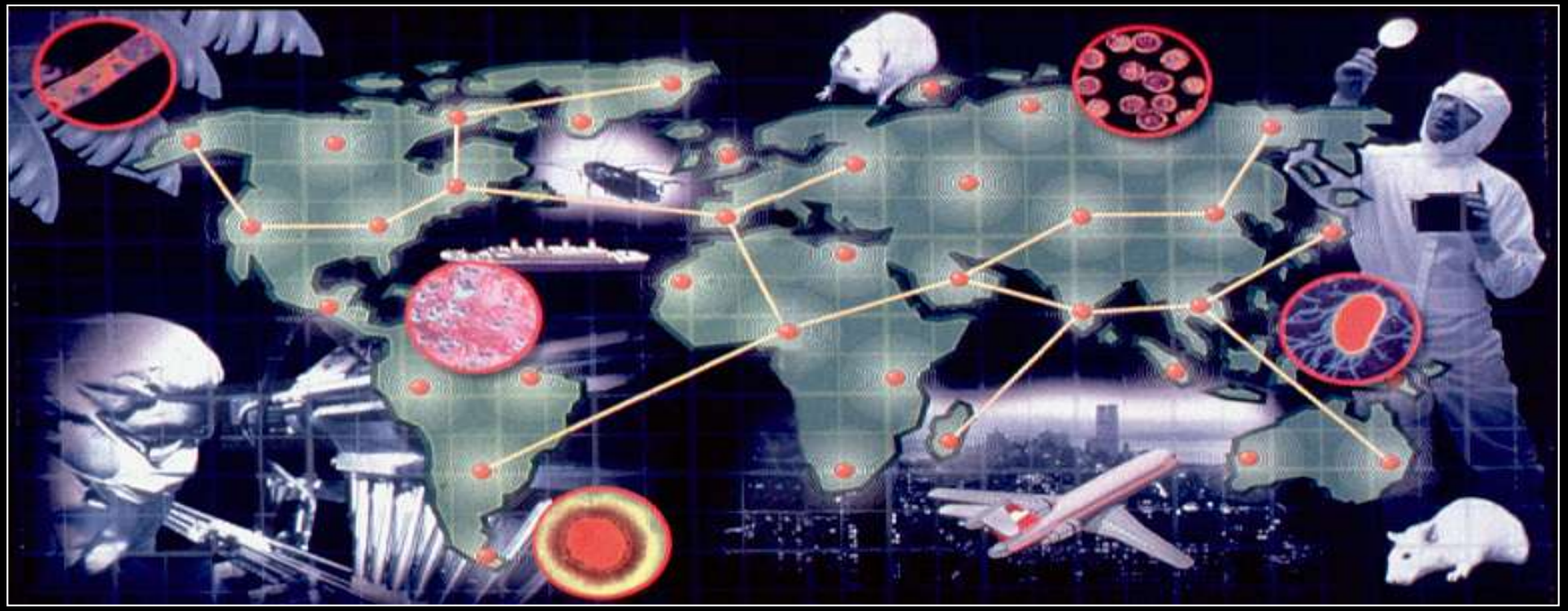
Engineering Sentinel Organisms as Environmental Sensors



D. N. Dhanasekaran et al (2007) Nature Chem. Biol.

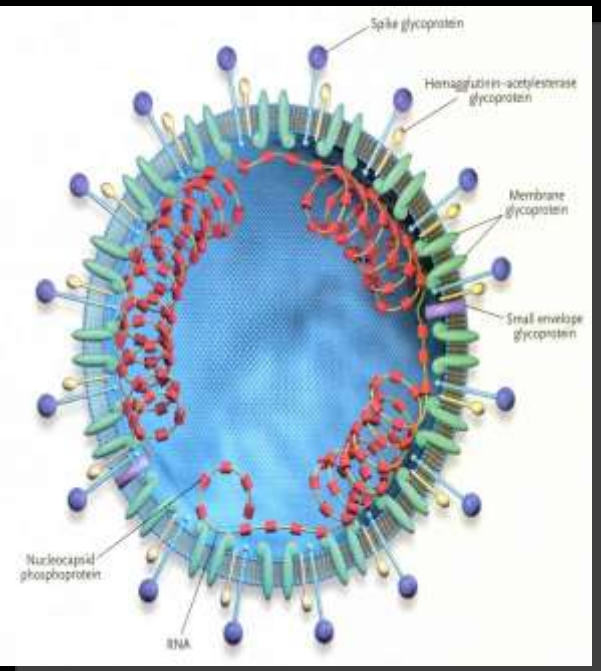
DOI: 10.1038/nchembio882

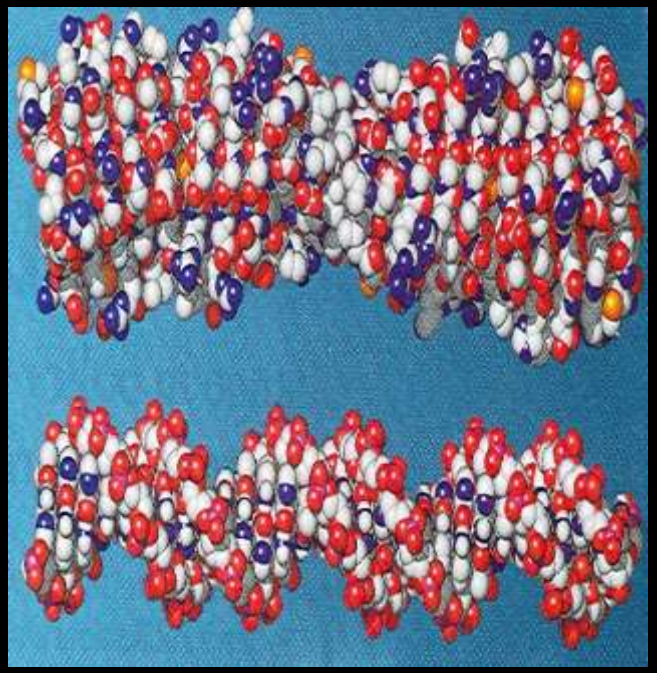
EIDs: Global Reach and Global Consequences

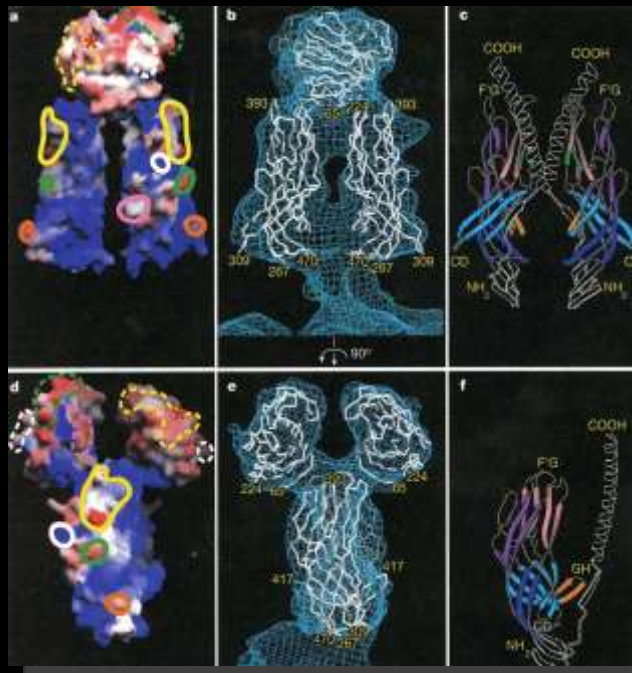


The Lack of Public Health Infrastructure in Developing Countries: Urbanization and New Zoonoses

Engineered Microorganisms and Cells as Novel Delivery Systems for Drugs and Vaccines







No One Walks Alone

- every adult human carries two pounds of bacteria
  - 100 trillion non-human cells
- microorganisms as key substrates for therapeutic/diagnostic interventions
  - in-body sensors
  - regulated production of biomediators
  - gene-centered implants, copies, upgrades
- genetics will be scaleable and upgradeable
- plug and play genetics : the “undo” button

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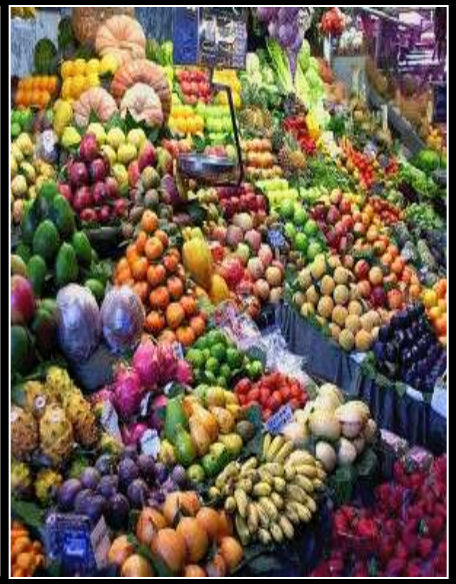
Synthetic Biology and Engineering Enhanced Traits in Food, Feed and Fiber Products







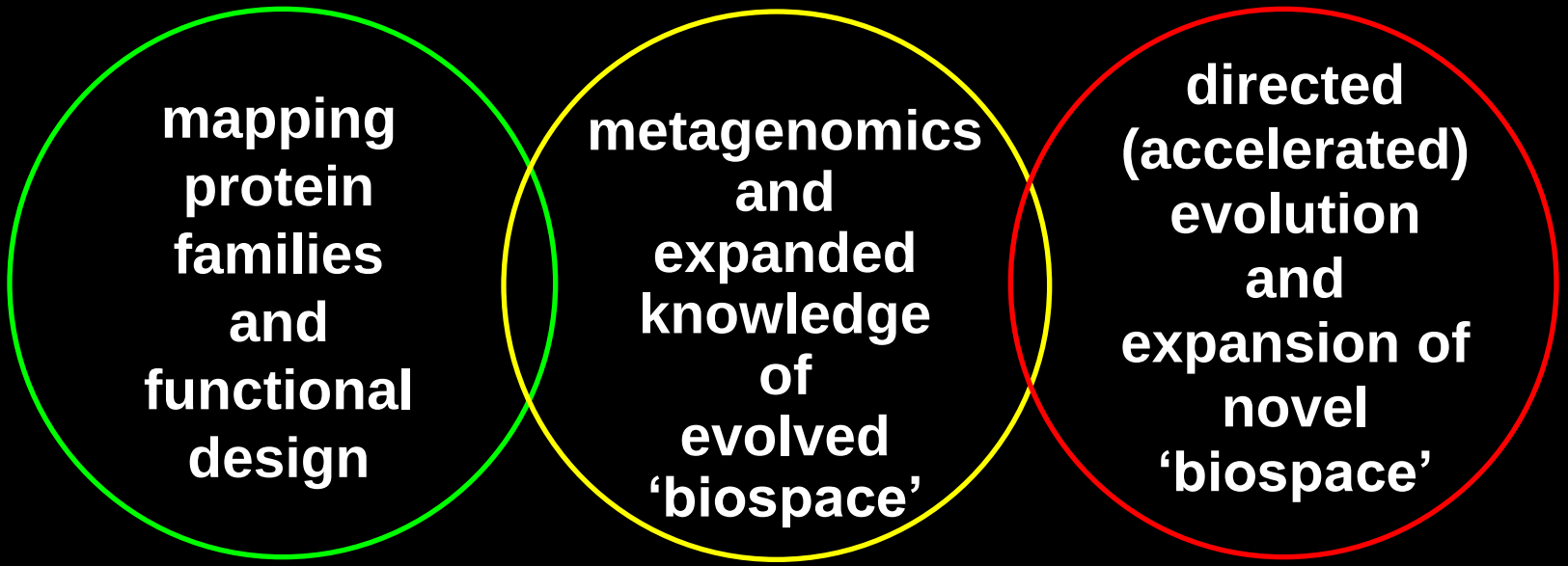

Directed Evolution and Design of Novel Enzymes for Catalysis of Lignocellulosic Biomass

- cellulosic energy crops
- agricultural, forestry and mill residues
- food processing residues
- municipal solid waste
- non-recycled paper
- construction and demolition wood

Synthetic Biology and Novel Industrial Process Chemistry

The Natural World (Evolutionary Biospace)

The Synthetic World (Exploring Unexplored Biospace)



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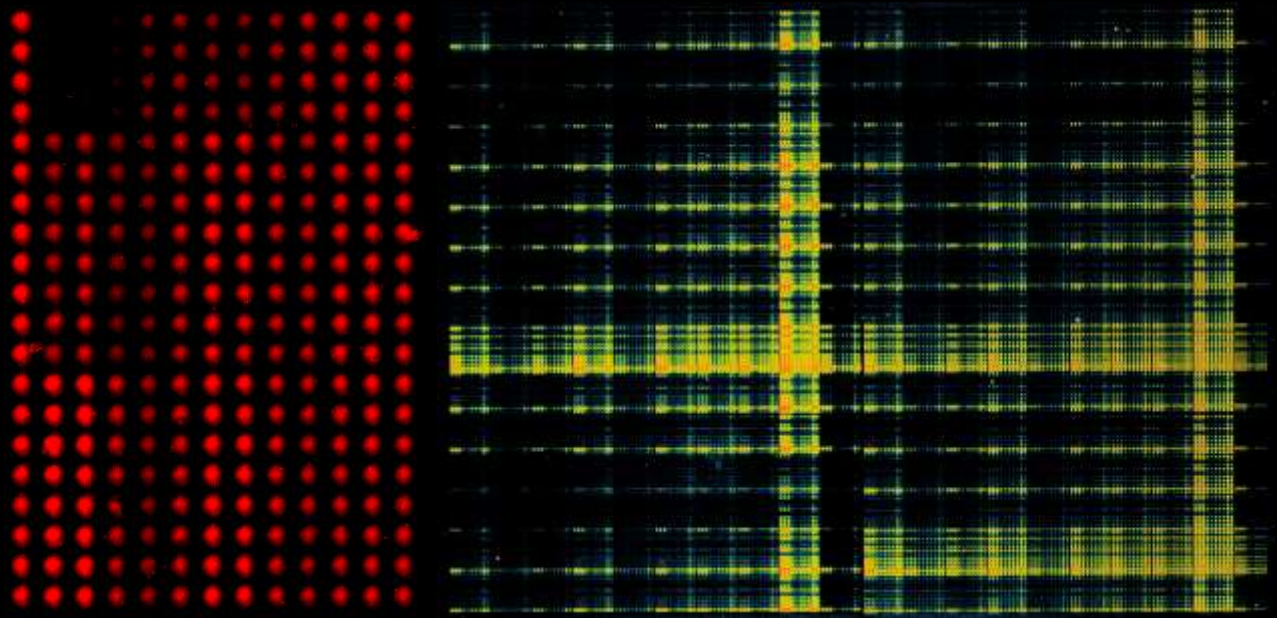
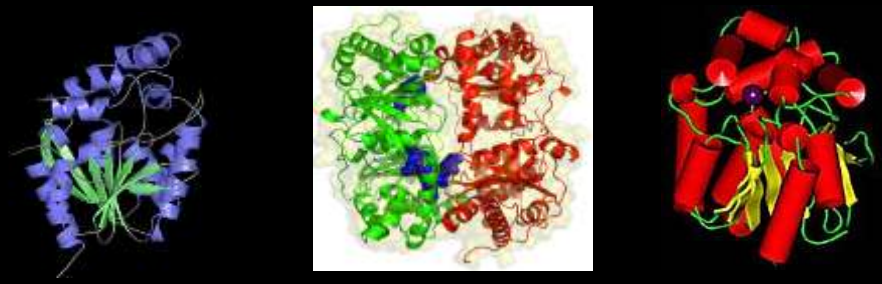
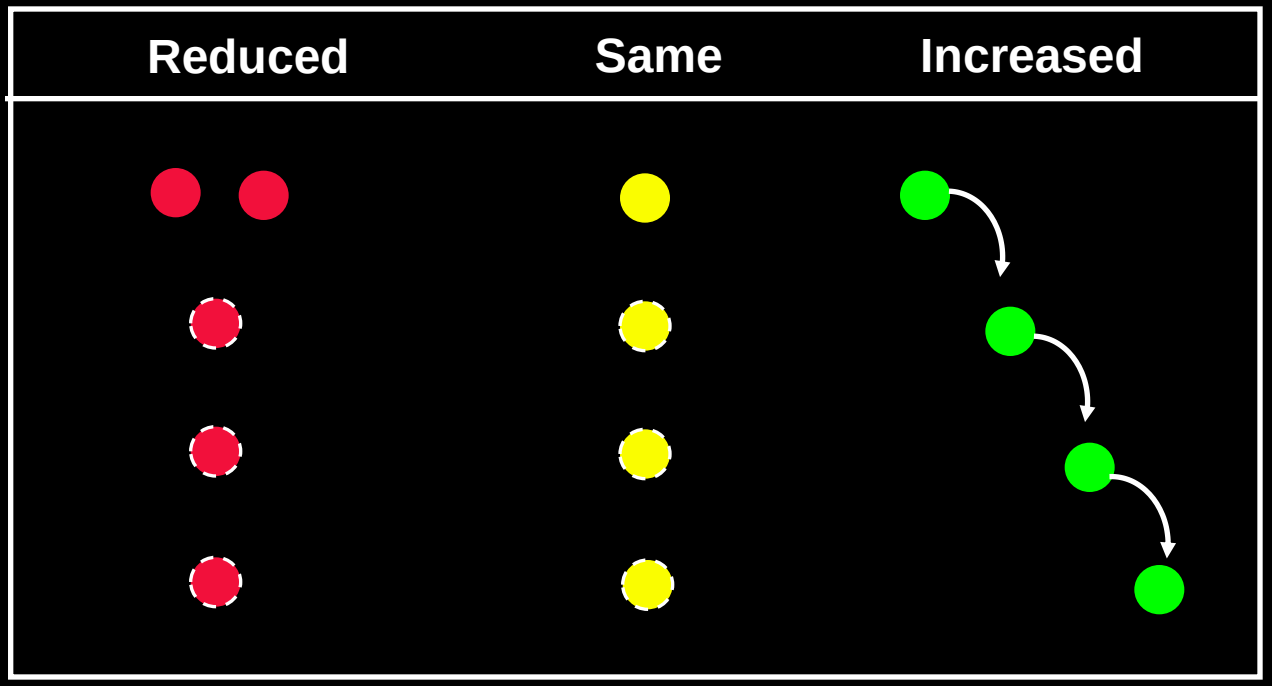
Accelerated Evolution and Design of Novel Catalysts



Exploring Biospace: Iterative Selection of Novel Variants for Substantial Functional Performance Improvements Versus Naturally Occurring "Parent System"



Activity Versus Starting Material

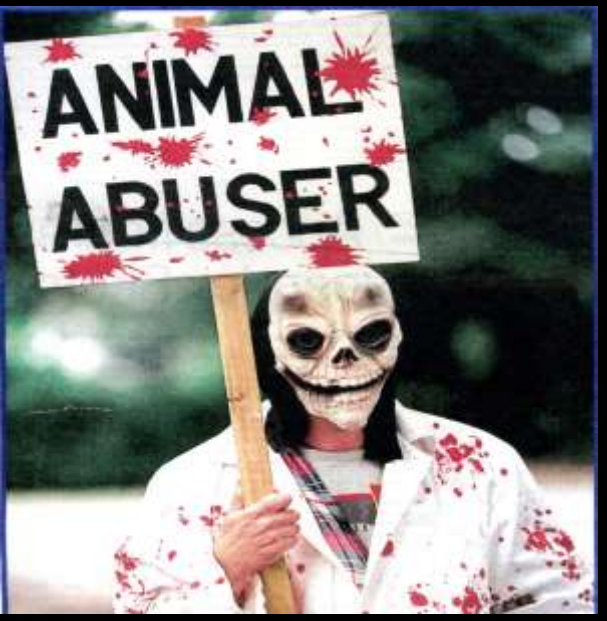


Silicon Valley Cleans Up

HOW TECH TITANS BECAME ENERGY ENTREPRENEURS. A WIRED FLOWCHART.

INFOGRAPHIC BY BOB DINETZ

Controversy and Divisiveness of New Technologies



Synthetic Biology

- complex policy issues
- design of novel life forms and societal response
- dual-use applications
- public and media attitudes to perceived risks and benefits
- proactive, predictable, evidence-based regulatory frameworks

The End of the Darwinian Interlude

- early ‘biotic’ world
  - massive lateral gene transfer and ‘loose’ definition of species
  - rapid evolution as a communal affair
- the Darwinian interlude
  - majority period in evolution (3 billion plus) years
  - slow pace of change and species ‘isolationism’
- synthetic biology
  - revival of pre-Darwinian era of horizontal gene transfer

Synthetic Biology

- emerging technology with myriad applications across diverse industrial sectors

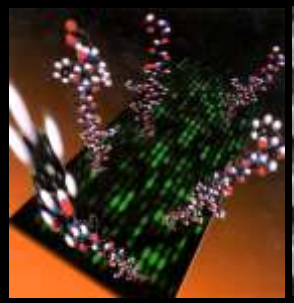
Healthcare

Public Health

Agriculture

Functional Foods

Novel Materials



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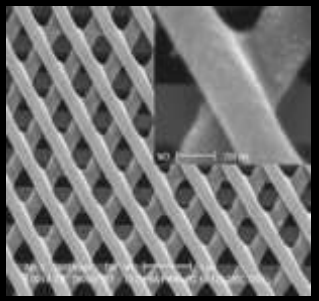


Bioenergy and Biofuels

Industrial Enzymes

'Green' Mfg

Bio-remediation

Clean Water

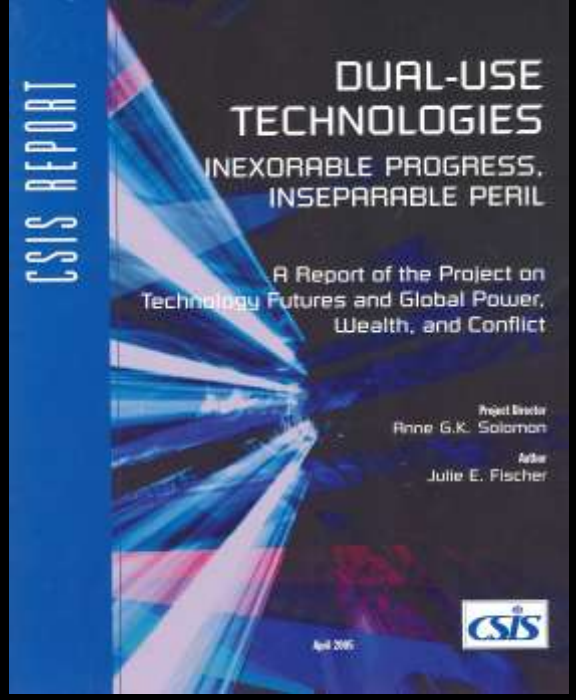
Ubiquitous Sensors

Synthetic Biology

- new bioprocess technologies based on the ‘design principles’ of biological systems will progressively transform industrial manufacturing methods
  - cost-effective use of renewable resources
  - reduced depletion of scarce/non-renewable resources
  - mitigation of adverse environmental impacts via bioremediation of waste streams and contaminated environments
  - economic and security benefits of bioenergy and biofuels
  - novel goods and services

Synthetic Biology

- anticipated powerful driver of industrial innovation and market disruption
- new aspirants, new cross-sector relationships and new markets
- the next era in the evolution of human mastery of the environment
  - agronomic, industrial, informational, genetic, biomimetic, designed life forms
  - enhancement and eugenics?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INEXORABLE PROGRESS, INSEPARABLE PERIL
A Report of the Project on Technology Futures and Global Power, Wealth, and Conflict
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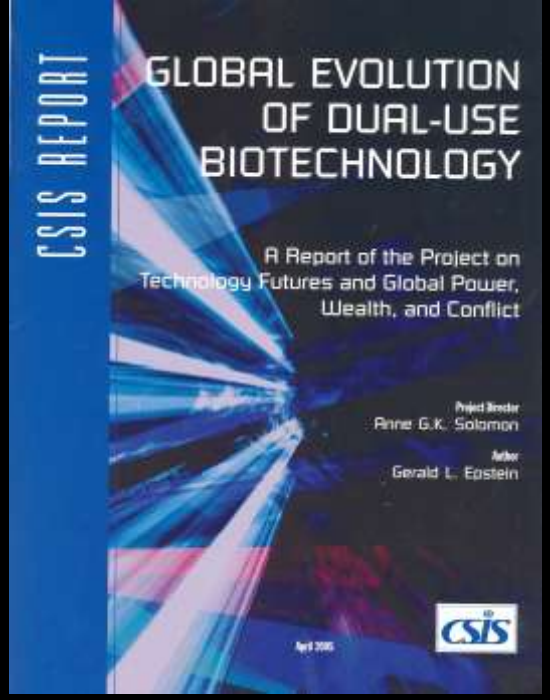
Anne G.K. Solomon
Author
Julie E. Fischer
CSIS
April 2005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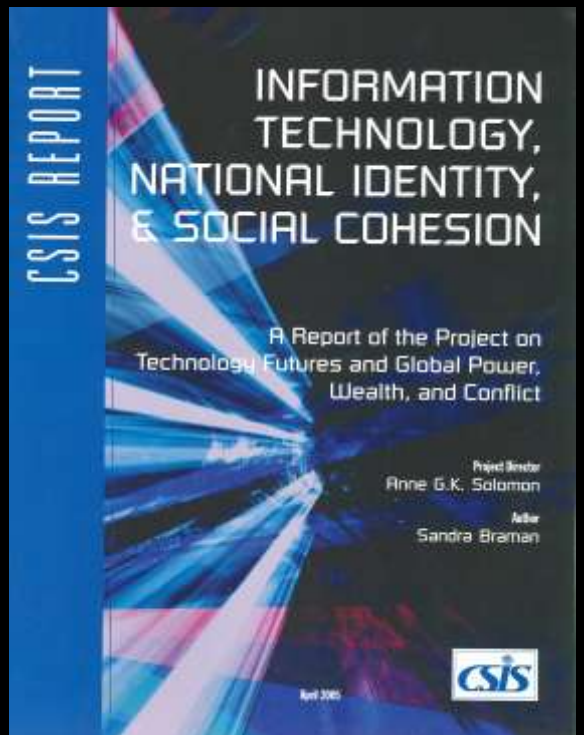
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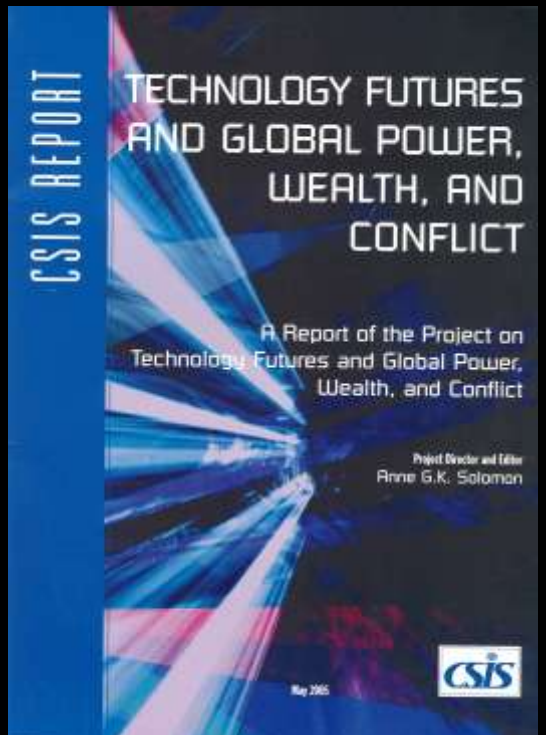
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