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Exceptional service in the national interest

Sandia National Laboratories

Global Futures

Biotechnology: A Bio-Empowered World

November 3rd, 2016

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U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration

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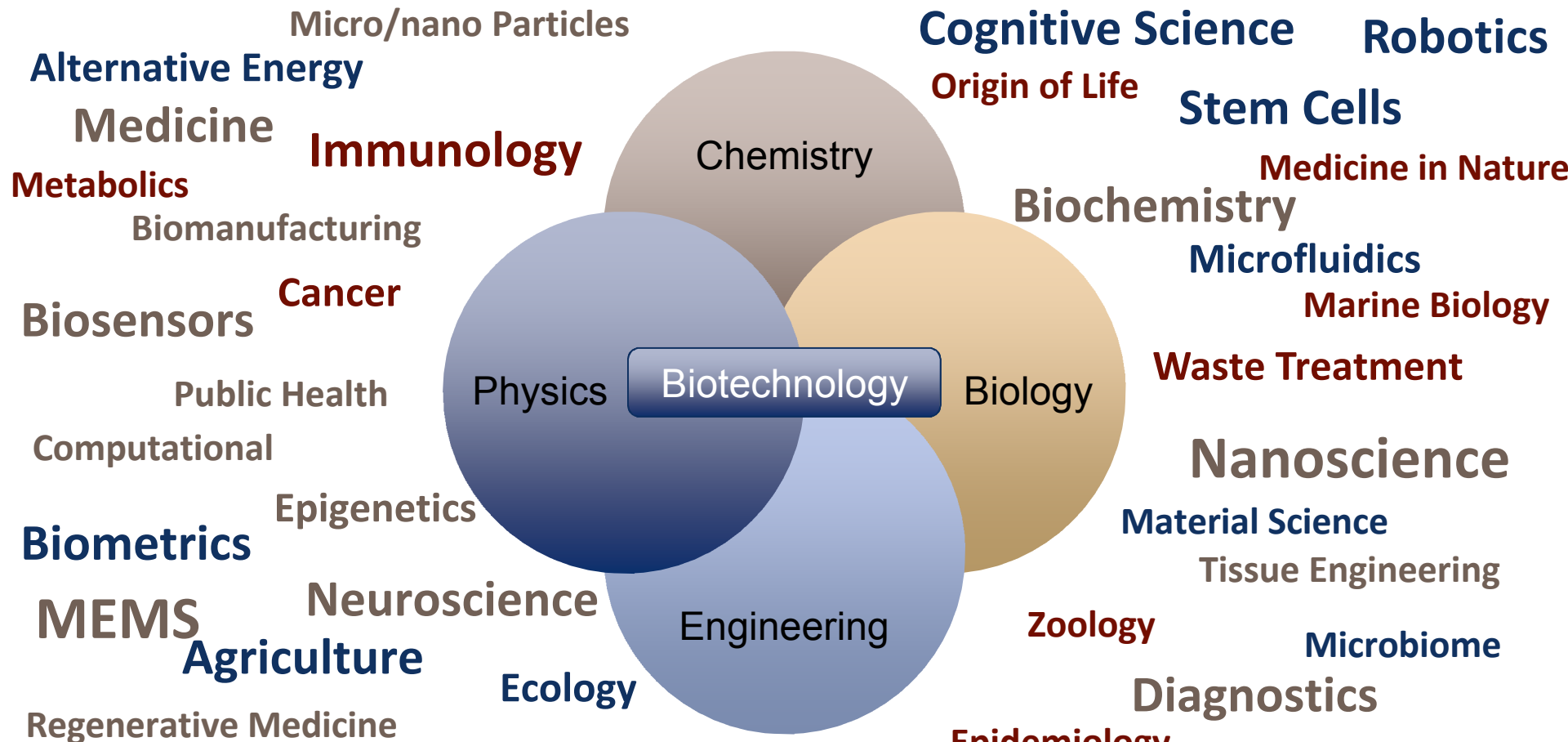
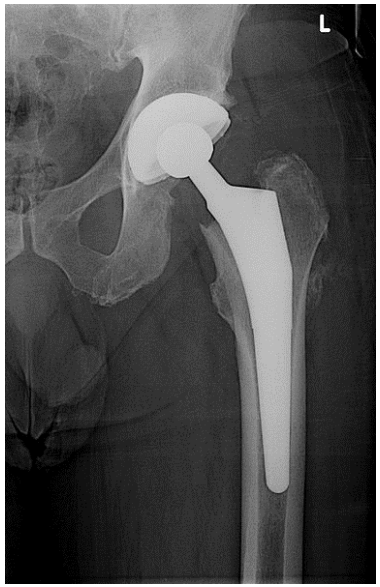
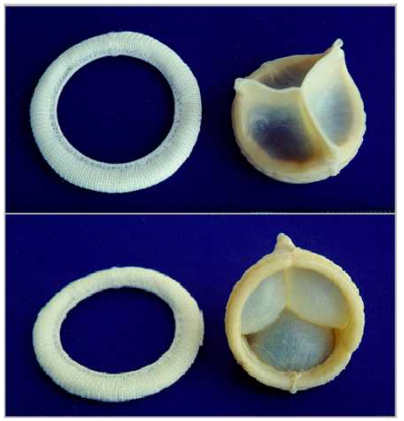
What is Biotechnology?

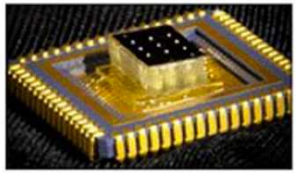


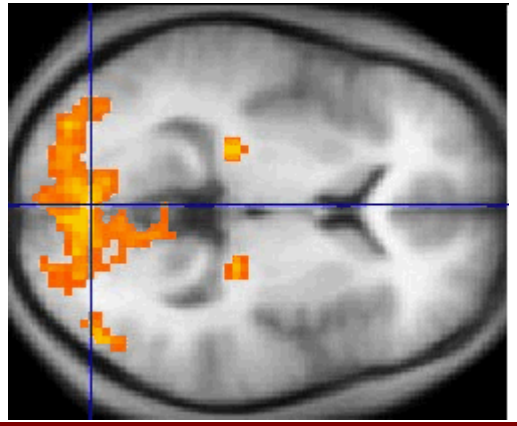
The future of biotechnology stems from the convergence of multiple disciplines

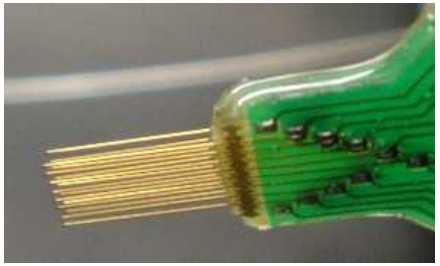
What is Biotechnology?









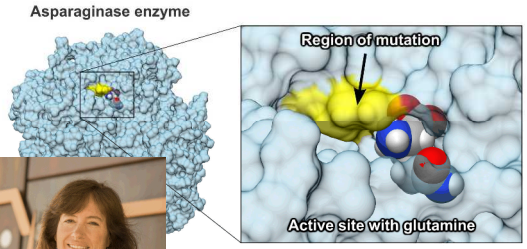


Sandia's Biotechnology Work

Sandia Protocells

(Photo by Randy Montoya)

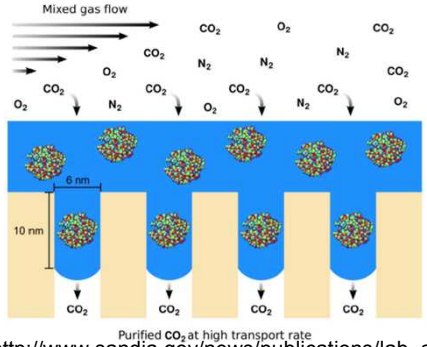
Computational enzyme design



(Graphic by Juan Vanegas)

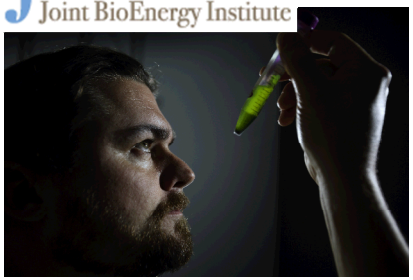
(Photo by Randy Montoya)

CO_2 Memzyme



(http://www.sandia.gov/news/publications/lab_accomplishments/articles/2016/bioscience.html)

jbei Joint BioEnergy Institute



(Photo by Dino Vournas)

BaD_x

(Photo courtesy of Melissa Finley)

(Photo by Thayne Edwards)

Sky Bridge

(Photo by Regina Valenzuela)

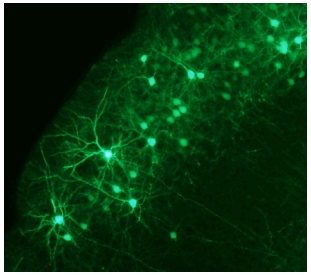
Microneedle fluidic sensor

(Photo by Randy Montoya)

Peripheral Nerve Interfaces

(Photo by Randy Montoya)

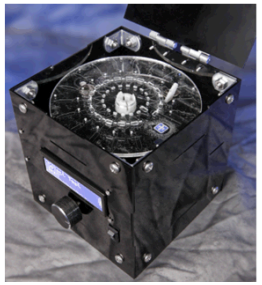
Neural computing



(Photo by Frances Chance, courtesy of Janelia Farm Research Campus)

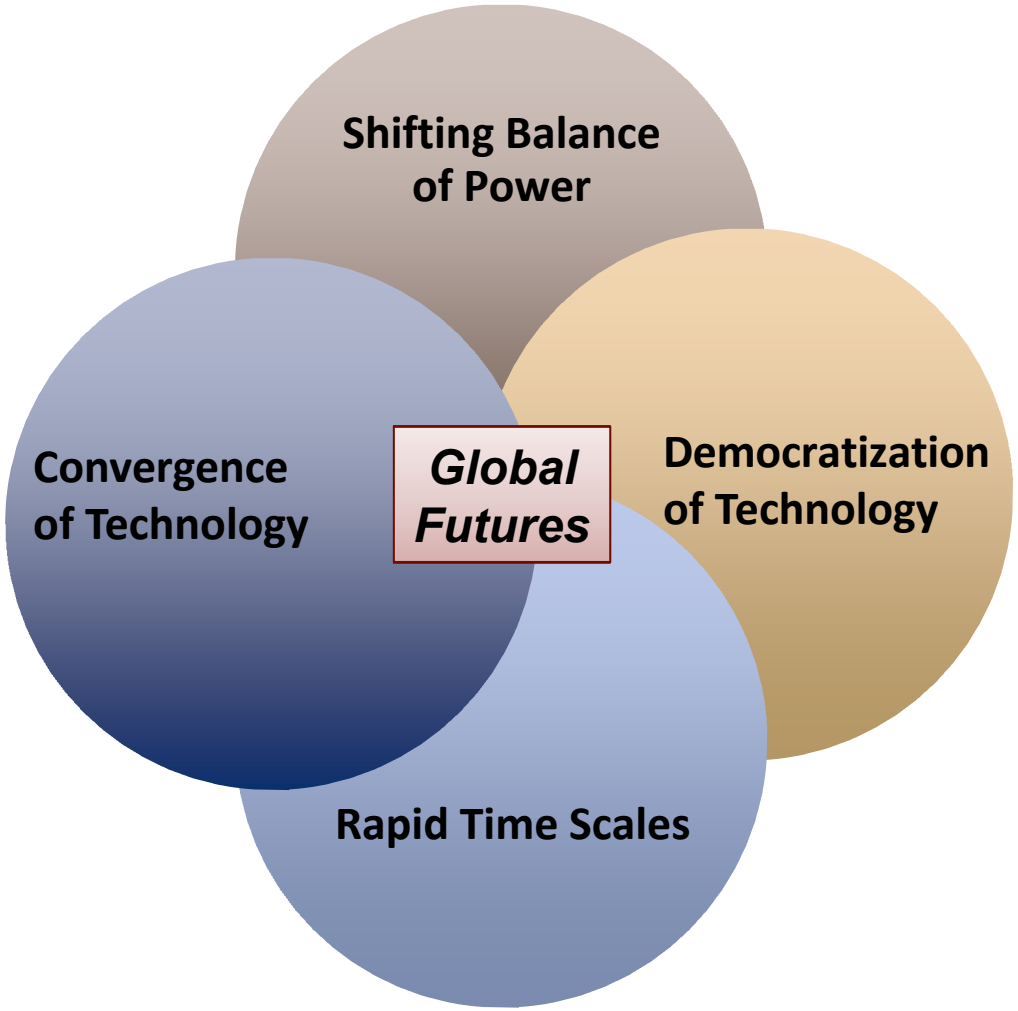
BIOWATCH INDOOR REACHBACK CENTER

SpinDx



(Photo by Randy Wong)

Biotech Primed for "Golden Age"

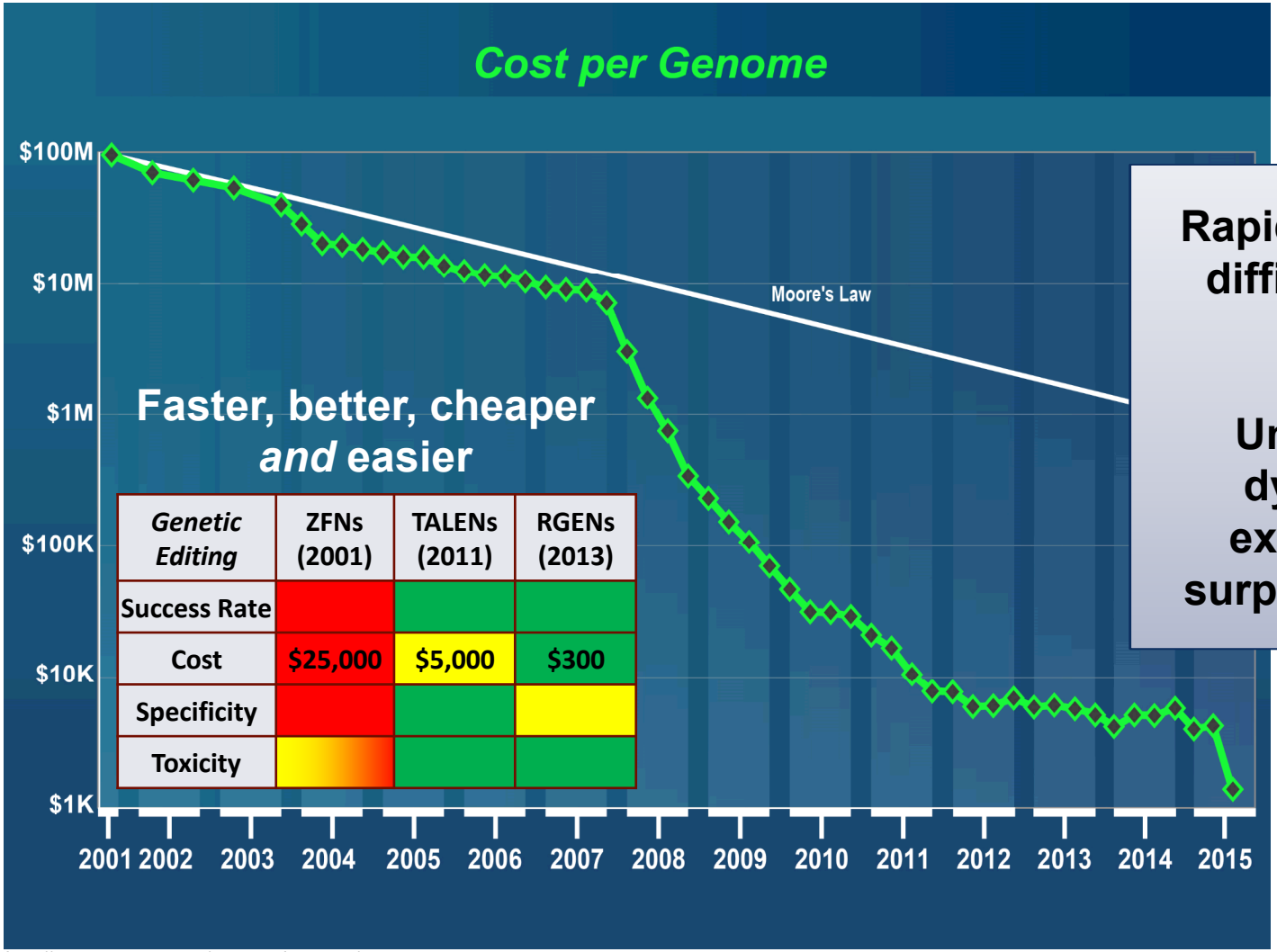


Global Futures theme:

Potential of a networked, platform-centric world

These elements are not unique to biotechnology but seem to be crossing critical thresholds.

Accessibility of the Human Genome



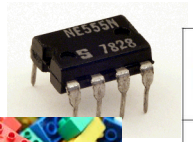
Rapid pace makes it difficult to predict advances.

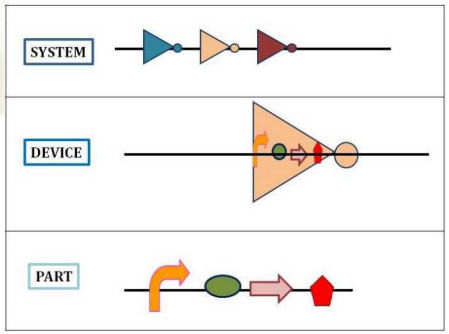
Understanding dynamics and expecting to be surprised may help.

http://www.genome.gov/sequencingcosts/

Transformative Nature of Synthetic Biology

BioBricks™ and Biohacking

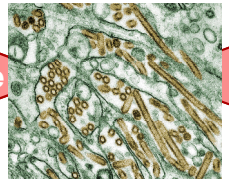




>20,000 registered sequences

Gain of Function

Highly Transmissible



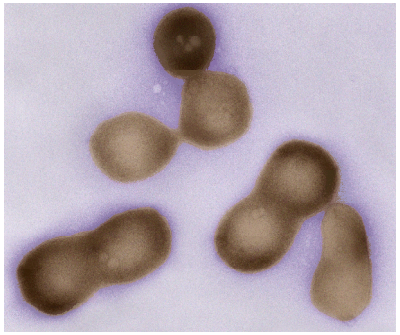
Highly Pathogenic

super-influenza

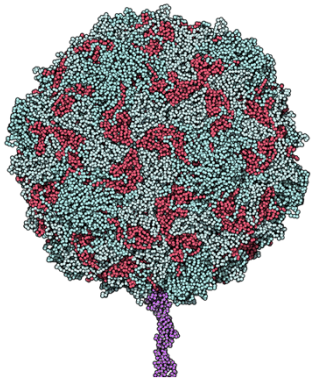
Natural evolution, research accident, hobbyist, or malicious actor

De novo synthesis of…

Novel, self-replicating bacteria cells with entirely manmade DNA



Infectious poliovirus from a test-tube



$C_{332,652}H_{492,388}N_{98,245}O_{131,196}P_{7,501}S_{2,340}$

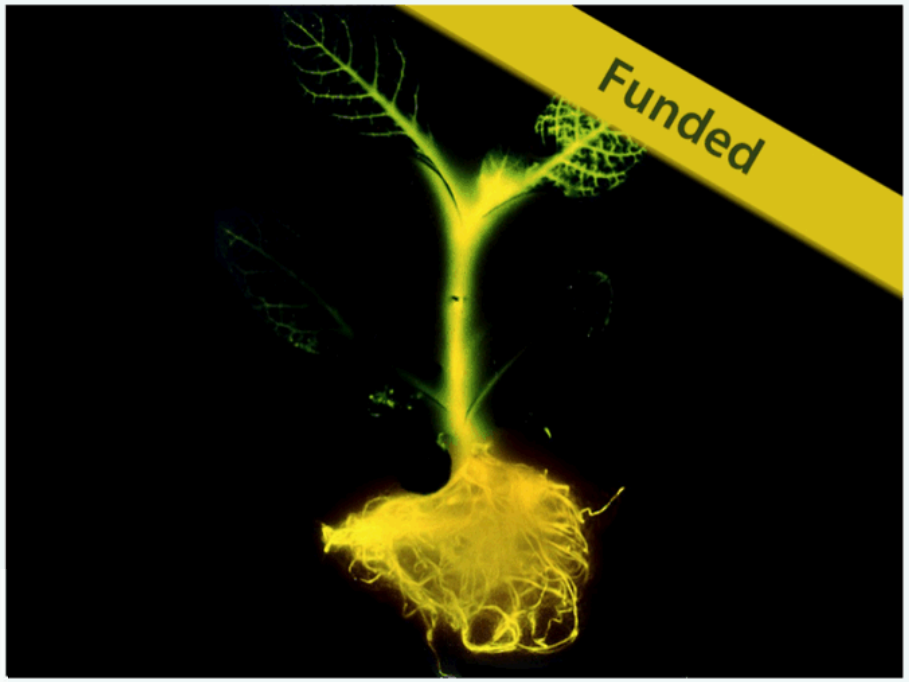
Democratization of Biotechnology

Sandia National Laboratories

Synbiota Platform RDP Standard DNA Market Blog

DNA Tinker Studio - $1195

Rainbow Factory - $295
DIY Incubator - $125



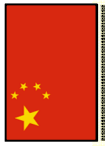
KICKSTARTER

Improvements in cost, information, and collaboration lower barriers, support democratization, and unlock creativity (unpredictability).

Shifting Balance of Power

Shifts in power collectively lower influence of US Government over future of these technologies.

US + Western Europe	→	New International Players
In-House	→	Outsourced (stimulates new environment)
Large Organizations	→	Many size scales



MIT Technology Review — Monkeys Modified with Genome Editing

nature — International weekly journal of science

Super-muscly pigs created by small genetic tweak

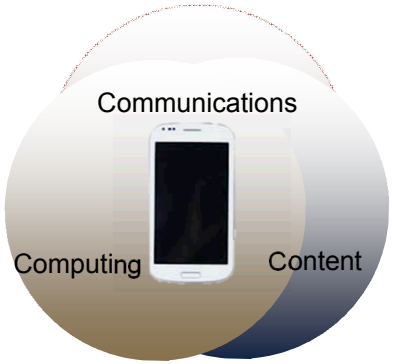
BIO ECONOMY MALAYSIA

IDT INTEGRATED DNA TECHNOLOGIES

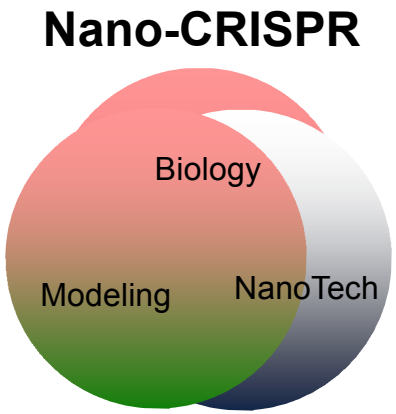
GenScript Make Research Easy

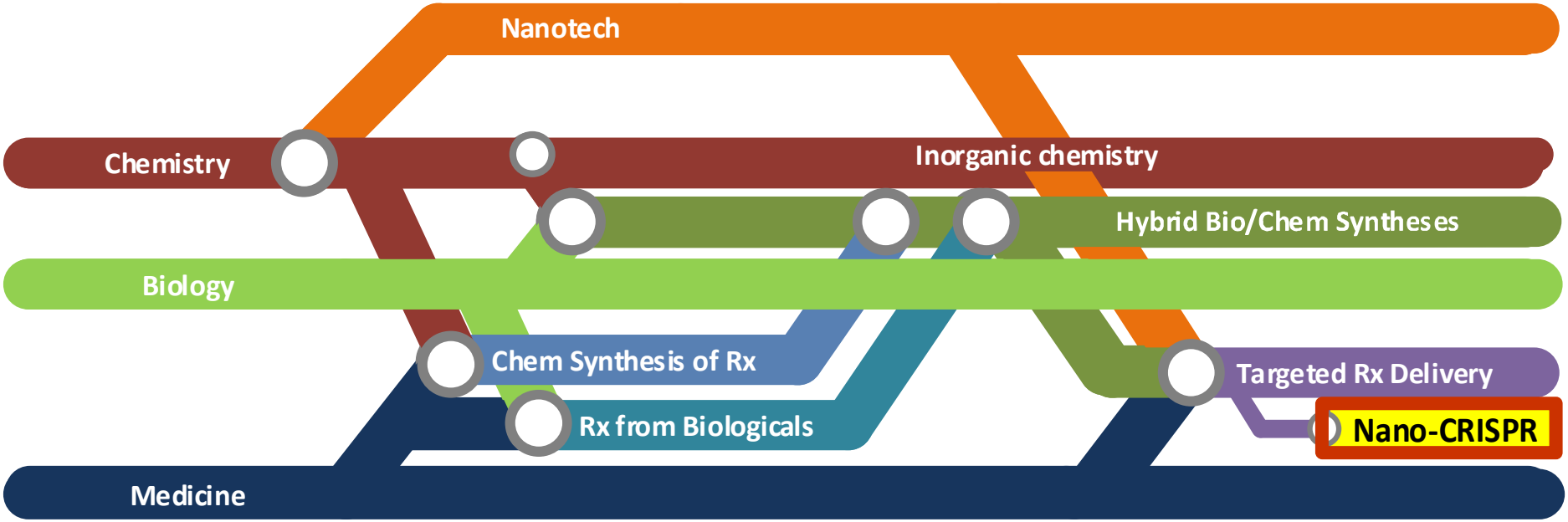
Convergence of Technologies

1980



2010

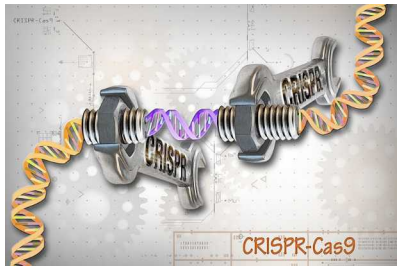




Examples of Convergence of Technologies

Gene Editing and Gene Drive

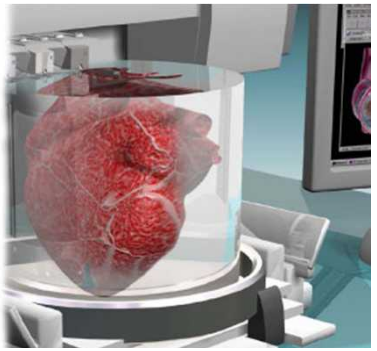
Targeting therapeutics both *in vivo* and *in utero* using nanotechnology and biochemistry



Malaria

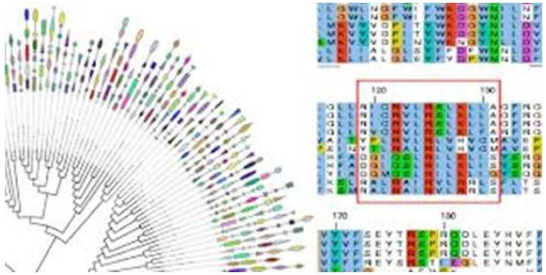
Tissue Engineering

On-demand printing of new organs with the aid of novel materials science

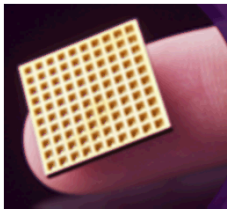


Biocomputing

Supercomputing to understand the genome and vice-versa



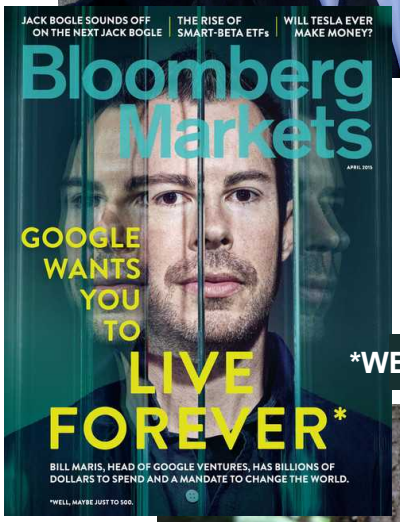
Wearables and Implantables



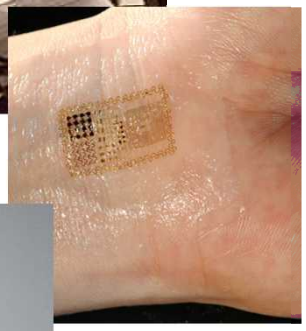
Continuous monitoring of vitals and delivery of drugs in response using MEMS technology

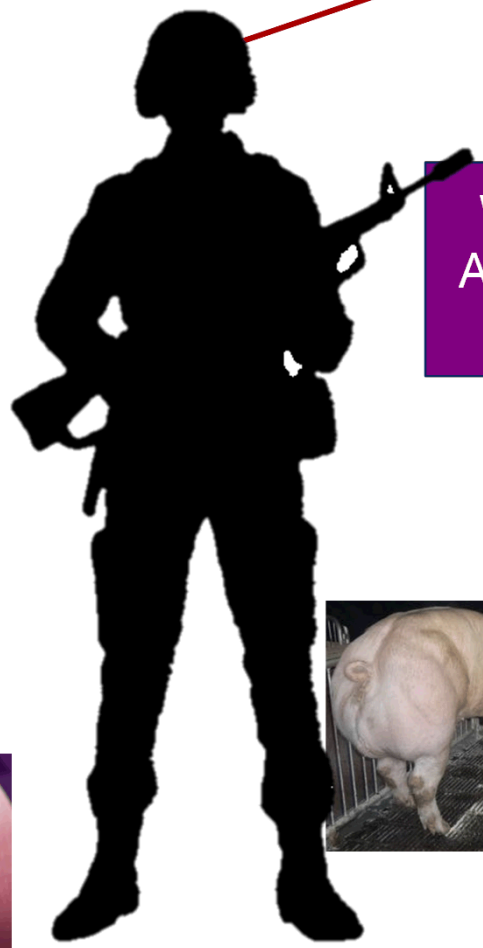
Possible Geopolitical and Socioeconomic Impacts

- Rapid democratization requires new approaches
  - Technological superiority not viable
  - Reactive responses too late (esp. with traditional R&D cycle)
  - **Preparedness must coevolve with technology**
- Medical revolutions both address and cause national security concerns
  - 500-yr lifespan?
  - Only for the world's 1%?
- Biotech applications limited by concerns over poorly understood complex systems
  - Ecological effects
  - Optimized, but fragile, engineered species
  - Bioethics made real
  - Bio-intellectual property

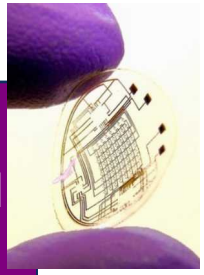


Human Engineering



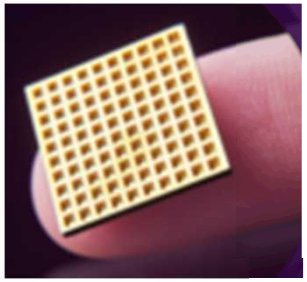


Wearable Augmented Reality



Genetically Enhanced Senses

Genetically Enhanced Muscle Growth



"Sputnik moment"?

US policy?

Ethics?

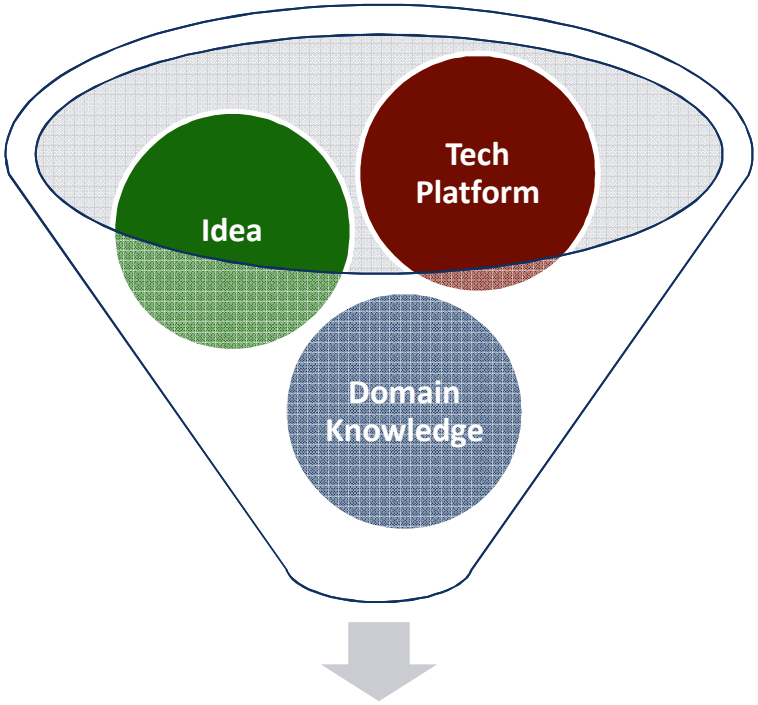
Summary

Key Findings

- Biotechnology is experiencing rapid advances and significant convergence with other domains, leading to an apparently inevitable future in which it enables both the wondrous and the threatening.
- The spread of capabilities includes a broad set of international participants.
- Many advances are expected to offer dual-use capabilities, and the impact to the nation will be significant and largely unpredictable. A strategy of control is futile, so the US needs to emphasize anticipation, resilience and agility.

Closing thoughts

As R&D advances knowledge, innovations can occur quickly.
The technology is waiting….



For you!!

Acknowledgements

- Matthew Sumner, Brandon Heimer, Patricia Pacheco, Todd West, George Backus, Thor Osborn, Cathy Ann Connelly, Wendell Jones, Tom Nelson
- SME Input: George Bachand, Cathy Branda, Jen Gaudioso, Carlos Gutierrez, Sheryl Hingorani, Dennis Imbro, Michael Nacht (UC Berkeley), Blake Simmons, and Anup Singh

QUESTIONS?

References

BACKUP SLIDES

Challenges of Oversight

- Society (and regulators) have difficulty keeping up with rapid pace of advances
- It may not be possible to regulate heavily democratized technologies
  - High standards for professionals, but hobbyists and malicious actors create challenges
- International variations in oversight may…
  - Drive research to less restrictive countries
  - Create asymmetries in capabilities
  - Render local standards ineffective
- If security-relevant capabilities are not domestic, US could be at the mercy of another nation
  - Biofuels, food, vaccines, drugs, …

nature International weekly journal of science

Chinese scientists genetically modify human embryos

"A Chinese source familiar with developments in the field said that at least four groups in China are pursuing gene editing in human embryos."

2003
Funding denied by USDA

2008
FDA receives application

2011
Research moved to Brazil

"Error bars" on future states encompass the miraculous and the terrifying.