

## Emerging and Foundational Technologies

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former IEEE-USA Vice President for Government Relations
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#### Context

#### My Background

- 23 years at LANL researching emerging and disruptive technologies
- Chairman of Emerging Technologies and Research Advisory Committee (ETRAC) for ~10 years
- Science Advisor to State Department's Coordinator for Counterterrorism

#### **About LANL**

- Large S&T student and postdoc program (~1,850 in 2019).
- LANL employs ~1,000 foreigners, (~300 are permanent resident aliens).
   Approximately 2/3 from "sensitive countries" (e.g., China, Russia, India, Iran, and Former Soviet Union).
- LANL applies for hundreds of EAR and ITAR deemed export licenses each year.

Jean-Luc LACOUR / 2004

# LANL engages in a wide range of export controlled research: explosives, accelerators, biotech, space...













UNIVER OF

#### **Emerging and Foundational Technologies**

- Export Control Reform Act of 2018 (ECRA) 50 U.S.C. sections 4801-4851, mandated regulations for *Emerging and Foundational* **Technologies** 
  - Unilateral controls initially—requires proposals for multilateral regime controls
- Commerce issued Advanced Notice of **Proposed Rule-Making** (November 2018) for defining and identifying "emerging" technologies – over 230 responses

132 STAT. 2218

PUBLIC LAW 115-232-AUG. 13, 2018

carried out, or funded by, the Department of Defense or other Federal department or agency to advance the national security of the United States, or a federally funded research

and development center.

(C) A reduction in the employment of United States persons whose knowledge and skills are necessary for the continued production in the United States of an item that is likely to be acquired by the Department of Defense or other Federal department or agency for the advancement of the national security of the United States.

(a) System for Seeking Assistance.—The President may authorize the Secretary to establish a system to provide United authorize the secretary to estainsh a system to provide United States persons with assistance in complying with this part, which may include a mechanism for providing information, in classified form as appropriate, who are potential customers, suppliers, or business partners with respect to items controlled under this part, in order to further ensure the prevention of the export, reexport, or in-country transfer of items that may pose a threat to the

antional security or foreign policy of the United States.

(b) Security Clearances.—In order to carry out subsection

(a), the President may issue appropriate security clearances to persons described in that subsection who are responsible for com-

plying with this part.

(c) ASSISTANCE FOR CERTAIN BUSINESSES.—
(1) IN GENERAL.—Not later than 120 days after the date of the enactment of this Act, the President shall develop and submit to Congress a plan to assist small- and medium-sized United States businesses in export licensing and other processes

(2) CONTENTS.—The plan shall include, among other things, arrangements for the Department of Commerce to provide counseling to businesses described in paragraph (1) on filing applications and identifying items controlled under this part, as well. as proposals for seminars and conferences to educate such businesses on export controls, licensing procedures, and related

#### SEC. 1758. REQUIREMENTS TO IDENTIFY AND CONTROL THE EXPORT

(a) IDENTIFICATION OF TECHNOLOGIES.—

(1) IN GENERAL.—The President shall establish and, in coordination with the Secretary, the Secretary of Defense, the Secretary of Energy, the Secretary of State, and the heads of other Federal agencies as appropriate, lead, a regular, ongoing interagency process to identify emerging and foundational technologies that—

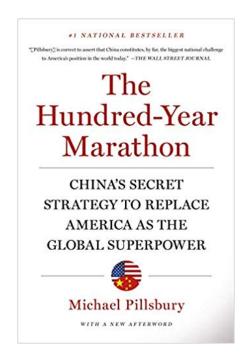
(A) are essential to the national security of the United

(B) are not critical technologies described in clauses (hrough (v) of section 721(a)(6)(A) of the Defense Produc-tion Act of 1950, as amended by section 1703.

(2) PROCESS.—The interagency process established under subsection (a) shall— (A) be informed by multiple sources of information.

(i) publicly available information;

#### Hundred Year Marathon: a message for a new age





https://thehundredyearmarathon.com/

China's aggressive technology-acquisition strategy is driven by its ambition to supplant the United States as THE world economic, military, and diplomatic leader by 2050



#### U.S. Maintains a Lead in Certain Technologies, but...



Michael Brown

Director of Defense Innovation Unit (DIU) U.S. Department of Defense

#### **China has concerning leads over U.S.**:

- 5G cellular networks
- Drones/autonomous systems
- batteries
- hypersonic systems
- wind and solar energy
- cryptocurrency

# Today's Technology Market is VERY different than when Export Controls began 75 years ago

- Technology companies are more multinational;
- Research and technology development is increasingly global; and,
- Foreign talent is highly desired worldwide for competitiveness.



To remain the technological leader in the 21st century, it is imperative that the U.S. simultaneously enable scientific discovery, promote economic growth, and preserve national security.

-- ETRAC (2010)

#### **Emerging and Foundational Technologies**

#### **Emerging Tech:**

<u>Definition varies!</u> Depending on evaluator, it can be technology that:

- recently entered market, but hasn't reached market peak
- is 2-5 years from commercialization
- is 5-10 years from being a commodity
- is "over the horizon" (> 10-20 years) to market

#### Foundational (Science) Tech:

- Generally underpinning science for a variety of technology areas
- Enable progress and applications across disparate technology markets
- Sometimes emerges as a bridge between "convergent technologies"
- Often creates new technology market/application

In the export control context, IEEE defines an "emerging technology" as being currently under development, reasonably expected to be available within the next 5-10 years, and predicted to have significant socio-economic or military effects.

# **Emerging Technologies**

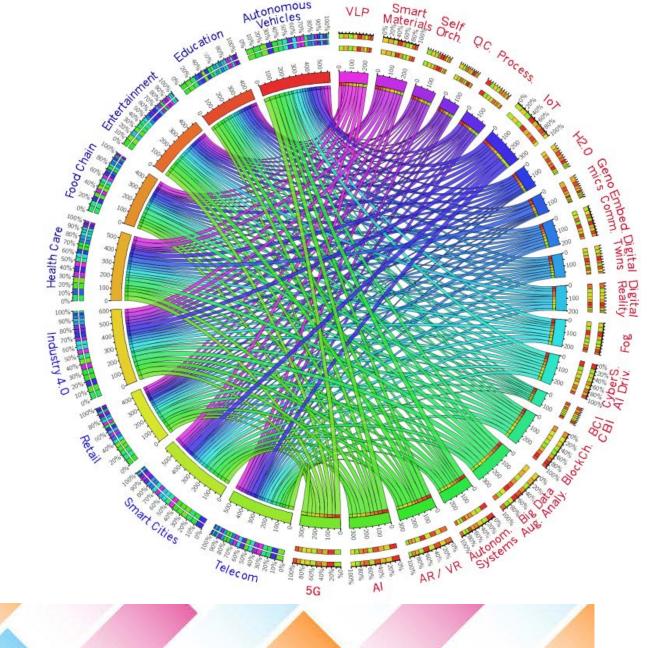


# Anticipated Market Impacts of Emerging Technologies

Predicting potential applications for an emerging or foundational technology is more challenging the longer it is before emergence.

But once it has "emerged" ...

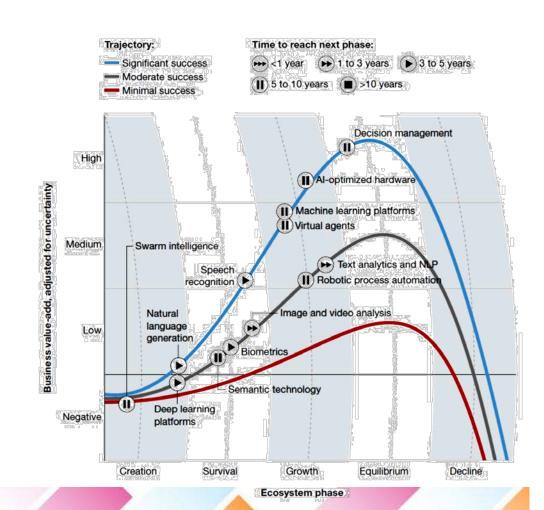
new market applications, as well as military uses, often evolve more rapidly than the export control regulations





#### Top 10 Emerging Technology Areas Today

- Artificial Intelligence / Machine Learning
- Internet of Things
- 3. 5G Networks
- 4. Quantum Information Sciences
- Augmented / Digital Reality
- 6. Autonomous Systems (Robotics / Drones)
- 7. 3D Printing / Additive Manufacturing
- 8. Advanced and Adaptive / Smart Materials
- Blockchain
- 10. Human-digital augmentation: digital twins, brain-computer interface, electrogenetic and neuro-electronic tech





#### **Commerce Identified Critical Technology Areas:**

- Additive manufacturing (e.g., 3D printing)
- Advanced materials
- Artificial intelligence (AI) and machine learning technology
- Biotechnology
- Brain-computer interfaces
- Logistics technology
- Hypersonics
- Robotics

- Data analytics technology
- Advanced computing technology
- Microprocessor technology
- Quantum information and sensing technology
- Position, Navigation, and Timing (PNT) technology
- Advanced surveillance technologies

# Foundational Technologies



#### Example of a Foundational Technology: Laser

- Theoretical development by Townes and Schawlow, then first experimentally developed in 1960 by Theodore Maiman (Hughes Research Labs)
- Today produced through wide range of technologies
  - Electrical discharges through gases (HeNe, Excimer)
  - Chemical reaction
  - Solid-state "Glass"
  - Fiber
  - Photonic Crystals
  - Semiconductor/Diode
  - Free Electron
- Light Amplification by Stimulated Emission of Radiation :
  - Process is "Fundamental Science"
  - Photons from excited atoms or molecule
  - Requires "pumping" of atoms or molecules into excited states

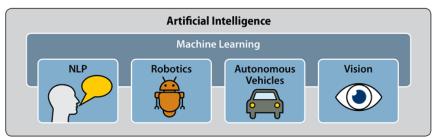


# Artificial Intelligence / Machine Learning



#### **Artificial Intelligence**

- Business management
- Predictive Maintenance Services (Facilities, Logistics, and Infrastructure Management)
- Energy resource allocation (source and endpoint)
- Robotics for manufacturing and automated warehouses
- "Smart Shelves" with predictive models
- Big Data Analytics
- Autonomous Systems
- Cybersecurity
- Investigative Services
- Defense and Military Systems
- Network / Insider Threat Monitoring
- ..





Artificial Intelligence and Machine Learning Applied to Cybersecurity

Generally Relies Upon Multiple Data Inputs
Coupled with MACHINE LEARNING



### Some Commercial Examples of Artificial Intelligence

- Siri / Alexa
- Google Search and Google Ads
- Pandora, Amazon, and Netflix Suggest Engines
- Robotics (manufacturing)
- Autonomous vehicles
- Kroger warehouses, smart shelves, and marketing



UC Berkeley's "BRETT"
Berkeley Robot for the Elimination of Tedious Tasks

#### Key Technologies behind Artificial Intelligence

#### Data collection:

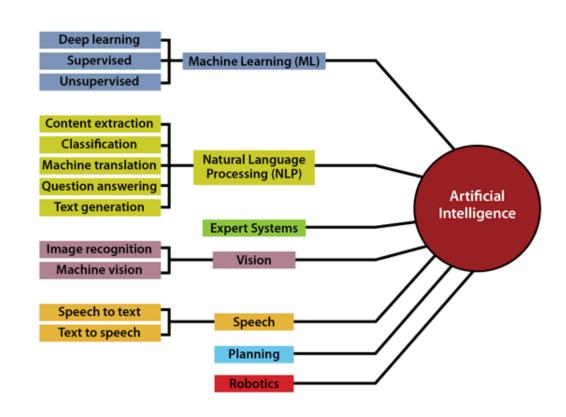
- Audio feeds, Images, Videos
- System data (e.g., electricity use)
- Signals (e.g., radio, etc...)

#### Data storage:

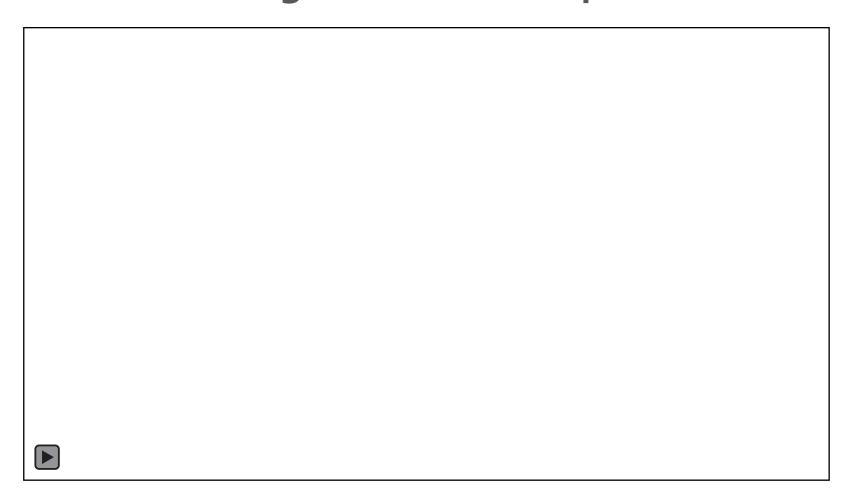
- Big Data
- Data Centers: Hadoop, Spark, ...
- Cloud: Amazon Web Services, Microsoft Azure

#### Data processing and analytics:

- Al uses machine learning, deep learning, image recognition, natural language processing, ... to process data into a data taxonomy that can be used for outputs
- Generally programmed with Application Programming Interfaces (API)
- Computing hardware generally includes GPUs
- Data output and reporting:



### AI is the Engine Behind Deep-Fake Videos



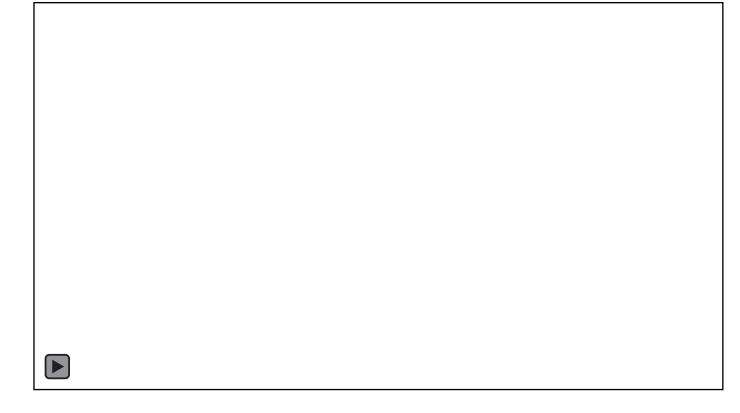
#### **Machine Learning**

# Generally involves "trained" computer processing of data

- Repetitive process automation
- Data analysis
- Business knowledgebase

#### Key technologies:

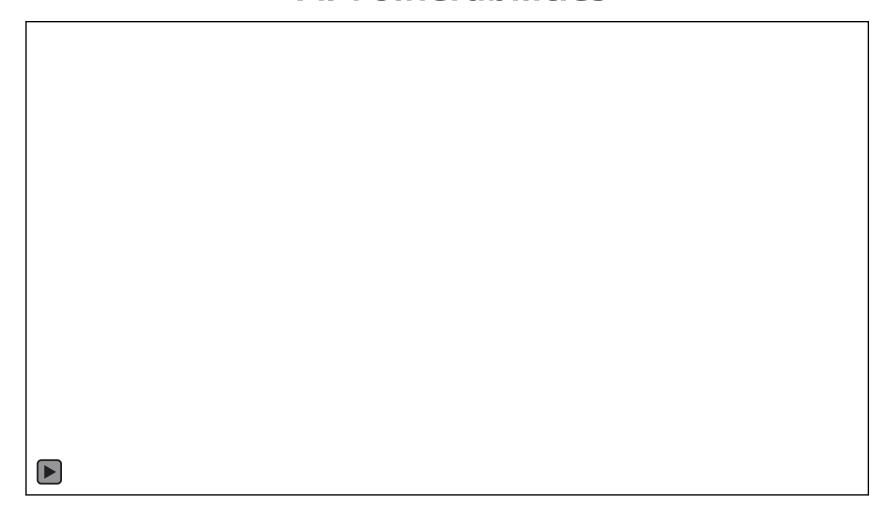
- Hardware for data acquisition, fusion, and processing
- Software for process tracking



Adapting ML to counter AI produced Deep-Fake Videos



#### **AI Vulnerabilities**





# Hypersonics



#### Hypersonics vehicles sustain speeds greater than Mach 5

- Hypersonic Glide Vehicles (HGV) "Boost-Glide" Vehicles
- Powered Hypersonics: e.g., Hypersonic Cruise Missile (HCM)
  - Scramjets
  - Hybrid Air-Breathing Rockets





Fig.2 Test model

Powered Hypersonic Vehicles

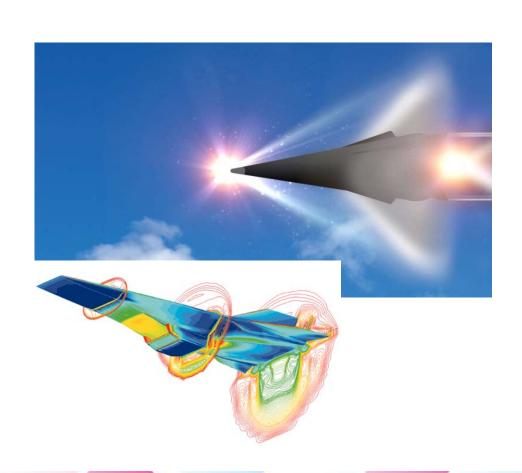
Hypersonic Glide Vehicle (HGV)



**Ethics, Compliance & Audit** Symposium **REACHING NEW HEIGHTS** 

#### Hypersonics – Technology Challenges

- Aerodynamics
- Thermal Management and Protection System
- Control systems and maneuvers
- Navigation and communications
- Computation/Simulations
- High Mach-# Wind Tunnels



#### Military Applications of Hypersonics

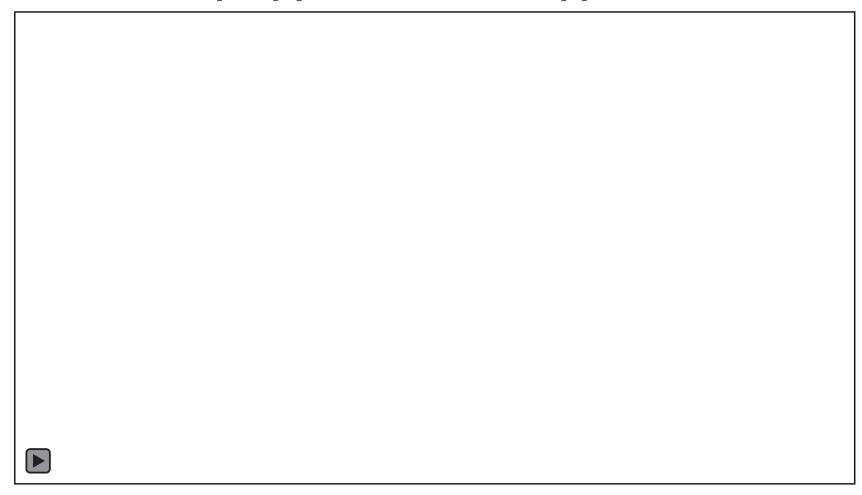
"Russia and China are aggressively pursuing hypersonic capabilities... We don't have any defense that could deny the employment of such a weapon against us."

-General Hyten, Former Commander of U.S. Strategic Command (2018)



Russian Hypersonic Cruise Missile

### **Military Applications of Hypersonics**

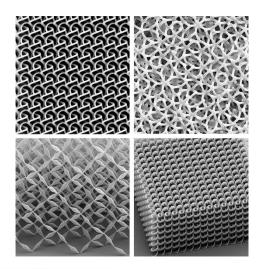


### **Advanced Materials**



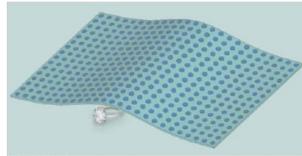
#### **Metamaterials – Emerging Capabilities**

- "Cloaking" in specific wavelength regimes
- Conformal antennae
- Energy-absorption materials
- Some applications for Defense and Treaty monitoring and verification



Introducing a New Material for Invisibility Cloaks

Dy Netl Savage Rested 14-0-12015 | 14-01/GMT



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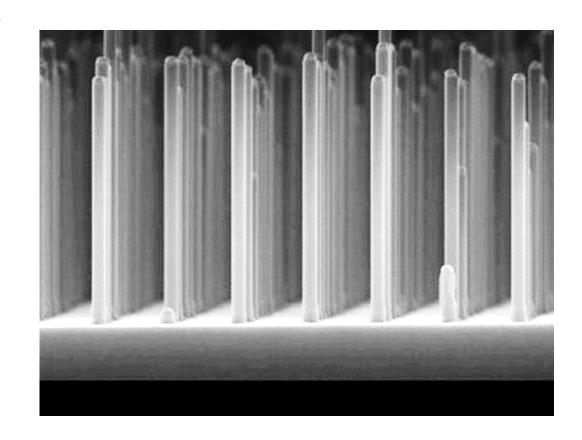
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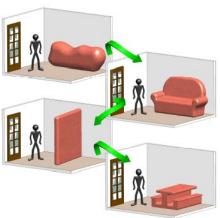
#### Nanowires boost hydrogen production from sunlight tenfold

- Published in Nature Communications July 2017 by a group at Eindhoven University of Technology
- Intent is to produce hydrogen for energy storage (fuel-cell technologies)
- GaP nanowires about 500nm long and 90 nm thick doped with platinum increased catalytic properties for producing hydrogen.
- Possible application to "heavy water" production if coupled to isotope separation.



#### **Shape-Shifting/Morphing Materials**

- Programmable, on demand changes to structures
  - 2-D shape to 3-D shape, or
  - 3-D shape to another 3-D shape
- Household "furniture"
- Morphing vehicles (cars, aircraft, ships)
- Compact storage









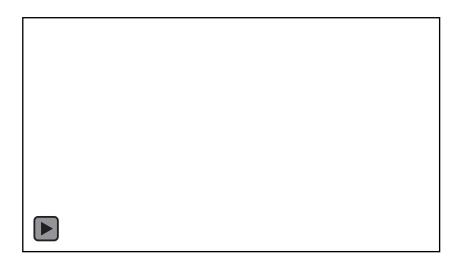
#### **Drag Reduction Technologies**

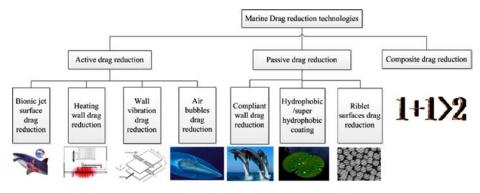
# Friction drag increases energy costs by 10-20% • ≥25% of automotive power • ~60% of ship's propulsion power • ~75% of submarine propulsion power

- Active drag reduction
  - Wall vibration
  - Air bubbles
  - Thermal surface
  - Bionic jet
- Passive drag reduction
  - Pliant wall
  - Hydrophobic or Superphobic coating
  - **Riblets**

#### Military interests:

- Fuel efficiency
- Noise generation
- Reduced heating







# **Hovering Technology**



#### Emerging levitation technologies – Lexus hoverboard

- Lexus research project
- Combines liquid nitrogen-cooled superconductors and permanent magnets to provide a smooth "frictionless" ride across surfaces.
- Could revolutionize several industries including automotive, shipping, and manufacturing.
- Military applications.







# 3D Bioprinting



#### 3D Bioprinting – Could this become dual-use?

- 3D printing is increasingly permitting the direct digital (DDM) or additive manufacture (AM) of a wide variety of plastic and metal items.
- 3D printing (Additive Manufacture) technologies have been used to create body parts and medical instruments with plastic scaffolds.
- University and Industry research into scaffoldfree 3D bioprinting on a cell-by-cell basis is advancing rapidly.

Are there potential applications that would provide US with a significant military and/or intelligence advantage?

Tissue Engineering by Self-Assembly of Cells Printed into Topologically Defined Structures

KAROLY JAKAB, Ph.D., <sup>1</sup> CYRILLE NOROTTE, <sup>1</sup> BROOK DAMON, Ph.D., <sup>1</sup> FRANCOISE MARGA, Ph.D., <sup>1</sup> ADRIAN NEAGU, Ph.D., <sup>1,2</sup> CYNTHIA L. BESCH-WILLIFORD, Ph.D., <sup>3</sup> ANATOLY KACHURIN, Ph.D., <sup>4</sup> KENNETH H. CHURCH, Ph.D., <sup>5</sup> HYOUNGSHIN PARK, Ph.D., <sup>6</sup> VLADIMIR MIRONOV, M.D., Ph.D., <sup>7</sup> ROGER MARKWALD, Ph.D., <sup>7</sup> GORDANA VUNJAK-NOVAKOVIC, Ph.D., <sup>8</sup> and GABOR FORGACS, Ph.D., <sup>1,9,10</sup>



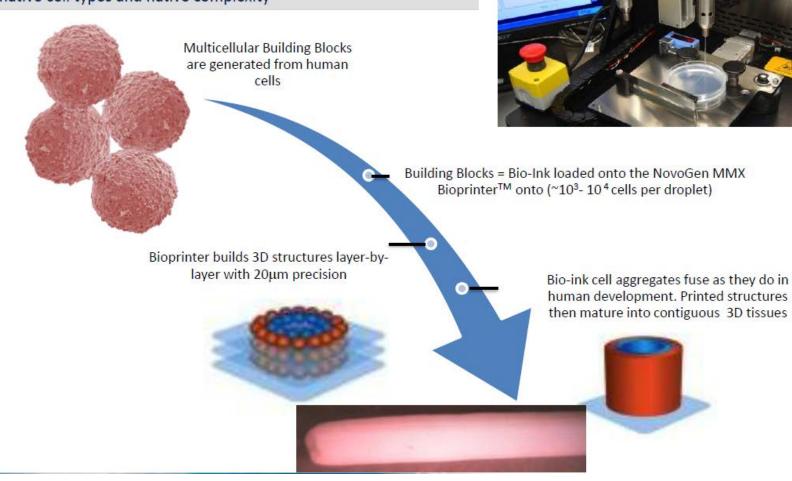


### Video: 3D Bioprinting



#### What is 3D Bioprinting?

A proprietary process enabling tissues and disease models with native cell types and native complexity

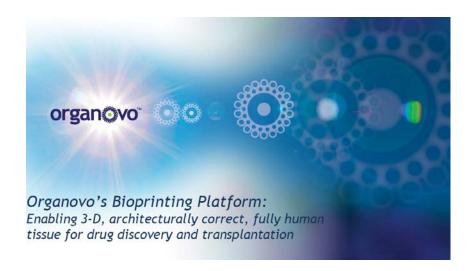


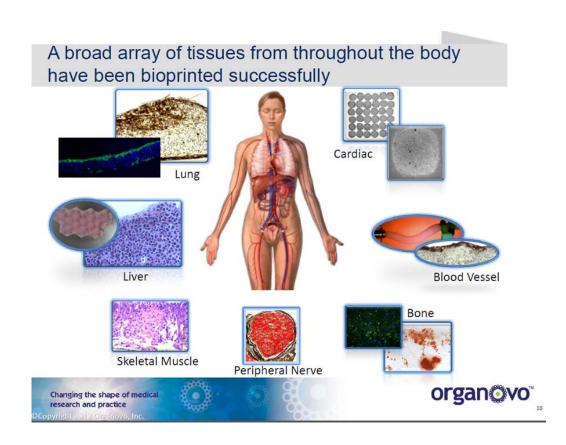


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#### **Example: 3D Bioprinting**

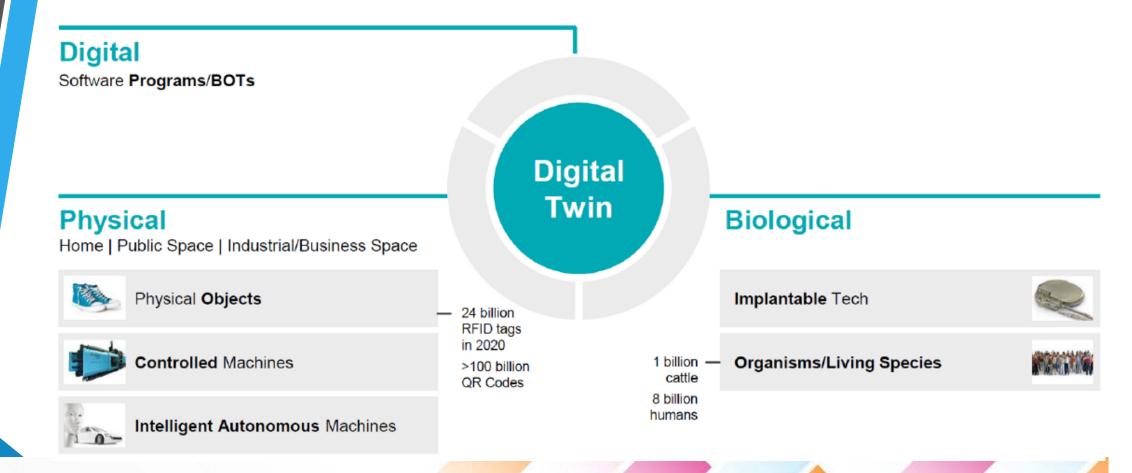
- Potential medical applications including organ or bone replacements and pharmaceutical RDT&E.
- US leadership is crucial to pharmaceutical industry







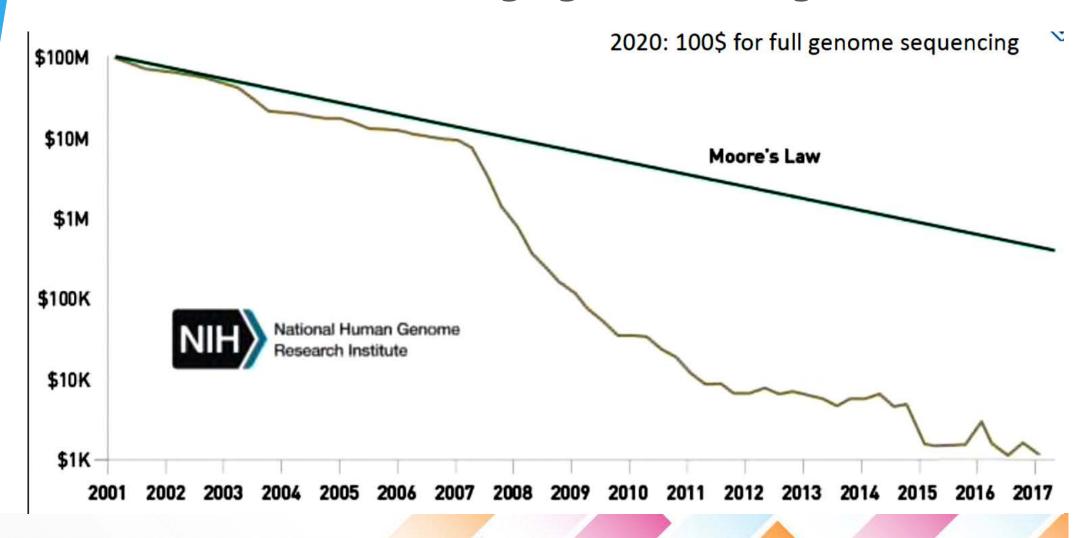
## Digital Twins – Bridges Spheres





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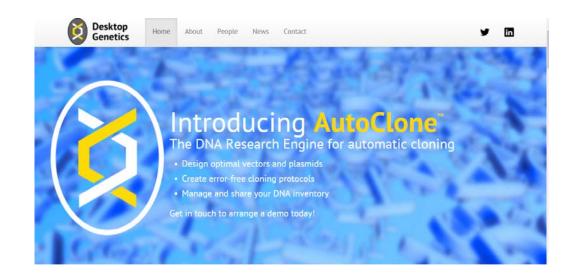
#### Genomics – a challenging and exciting science





#### **3D Genetic Desktop Printers**

- UK-based Desktop Genetics is developing a 3D genetic printer that can be used by anyone.
- AutoClone<sup>™</sup> is a DNA Research Engine that enables the optimal design, synthesis, management and sharing of DNA constructs.
- Intend to institute "software" controls for what can printed.



Are there potential applications that would provide US with a significance military and/or intelligence advantage?

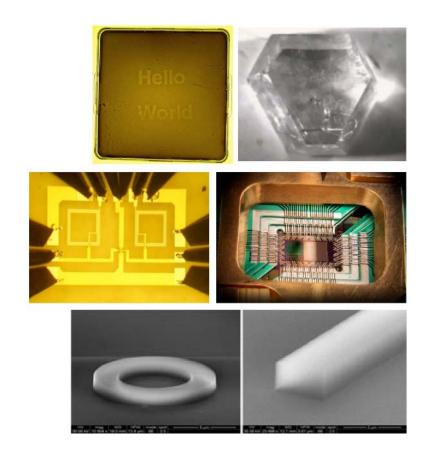


# Wrap-Up



#### Additional Examples of Emerging (dual-use) Technologies

- Graphene circuits
- High performance and cloud computing
- Microelectronics manufacturing
- Microreactors
- Nonlinear laser optical crystals
- Optical-limiter coatings
- Plasmonic antennas
- Quantum encryption
- Quantum computing
- Synthetic biology
- 3D Bioprinting and Geneprinting





# Science and engineering can affect national security, therefore policy must be considered.



"Science knows no country, because knowledge belongs to humanity, and is the torch which illuminates the world.

Science is the highest personification of the nation because that nation will remain the first which carries the furthest the works of thought and intelligence."

- Louis Pasteur, Chemist and Microbiologist

# Compliance with Export Controls on Emerging and Foundational Technologies will be Challenging and Dynamic

- Formal regulations on emerging or foundational technologies has not been released and will probably be evaluated on a technology-by-technology basis
- Cognizant Government Authority may have an application in mind and may require technology review before publication
- Researchers should be ready to consider potential broader applications of innovative technologies:
  - Commercial/Civil
  - Military
  - Law Enforcement
  - Intelligence

# When in doubt – ask your UCOP Export Experts

