

# bio:MADE

AN EXHIBIT OF  
FUTURE CREATIONS

*Where the tech revolution meets the bio evolution*

The urgent challenges we face at the personal and planetary levels are deeply rooted in biology. From lack of access to clean water and food system disruption, to global warming, vaccine shortages, and antibiotic resistance—we will meet these challenges at the intersection of biology and technology, *creating a bio:made future.*



INSTITUTE FOR THE FUTURE



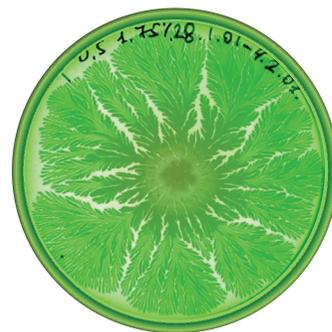
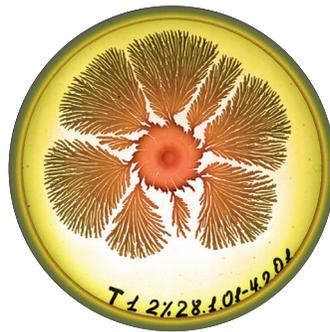
Today, digital technologies are our go-to tools for creation. 1s and 0s, bits and bytes have become the most powerful and affordable medium to express ourselves, make art and commercial products, and craft solutions to our biggest and smallest problems. Over the past decade, we've seen biological and information sciences rapidly converge. Today, this convergence is opening biology, bringing it out of academia, and putting it into the hands of a new breed of innovators and biodesigners, with their own motivations, priorities, and desires. From a surgeon 'growing' meat in a petri dish to a fashion designer cultivating clothing from bacteria and yeast, we're already seeing what happens when biology inspires innovators from all walks of life.

# WELCOME

## to a bio:made future

In the next decade, anyone will be able to design and build with nature's smallest and most sophisticated materials almost as easily as using a computer. We'll edit genes and birth entirely new organisms—and program life itself.

With this *Exhibit of Future Creations*—our forecasts for this bio:made future, we invite you to tour this new landscape of the forces of change and signals of innovation that are happening today.



# TECH REVOLUTION MEETS BIO EVOLUTION

The bio:made future is being shaped by four forces—abundant data, accelerated experimentation, democratized design, and the bio arms race. Together, they are amplifying, spurring competition and investment, and opening biology to more innovators, driving us all toward a bio:made future, where biology serves as both inspiration and a tool for creation.

## ABUNDANT DATA

### Ubiquitous sensors provide new foundations of biological knowledge

Biology and IT have converged for over a decade, and we can already see democratizing effects. Sequencing the first human genome in 2003 established genomics as a data science and cost about \$2.7 billion. By 2015, with over 228,000 genomes sequenced and the cost of sequencing a genome dropping five- to tenfold annually, a \$1,000 genome appears not far off. But with the rise of cheap, accessible sensors in, on, and around our bodies, and in the natural world and built environment, we'll generate massive amounts of data, from how what we eat affects our health, to how the collective microbiome of a city evolves. We'll be able to do this almost effortlessly. Advances in inference engines and artificial intelligence will drive data to actionable insights about the way natural systems within and outside our bodies work. The ease of collecting data and creating valuable insights will amplify discovery in scope and scale, opening new experimental possibilities for us all. Our discoveries will shape how we live and build at every scale, from personalized foods and beauty products to healthier, dynamic office buildings, and regulation around the use of biological data.

## ACCELERATED EXPERIMENTATION

### Investment and automation speed scientific inquiry

Increased investment and new automation technologies are dramatically accelerating the rate of experimentation. The 126 deals struck during the second quarter of 2015—a total of \$2.3 billion—marked the biggest quarterly investment in biotech in 20 years. The real driver of financing has been participation of nontraditional biotech investors, such as hedge funds and public market crossover investors, who are sensing that biotech is evolving and want to get in early. Simultaneously, lab automation accelerates testing from a few hundred assays a month to hundreds of thousands, with increased accuracy and reproducibility. Lab automation isn't new, but we've entered a new age of automation with improvements in artificial intelligence, powerful cloud computing, and networked labs, enabling researchers of all sorts to design and outsource experiments via companies like Science Exchange or to cloud labs, like Emerald Therapeutics. The accessibility of cloud labs and automation tech will lower barriers to sophisticated experimentation, enabling small, early-stage actors to creatively conduct research and development.

## DEMOCRATIZED DESIGN

### The Maker ethos meets biology

Maker culture and the open-source computing community have always overlapped. And, as information technology integrates into biology, it's bringing the open-source and maker communities with it. Already, we see artists and citizen scientists, with open-source and maker mindsets of transparency and sharing, prototyping with biology. Community labs and biohacker spaces, like Genspace and BioCurious, are emerging in cities all over the globe, providing diverse individuals the tools and guidance to think like biodesigners. Already, we're seeing glow-in the dark plants, CRISPR kits, bacteria and yeast based clothing, and fungal furniture. This early-stage, bio:made innovation is seeded in part by crowdfunding, like Indiegogo and Experiment.com, and accelerators, like Y Combinator and IndieBio. As the creativity and ethos of makers, hackers, and tinkerers grow in parallel to technological advances, we will see radically democratized biodesign, and changes to the entire ecosystem, including new pathways in, out of (and around) academia, and independent scientists building their own biofutures.

## BIO ARMS RACE

### Global competition creates commons

The intense, global race to control the biotech market is inadvertently contributing to a more open biofuture. Historically, the fierce competition to dominate new fields of technology—like railway travel or personal computer technology, which were both considered monopolized fields at their peak—have created incredibly important infrastructure that, ultimately, become a resource for all. In biotech, we can already see this happening. BGI, the self-described "world's largest genome center," for example, is attempting to sequence nearly every life form of interest on Earth—simultaneously causing concern about the control of sensitive, genetic information, and creating a trickle down effect of resources for everyone from biohackers to private companies to academic institutions to benefit from and build on. The bio arms race will result in global conflicts over ownership, but not without driving incredible innovation in the field and inspiring activist efforts to ensure research and its tools serve the public good, paving the way for innovators of all sorts to create a bio:made future.

# FORECASTS

## An exhibit of bio:made creations

While bio has long been a crucial tool for creating medicines, materials, and foods, innovators will bring their own values and priorities to biotech and, in doing so, vastly widen the applications of biology. This portion of the map is an exhibit of bio:made creations. It contains forecasts of a bio:made future, each of which is accompanied by two signals, present day projects, products or initiatives that illustrate that change is already underway.

### OPEN-SOURCE SOLUTIONS

While mainstream pharma struggles to create new blockbuster drugs, science activists are using the building blocks of biologicals to make open-source versions of drugs and other medications and solutions freely available to the public.

#### *Open-source Insulin*

A team of biohackers is developing the first open source protocol to produce insulin simply and economically. The work aims for generic production and continued research into improved versions of this life-saving drug.

#### *Life-saving Bread*

Johns Hopkins 2011 iGEM team added beta-carotene to a yeast and baked it into bread. VitaYeast and Golden Bread offer potentially sustainable solutions to beta-carotene/vitamin A deficiency that can cause blindness and death.

### REINCARNATION REDEFINED

De-extinction is becoming a possibility thanks to the CRISPR/Cas9 system, a gene editing technique that's been called effortless. This system could be used for everything from eliminating forms of human blindness and developing drought-resistant crops to bringing back the woolly mammoth.

#### *Resurrecting the Woolly Mammoth*

Geneticist Vincent Lynch's team is working to take DNA from modern Asian elephants and revert the genome to its ancestral form, the woolly mammoth.

#### *Cloning Puppies*

Korea's Sooam Biotech has cloned over 700 dogs. The lab starts with biopsy samples, inserts a cloned embryo into a surrogate mother, and has a puppy ready in 60 days.

### THE MICROBIOME OF BEAUTY

The microbiome has opened a new frontier for personal care companies. Be on the lookout for custom microbial creams and serums with promise for maintaining the delicate ecosystem of your skin's microbiome.

#### *Restoring Skin with Sweat-eating Bacteria*

Beauty products such as Mother Dirt AO+ Mist from AOBiome claim to restore the skin's natural microbiome, which may have been damaged through washing with conventional products.

#### *Measuring Microbial Impacts of Skin Care*

NERD Skincare first created face masks from a proprietary strain of bacteria. It is now developing a sequencing program for collecting and analyzing skin microbiome profiles of customers before and after product use.

### DNA DISPUTES

Personal and broad human rights have often been compromised in the name of medical progress or social harmony. Individuals' control over their bioinspired identities will be hotly and widely contested across different cultures.

#### *Outing Litterers with DNA-derived Portraits*

An Ogilvy & Mather media campaign shamed Hong Kong litterbugs through billboard portraits made using DNA from trash found on local streets. The promotion reached over four million people on social media.

#### *Gene-editing Tech Declared 'WMD'*

The U.S. director of national intelligence added gene-editing technologies like CRISPR to a list of "weapons of mass destruction," citing, in particular, how easy to access and use they are becoming.

### MASS MANUFACTURING ON THE CELLULAR LEVEL

Thanks to bacteria, yeast, and connected, partially autonomous machines, networked rapid prototyping labs enable experimenters to create more sustainable and healthier versions of existing products, ranging from synthetic silk to living concrete.

#### *Spider Silk Made From Yeast*

Bolt Threads is disrupting textiles with engineered, spider silk-inspired polymers that are stronger than steel and softer than wool. Future materials will be "programmed" with UV resistance, stretchiness, and strength.

#### *Designer Cultured Rose Extracts*

Ginkgo Bioworks is teaming up with professional perfumers to design new fragrances. Beyond altering wild rose species to be more fragrant, rose breeders will be able to control the exact makeup of a rose essence.

### EDIBLE EXPERIMENTATION

Today, cheese grows in fermentation vats and meat grows from stem cells. As debates about GMOs roar on, key drivers of bioengineered foods include health and ethical treatment of animals as well as cost and demand to feed our planet's hungry.

#### *Ethical Cheese*

Biohacker-made, Real Vegan Cheese is a not a substitute, but a lab-created replication of cheese that starts with baker's yeast. Synthetically engineered yeast become milk-protein factories that produce real cheese.

#### *Lab Grown Meat*

Stem cell grown meat pioneer Mark Post believes commercially viable lab-grown meat will be sold at scale by 2022, potentially drastically reducing the need to farm cows.

### AUTOMATED CLOUD LABS

Top scientists will manage networks of automated lab robots in a setting far from the physical workflow of today's labs, bringing unprecedented speed, precision, and accessibility to experimentation.

#### *Remote AI Experiments*

Emerald Therapeutics used automated labs to run end-to-end experiments remotely and teaches its scientists computer programming, crafting a language of science that promises reproducibility never seen before.

#### *Automated Labs in Worldwide Network*

Science Exchange already connects research labs worldwide to researchers outsourcing their work. Soon, we may see bridges linking scientists to automated labs, amplifying their capabilities by orders of magnitude.

### GOING VIRAL

Microbiome-related momentum and antibiotic resistance scares have convinced us that bacteria can be our allies. Now due for a reputation overhaul, viruses are helping us laser-target tumors and other localized diseases.

#### *Eradicating Brain Tumors with Polio*

Researchers at Duke University reengineered the polio virus to cure brain tumors by removing a key genetic sequence. Infecting a tumor with modified polio—which removes the tumor's protective shield—enables the immune system to attack.

#### *Engineering Herpes to Treat Melanoma*

An experimental treatment used genetically engineered herpes simplex virus—injected into a melanoma—to destroy the deadly cancer cells. The virus can work alone against advanced melanoma or with other treatments.

### BLOCKCHAIN FOR DNA

As medical records move online and more genes get sequenced, data security will be paramount. Blockchain may be key to transacting sensitive data across disparate health systems and enabling secure recommendations.

#### *Blockchain-secured Medical Records*

The Israeli startup DNA.bits has announced plans to store genetic and medical record data using blockchain technology similar to the underpinnings of the bitcoin network.

#### *The Rise of Medical Record Theft*

Incidents of medical identity theft in the U.S. have doubled since 2010. In the first quarter of 2015, one-third of all data breaches occurred in health care: 82 instances exposed over 1.7 million records.

# BIO:MADE

## AN EXHIBIT OF FUTURE CREATIONS

Where the tech revolution meets the bio evolution

Over the past decade, we've seen biological and information sciences rapidly converge. This convergence is opening biology, bringing it out of academia, and putting nature's materials into the hands of a new breed of innovators and biodesigners, with their own diverse motivations, priorities, and desires.

We're moving steadily towards a world in which anyone will be able to design and build with nature's smallest and most sophisticated materials almost as easily as using a computer. We'll edit genes and birth entirely new organisms—and program life itself.

As we look out over the next decade, we have countless pressing challenges. And while biology has helped us meet challenges, such as food shortages in the past, we can now look to biology for answers to a wider array of our pressing issues. And as cutting-edge biotech becomes democratized, it creates an opportunity for all of us to get involved.

This Exhibit of Future Creations is a set of forecasts of a bio:made future, each of which is accompanied by two signals—present day projects, products or initiatives that illustrate that change is already underway. It can be used as inspiration for you to embrace biology to meet the urgent challenges of the next decade and help you create the biofutures you want.

### BALANCING A BIO:MADE FUTURE

The power of biotech over the next decade means responsible use is more important than ever. This future presents several challenges, however, the need to overcome these challenges can, in itself, become an important source of innovation. We must balance:

**Curiosity | Caution** Biological systems are complex and delicate. Tampering may have extreme unforeseen and adverse consequences. What can we do to proceed cautiously and prevent unintended outcomes?

**Sharing | Security** Genome sequences are valuable information that are likely to be targets of hacking. How can we ensure security and privacy for individuals?

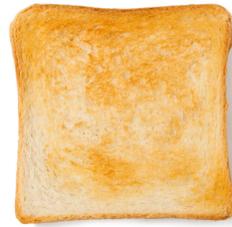
**Investment | Openness** Beware of monopolies—no one entity should own what it means to be human. How can we encourage investment while preserving the openness and accessibility that leads to massive bio-innovation?

## OPEN-SOURCE SOLUTIONS

Massively accessible medications through open synthetic biology



Open-source Insulin  
experiment.com



Life-saving Bread  
igem.org

## DNA DISPUTES

Protecting and controlling sensitive bio-identities



Outing Litterers with DNA-derived Portraits  
beautifuldecay.com  
Image courtesy of Heather Dewey-Hagborg



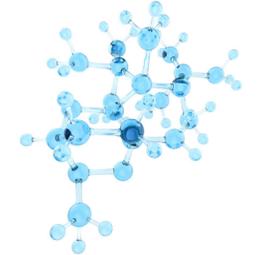
Gene-editing Tech Declared 'WMD'  
technologyreview.com

## AUTOMATED CLOUD LABS

Experimenting with unprecedented speed, precision, accessibility, and reproducibility



Remote AI Experiments  
emeraldcloudlab.com



Automated Labs in Worldwide Network  
scienceexchange.com

## REINCARNATION REDEFINED

Defying death to rebalance the natural world



Resurrecting the Woolly Mammoth  
lynchlab.uchicago.edu  
flickr user William Hartman



Cloning Puppies in the Lab  
en.sooam.com

## MASS MANUFACTURING ON THE CELLULAR LEVEL

Reengineering products to be more sustainable and healthy



Spider Silk Made From Yeast  
bolthreads.com



Designer Cultured Rose Extracts  
ginkgobioworks.com

## GOING VIRAL

Turning viral enemies into allies that fight disease



Eradicating Brain Tumors with Polio  
cancer.duke.edu  
Netali/Shutterstock.com



Engineering Herpes to Treat Melanoma  
nature.com  
flickr user Yale Rosen

## THE MICROBIOME OF BEAUTY

Balancing beauty with bacterial health



Restoring Skin with Sweat-eating Bacteria  
motherdirt.com



Measuring Microbial Impacts of Skin Care  
nerdskincare.com  
alibaba.com

## EDIBLE EXPERIMENTATION

Engineering around food shortages and ethical issues



Ethical Cheese  
realvegancheese.org



Lab Grown Meat  
culturedbeef.net

## BLOCKCHAIN FOR DNA

Secure storage and analysis of genetic data for personal and global medical research



Blockchain-secured Medical Records  
dna-bits.com  
flickr user fdecomite



The Rise of Medical Record Theft  
Forbes.com

# ABOUT THIS EXHIBIT

This Exhibit of Future Creations is an introduction to the bio:made future. Use it as inspiration to embrace biology to meet the urgent challenges of the next decade and create the biofutures you want to see in the world. To get started:

**READ** the Tech Revolution Meets Bio Evolution section to get familiar with the future forces driving bio:made innovation.

**EXPLORE** the Exhibit of Future Creations inside. They hint at the range of innovations we'll see emerge in the next decade.

**CONSIDER** the Balancing a bio:made Future section to think through how to responsibly engage in your our own bio creations.

This research highlights opportunities and offers caution. Use it to help you anticipate future possibilities, to spark your imagination, and to unlock the potential in the bio:made future.

## ABOUT TECHNOLOGY HORIZONS

ITF's Technology Horizons combines a deep understanding of technology and societal forces to identify and evaluate discontinuities and innovations in the next three to ten years. We help organizations develop insights and strategic tools to better position themselves for the future. Our approach to technology forecasting is unique—we put people at the center of our forecasts. Understanding humans as consumers, workers, householders, and community members allows ITF to help companies look beyond technical feasibility to identify the value in new technologies, forecast adoption and diffusion patterns, and discover new market opportunities and threats.

## ABOUT THE INSTITUTE FOR THE FUTURE

The Institute for the Future is an independent, nonprofit strategic research group with over 48 years of forecasting experience. The core of our work is identifying emerging trends and discontinuities that will transform global society and the global marketplace. We provide our members with insights into business strategy, design process, innovation, and social dilemmas. Our research generates the foresight needed to create insights that lead to action. Our research spans a broad territory of deeply transformative trends, from health and health care to technology, the workplace, and human identity. Institute for the Future is based in Palo Alto, CA.

## ACKNOWLEDGMENTS

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Petri dish images courtesy of the laboratory of Professor Eshel Ben-Jacob of the Tel-Aviv University.



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