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Keynote Address: Nancy J Kelley

A Century for Biology: Opportunities and Challenges

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In 1997, Craig Venter and Daniel Cohen, two of the world's leading genetic scientists, published an article entitled "The Century of Biology." In it, they prophetically stated that,

> "If the 20th century was the century of physics, the 21rst century will be the century of biology."

We are now nearly fifteen years into the Century of Biology and that phrase is morphing from a prophecy to a fact. In this short time, new disruptive technologies and scientific fields are being created that are transforming industries. Lets look at just two of them.

Genomics

The decreased cost and increased speed at which we are able to sequence a single human genome has made it possible to create new kinds of diagnostic tests based on a patient's unique genetic blueprint that can **diagnose a disease and predict which treatments are going to be most effective.**

Under the old regime of **single analyte testing**, patients often underwent **multiple rounds of testing** with **inconclusive results causing delays** in identifying and

administering the most effective treatments. This is especially important in cancer care when time is short and the necessity of making an accurate diagnosis with the targeted treatments is critical.

Today, **multi-analyte panels** are being developed that can **test patients for multiple chemical and genetic substances** at one time. Determining the genetic variation that is causing a cancer is important to the **avoidance of ineffective and often toxic treatments like chemotherapy**, assuring the highest quality of care.

Even more important is determining if a patient has **variants that are actionable**… meaning for which there is currently a therapeutic intervention that might work.

The application of this technology has caused a **seismic shift in clinical care** right now, as medicine moves away from treatment based on **one-size fits all** to **targeted interventions** based on a patient's genetic makeup.

- The goal is now **preventive, prospective interventions** before one gets sick rather than retrospective interventions.

- When a patient does get sick, the ability to **predict whether and how a patient will respond to available treatments** – means doctors and patients can make **more informed decisions about choosing treatment over other approaches** such as palliative care… especially at the end of life.

We are observing the power of this technology in dealing with the current global health crisis – the outbreak of Ebola as public health professionals sequence strains of the virus in order to identify how strains propogate and to trace the history of mutations.

And its power is in no way limited to healthcare. Scientists are sequencing all kinds of life forms to unlock secrets of life that can be applied to solve problems in many areas.

Synthetic Biology

The boundary between the synthetic world and the natural world has been collapsing for the last 200 years.

From 1828, when Friedrich Wohler turned ammonium cyanate, a plain inorganic salt, into urea, a natural chemical produced by the kidneys, **we have been exploring the boundaries between the synthetic and the biological.** Synbio is that exploration continued with the promise of incredible benefits for our planet.

Instead of reading DNA to find genetic variations and biomarkers, scientists are now writing DNA to create new life forms and recreate naturally occurring compounds that have great social value but are in short supply or hard to obtain.

First established as a scientific discipline around 2000, technical advances in synthetic biology continue to open up new possibilities in healthcare, agriculture, chemicals, materials, energy and bioremediation.

Estimates of global market size show a growing and maturing industry – some estimate from a small start in 2011 of $1.6 billion, the synbio market will grow by 45% CAGR to $10.8 billion in 2016, within a global bioeconomy of $350 billion.

This is reflected in the rapidly growing number of registries, software tools and standards, as well as by the number of new companies engaged in synbio, which tripled from 2009 to 2013, growing from 61 to 192, most of them in the United States.

Implications for the Century of Biology

Each of these areas of science has important implications for our ability to feed, fuel and heal the world, significantly influencing global leadership and the nature of employment over the next century. Consider how biological technologies and discovery are driving these important developments:

In Genomics,

- We are currently working with a national cancer institute to launch a new company based on a multi-analyte test for cancer with targeted treatments, that is

embedded in a system of clinical care, supported by clinical decision support and linked to the electronic healthcare record.

In Synthetic Biology,

- **Energy** (Solazyme is creating the first consumer-ready algae based fuel for cars, planes and boats.)

- **Chemicals** (Synthetically derived palm oils could reduce deforestation. Some claim that in 15 years, 98% of rainforest in Indonesia and Malaysia will be gone unless we can create a sustainable way of harvesting palm oil).

- **Agriculture** (With 7 billion people, the global population is growing exponentially while food production is growing arithmetically. Higher yielding crops will be needed, that can grow in more arid climates and are resistant to pests.)

- **Public Health** (Novartis is working to establish real-time geographically dispersed vaccine production for pandemic virus outbreaks, making faster cures available, the importance of which was demonstrated in 2009, when vaccines for the H1N1 virus became available only after human infections peaked.

- **Environment** (Modular Genetics engineered a microorganism that produced soy-based biodispersants for oil-pollution management, used to assist in cleaning up the 2010 Deepwater Horizon oil spill in the Gulf.

The US has led the world in the intellectual conception, research and commercial development of technologies in all of these areas, but is in danger of falling behind.

In addition, the frontiers of biology are still just beginning to be explored and there is much to be done to fulfill the promise of engineering biology safely and responsibly.

Some major areas that we need to be collectively thinking about are:

1) Funding.

2) The Scientific Process and Establishment.

3) Education in Science, Technology, Engineering and Mathematics.

4) Regulation.

What do we need today?

1) **Roadmaps.**

The US lacks a solidly coordinated, integrated and strategic research strategy. Although some road map activities in synthetic biology are beginning to take place, as in the case of recently released Road Map for Ecology and current one underway for specialty chemicals, these do not address the strategic needs of the field as a whole. Since the

completion of the Human Genome Project, the US has not had a strategic vision for the Century of Biology that could drive substantial new funding for research, infrastructure and training.

2) **New ways of working.**

Consider – scientific discovery is no longer a single scientist in a lab surrounded by a group of post-docs working on a single problem alone. There is a new paradigm, where there are…

a. **Virtual global laboratories.** Companies like Science Exchange are providing services to budding scientific entrepreneurs, making use of excess capacity in experienced laboratories around the world. Their web site allows scientists to post an experiment needed, choose a lab based on quality and price, then collaborate with that lab to get the experiment done. Payment is made based on the job without the enormous investment in infrastructure needed to accomplish proof of concept in early stage life science companies.

b. **Crowd sourcing** is the process of obtaining needed services, ideas or content by soliciting contributions from a large online community, rather than from traditional employees or suppliers. Crowd sourcing is the new innovative platform for:

i. **Funding:** Kickstarter and Indiegogo organize global networks where passionate people around the world can raise money and invest in ideas that interest them.

ii. **Problem solving:** By distributing tasks to a large group of people, you can mine collective intelligence, assess quality and process work in parallel. See Mashable for examples across industries. As one young scientist described it, Now, "citizen scientists" — like you, me and our Ph.D.-challenged friends — can brainstorm and partake in the grunt work for big-scale scientific research. It's a win-win way to help out and get introduced to some of the top researchers in the biz." These teams working in parallel can also solve problems faster than the traditional teams working serially.

iii. **Crowd labor:** Companies specify services needed. Self employed free lancers can present their ideas and bid on employment opportunities. Categories can include anything from web design, clothing design, corporate identity, product packaging, or applications among other things.

iv. **X-Prizes**: "Think big, win big. Do you have what it takes to change the world?" The X-Prize Foundation is an educational

nonprofit organization whose mission is to bring about radical breakthroughs for the benefit of humanity.

v. **DIY Movement**: Literally meaning "do it yourself," the DIY ethic promotes the idea that anyone is capable of performing a variety of tasks rather than relying on specialists. DIY champions the average individual seeking knowledge and expertise toward the empowerment of individuals and communities.

This movement best represents the democratization of science through such groups as Biocurious and Genspace. Its most successful, and controversial project is Glowing Plants, which produced genetically modified plants that would glow in the dark at Biocurious, funded its initial activities through Kick Starter, and has now received VC funding through YCombinator, an early stage investment firm founded by Paul Graham who was an early investor in Drop Box.

Break out Labs. Helps scientists and innovation get out of the lab and into the economy in order to change wild ideas into world-changing technologies by linking innovators with a network of investors, advisors and strategic partners to create a community.

3) **New kinds of institutions:**

a. **Multi-disciplinary**. That bring scientists from different disciplines to work together on common problems.

b. **Multi-institutional.** That engage multiple institutions in problem solving directed to our most pressing social problems.

c. **Public/private/academic collaborations.** That are driven by support from not only public institutions, but the private, academic and philanthropic sectors as well.

4) **Blended funding mechanisms**

Continued development in many areas of biology is almost entirely dependent upon on govt funding, which is not coordinated and difficult to track in terms of size of investment. Funding from multiple sources will reduce the risk of funding shortages and help to smooth out the challenges of the development cycle.

5) **Public engagement.**

Many areas of biology are facing a skeptical public unaware of the latest advances in technology and unable to understand the implications with proper education and debate. In the absence of a legitimate, responsible scientific voice, opposition will mobilize.

Conclusion

In the Century of Biology, biology has become part of America's innovation narrative.

But the Century of Biology is really the Century of Biology and related technologies. Each of the areas we have discussed this morning requires a constellation of technologies to produce social value: Biology + chemistry + engineering + bioinformatics.

In addition, Interconnectedness + Biology is what is distinguishing the century. Many of the new technologies are opening new ways of relating and working. But for all the possibility, so much of the world is still left out.

Finally, we must find the wisdom to bridge the disconnect between fear, lack of knowledge and understanding because the century of biology has the potential to remediate some of the worlds most intractable problems. As TS Eliot wondered, "Where is the wisdom we have lost in knowledge?"