CASE STUDY: ANGELA BELCHER

Introduction

Angela Belcher, entrepreneur and James Mason Crafts Professor of Biological Engineering and Materials Science at the Massachusetts Institute of Technology, uses biological materials to solve nonbiological problems. She is a leading scientist in nanotechnology and alters the DNA in benign bacterial viruses to create materials for practical human use by exposing them to a variety of inorganic elements in the periodic table. Her groundbreaking work has resulted in "self-assembled" materials that may be used as components in electronic devices such as batteries, display screens, solar cells and fuel. Belcher received the Lemelson-MIT Prize in 2013 for her pioneering inventions in biological engineering, commitment to mentorship in science and engineering, and improving society through environmental sustainability.

Angela Belcher (Photo/Lemelson-MIT Program)

Background and Early Life

Angela Belcher, a seventh-generation Texan, grew up in San Antonio and Houston with her parents and older brother. Belcher's mother suffered from several occurrences of cancer, and her family experienced financial difficulties. Belcher wanted to go to college, which her parents had not attended, but with limited financial resources it was difficult to imagine a path forward. She learned from a young age that she would have to be self-motivated, self-reliant and chart her own course. Belcher spent her childhood outside, exploring and trying to understand the origins and processes of living things. Inspired by the natural world, she always knew that she wanted to be a scientist or physician, and most of all, an inventor.

Belcher as a child. (Photo/Angela Belcher)

Growing up near Texas Medical Center in Houston provided Belcher with opportunities that fueled her exploration of science. One of her neighbors was a resident physician at the hospital, and when Belcher was in eighth grade he brought her on rounds with him. This firsthand experience sparked Belcher's curiosity — she began to conduct her own research and read medical journals. She put her interests into practice during high school, where she attempted to build molecular biology tools, including electrophoresis equipment for separating out DNA.

Belcher attended the University of California at Santa Barbara, enrolling in the College of Creative Studies. Her self-designed major allowed her to take any class at the university, regardless of level, department, or prerequisite. Belcher immersed herself in what she found interesting, combining science disciplines and pursuing a diverse course load that included a graduate-level proteins chemistry class, working in plant molecular biology and physics labs, studying feral honeybee foraging behavior, and working at the Gravitational and Space Biology Lab at Kennedy Space Center.

Belcher remained at UCSB for her doctoral studies. She maintained an interdisciplinary approach to her research, designing a program of study that blended chemistry, molecular biology, physics and marine biology. Belcher completed her Ph.D. in inorganic chemistry in 1997 and defended a dissertation that examined the self-assembly of abalone marine snail shells.

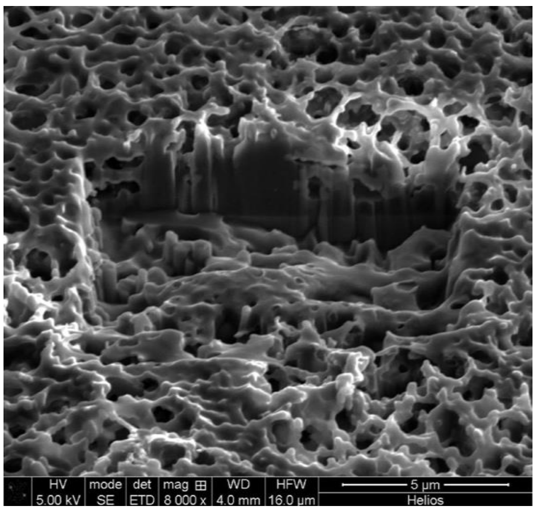
Belcher believes that technology and engineering can help solve societal issues. She began to think seriously about how her work could benefit society and the planet while conducting her graduate and postdoctoral research. She attributes this mindset to her mentor, Evelyn Hu, an electrical engineering professor at UCSB. Hu supervised Belcher's postdoctoral fellowship and taught her the value of thinking about the impact of one's research on humanity. She stressed the importance of putting what is good for the field of study, science, and the planet ahead of personal gain. Hu's mentorship informed Belcher's view of engineering as a service profession, where her role is to teach, listen, learn and identify where she can make a difference in solving society's problems.

Belcher, left, with Hu, right. (Photo/Lemelson-MIT Program)

Process: From Intent to Impact

Belcher joined the University of Texas at Austin faculty as an assistant professor in 1999. Applying her work on DNA coding of abalone shells to proteins building inorganic materials, Belcher organized her lab at UT around solving problems. While she has a strong background in science, Belcher considers herself an engineer. She has been a dreamer and problem-solver throughout her career, excited by the possibility of making things, testing them and finding solutions. Instead of utilizing the scientific approach and starting with a hypothesis, Belcher generally identifies the specific problem she's trying to solve first, working backward to find the solution.

The electronic component manufacturing process uses materials that require extraction from the earth and produces wastes that can be harmful to the environment. To combat this problem, Belcher's lab at UT developed a biological toolkit that employs viruses to organically manufacture inorganic materials. The DNA of viruses instructs them to generate proteins on their surfaces. Depending on their particular DNA, some viruses have affinities for specific inorganic materials. Their surface protein can recognize a material, bind to it, and even evolve a biological structure to recreate it. Belcher's team began genetically altering bacteriophage viruses — which infect bacteria and are harmless to humans — and binding them to molecules of inorganic materials to create "self-assembled" semiconductors. These inorganic materials include particular nanoscale wires and crystals that can be employed in a variety of contexts: for batteries, solar cells, and cancer diagnosis and imaging, among others. Without the biological aid of viruses, these inorganic materials would be far more difficult to make. Moreover, the products are self-assembled by the viruses at room temperature, which significantly reduces the pollutive output and environmental impact of producing electronics.



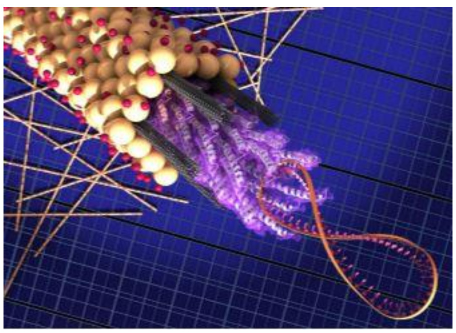
A mesh of metal nanowires built by genetically engineered viruses. (Image/MIT Biomolecular Materials Group/John Burpo, Angela Belcher)

Belcher struggled to obtain funding for her lab at UT early on, primarily because of the interdisciplinary nature of her work and what grant reviewers perceived to be her lack of expertise. When she submitted a proposal for the grant that eventually led to her Lemelson-MIT Prize-winning invention — virus-synthesized semiconductors — one of the grant application reviewers responded, "She is insane!" Another reviewer commented that although Belcher's idea was a good one, the reviewer did not think Belcher had the skills or background to pull it off. However, the U.S. Department of Defense took an interest in Belcher's work, providing funding and recommending her for the Presidential Early Career Award for Scientists and Engineers. The federal government selected her for this award in 2002. The award is bestowed on outstanding scientists and engineers at the beginning of their careers and includes a $500,000, five-year research grant.

Belcher helped raise interest in nanotechnology in Austin during her three years at UT. She appeared on the cover of *Forbes*, won large grants, and published research on the self-assembly of tiny semiconductors in the journal *Nature*. Her innovations in nanotech and semiconductors helped spur investments from a number of technology firms. Several universities recruited Belcher for her pioneering work, including the Massachusetts Institute of Technology, which she refers to as "an intellectual playground." Impressed by the collaborative community she witnessed during visits, Belcher joined MIT as a professor in the departments of biological engineering and materials science and engineering in the fall of 2003. In 2004, the MacArthur Foundation awarded her a $500,000 “genius” grant in recognition of her originality and creativity.

Belcher launched her first company, Cambrios Technologies, during her first year at MIT. The company applied her virus-inspired technology to commercial products, such as silver nanowires for use in touch screen displays. A few years later she started her second company, Siluria Technologies, to transform methane into transportation fuels normally produced from petroleum. This technology decreases environmental emissions and reduces reliance on crude oil.

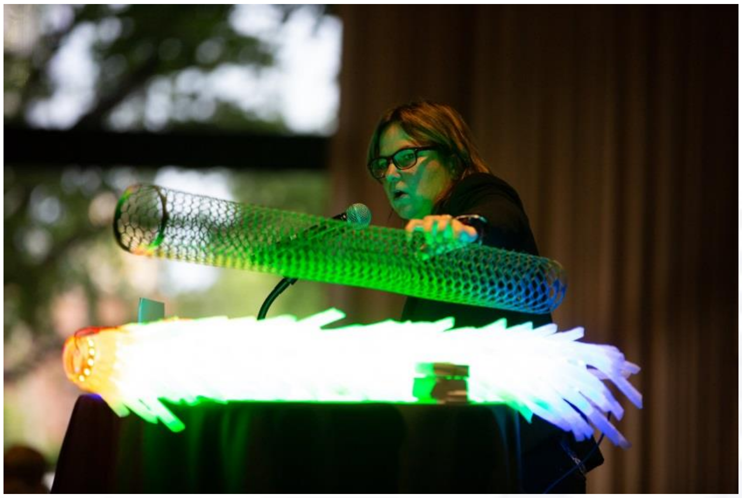
Belcher continued to break through disciplinary boundaries at MIT, creating an environment that fosters cutting-edge research and brings together experts in diverse fields, including chemists, molecular biologists, physicists and engineers. Belcher focuses on collaboration and the joy of being part of a team with her group, finding that the back-and-forth exchange of ideas is key to transforming an idea into reality. She worked on battery research with MIT chemical engineering professor Paula Hammond and materials scientist Yet-Ming Chiang, along with professors Gerbrand Ceder and Michael Stano. Belcher’s group used the M13 phage, a long, thin virus, in a process to form an electrode that can be used in a lithium ion battery. They manipulated the virus’s DNA until it had an affinity for carbon nanotubes and iron phosphate, and would bind to and recreate these materials. The resulting flexible, durable, and light battery could be fitted to almost any shape and store two to three times the energy of traditional lithium ion batteries. The United States Army helped fund the development of this technology, which might one day lead to these small batteries powering military battle suits.



A diagram of the M13 phage. The figure-8 coil is a strand of DNA connected to a bundle of peptides, which attach to the gray carbon nanotubes and keep them in place. The yellow and pink spheres signify a coating of titanium dioxide and dye molecules, respectively. (Image/MIT Biomolecular Materials Group/Matt Klug)

Driven to broaden her impact, Belcher also tackled solar power improvements, collaborating again with Hammond. Belcher, who often started her research endeavors by asking, “what if?”, approached this research by imagining how they might apply biology in a new way. Her lab engineered a virus to assemble carbon nanotubes in order to improve the efficiency of solar cells made with dye-covered titanium dioxide. Similar to her battery work, the virus grows an outer layer of titanium dioxide around the nanotubes, and the nanotubes create wires for electrical current in the solar cell. The resulting virus-assembled material boosts cell efficiency by more than 30 percent. Belcher’s lab built on this success and began experimenting on solar cells made from other materials, such as silicon.

Invention is always important to Belcher's thought process, which she describes as being more problem-focused than science-focused. Sometimes, the research for a solution to one problem creates a chain of solutions for new problems. Belcher and her team attempted to build lithium sulfur batteries using structures built by viruses, but they were unable to achieve the desired outcome. What they did learn was that although the structures were unable to enhance the effectiveness of lithium sulfur batteries, they were 30 times more effective than other methods at soaking up toxins, such as industrial dyes and narcotics, in the human body. The Department of Defense, which found that it could use this technology to protect soldiers against chemical warfare neurotoxins, has an ongoing collaboration with Belcher to create more materials for new military and industrial uses.



Belcher presenting at EurekaFest. (Photo/Lemelson-MIT Program)

Belcher's enthusiasm for delving into new areas of research has continually yielded cross-disciplinary innovations. An out-of-the-box thinker who is unafraid to change fields, Belcher's desire to improve lives inspires her to push the boundaries of what nanotechnologies can do for humanity in the realms of climate, energy and health care. Robert Langer, a vanguard of drug delivery systems, encouraged Belcher in 2012 to apply her knowledge of nanotechnology to develop cancer imaging devices. Belcher had no previous experience with this, but used her expertise with nanomaterials, optical materials, and virus engineering to make significant progress in this area. Standard CT scans can typically identify tumors as small as one centimeter, but, by 2020, Belcher's lab had developed imaging devices that can spot tumors as small as a half-millimeter. Belcher's embrace of new areas of study led her to find a passion for developing an early diagnostic for ovarian cancer, identifying it as one of her true callings. In May 2020, Belcher received research funding from the Massachusetts Consortium on Pathogen Readiness to work on fighting the COVID-19 pandemic. She proposed using nanocarbon materials to create textiles to protect people from dangerous viruses and bacteria. Belcher's passion for discovery, innovation, and service has led to breakthroughs that can improve health outcomes and quality of life for people all over the planet.

Belcher views learning like receiving a little package. When you unwrap it, you get a new way of looking at the world. She imparts her excitement and passion about the path of discovery, sharing information and interacting with others, on younger generations. Belcher leads hands-on experiments at schools and museums to encourage students' interest in science, mentors middle school girls in science and math, and co-chairs MIT's pK-12 Action Group. The Action Group works to improve global education and initiates new

Belcher, right, talking with young inventors. (Photo/Lemelson-MIT Program)

research, design, and outreach programs in STEM education. It brings people together and prepares children to solve the challenging global issues they will face, ranging from climate change, food security, energy and inexpensive health care for all.

As a professor, Belcher views her role as an educator as a privilege and the most important part of her job, and she works hard to learn how to present information in ways that every undergraduate student can relate to. Belcher also tries to match her mentoring style to each graduate student's needs. She teaches them to focus on their strengths, and to let go of what they are not as good at, empowering them to take their skills and passions in new directions. Belcher's mentors, such as Evelyn Hu and Doug Lauffenburger — the first head of the biological engineering department at MIT — have always encouraged her to keep going in the face of doubt and criticism. She tries to teach students how to work through frustration and rejection by taking an objective look at their ideas, figuring out how to make them stronger, and working toward goals in an even better way. Belcher imparts the same service-oriented mindset to her students and postdoctoral fellows that her mentor, Evelyn Hu, passed onto her: Use your knowledge to help society because that is the job of an engineer.