Valerie Ding, a high school senior from Portland, Oregon, with a lifelong interest in math and science, wanted to improve on them. It was in high school that Valerie learned about quantum physics—the science of things so small that laws governing matter don’t apply. While quantum materials provide a new realm of possibilities for renewable, green energy, the concepts involved in quantum physics are notoriously difficult to grasp. In fact, Valerie realized, leading researchers were struggling to apply them. But that meant there were opportunities that had yet to be explored.

To learn more, she asked a professor at Portland State University if she could observe quantum computing and physics classes. Then, while on a visit to CERN in 2012—a trip she won at the 2012 Intel ISEF for a project on LEDs—Valerie learned about quantum dots, tiny particles of semiconductor material that, when grouped on a solar cell, do a great job of absorbing light. No one, however, had found a way to determine the ideal design parameters to dictate quantum dot solar cell efficiency, so their potential remained untapped.

Working independently over three years, Valerie combined elements of computer programming, physics, materials science, and engineering to develop an algorithm that simulates the quantum mechanical properties of lead sulfide quantum dot solar cells. Then, using her algorithm to predict the efficiency of a variety of quantum dot solar cells, Valerie found that the lead sulfide quantum dots are theoretically twice as efficient as the solar cells we typically see on roofs today. Her model, which may be used to help design the next generation of solar cells, has the potential to save years of research—and the millions of dollars needed to fund it. For her research, Valerie won a Fourth Award in Physics and Astronomy in the 2014 Intel Science and Engineering Fair (ISEF). She was also a Google Science Fair regional finalist, a Davidson Fellow, a Siemens Competition regional finalist, and an Intel Science Talent Search finalist.
Why would someone consider using eggplant to power electric cars? The better question, says Shannon Xinjing Lee of Singapore, is why wouldn’t they?

Electric cars use a lot of energy just transporting the heavy lithium-ion batteries they run on—batteries that also require frequent charging. When Shannon began looking at possible alternatives, she learned that, unlike lithium-ion batteries, zinc-air batteries are lightweight and inexpensive. They also have around three times the energy storage capacity as the lithium-ion variety. But as Shannon found, there are some issues that need to be overcome before they can be used in electric cars.

Batteries consist of one or more electrochemical cells that convert stored chemical energy into electrical energy. In zinc-air batteries, each cell contains a positive terminal, or anode, and a negative terminal, or cathode, which is composed of a porous carbon support and an electrocatalyst. Current carbon supports for zinc-air batteries are time-consuming and expensive to synthesize, an impediment to using them in electric cars.

At 17, Shannon began working with Dr. Li Bing at Singapore’s Institute of Materials Research and Engineering (IMRE) to find a better carbon support. She came up with the idea of using Chinese eggplant as a carbon support for the cathode because of its porous structure and because it’s a simple and green material. (She tried working with apples, too, but didn’t get very far with them.) But when the carbonized eggplant showed some catalytic activity, it changed the course of Shannon’s research. “It was only when we analyzed the data of an experiment that we discovered eggplant could be used as an efficient electrocatalyst,” Shannon says. And because the lack of an ideal electrocatalyst was an even bigger problem in zinc-air batteries than lack of an efficient carbon support, they began instead to focus on developing carbonized eggplant as an electrocatalyst.

Over a seven-month period, Shannon experimented to find the best temperature at which to synthesize the sample. She then compared her sample’s performance with the standard commercial electrocatalyst, Pt/C (carbon-supported platinum nanoparticles), which, while efficient, is difficult to synthesize, costly, and non-durable. After tweaking her sample to improve its performance, she found that it was not only comparable to Pt/C in activity and efficiency, but it was much more durable, easier to synthesize, and inexpensive.

Shannon’s research showed that a cheap organic material can be used as an efficient electrocatalyst, which Shannon says could change the way we think about solving technological problems. “It’s likely that some of the simplest and best solutions lie in the untapped potential of nature,” she says. For her project, Shannon won an Intel Science Foundation Young Scientist Award at the 2014 Intel ISEF.
A Window of Opportunity

As high school juniors, Jonathan Zong and Gabriel Valderrama shared a love of music—Jonathan plays cello, and Gabriel, violin—as well as a love of science. When they decided to collaborate on a science fair project, they knew they wanted to do something energy related. “The long-term implications are too important to ignore, given that we are constrained by the resources of our one planet,” says Jonathan. To generate ideas, the pair watched TED talks and read articles on interesting materials. After the pair shot down dozens of ideas, Gabriel pitched the idea of windows that aid heating and cooling efficiency by adjusting their tint in response to sunlight over the course of the day. When they couldn’t find a reason not to pursue it, they knew they had their project.

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Thinking Outside the Barrel

Algal biodiesel is a carbon-neutral alternative to fossil fuels. It can be produced using wastewater and is relatively harmless to the environment if spilled, so there’s great interest in understanding how to increase its production. As a rising high school junior, Augustine Chemparathy of San Ramon, California, wanted to determine factors that increase or inhibit the production of algal biofuel.

It is known that stressing algae by depriving it of nitrogen increases production of an important biodiesel precursor called triacylglycerol (TAG). Working with Dr. Xiaobo Li at the Carnegie Institution for Science at Stanford University, Augustine investigated the mechanism responsible for this increase. He theorized that in the absence of nitrogen, TAG protects the algae from the toxic buildup of electrons during photosynthesis, acting as a sort of electron safety valve. If this were true, he hypothesized, then cells that are less able to handle electron buildups should show a greater reliance on TAG and synthesize more TAG when stressed. They should also show high growth—unusual since in principle, reduced growth usually leads to enhanced energy storage. And high-growth, high-TAG strains would have a lot of potential for biodiesel technology.

To test his theory, Augustine searched the Institution’s Chlamydomonas Mutant Library for strains that had been genetically modified to produce high growth. Of the nineteen he identified, four showed significant increases in TAG accumulation. He then treated the cells with a compound called cerulenin to prevent them from synthesizing fatty acid components for TAG.

When he limited their ability to produce TAG, Augustine observed that electrons accumulated in the cells’ photosynthetic apparatus, supporting his thesis. He also characterized the photosynthetic efficiency of the strains—information that could be helpful when it comes to mass production of algal biofuel. For his research, Augustine was named a 2015 Intel Science Talent Search finalist, as well as a semi-finalist in the Siemens Competition in Math, Science & Technology.
REALIZING THE POTENTIAL OF SYNTHETIC FUELS

For two years, high school student Lena Foellmer of Santa Monica, California, worked as an assistant to grad student Lily Zhang in the Williams Organometallics Laboratory at the University of Southern California. The lab’s focus is on developing synthetic chemicals and reactions with potential biological applications. In her third year at the lab, Lena decided to use the knowledge she’d gained to pursue her own research project. “While we knew the compounds we had synthesized at Williams had the potential to support an alternate fuel source, no one had demonstrated their practical workability,” she says.

Lena planned to modify a hydrogen-fuel-cell-powered toy model car: Instead of running on a hydrogen fuel cell that used hydrogen produced by hydrolysis, Lena’s car would run on hydrogen derived from ammonium borane that utilized the lab’s novel Shvo catalyst. The goal was to demonstrate not only that ammonia borane is a potential fuel source, but that with the right catalyst, it is far more effective than hydrolysis.

Lena applied for and won a 2014 CTY Cogito Research Award, which provided mentor support and funds to carry out her three-month project. Running the experiment required that she build or adapt two model car parts: the H₂-generating system, and the pneumatic system that would channel the gaseous H₂ into the electrolyte membrane of the fuel cell while filtering out harmful borazine and ammonia gases.

Lena created the H₂-generating system using nichrome wire coiled around a vial containing the reaction. The wire was attached to a switch and a temperature-modulating potentiometer, which was in turn connected to a 9-volt battery. She constructed the pneumatic system using cut segments of 1 ml syringe, rubber tubing, and—to remove the ammonia and borazine gases—a filter she fashioned from cotton, activated charcoal, and citric acid. She then bundled the whole contraption together with electrical tape before mounting it on the back of the car.

After one false start caused by a leak in the system, Lena’s model worked—at three times the efficiency of the hydrolysis model! Her results indicate that ammonia borane may be a viable fuel for use in transportation. “The biggest challenge,” Lena says, “was taking what I knew conceptually and making a physical system that would allow my car to run.” Interestingly, the fuel cell continued to perform even when not plugged in for charging, suggesting that the model car might run without requiring charging time. This is an area of investigation Lena intends to explore in the future. “Knowing that my engineering and chemistry is viable in the real world really bolstered how I feel about the value of my ideas,” she says.

Jonathan and Gabriel submitted a proposal for their project to the MIT THINK program, which provides networking opportunities, mentorship, and funding for three high school students each year to pursue science-related projects. Jonathan and Gabriel were thrilled when their proposal was selected. Under the guidance of MIT undergraduate students Somak Das and Daniel Lerner, the pair created their prototype. First, they set up temperature and brightness sensors, which they wired to an Arduino microcontroller. To this, they added a Wi-Fi component to transmit the sensor data to a cloud server. After integrating variable tint material with the sensor electronics—a challenge since the material ran on AC power while the Arduino used DC power—they wrote some code that ran on the cloud to process the sensor data and respond with a value to set the window tint. Then, using a cardboard box to simulate a house, they tested the system. “We plotted the change in temperature over time as well as the change in brightness to determine if the system would maintain enough brightness for indoor visibility while also reducing unnecessary heat gain through the window,” Jonathan explains. And it did. He and Gabriel, who are now freshmen at Princeton and NYU, respectively, plan to look for other opportunities to work together. Says Jonathan, “The interests that guided me to this project—designing things with a positive impact—will always motivate what I do in the future.”