# Physics

## Alternate Method of Instruction Plan

**Mrs. LaDonna Mendleski - lmendleski@cotterschools.net**

- In the event we are not in school due to inclement weather, and the superintendent has determined it is an AMI day, you will be required to complete a case study of engineering.

- Follow the instructions on the top of each packet/lesson. You will be reading a passage, answering a set of multiple choice questions, and answering a set of analysis questions.
  - ➔ Day 1: Cardeon: The Rise and Fall of a Medical Startup
  - ➔ Day 2: Keeping Fallingwater from Falling
  - ➔ Day 3: Pay-as-you-go Solar
  - ➔ Day 4: Makers
  - ➔ Day 5: Zapping Trash

- These assignments may be typed and turned in on Google Classroom or handwritten. Please include your name and the date in the top right corner if it is handwritten.

If you have questions you should email me. I will be available by email from 8am - 3pm (and will do my best to answer emails at other times as well).

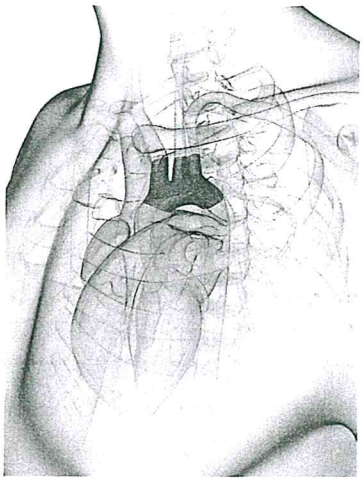
# Appendix D

## Case Studies

The following five case studies of engineering were developed by Cory Culbertson for Project Infuse.

## CARDEON: THE RISE AND FALL OF A MEDICAL STARTUP

Heart bypass surgery has saved the lives of thousands of people around the world. The procedure involves stopping the heart to reroute blow flow around blocked blood vessels, and it is one of the triumphs of modern surgical technique. However, it is also a procedure that is very stressful to the body. Serious complications after surgery are common. Even though the procedure takes place in the patient's chest, many patients experience brain injuries ranging from minor memory loss to life-threatening strokes.



Aortic arch

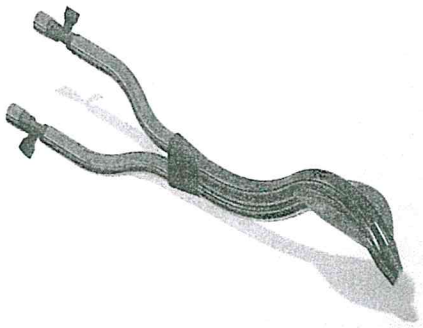
Initially, these brain injuries were a mystery. However, in the 1990s it became clear that brain injuries were linked to small debris particles that blocked blood vessels in the brain, causing a condition known as embolism. These particles –mainly calcium and fat—normally collected on the walls of blood vessels, but were dislodged during bypass surgery. Researchers realized that reducing post-operative brain injuries meant that they needed to find a way to prevent these debris particles from entering the brain, at least long enough for them to be collected somewhere else.

A group of medical professionals hit upon an idea that was amazingly simple in theory, but very complex to execute in practice: place a "roadblock" in the patient's aortic arch at a point where the carotid arteries branch off to take blood to the brain. Then, blood circulating through the body could not carry debris up into the brain. However,

such a barrier would have to be fairly large—larger than could fit through the blood vessels that doctors use to access the aorta. There would also have to be a way to supply the brain with clean, filtered blood while its supply arteries were blocked off. These medical professionals thought they had a way to solve these problems, but needed a team of engineers to develop the idea into a working medical device. In 1996, they attracted investment funds, formed a company known as Cardeon, and set to work developing a device.

Cardeon's engineering team was not starting from scratch. For many years, surgeons have used a device known as a catheter inside blood vessels. Many of the engineers at Cardeon had designed different types of catheters before. What was different now was the function of the device at the end of the catheter. The plan was to develop a baffle that could be rolled up, and then expanded when in the proper place in the aorta. The catheter would also contain a blood delivery tube that would supply clean filtered blood directly to the the patient's brain. Because the shape of the baffle at the end of the long catheter resembled a cobra's hood, they named the device the Cobra Catheter.

There were many challenges in designing the Cobra Catheter, particularly in the specially-shaped baffle at the end. Other companies had already patented a flexible "roadblock" baffle and a mesh "sieve" baffle that could block debris in the aorta. Cardeon's design would have to be different. Cardeon's engineers decided to design a baffle that would use extra blood flow on the brain side to push debris back out into the aorta. Engineers spent many hours trying to prefect the location of the blood delivery vents and the amount of blood flow. They tested their designs on a model of the human aorta made out of polyurethane plastic. Over and over, they simulated blood circulating in the aorta and measured the level of debris getting to the brain. The original design turned out to be very inefficient, and a complete redesign was required. Eventually, one engineer was able to design a baffle that pushed almost all of the debris away from the brain. It worked perfectly on the model aorta. Would it work on a real patient?



**A conceptual CAD model of the Cobra Catheter (image credit: C. Culbertson)**

In 2001, Cardeon had a prototype ready for testing. For safety, the first patients would not be humans. Instead, 16 pigs were the first test subjects. Each one underwent heart surgery, eight with the new Cobra catheter, and eight without. The device was a clear success: 89% of the particles in the blood stream were prevented from reaching the brain.

The Cardeon team felt that they had a good solution to the problem of brain embolism following cardiac bypass surgery.

However, the road ahead was still long and hard. Medical devices used in the United States must be approved by the Food and Drug Administration. The FDA's approval process would require careful clinical tests. In addition, the FDA required that the entire manufacturing process used to make the Cobra Catheter be carefully planned and then strictly followed. Any defects in the products would need to be analyzed, and then eliminated by changing the manufacturing process plan. All of these steps meant that Cardeon would have to hire a new crew of support personnel. Cardeon would also have to create a marketing team to promote the product and convince surgeons that it was worth using. Medical research and design is an expensive process. The company had already spent millions of dollars to get to this point, and had yet to sell a single Cobra Catheter. The promising surgery results were enough to raise more funding from the company's investors, but this was make-or-break time for the company. Success depended on positive clinical trials and quick approval of the company's manufacturing process.

It didn't happen. The Cobra Catheter was tested on more than 1,300 patients, and these patients responded well. The FDA appeared ready to approve the Cobra Catheter. However, the investors backing Cardeon wanted to see clear neurological benefits—backed up by statistical analysis—that the Cobra Catheter was a complete success. Unfortunately, Cardeon could not prove these clear benefits. Both surgeons and investors can be very conservative, and these mixed results weren't enough to convince them that the Cobra Catheter was worth taking to market. In addition, other ways of minimizing bloodstream debris were starting to show promise, including a way of doing minimally-invasive heart surgery that did not produce as much debris in the first place. Without a source of funding, Cardeon ceased operations in 2005. Many employees went on to other medical device companies, where they set to work designing and building the next device to revolutionize modern medicine. The Cobra Catheter never became the surgical miracle that its inventors hoped for, but it remains a brilliant example of engineering at the limits of medical knowledge.

## DISCUSSION QUESTIONS

1. Outline the major steps in the design process for the Cobra Catheter.
2. Describe the constraints that were involved in the design of the Cobra Catheter.
3. How did iteration play a role in the design process?
4. What different purposes were the catheter prototypes used for?
5. Medical device design is a world where engineers must often innovate rapidly, but surgeons must often exercise caution and conservative judgment in which

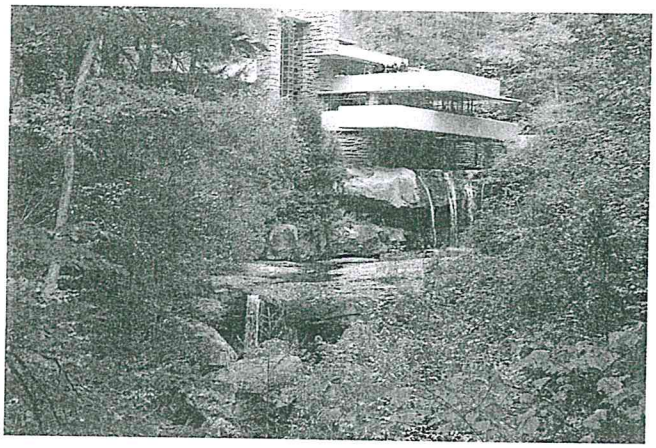
devices to use. What explains the difference in the perspective of these two groups?

6. What influences, both positive and negative, does governmental regulation exert on the design process for medical devices?

7. Medical device design is like many areas of engineering, in that much time and expense is spent on designs that ultimately do not succeed. Is this method of design appropriate? Why or why not?

# KEEPING FALLINGWATER FROM FALLING

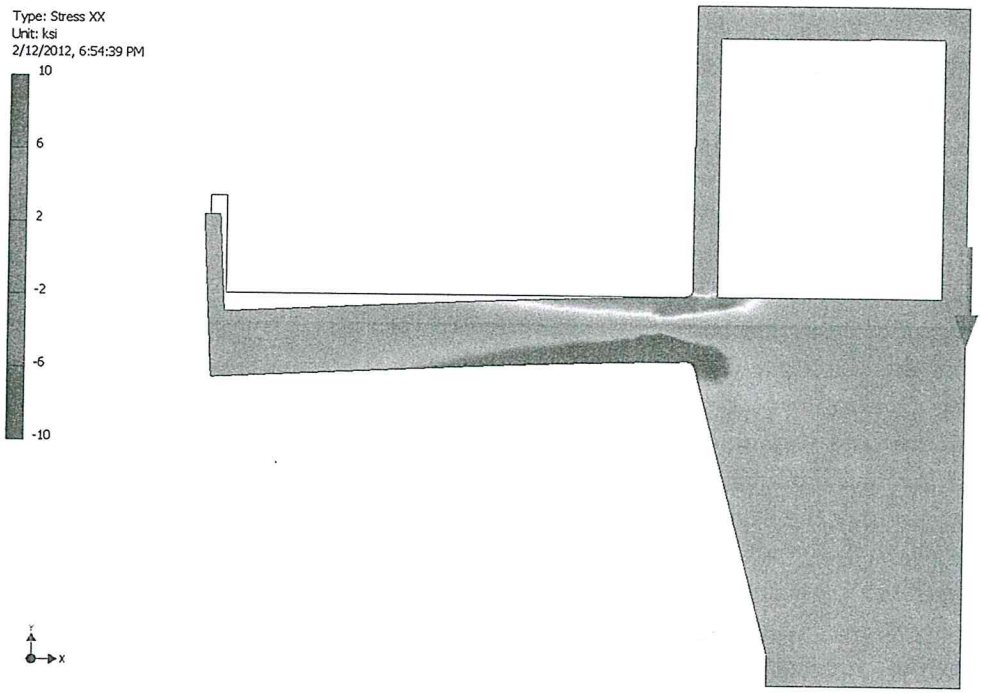
Frank Lloyd Wright is America's best-known architect, and perhaps no other building better represents Wright's iconic style than Fallingwater in Mill Run, Pennsylvania. Built in 1936, Fallingwater was commissioned by the Kaufmann family to be a vacation house with a view of the beautiful waterfall on their property. Instead of building the house *next* to the waterfall, Wright boldly decided to place the house *over* the waterfall. Its broad flat lines echo the stone ledges around the waterfall. Fallingwater is considered an architectural masterpiece for the way it not only complements the natural surroundings but even enhances them.



**Frank Lloyd Wright's Fallingwater (image credit: Ron Shawley, Wikimedia Commons, CC BY 3.0, *https://commons.wikimedia.org/wiki/File:FallingWaters_fall_colors_-_panoramio_(19).jpg*)**

However, Wright's design stretched the limits of structural engineering in his day. The home's wide terraces stretched over the falls, supported only at one end, in an arrangement known as a cantilever. While graceful, the cantilevered terraces were under enormous stress at their support points. Wright chose to use reinforced concrete as his building material. Reinforced concrete is a durable and versatile material that allowed him to create the forms he envisioned. However, concrete does best when stressed in compression, not tension. The cantilevered terraces had areas of high tension that posed a real challenge for Wright's engineers. Their design called for inverted T-shaped beams to support the terraces, with a small number of steel bars in the top of the beams to resist tension forces. Careful analysis of the building's loads allowed them to create a design in which the tension loads were within the safe limits of the concrete and steel. However, Wright felt that their analysis was too conservative. He also sharply disagreed with an outside engineering firm that recommended a large increase in the amount of reinforcing steel in the terraces.

Soon after construction, the terraces began to sag noticeably. Later, cracks began to appear at the stress points. It appeared that the concrete would not be able to resist the tension forces indefinitely. Stopgap repairs were made for decades, but it was clear that

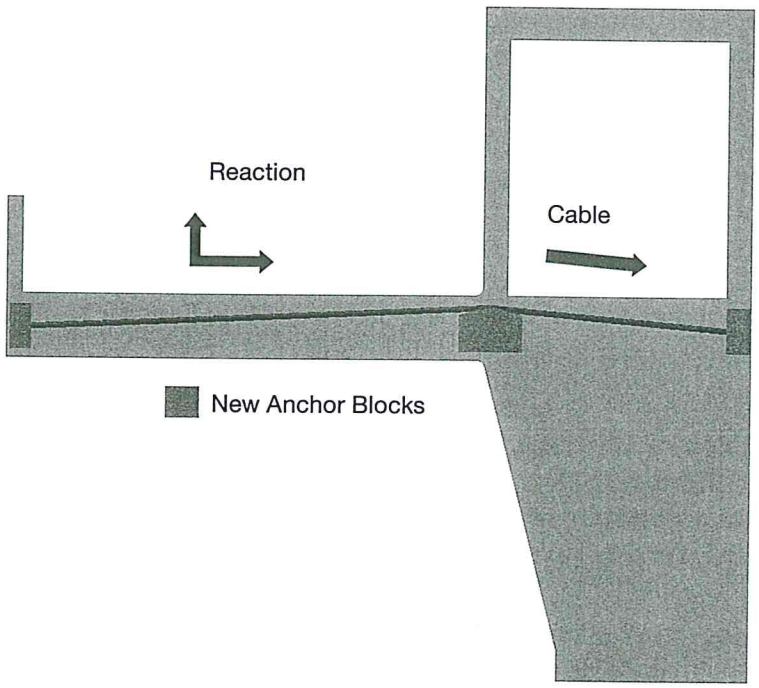



**Computerized stress analysis of a cantilevered terrace similar to that at Fallingwater. Red shows areas of high tension. Blue shows areas of high compression. (image credit: C. Culbertson; full-color version available at *www.nsta.org/eggdrop*)**

the problem was in the original design. In 1995, Robert Silman Associates was hired to investigate. By using new computer modeling techniques and radar images of the interior of the concrete, RSA discovered that the terraces were dangerously close to failing. It was time to finally correct the problem. The challenge was not only to fix the damaged structure but to find a way to reduce the stresses in Wright's original design without altering its historic appearance.

RSA's engineering team came up with a solution that placed a hidden support structure inside Wright's famous terraces. The key to the new design was the use of the same reinforcing material that Wright had originally undervalued—steel. Unlike concrete, steel is able to resist high tension forces. In fact, suspension bridges make dramatic use of steel tension cables to support their high-flying structures.

Unlike a suspension bridge, though, Fallingwater could not have its new steel cables strung up for the world to see. They had to be hidden inside the existing terrace floors and walls. This presented the engineers with a new problem: as the angle of the support cables became closer to horizontal, the amount of vertical load that they could support decreased significantly. At such a shallow angle, the steel cables would be stressed




**Placement of one of the steel cables within the terrace. As the angled cables are tensioned, the reaction forces pull the outer edge of the terrace inward and upward. (image credit: C. Culbertson; full-color version available at *www.nsta.org/eggdrop*)**

almost to their limits. Once again, Fallingwater engineers found themselves doing careful load analysis to keep their structure within safe limits of material stress.

The final design took advantage of the best properties of steel and concrete—steel to resist tension forces, and concrete to resist compression forces. The steel cables were carefully anchored into blocks buried inside the terrace floors. Then, they were slowly pulled into tension. The engineering team watched carefully as the lip of the main terrace rose by almost an inch. By careful placement of the new reinforcements, the engineering team had provided a much greater margin of safety and a longer life for the house.

Of course, visitors to Fallingwater will not see any of this. Instead, they will see Frank Lloyd Wright's house as it originally appeared when it was built. Only now, this architectural masterpiece will be able to majestically float over its waterfall for many more years to come.

## DISCUSSION QUESTIONS

1. Identify some points where engineering analysis played a critical role in the history of Fallingwater.

2. If engineering analysis is largely based on mathematics, how can there be disagreements over whether it is accurate or not?

3. Design is often described as an iterative process. However, few buildings are reworked until they are satisfactory, as Fallingwater was. Does the concept of iterative design apply to large structures and other one-time designs? If so, then how?

4. Steel-reinforced concrete was a relatively new material in Frank Lloyd Wright's time, and it was not as well understood as it is now. Does Wright deserve blame for using a material that was still somewhat unproven? Describe more recent examples of situations in which somewhat unproven materials have been used.

5. Wright's vision for Fallingwater sometimes conflicted with the more conservative desires of both his clients and his structural engineers. Does the engineering design process have room for highly innovative, visionary people? What benefits and costs are associated with highly innovative design?

# PAY-AS-YOU-GO SOLAR

Marakaru is a small farming village in the lush green highlands of western Kenya near Lake Victoria. A visitor to the area might see the residents out working, hand-cultivating the fertile fields of corn, sweet potatoes, tomatoes, coffee, and vegetables. At night, a Marakuru farmer might retire to his home, light a smoky oil lamp to see by—and pick up a cell phone to contact a buyer for his crop.

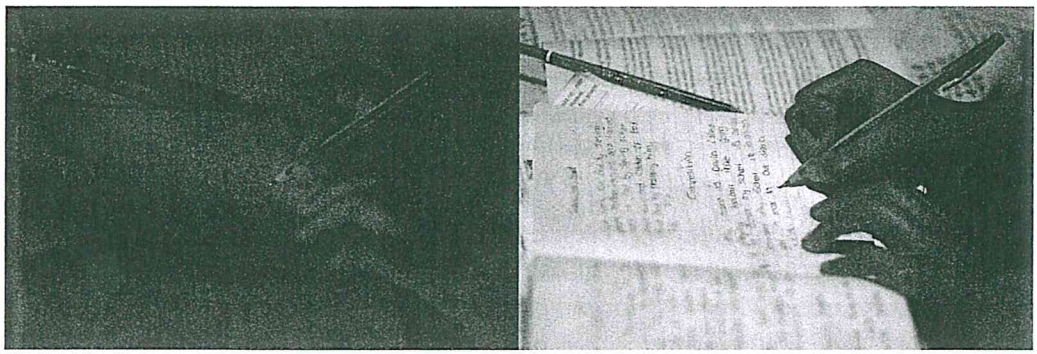
Marakaru, like most of rural Kenya, has mobile phone coverage. But like most of rural Kenya, the village lacks any source of electrical power. This seemingly strange arrangement makes sense in rural Africa, where raising mobile phone towers is realistic, but stringing electrical lines to every village would be an impossible luxury. Still, Marakaru residents have come to rely on mobile phones for communication, and the lack of electrical outlets means that recharging a phone can become a major chore: an hour walk to the nearest town with electricity, a long wait and expensive fee at a recharging kiosk, and another hour walk back home.

A company called Azuri Technologies sees this hassle as an opportunity. It has developed a solar charging system called Solar Home that promises to provide a small, inexpensive source of electricity for people like the residents of Marakaru. The system has a solar panel, battery/control box, two white LED lamps, and a phone charging cord with adapters for the most common cell phones in Africa. The LED lamps help reduce another expensive inconvenience for rural Africans, since the only light sources in many rural homes are smoky kerosene-burning lamps.

The use of solar panels in rural African areas is not a new idea. Many universities and private companies have tested solar power in Africa, with varying degrees of success. The Azuri system shows promise for two reasons, one technical and one economic. On the technical side, Azuri has found ways to maximize the amount of light that their customers have available at night. The LED lamps in the system had to be bright enough

**The Azuri Solar Home system, including charger, LED lamps, and phone adapters, is shown. (image credit: Azuri Technologies Ltd / used with permission)**

to replace the old kerosene lamps, but increasing the brightness means that the light will not last as long before the battery runs down. A larger battery could be used, but would add a great deal of weight and require a larger solar panel to charge it each day. To get the most light out of the limited energy stored in the battery, Azuri developed a "smart" electronic controller. The controller remembers how long a customer typically uses the LED lights at night. Each evening, it calculates how much energy the solar panel generated during the day and then automatically adjusts the brightness of the lights so that they will last as long as the customer needs. While the controller adds some extra expense and complexity to the system, Azuri considers this a good tradeoff to provide a more useable system for its customers.



**Studying is much more comfortable with LED lighting (right) instead of kerosene lighting (left). (image credit: Azuri Technologies Ltd / used with permission)**

When designing the Solar Home system, the product development team had to make choices for the solar panel, battery, and lights that they felt represented the best balance of cost, size, power, and other criteria. However, the engineering team also realized that one specification point would not fit all customers, and designed other versions of the system with different combinations of features.

Despite all this clever engineering, Azuri's largest innovation may be its business plan: "pay as you go solar." Even the most basic solar electric system is too expensive for most rural Africans to purchase, and there is no bank willing to give loans. Instead, Azuri will sell the solar power systems at a small fraction of their actual price. To use the system, customers will send a payment via cell phone, a system that is already common in Africa. They will then receive a text message containing a code that will activate the system for a set number of days. While pay-as-you-go plans sometimes get a bad reputation, this one is intended to be a win-win for the company and its customers. The company can sell units at an attractive price and generate repeat business. In exchange, the customer gets a solar electric system without going into debt, and can pay for as much or little electricity as needed. Most importantly, once the full cost of the solar power

system is paid, the customer owns it and can use it freely without having to purchase any more access codes.

It is clear that a need exists for better sources of light and electricity for rural Africans. Time will tell whether Azuri's Solar Home system has the right mix of features to successfully fill this need.

Solar panels are being installed on a home. (image credit: Azuri Technologies Ltd / used with permission)

## DISCUSSION QUESTIONS

1. How did technical constraints limit the design of the Solar Home system?
2. How did economic constraints limit the design of the system?
3. Besides those listed, what other design tradeoffs might Azuri's designers have had to make?
4. How would the design specification point (battery size, lamp power, and solar cell) have to change for use in different locations—such as Greenland, Indonesia, or rural New Mexico?
5. Do you predict that the pay-as-you-go model will be successful? Why or why not?
6. What are some possible societal changes that could occur if most rural African homes had access to better lighting and cell phone power?

# MAKERS

*Limor Fried graduated from MIT in 2005 with a master's degree in electrical engineering. She is a young woman who is well-known by her screen name* ladyada, *and who has been known to wear a lip ring and stoplight-red hair. She is also the CEO of an influential electronics company, a pioneer who has been hailed as the "queen" of her field, and a minor celebrity who has graced the cover of* Wired *magazine. Which of these characteristics don't fit with the normal concept of an engineer?*

**Limor Fried (image credit: TechCrunch, Flickr, CC BY 2.0, *https://flic.kr/p/efCWuM*)**

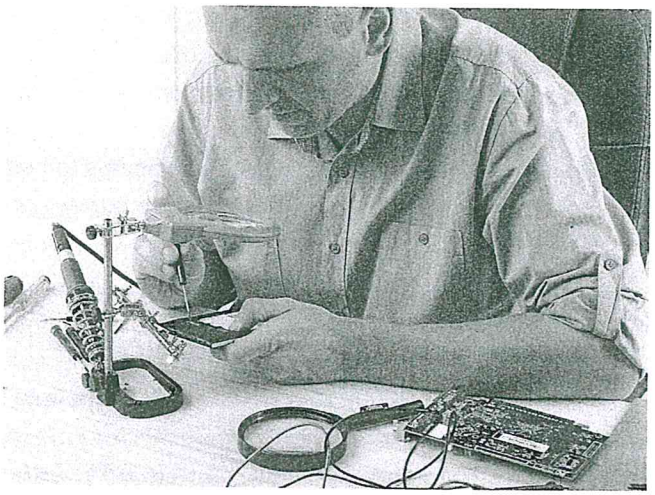
*Limor Fried is one of the driving forces behind the rising "maker" movement in electronics and robotics. If any of the above descriptions seem out-of-place, it probably has more to do with the eclectic nature of the maker movement than anything else.*

*Makers* is the current term for a loose-knit group of enthusiasts who use modern electronic technology to create designs for their own personal use and to share with others. Some makers are immersed in the technical side of designing, and relish a challenge like reverse engineering the Microsoft Kinect box. Other makers are more interested in the artistic aspect of design, and gravitate toward projects like using colored LEDs to create portraits on the side of buildings. Some makers are hard to categorize, such the one who built a solar-panel covered swimsuit for charging a cell phone at the beach.

It can be easy to dismiss the maker movement as an interesting hobby for technically-minded people. Many maker web sites are full of amateurish contraptions that do neat things, but are too unique, personal, or totally weird to have any chance of hitting the mainstream. Not many people have a yearning to own a solar-panel swimsuit. For most makers, though, following personal interests is the key to true innovation. As maker Eric Stackpole points out in an interview on Metroactive.com: "When people follow their passion, they try things businesses that rely on market research never would."

In a sense, makers are like chefs than can create interesting new dishes from the ingredients available in any grocery store. Electronic components like chips and resistors

are very difficult to manufacture, but they are cheap to buy and there are thousands of different varieties. It is easy for a maker to buy a handful of components, connect them together, and create a new product that has never been imagined before. Internet sites such as Limor Fried's adafruit.com support these inventors by providing information, components, and even discussion forums to help solve difficult design problems.



**Makers frequently rely on soldering and other electronics prototyping skills**

Limor Fried leads the maker movement as both an innovator and a collaborator. Some of her designs like the MintyBoost (a cell phone charger built into an Altoids tin) are among the most popular projects for beginning makers. However, it is her ability to

**Portable electronic devices like the MintyBoost charger are popular projects with many makers (image credit: Agrohmann, Wikimedia Commons, CC BY 4.0, *https://commons.wikimedia.org/wiki/File:2016_09_UJ_Meet_Up_Makerspace_(c)_Lukas_Boxberger.jpg*)**

communicate and collaborate that truly led to her success. Fried has filled her web site with detailed descriptions, photos and diagrams of her designs, and she frequently posts on discussion forums to help other makers with their projects. The web site began just as a way to share ideas, but when her projects became more popular, Fried began to sell ome of the harder-to-find electronic components to help her fellow makers. Now, Fried's company, Adafruit Industries, sells a wide variety of electronic hardware. The design help is still provided for free.

Modern makers like Limor Fried carry on the tradition of innovation and collaboration that has long been part of the electrical engineering world. Over thirty-five years ago, one of the first maker groups started meeting in Menlo Park, California. Called the Homebrew Computer Club, it was a place for people to work together and share ideas about the then-unheard-of idea of personal computers. The club meetings often were the spot for the unveiling of new inventions. In 1976, Steve Wozniak and Steve Jobs attended a meeting of the Homebrew Computer Club and demonstrated their newly-built computer. It was called the Apple 1.

## RESOURCES

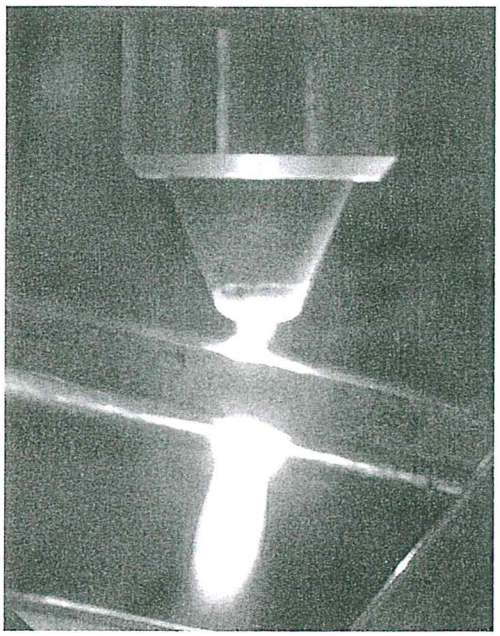
- *Wired* interview with Limor Fried: *www.wired.com/magazine/2011/03/ff_adafruit/all/1*
- *Economist* article on the maker movement: *www.economist.com/node/21540392*

## DISCUSSION QUESTIONS

1. In what ways is the maker movement "engineering?" In what ways is it not?
2. Do makers follow a design process? How is it similar to or different from the process followed by a professional engineer?
3. Which stereotypes of an engineer does Limor Fried break? Are there any stereotypes that she reinforces?
4. Besides electronics, are there other areas of engineering in which amateur designers can be highly innovative? If so, which areas?
5. What constraints do makers face that professional engineers do not? What about the other way around?
6. One popular maker slogan is "If you can't open it, you don't own it." What attitude toward technology does this sentiment reflect?
7. Some makers consider their goal to be making engineering into an activity for everyday people, instead of an activity that is only for professionals in major corporations. Is this goal reasonable? Why or why not?

# ZAPPING TRASH

For thousands of years, people have been doing the same thing with their trash: digging a hole and putting it out of sight. But with billions of people now needing room to live on our planet, burying trash has become much less attractive than it used to be. Waste landfills require huge areas of undeveloped land, and they emit tons of greenhouse gases as the refuse decomposes. Landfills also don't solve the problem of toxic chemicals in our trash. The toxins are merely hidden away, still holding the potential for serious land and water contamination in the future.



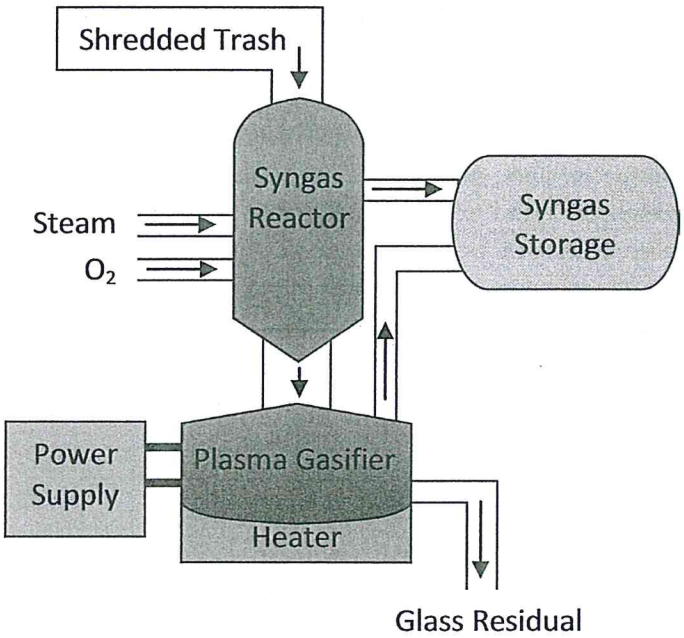
**Plasma can be used to melt or even vaporize materials, as in this demonstration of a plasma cutting torch. (image credit: Submarine007, GNU Free Documentation, *https://commons.wikimedia.org/wiki/File:Plasma_drilling.JPG*)**

Incineration is another potential solution for dealing with garbage. Burning trash can drastically reduce the volume of waste, and possibly even generate some energy at the same time. Yet incineration has some strong opposition due to actual and perceived environmental hazards. Even though modern incinerators are much cleaner than almost any other form of combustion, the public has generally remained skeptical that toxins are truly being kept out of the air.

Engineers at a startup venture called InEnTec hope to solve the technical and image problems of garbage incineration. If successful, InEnTec engineers may even be able to turn trash into a profitable resource instead of a liability. The key component of their strategy is a technology called *plasma gasification*. While normal incinerators burn most of the easily-combustible materials in trash, many other compounds are left untouched. Plasma gasification goes further – thousands of degrees hotter – to break apart almost every known compound into its basic atomic building blocks. At these temperatures, toxic compounds are completely broken apart. The output of a plasma gasification unit is simple elements such as carbon, oxygen, and iron.

However, two big challenges stand in the way of simply turning our trash into plasma-induced atomic flux. The first is that plasma gasification requires immense

amounts of energy, making it an expensive form of waste disposal. The second challenge is that household trash contains a wide and unpredictable variety of materials. Some of them are easy to process, but others will remain toxic even after plasma gasification. For example, toxic metals like lead and cadmium pass though the gasification chamber completely unchanged.




**A schematic representation of the InEnTech waste treatment system. (image credit: C. Culbertson)**

InEnTec's solution to these challenges is to create an entire waste-treatment system, not just a single device. In this system, trash is first delivered to the InEnTec processing facility via truck and shredded into easily-combustible chunks. From there, it goes into a reaction chamber that heats the shredded garbage and mixes it with steam and oxygen. The steam and oxygen react with organic compounds in the trash to produce syngas—a valuable commodity that can be used to make natural gas. Syngas production is the key to making the whole system economically feasible. By vaporizing the organic part of the trash, the syngas reactor vastly reduces the amount of trash and creates a revenue source at the same time.

After the syngas is extracted, the remaining trash is fed into the plasma gasification chamber. Here, it is hit with an electric arc that is essentially a manufactured lightning bolt. The intense blast breaks apart the compounds in the trash stream, vaporizing most of what is left after syngas production. The challenge at this step is to process as much trash as possible, but to insure that all of the trash receives sufficient heat to be fully atomized.

After most of the trash has been vaporized, the remaining heavy atoms fall to the bottom of the chamber, where a final heating system turns them into a thick, molten soup. This tough trash is extracted and cooled into glass-like chunks. While these leftover chunks contain some toxic elements, they are encased in a solid glass form which keeps them inert and out of the environment. This glassification process is considered one of the safest

options for handling hazardous materials.

**InEnTec's waste treatment system has attracted investors such as Waste Management Inc., which operates 273 landfills in North America. (image credit: Redwin Law, Flickrs, CC BY 2.0, *https://tinyurl.com/ycf8t483*)**

InEnTec has already built a large test system at a landfill in the northwest US, but the company still has more engineering development to do. To be profitable, the plasma gasification system must come close to maximizing the amount of syngas produced per pound of trash, while minimizing the energy input into the plasma arc. Engineers at InEnTec are still working to find the best balance of mass and energy inputs into the syngas reactor and the plasma gasification chamber. These engineers also need to balance many other system variables. For example, higher plasma temperatures can guarantee that even the toughest compounds are broken apart, but high temperatures require more energy input and shorten the life of the reactor. Developing a system that is both technically and economically successful is still a future goal.

If the engineers at InEnTec succeed, our society may finally have a modern solution to an age-old problem.

## DISCUSSION QUESTIONS

1. What are the main subsystems of the InEnTec design?
2. Are these subsystems modular? That is, can they be altered without significantly affecting the design of the overall system?
3. Suppose you were a potential customer for a waste treatment system such as this one. What would be some of your requirements for its successful operation?
4. If the InEnTec design is successful, how will it fit within large-scale waste management and energy systems in the United States?
5. Landfills are usually sited far away from urban areas so that they can use less-expensive land. Would the InEnTec system change this practice? If so, how?
6. Will a plasma gasification system be able to overcome the perception of incineration as a "dirty" technology? Why or why not?