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OCTOBER 2019

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Special
Product Guide
Inside

technically speaking

Vanessa Revelli vanessa@techdirections.com

I'm excited to share a technology that is coming to my hometown, Ann Arbor, MI. This fall, residents will be able to have their food delivered from selected restaurants by an autonomous robot called REV-1. The robot is the brainchild of a local business called Refraction AI, which was founded by University of Michigan professors, Matthew Johnson-Roberson and Ram Vasudevan. The two have a long history with autonomous vehicles and work together at the university's Robotics program.

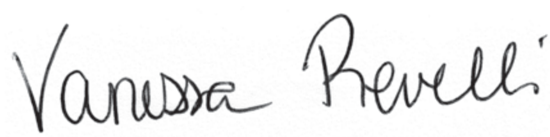
Photo courtesy of Refraction AI

The story behind how they came up with the idea was from a food delivery that went wrong. Two years ago, they placed a delivery order and when they received it, it was half an hour late and was missing items. They called the restaurant to fix the issue and were surprised when the owner herself came to deliver the food and apologize. She explained that the restaurant was having a bad day, and it was her birthday.

"We were hearing this really sad story and we thought, 'Hey, we work in the autonomous vehicle space. This seems like a really great opportunity to start addressing some real problems,'" Vasudevan says. So, the two started working on developing the three-wheeled vehicle. It travels between restaurants and delivery locations primarily using bike lanes because of its slow speed—it only travels 10-15 mph. It carries the food in a large storage compartment which is accessed by using a unique passcode entered on a keypad.

"We'd been working in the space for a fairly long time and working on the large self-driving vehicle problems," Vasudevan says. "We wanted to see if there was a way that we could bring some of those things that we'd been thinking about into the real world, without having to worry about solving the full self-driving car problem", says Vasudevan.

"We thought that deploying in a place like Ann Arbor, where there's a young community that's more willing to engage with this type of thing, and also making it accessible to places that have winter weather, was really important. So, Ann Arbor fit that set of requirements in a really nice way." Refraction has partnered with two restaurants in town, one of which, of course, is the one that started the whole thing.



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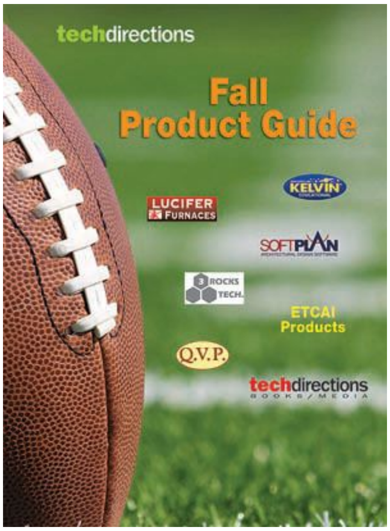

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About the cover: The shape-shifting Aquanaut Transformer becomes a very powerful humanoid robot that can perform all kinds of underwater construction tasks. See more on page 8. Photo courtesy Houston Mechatronics. Cover design by Sharon K. Miller.

the news report

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Win Classroom Prizes in This K-12 STEM PBL Competition

The Toshiba/NSTA ExploraVision science competition challenges students to envision and communicate new technology 20 years in the future through collaborative brainstorming and research of current science and technology. ExploraVision is a STEM competition for K-12 students. It encourages students to combine their imagination with their knowledge of science and technology to explore visions for the future.

Teams of 2-4 students select a technology, research how it works, learn why it was invented, and then predict how that technology may change in the future. Students identify what "breakthroughs" are required for their idea to become a reality and describe the positive and negative consequences of their technology on society. The students write a paper and draw a series of web pages to describe and communicate their idea. Finalists make an actual website, video, and a prototype of their future vision.

ExploraVision is more than a science fair or a competition—it can be a tool to ignite every student's enthusiasm for STEM subjects! Deadline for submissions is February 10. For more details and to register, visit www.exploravision.org.

Victor® "Rulers of the Flame" 2019 Student Contest

Building on Victor's "Rulers of the Flame" brand campaign, Victor, an ESAB brand, launched its 2019 "Rulers of the Flame" student contest, which is open to students in cutting, welding, and related programs (e.g., ag mechanics, metal art, engineering) at secondary, post-secondary, technical, and vocational schools. Victor will award more than $50,000 in equipment and cash prizes as part of the contest. Entries will be accepted from now until December 2, 2019, and winners announced on December 14.

"The Rulers of the Flame contest encourages students to demonstrate leadership, character, and empowerment through individual essays and team fabrication projects," says Bill Wehrman, Global/North American Marketing Communications, ESAB. "Thousands of students use oxy-fuel equipment everyday, and we want to encourage their passion and vocation."

ESAB judges will select three winners in each of the contest's two categories—individual essay and team fabrication project. Individuals will win $250 and a Victor Medalist 350 Outfit by submitting a 500-word essay that best supports the contest theme. Teams will submit a metal fabrication project that incorporates an oxy-fuel equipment process (cutting, heating, welding, or brazing) as one or more of the fabrication steps and MUST incorporate the Rulers of the Flame logo. To obtain the logo, rules, details, entry forms, and tips for winning, visit esab.com/rulerscontest.

Each member of a winning team receives $250 as well as a Victor Medalist 350 Outfit, while the school associated with the winning team receives a cutting and welding package valued at more than $8,400, which consists of the following items:

Two Victor Journeyman EDGE 2.0 Outfits and an assortment of Victor tips for cutting various thicknesses of metal,

One Thermal Dynamics® Cutmaster® 60i Manual Plasma System,

One ESAB Rebel™ EMP 235ic Welding System,

Two Sentinel™ helmets, and

Six pairs of MIG gloves and six pairs of TIG gloves.

The student contest coincides with Victor's "Rulers of the Flame" social media campaign, which encourages anyone who wants to share their best work with Victor gas equipment to use #rulersoftheflame for recognition on Victor's social channels. Or, projects may be submitted at www.esabna.com/us/en/rulers/index.cfm for the chance to win a Victor Performer EDGE 2.0 Outfit. Eligible entries will be entered for monthly drawings.

"Victor's 'Rulers of the Flame' social media campaign is a great opportunity for non-students to participate in oxy-fuel projects and share their gas cutting skills on social channels, not to mention the chance to win a Performer EDGE 2.0 outfit," says Wehrman. "The student contest and the campaign coincide to inspire fabricators of all ages to take pride in their craft."

The student contest is open to students with a passion for welding and cutting who are residents of the United States or Canada (excluding Quebec). Offer/participation void where prohibited or restricted by law. No purchase necessary for entry. For more information, visit www.esab.com or call 1-800-ESAB-123.

Hypertherm Expands Spark Something Great Grant Program to 12 North American Schools

Hypertherm, a U.S. based manu-

Vanessa Revelli is managing editor of **techdirections**.

facturer of industrial cutting systems and software, is now accepting applications for its Spark Something Great educational grant program. This year, in response to demand and school need, Hypertherm is expanding the program to 12 schools in the United States and Canada. Winning schools will receive a Hypertherm Powermax45® XP plasma system, the full AWS SENSE-approved Plasma Cutting Technology: Theory and Practice curriculum kit, and in-person training from a Hypertherm plasma expert.

The program, now in its fifth year, is meant to support the next generation of welders and metal fabricators by making the newest generation of plasma cutting equipment and standardized instruction available to schools. To date, the company has awarded systems to 40 schools. More information, including instructions for applying, are available at www.hypertherm.com/grant.

"Interest in the grant program grows every year as more and more schools struggle with falling budgets and increasing enrollment. In keeping with our commitment to provide the latest cutting technology to today's students, we are pleased to expand the program for 2019," said Betsy Van Duyne, who manages Hypertherm's educational program. "The Powermax45 XP is a perfect system for schools since it gives teachers the flexibility to teach both handheld and mechanized cutting, as well as applications such as gouging, flush cutting, and marking with air plasma. In addition, it ensures students are aware of the capabilities of our Powermax plasma systems."

In addition to the grant program, Hypertherm will continue to make all ten hours of its AWS SENSE-approved Plasma Cutting Technology: Theory and Practice curriculum available for free download to teachers. The curriculum covers the plasma cutting process, common industrial uses for plasma systems, the differences between various cutting methods, safety procedures, as well as proper setup and operation. Electronic versions of each lesson, a facilitator's guide, student workbook, and supporting reference material are all available at www.hypertherm.com/plasmaeducation. To date, teachers from more than 2,000 schools have taken advantage of the free download, helping standardize the teaching of plasma cutting to tens of thousands of students.

Hypertherm designs and manufactures industrial cutting products for use in a variety of industries such as shipbuilding, manufacturing, and automotive repair. Its product line includes cutting systems, in addition to CNC motion and height controls, CAM nesting software, robotic software, and consumables. Hypertherm systems are trusted for performance and reliability that result in increased productivity and profitability for hundreds of thousands of businesses. The company's reputation for cutting innovation dates back 50 years to 1968, with Hypertherm's invention of water injection plasma cutting. The 100% associate-owned company has more than 1,400 associates along with operations and partner representation worldwide.

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The Aquanaut Transformer

The 2018 Paramount movie *Bumblebee* tells the story of a transforming robot that shape-shifts into a 1957 yellow Volkswagen Beetle. It was a movie I truly enjoyed as much as my grandchildren and it was the first thing that popped into my mind when I selected the Aquanaut Transformer as this month's topic. If you never saw the movie, it is already listed on Netflix.

The Aquanaut Transformer is real, and it shape-shifts between a submarine and an Aquanaut robot (Photos 1 and 2). Its submarine shape allows it to quickly move through the water to get where it needs to be. Once there, it shape-shifts into a very powerful humanoid robot which can perform all kinds of underwater construction tasks.

Prior to the development of the Aquanaut, two types of underwater robotic systems have already been at work under the sea. Autonomous Underwater Vehicles (AUVs) are used to photographically inspect the hulls of ships, visually map ocean floor features, and find ship wrecks that lie beneath the sea. They operate autonomously and when they surface the operators of these AUVs download the information they gathered for analysis.

So, an AUV might be used to find a problem and then a Remotely Operated Vehicle (ROV) might be sent down to physically do the repairs. ROVs are robotic systems that can perform physical tasks in deep water.

Photo 1—In its submarine form the Aquanaut Transformer has an aerodynamic shape which allows it to easily move through water.

These robots are tethered by a line to a ship or drilling platform which supplies them with the electricity they need to power their robotic arms and systems.

The tether to the ROV also allows the robot's operator to have total control over the robot's systems even though they are in a control room on the ocean surface. Because of the tether, the people in control of an ROV need to be almost directly above the robot that they are observing on a video feed. They controll its movements in the same way that you control the movements of your avatar in a video game.

The Aquanaut Transformer is very different from these other underwater robotic systems, beyond its ability to transform its shape between a submarine and the working Aquanaut. As a submarine it can travel 108 nautical miles from the point it is released in the ocean to the location where it is going to perform its assigned tasks. Its aerodynamic shape allows it to easily move through the water. In this configuration it is a mini submarine with all the vertical and horizontal thruster controls and hull features necessary to travel and maneuver underwater. See Photo 1 again.

The Aquanaut Transformer travels under its own power without a tether; its power is supplied by its own internal batteries. Most of the Houston Mechatronics engineers who designed and built this transformer are former NASA employees; they designed the control system so that it is under human control for parts of its mission and under AI autonomous control for other parts of the mission.

Its ability to travel to the worksite becomes critical when the body of water where a robot is needed to do physical work has no safe place to park an ROV support ship. Physically it is about as big as Bumblebee after it shape-shifted out of its Volkswagen Beetle form (Photo 3). This YouTube video https://www.youtube.com/watch?v=DZPjsB–qas can give you more insight into this Aquanaut

Photos courtesy Houston Mechatronics

Photo 2—When the Aquanaut Transformer shape-shifts, it becomes a very powerful humanoid robot that can perform all kinds of underwater construction tasks.

Alan Pierce, Ed.D., CSIT, is a technology education consultant. Visit www.technologytoday.us for past columns and teacher resources.

Photo 3—A scuba diver swimming next to the Aquanaut helps you visualize the physical size of the robot.

Transformer's capabilities. It is not surprising that NASA is now very involved with Aquanaut's continued development.

The Aquanaut Transformer does underwater what NASA eventually needs robotic systems to do in space. To physically send astronauts to Mars, NASA is going to need to build similar transforming systems that can travel great distances in outer space and then transform into robots that can build the infrastructure that people will need to survive in an alien environment when they arrive as explorers.

Taking It a Step Further

Working in teams and using plans from the Internet build classroom robots and have classroom competitions. td

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Laura Bassi—The First Female University-Level STEM Department Head

The acronym STEM stands for science, technology, engineering, and mathematics. The letters often describe specific educational delivery systems. A 1990s Washington, DC, summer program known as the STEM Institute was among the first to use the term and the National Science Foundation popularized its use shortly afterward. There are about 17,000 high schools in the United States and many of them have connections to a STEM program.

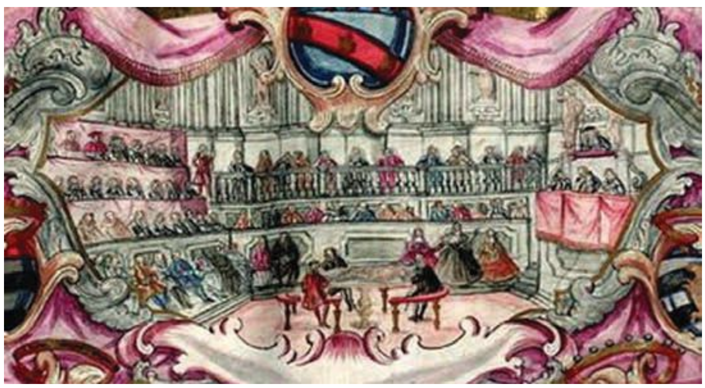
Portrait of Laura Bassi, circa 1732

Universities also support STEM programs and until 1732, all university STEM subjects were taught by men. That was the year the University of Bologna in Italy approved Laura Bassi to teach experimental physics. The university made her the department head in 1776—the first woman to ever hold such a position in a technical field.

Bassi was born in 1711 in Bologna, Italy, about 250 miles north of Rome. She was an only child and her father was a moderately successful lawyer. Bassi had a personal tutor who taught her classical subjects like literature and languages. Her father often invited friends and politicians to their home so Bassi could engage them in scholarly debates.

She was a child prodigy and developed an interest in the writings of Isaac Newton (1643-1727), the world's most influential scientist. Technical topics were beyond the capabilities of her tutors so Bassi studied independently during her teen years. She was particularly interested in light refraction, pneumatics, and the nature of electricity.

A family physician who attended to Bassi's chronically ill mother introduced her to Prospero Lambertini (1675-1758). He was a local leader with a connection to the university. Bassi's knowledge so impressed Lambertini that he arranged a 1732 public debate between Bassi and four university professors. Independent judges found that Bassi successfully defended 49 academic points of view. The largest number was on physics.



A depiction of Bassi (in black dress) at the 1732 public debate

She quickly gained fame throughout Europe as the "Bolognese Minerva" (Minerva was the Roman goddess of wisdom). Bassi earned a doctorate degree and the university approved her to teach physics that year. She also became the first female member of Italy's Academy of Sciences.

Bassi organized a well-equipped teaching laboratory in her home. Her reputation encouraged students to come from as far away as Greece, Spain, and Germany. She did a scientific demonstration in 1764 for the founder of Philadelphia's College of Physicians. Bassi developed a professional collaboration with Giovanni Veratti and they married in 1738. The two taught various science and technical subjects. They had five children who reached adulthood.

Bassi was interested in the new techniques of experimental observation and wrote about 50 scientific papers during her lifetime. All were in Latin, the language of instruction at that time. Most have been lost to history, but a few have survived.

Bassi regularly corresponded with technical professionals such as electricity pioneers Alessandro Volta (1745-1827) and Luigi Galvani (1737-1798). The Bassi-Veratti Collection of digitally archived publications is at Stanford University in California. There, she is described as "one of the most important and visible scientific women 18th-century Europe."

Bassi was a tireless experimenter and a prolific writer who became the highest-paid faculty member at the

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Dennis Karwatka is professor emeritus, Department of Applied Engineering and Technology, Morehead (KY) State University.

A commemorative medallion shows Bassi (at left) and the Roman goddes Minerva

University of Bologna. The university offered her an appointment in 1776 as Chair of Experimental Physics. She became the first woman in the world to head a university department in a scientific or technical field. She died unexpectedly just two years later. Her husband and youngest son continued her innovative teaching program. The son sold all the laboratory equipment in 1818 and no items remain.

The University of Bologna, established in 1088, is the world's oldest university. Many of its graduates are world-renowned individuals. The list includes Polish astronomer Nicolaus Copernicus (1473-1543), Italian radio inventor Guglielmo Marconi (1874-1937), and modern American artificial heart pioneer Robert Jarvik (1946 -).

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Collage of some surviving Bassi publications

Electronics, 3D Carving, and Molding and Casting at Fab Faculty Institutes

By Sallye Coyle
info@shopbottools.com

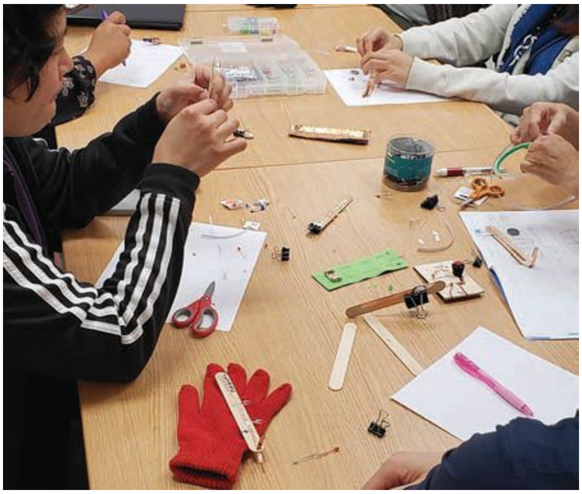
THE first three months of 2019 saw a flurry of professional development in Fab Labs from Mississippi and Louisiana to California. The goal for these professional development workshops or FFI's (Fab Faculty Institutes) is to do some cross-platform training that introduces faculty and lab managers to equipment and techniques that are often underutilized.

While the Fab Labs have an agenda for each day, the most important aspect is for faculty and managers to have time to "mess about" with some guidance from the FFI leaders. Fab Labs have a full quiver of digital fabrication tools and a well-stocked electronics station.

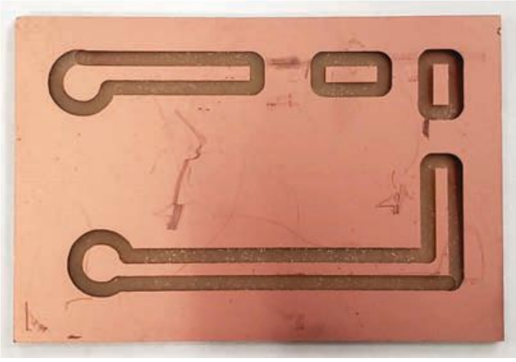
Simple Electronics, Sewing, and Embroidery

In Santa Clara, CA, middle school and high school teachers expressed an interest in learning about Arduinos so that they could help their students in robotics competitions. Arduino is an "open-source electronic prototyping platform enabling users to create interactive electronic objects." Instead of using actual physical components such as capacitors and resisters to control inputs and outputs, one can write code and load it onto the Arduino. Rather than leap to Arduino without understanding the basics of circuits and electricity, we started

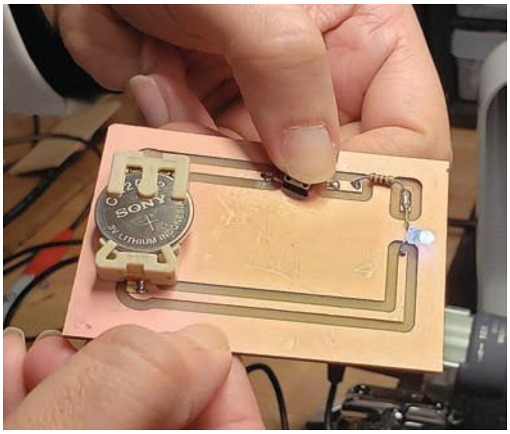
Sallye Coyle leads ShopBot's Community Outreach programs. She is a proponent of digital fabrication working across multiple platforms—particularly in the realm of education.



Teachers using popsicle sticks, copper tape, LED's, batteries, and clips to prototype circuits



PCB blank with a thin layer of copper on the board, machined on the ShopBot PRTalpha with a 1/16" bit

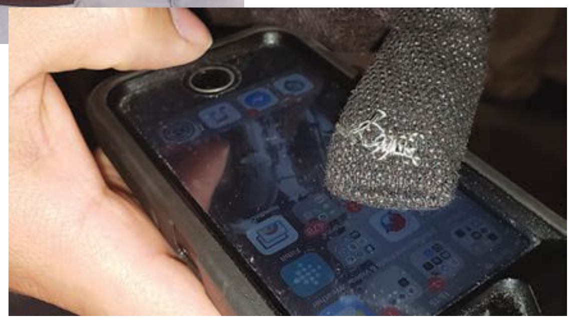


A functioning flashlight

with some simple circuits using conductive thread or copper tape, LEDs, batteries, and switches.

With help from FFI leaders, one teacher used VCarve Pro to create a drawing for a circuit, machined a copper blank using a 1/16" bit on the ShopBot CNC, and soldered the surface mount components to the PCB to make a flashlight. One project, several skills.

Hand sewing conductive thread onto the fingertips of gloves



With a simple pad of conductive thread, an ordinary glove now works with a smart phone screen

In Jackson County, MS, managers from three Fab Labs joined together: Jackson County (Vancleave, MS), NOLA (New Orleans, LA), and the newest, Jackson (Jackson, MS). They were interested in learning about the sewing/embroidery machines that often sit idle because a) sewing is a skill that is seldom taught in schools or at home, b) the digitizing software is unfamiliar to them and, c) they had never taken the time to actually use the machines.

Again, we started with the basics—hand sewing. In a room of adults, several had never even threaded a needle or tied a knot in thread. To make the project a bit more interesting, we used conductive thread to make ordinary gloves into “smart” gloves that could be used with smart phones.

Using utility stitches with a sewing machine

From there, we threaded the sewing machine and used utility stitches to make a little bag, and the embroidery stitches to personalize it. What does this have to do with ShopBot? The digitizing softwares for embroidery machines are CAD programs. Many of the terms and tools used in one software are the same as the CAD software used for the ShopBot CNC or a laser cutter. Who knows which machine will spark enough of an interest in a teacher or a student to get them over their fear of using a computer-controlled or digital fabrication tool? Success on one digital fabrication tool can open up worlds.

This math teacher from Santa Clara didn’t know she could have an interest in an embroidery machine. Check out that smile after digitizing *pi*, embroidering it onto fabric, and sewing up a pillow!

3D Carving, Molding, and Casting

3D printing was intended for rapid prototyping of designs and was not intended for production of multiple copies of the same thing, like rubber duckies or Yoda heads. But its rise in popularity has contributed to the development of many CAD software applications, and even 3D scanners that can create 3D models on the com-

Model 3D carved on the ShopBot (27 minutes), and mold made from a two-part material from Smooth-On

Below, carved model, mold, and paraffin and crayons cast in the mold

puter. Many of the same files that can be used with a 3D printer can be 3D carved on a ShopBot, and the resulting model can be used to create molds to aid in the production of many copies.

At Santa Clara, we imported an .stl file into VCarve Pro for machining on their ShopBot PRTalpha. After sizing onto a 2"× 6" from the local building supply store, we created a roughing pass to clear out the majority of the material. We then used a ¼" ball nose bit to finish the 3D carving. Time from start to finish for the roughing and finish passes was 27 minutes.

Once we had the model, we added a bit of hot glue around the edge to give the mold a little more depth, then filled the model with a two-part flexible mold making material from Smooth-On. After it cured, we pulled the mold from the model. For this experiment, we filled the mold with melted paraffin and crayons. Think soap, plaster, or, with food-grade mold material, chocolate!

The leaders of the FFI in Mississippi: Sallye Coyle and Chris Carter
The leaders of the FFI in Santa Clara: Sallye Coyle, Andrea Fields and Chris Carter (www.TIESteach.org)

Right, another object cast in a two-part mold made from a 3D-printed model. Notice the "nobbies" added to align the two sides of the mold, and sprues added to allow the material to be poured into the mold, and air to escape while the material is poured in.

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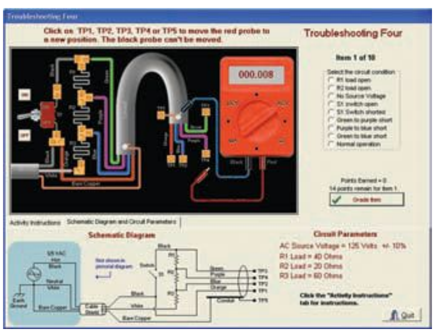

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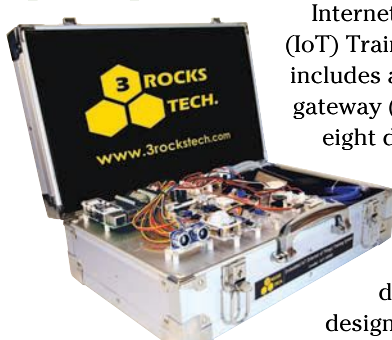

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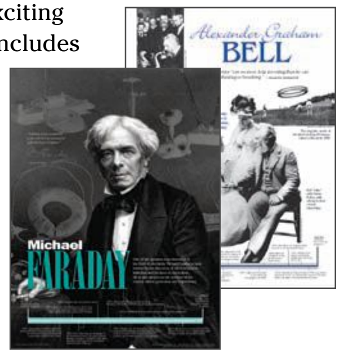

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New PV Cells Benefit Energy Harvesting

By Steven Keeping for Mouser Electronics

TODAY, some 85% of installed photovoltaic (PV) cells are manufactured from silicon, as it's both particularly suited to turning light into electricity and plentiful. Too, PV cells can be produced in volume by adopting wafer manufacturing techniques pioneered by the integrated circuit (IC) industry. However, silicon has some downsides, including a maximum efficiency of around 33%, energy-intensive high temperature processing, and fragility.

Alternative PV technologies using new materials, architectures, and assembly techniques have been developed to address silicon's drawbacks. New materials include the compound semiconductors gallium arsenide (GaAs) and gallium phosphide (GaP), as well as the mineral perovskite (CaTiO). The new energy-focusing Concentrated PV (CPV) architecture and assembly techniques use multi-junction, thin-film, and large crystals for high energy efficiency and durability.

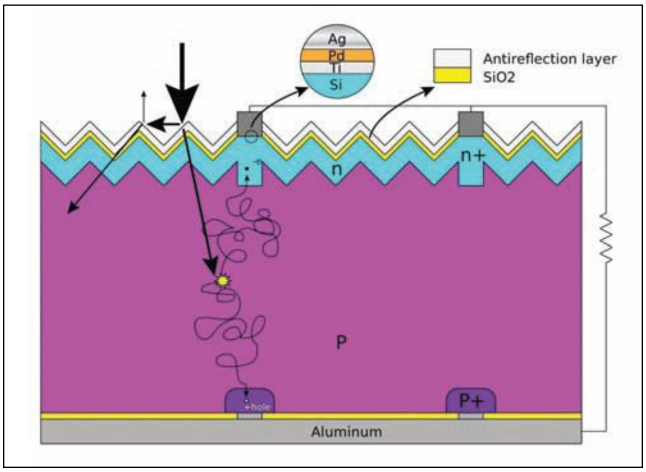
While silicon PV cells are likely to dominate large-scale electricity generation due to mass production and falling prices, alternative technologies will find use in niche applications. One such application is wireless IoT sensors where efficient, compact, durable, and inexpensive PV technology could harvest solar energy to charge device batteries. Such technology would be a boon for the Internet of Things (IoT) roll-out because it would enable wireless sensors to operate reliably with little or no maintenance.

This article explores how PV cells work, the role of silicon, and the advantages and disadvantages of silicon as the underlying semiconductor, as well as the potential of new semiconductors, architectures, and assembly techniques.

Photovoltaic Process

Although a deep understanding of the photovoltaic (also called photoelectric) process requires familiarity with quantum mechanics, the basic principles of PV cell operation are relatively straightforward: PV cells take advantage of semiconductor p-n junctions. In the n-type material, electrons act as current carriers, with electron vacancies or "holes" doing the same job on the p side of the junction.

When a photon within a narrow band of wavelengths enters the semiconductor crystal matrix, there is some probability that it will be absorbed by an electron bound to an atom in the n-type material, endowing the particle with sufficient energy to escape from its parent atom. The excess electrons on the n-type side of the junction then diffuse across the junction to recombine with holes on the p-type side, creating a potential difference across the joint. The incorporation of a conducting return path between the two sides of the joint allows a Direct Current (DC) to flow (Fig. 1).



Cyferz at English Wikipedia

Fig. 1—Single-junction PV cell operation: Photons of appropriate energy liberate electrons, which cross the semiconductor junction and generate a potential difference.

As a PV cell is made up of thousands of these p-n junctions, the generated current is multiplied. In the commercial products, these cells are combined to form modules and ultimately create panels. The DC voltage can be turned into AC by an inverter to do useful work or send

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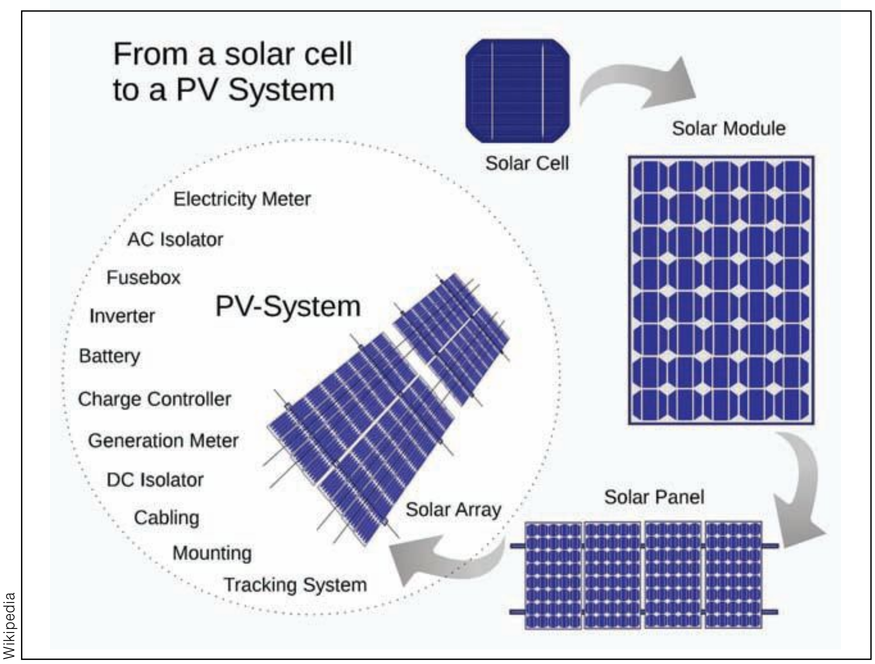

Fig. 2—PV cells are combined into modules then into panels to form end products.

power directly to the distribution grid (Fig. 2).

First Generation PV Cells: Single-Junction Silicon

First-generation PV panels are largely fabricated from a crystalline form of silicon ("c-Si"). The key drivers for silicon's large uptake is its PV performance and convenience of supply. The bulk material is plentiful (making up 28% of the Earth's crust), and the techniques and facilities for manufacture have been borrowed from the chip industry. However, processing the large-scale silicon wafers for PV panels is energy intensive, complex, and expensive.

Cost has been mitigated in part due to excess global manufacturing capacity; the price of silicon PV panels has declined by around 30% in the last year alone. Government subsidies designed to encourage the uptake of silicon PV panels to reduce reliance on fossil fuels for electricity generation have also played their part in encouraging adoption. Nonetheless, the technology remains too costly for many niche applications.

Silicon Advantages: Efficiency and Band Gap

Silicon offers several advantages for PV technology. First, its PV efficiency is good. (Efficiency, in this case, refers to the ratio of sunlight received by a PV cell to the energy it generates.) Averaged out over the surface of the planet, the sun delivers around 1,100 W/m^2 when directly overhead. A PV panel measuring 1 m^2 exposed to this level of sunlight and exhibiting 10% efficiency, for example, will output around 110 W.

The key characteristic that limits a semiconductor's maximum efficiency is its band gap. The band gap is the amount of energy required to liberate an electron from an atom into the "conduction band" and is measured in electron volts (eV); 1 eV is approximately equal to 1.602×10^{-19}J.

The energy of photons is determined by their wavelength, with photons of a shorter wavelength (higher frequency) being more energetic. Many sunlight photons entering a c-Si lattice will carry insufficient energy to liberate an electron and will therefore do little more than heat up the material. Photons with greater energy than that required to bridge the band gap might liberate a single electron, but their excess energy will again just contribute to heating up the crystal rather than doing anything useful.

In 1961, William Shockley and Hans-Joachim Queisser calculated the theoretical maximum PV efficiency for single-junction (cells made of just one semiconductor) PV cells across a range of band gaps (Fig. 3). The calculation revealed that the optimum band gap for a single-junction PV cell was 1.13 eV, which yielded a maximum efficiency of around 33%. It turns out that silicon's band gap of 1.10 eV is close to the optimum figure.

Silicon Drawbacks: Crystal Size, Energy, Efficiency, and Fragility

Silicon as a material is not perfect for PV cells, however. For example, band gap is not the only determinant of efficiency; crystal size also has a major effect. If a material is made up of small crystals, electron mobility is reduced by the large number of crystal interfaces. Reduced mobility restricts current flow and, in turn, efficiency.

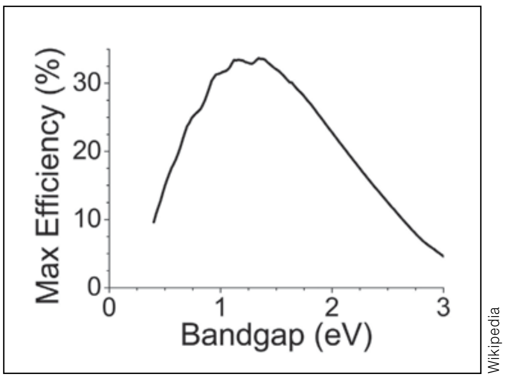

Fig. 3—Shockley and Queisser's calculation of maximum efficiency against band gap for single-junction PV cell semiconductors. Silicon has a band gap of 1.1 eV.

Additionally, these drawbacks further hinder silicon as an ideal semiconductor for PV cells:

• Maximum theoretical efficiency is just 33%. The best commercial c-Si PV panels achieve around 24% efficiency in practice, wasting over three-quarters of the sun's energy.

• Fragility, requiring mechanical

support from heavy glass panels, adding weight and cost.

• Energy-intensive, high-temperature, and complex processing.

• Inherently expensive, which could introduce challenges if supply becomes restricted and/or subsidies are withdrawn.

New Developments in PV Technology

In the last several years, second-generation PV products have been commercialized, and third-generation technology has entered the R&D labs. Second- and third-generation technologies look to build on the success of mature silicon technology, particularly the established support infrastructure—such as isolators, meters, controllers, and inverters that are largely independent of the PV technology type—while addressing some of silicon's drawbacks.

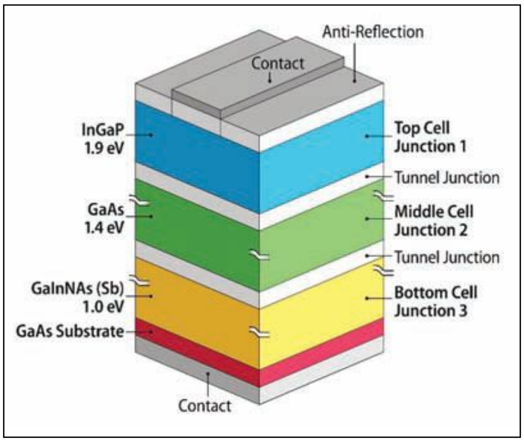

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Fig. 4—Multi-junction TFPV cell internal structure

Second-Generation PV Technology

Second-generation PV panels focus on nanometer to micrometer thick layers of PV material mounted on a glass, plastic, or metal substrate. These "thin-film" PV (TFPV) cells (also called "multi-junction" products because of the additional active layers) are cheaper and less energy intensive to manufacture, use less expensive material, are low in weight, and are suited to applications such as semi-transparent PV glazing material that can be laminated onto windows (Fig. 4).

The downside of TFPV panels is that the manufacturing, energy, cost, and weight advantages are traded-off against efficiency. Some of the potential efficiency gains of bulk material multi-junction PV panels is lost because the thin films comprise tiny crystals that affect electron mobility. Instead of c-Si, for example, which comprises comparatively huge crystals, commercial TFPV panels use either polycrystalline silicon (very small crystals) or amorphous silicon (no crystals). TFPV panels promise efficiencies of 20% although today's commercial products typically operate at 10% efficiency.

A second disadvantage of TFPV panels is relatively rapid degradation of the thin films reducing the panel lifetime. Second-generation PV cells are unlikely to challenge silicon's dominance for large-scale electricity generation but offer promise in applications where lower cost, weight, and durability can be traded-off against efficiency.

Third-Generation PV Technologies

PV technology is continually being developed to enhance first- and second-generation technologies. And research into new areas is uncovering technology that will form the foundation of a third generation of PV product. These developments and research generally fall into four sectors:

Materials: Complementing silicon with semiconductors of different band gaps so that photons of lower energy can liberate electrons and so that those of a higher energy convert more of that energy to electricity.

Structure: Introducing techniques that lower the energy intensity and complexity of first-generation PV panel production.

Processing: Improving semiconductor processing techniques to enhance the quality and size of crystals such that electron mobility is raised.

Mechanical: Amplifying the number of photons that fall on a unit area of substrate by focusing incident light with mirrors or lenses.

Material Developments

Converting more of the incident photon energy into electricity is possible by introducing materials with lower and higher band gaps than silicon. Silicon's band gap of 1.1 eV is the best of any single semiconductor for harvesting energy from visible light. However, much of the energy from the sun is carried by photons with energy below this band gap. For example, while a blue-light photon can carry three times as much energy as a red one, two-thirds of that energy is wasted even if the photon is absorbed by a silicon electron.

Semiconductors with band gaps lower than silicon enable photons that would otherwise be useless to contribute to the PV effect. Indium arsenide (InAs), for example, has a band gap of 0.36 eV and has been used successfully to complement silicon.

Semiconductors with higher band gaps than silicon allow more of the energy of shorter wavelength photons to contribute to electricity generation. Materials such as gallium arsenide (GaAs), which has a band gap of 1.43 eV, and gallium phosphide (GaP), which has a band gap of 2.25 eV, have also been used with success. Several lines of research have resulted in further compounding of these materials—for example, indium gallium arsenide (InGaAs) and indium gallium phosphide (InGaP)—to further optimize the PV effect.

Structural Developments

Alternative band gap semiconductors have a lower maximum efficiency than silicon alone, so there is no benefit in employing them singly. Instead, one or more semiconductors are used together in a multilayer structure. Materials with the largest band gap—requiring short wavelength (high energy) photons to dislodge electrons—are positioned at the top, allowing low energy photons to pass through without interaction to then be absorbed by lower band gap materials in the following layers. Transparent conductors are required at each layer to carry the generated current yet let photons pass through to the lower layers. This technology has been deployed with success in TFPV panels and remains the focus of a key area of research.

Silicon has a maximum efficiency of 33%, but this figure can theoretically be bettered by multilayer PV panels. A two-layer cell, for example, with one layer featuring a band gap of 1.64 and the other 0.94 eV, could reach a maximum efficiency of 44%. Similarly, a three-layer PV cell with band gaps of 1.83, 1.16, and 0.71 eV, would have a maximum theoretical efficiency of 48%. Commercial multilayer products comprise two, three, or four layers.

Processing Developments

Researchers are investigating new groups of materials for third-generation PV panels that combine the high efficiencies of the first generation with the simpler and cheaper manufacturing of the second.

One group of materials that has caused much excitement is derived from the mineral perovskite (CaTiO). The group of materials has band gaps ranging from 1.4 to 2.5 eV. The theoretical maximum efficiency of the perovskite group can't match silicon, but recent rapid efficiency gains from around 4-20% have raised hope that commercial products will eventually be more efficient than TFPV panels.

The key advantage of the perovskite group over silicon is the comparative ease and low processing temperatures with which millimeter-sized perfect crystals can be grown. This is a huge size for a perfect crystal lattice, and it dramatically increases electron mobility

	Cell effic. (%)	Module effic. (%)	Record commercial and (lab) efficiency, (%)	Area/kW (m2/KW)[a)]	Life-time (yr)
c-Si					
Mono-c-Si	16 - 22	13 - 19	22 (24.7)	7	25 (30)
Multi-c-Si	14 -18	11 - 15	20.3	8	25 (30)
TF					
a-Si	4 - 8		7.1 (10.4)	15	25
a-Si/μc-Si	7 - 9		10 (13.2)	12	25
CdTe	10 - 11		11.2 (16.5)	10	25
CI(G)S	7 - 12		12.1 (20.3)	10	25
Org.Dyes	2 - 4		4 (6-12)	10 (15)	na
CPV	na	20 - 25	>40	na	na

IRENA

Table 1—Efficiency of c-Si, TFPV, and CPV technologies

and hence efficiency while slashing manufacturing costs. Current lines of research are aimed at growing even larger perfect crystals; for example, researchers at MIT in the U.S. have recently discovered how to “heal” crystal defects in a perovskite-based PV cell by exposing the cell to intense light.

Elsewhere, researchers at University of California, Berkeley have discovered that different facets of the perovskite crystals have markedly different efficiencies. The scientists are now focusing their research on ways of processing the bulk material such that only the most efficient facets interface with the PV cell electrodes as a method of boosting overall efficiency.

As with TFPV materials, a key challenge currently limiting the commercial deployment of perovskite-based PV cells is the speed at which the material degrades.

Mechanical Development

Another development objective for third-generation PV panels is Concentrated PV (CPV) technology. CPV is designed to focus sunlight using lenses and mirrors such that a dramatically higher number of photons fall on a unit area of PV panel. The technique typically employs high-efficiency, multi-junction PV cells constructed, as shown in Fig. 4. Focusing the light increases efficiency, enabling dramatic reductions in panel size, lowering the cost and weight of the product, and increasing the number of locations where it can be installed.

“Low” CPV focuses the equivalent of 2 to 100× sunlight onto the panel, while “high” CPV can multiply the light to the equivalent of 1,000× sunlight. CPV systems often use solar trackers and sometimes a cooling system to increase efficiency. Table 1 summarizes the efficiency of current PV cell technology.

Case Study: Energy-Harvesting Wireless IoT Sensors

The key application for PV technology is for renewable-energy generating capacity to feed the electricity grid. But third-generation technologies—which promise less expensive, more durable, and smaller PV panels—promise to introduce energy-harvesting niche applications.

Wireless IoT Sensors

Designers of IoT wireless sensors have long been keen to take advantage of energy harvesting. It is envisaged that the IoT will comprise billions of sensors with many positioned remotely and therefore isolated from main power and difficult to access for maintenance such as battery changes.

Many of the products will employ low-power wireless technologies such as Bluetooth low energy and zigbee, which have been designed from the ground up to run from modest power resources. Many applications are powered from compact primary cells with capacities around 220 mAh. In low-duty cycle operation, the average current draw from a low-power wireless System-on-Chip (SoC) is in the microampere range, extending battery life to thousands of hours (several months) of operation.

However, extending battery life by replacing a primary battery with a secondary battery and recharging via a PV cell extends self-contained operation to several years.

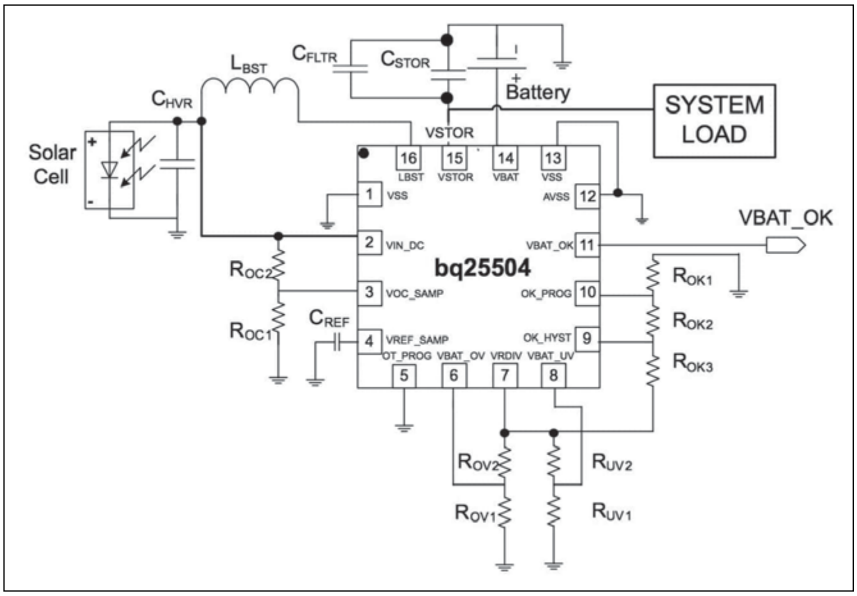
Energy-Harvesting Technology

Energy harvesting technology for small-capacity, Li-ion cell charging is a proven technology. For example, Mikroe’s energy-harvesting module is a silicon PV cell capable of producing up to 0.4 W at 4 V.

The voltage and current from a PV cell varies considerably. As such, the voltage/current output must be regulated for Li-ion battery charging, as Li-ion batteries require careful current/voltage management during the charging cycle. Purpose-designed, highly-integrated power management chips are available for the job.

For example, Maxim’s MAX17710 power management IC can manage poorly-regulated sources such as PV cells with output levels ranging from 1 µW to 100 mW. The device also includes a boost regulator circuit for charging the battery from a source as low as 0.75 V. An internal regulator protects the cell from overcharging. 3.3, 2.3, or 1.8 V outputs are supplied to the wireless IoT sensor via a Low-Dropout (LDO) linear regulator.

Texas Instruments also offers a power management IC, the bq25504. The device is specifically designed to efficiently acquire and manage power generated from PV cells. The chip integrates a DC-DC boost converter/



Texas Instruments

Fig. 5—Application circuit for energy-harvested battery charging using TI power management IC.

charger that requires only microwatts of power and a voltage as low 330 mV to commence energy harvesting (Fig. 5).

Third-Generation PV Technology Applied

While current PV cell energy-harvesting solutions work satisfactorily, they do have some downsides. For example, Mikroe's energy-harvesting module measures 7 × 6.5 × 0.3 cm (a surface area of 45.5 cm^2), and is relatively heavy and fragile. However, silicon PV cells like this product are currently the only practical choice because of their efficiency compared with alternatives.

Third-generation cells incorporate technology to boost efficiency beyond the current 10% enjoyed by commercial products. Technologies currently in the lab are projected to double efficiency in the next several years; that would introduce silicon PV cell-type performance to TFPV cells combined with advantages of lower cost, light weight, and greater robustness.

A third-generation TFPV cell measuring just 4 cm^2 in direct sunlight, for example, would receive around 0.22 W incident power. At 20% efficiency, the TFPV cell would output around 44 mW. While charging at an average of 3.5 V (voltage varies during a Li-ion battery charging cycle), the current supplied from the power management chip would be around 12 mA, sufficient to fully recharge a 300 mAh Li-ion battery in around 25 hours.

While such a charging regime would take several days of full sunshine, note that the Li-ion battery will only discharge at a rate of a perhaps a few mAh per day under typical low power wireless sensor operation, requiring the PV cell to only top-up the battery (rather that fully charge) ensuring it can easily cope with the energy demand even on days without full sunshine.

Compact third-generation PV cells are yet to be commercialized. And when mass production does commence, prices are likely to initially be too high for wireless IoT sensor applications. However, as the technology matures and demand increases, TFPV cells will become much cheaper and a practical proposition for this niche application.

Simultaneously, the efficiency of TFPV PV cells will continue to increase, bringing greater advantages to energy-harvesting wireless sensor designs including:

• Energy harvesting from artificial light for indoor sensors.

• Reduction in panel size for given power output for highly space-constrained designs.

• More power available to run complex software algorithms on advanced wireless SoCs.

• Increased wireless sensor range and throughput.

• Multiple sensors powered from a single PV panel.

Conclusion

An estimated 85% photovoltaic (PV) cells currently installed are manufactured from silicon, as it's both plentiful and suited to turning light into electricity. Second- and third-generation PV technologies are addressing silicon's downsides that include a maximum efficiency of only about 33%, energy-intensive high temperature processing, and fragility.

Second-generation PV panels focus "thin-film" PV cells that are mounted on a glass, plastic, or metal substrate. These are cheaper and less energy intensive to manufacture, use less expensive material, are low in weight, and are suited to applications such as semi-transparent, PV glazing material that can be laminated onto windows. These are unlikely to challenge silicon's dominance for large-scale electricity generation but offer promise in applications where lower cost, weight, and durability can be traded-off against efficiency.

Third-generation PV cells promise even more by matching the efficiency of silicon while building on the advantages of second-generation products. This will make the cells a good option for remote, low-maintenance IoT sensor applications using rechargeable Li-ion batteries continually replenished by the sun's energy. These PV technologies use new materials, structure, processing, and mechanical techniques to address silicon's drawbacks. New materials include the compound semiconductors gallium arsenide (GaAs) and gallium phosphide (GaP), as well as the mineral perovskite (CaTiO); the new energy-focusing Concentrated PV (CPV) architecture and assembly techniques use multi-junction, thin-film, and large crystals for high energy efficiency and durability.

Niche applications like energy-harvesting wireless IoT sensors, which require efficient, compact, durable, and inexpensive PV technology, stand to benefit from third-generation PV cells. Such technology would enable wireless sensors to operate reliably with little or no maintenance. As third-generation PV technologies evolve, we can expect to see additional wireless sensor designs, such as harvesting energy from indoor lighting and other applications that require compact, efficient, powerful, and robust designs.

• Silicon is the market-leading material for general-purpose PV panel applications because the raw material is plentiful, manufacturing infrastructure is established, and it offers high efficiency.

• Silicon PV cells have some notable downsides: They are heavy, fragile, energy intensive to produce, and expensive.

• This makes silicon impractical for energy harvesting applications for compact wireless IoT sensors.

• New materials and PV cell construction techniques address silicon's drawbacks, but lower efficiency limits usefulness for wireless IoT sensors.

• Third-generation cells' improved efficiency will make the technology suitable for wireless IoT sensors, and promises to increase computational power, wireless range, and throughput at an affordable cost.

Photos courtesy Visit Anaheim

Convention Preview

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The annual convention draws career and technical educators and administrators from across the United States and around the world.

General Sessions

On Thursday, Dec.5, Garrett Reisman gets things started as speaker at the Opening General Session. As a NASA veteran, Dr. Garrett Reisman empowers educators with the same innovation, determination, and vision required for living and working in space. During his experience as an astronaut, including a 95-day mission on the International Space Station, Dr. Reisman performed three spacewalks, operated the Space Station Robot Arm, and was a flight engineer aboard the Space Shuttle. While at NASA, Dr. Reisman was also an aquanaut serving as a crewmember on NEEMO V, living on the bottom of the sea in the Aquarius deep underwater habitat for two weeks. Dr. Reisman will share insights on the future of human spaceflight, high-demand career fields in space and on Earth, and a whole new golden age of exploration.

Saturday, Marcia L. Tate will speak at the general session. She is an acclaimed educational consultant, having taught more than 500,000 administrators, teachers, parents, and business and community leaders throughout the world. During her 30-year career with the DeKalb County School System in Decatur, Georgia, she has been a classroom teacher, reading specialist, language arts coordinator, and staff development executive director. She received the 2001 Distinguished Staff Developer Award for the State of Georgia and is the author of eight bestsellers.

Expanded Secondary and Postsecondary CTE Programming—VISION provides the postsecondary community with a venue for exploring multiple pathways to college and career readiness, networking with postsecondary CTE professionals and leveraging business and industry partnerships to enhance your CTE programs. Fifty sessions on the most current issues in postsecondary CTE will cover:

- Business, industry, and education partnerships and needs
- Designing successful CTE teacher education programs
- Effective teaching strategies for adult learners ▶

Anaheim Convention Center

• Re-skilling the middle-aged workforce

• Promoting and attracting CTE student diversity

• College and career readiness models

• Teacher recruitment and retention

Career Clusters—ACTE and Advance CTE are pleased to offer sessions focused on career clusters and programs of study, a comprehensive framework for organizing high-quality CTE programs, and cultivating collaboration between secondary and postsecondary CTE.

Pre-Convention Workshops

ACTE has scheduled several informative workshops for Wednesday, December 4. They include:

• **Create Powerful Student Learning Experiences by Creating Powerful Partnerships—**The challenges of the job market and the premium employers put on real-world knowledge and skills make meaningful work experience critical to the success of our young people. This workshop, geared for teachers, administrators, and academy coaches, will offer practical strategies, tools, and resources to support the opportunities to strengthen the connection between schools and business partnerships using the Ford NGL Powerful Partnership Process. Key topics to be addressed follow:

• What does quality partnership between schools and business look like

• Self-assessment tool to gauge your strengths and opportunities

• Protocols to use right away to build (or strengthen) the partnership

• Action plan to establish next steps.

• Access to additional tools via Ford NGL U

• **Data Driven Career and Technical Education: How Labor Market Information Can Guide Investment and Strategy—**Career and technical education (CTE) programs are facing increased pressure to use data to make decisions and guide strategy. Perkins V calls for states and districts to use data to shape programs, set performance targets and assess local needs. The volume and complexity of labor market data can be overwhelming for workforce development professionals. This interactive preconference workshop will provide an overview of labor market information, a hands-on demonstration of accessing, downloading, and analyzing labor market data, and answer questions such as:

• What kind of jobs in my region require less than a bachelor's degree?

• What are the hardest jobs to fill?

• What jobs are going to grow the most over the next decade?

• What is the labor shed for my region?

• Where do the workers in the region live?

• How have wages and employment changed in major industries?

This will be a bring-your-own-technology course where participants can use laptops and tablets to follow-along during the course.

• **High-Quality Work-Based Learning—**This workshop will focus on high-quality work-based learning, as defined in ACTE's Quality Program of Study Framework. We will explore how you transform a work-based learning program from a required to a desired experience for students, and ensure in-depth, firsthand student engagement with the tasks required in specific career fields. Join this interactive session to explore the criteria of quality work-based learning and leave with useful next steps to taking your program to the next level.

• **How to Finally Move the Needle on Women in CTE—** In this fast-paced workshop, you'll find out why most strategies to increase female enrollment in traditionally male CTE programs don't work and what colleges that have been successful do differently. Discover how Milwaukee Area Technical College went from zero to nine women in welding in only four weeks and City College of San Francisco enrolled 50% female students in a new Makerspace course in seven weeks. Learn the top secrets for recruiting and retaining female students in CTE and walk away with a mini-action plan. Designed for both secondary and postsecondary CTE professionals, this workshop is facilitated by Donna Milgram, Executive Director of the Institute for Women in Trades, Technology & Science.

• **STEM is CTE Symposium—** Back by popular demand, this event addresses crucial diversity, equity, and access issues to STEM fields via CTE programs, which encourage students and especially women to explore high-paying, high-demand STEM careers. CTE classrooms offer hands-on learning environments that bring science, technology, engineering, and mathematics (STEM) to life, apply core academics to real-world situations, and provide creative problem-solving skills to address our nation's most pressing issues. Together, STEM and CTE expand opportunities for youth to engage in some of the most exciting realms of discovery and technological innovation.

Tours

Tours organized for this year's CareerTech VISION include:

• **CyberPatriot Competitions: What Goes on Behind the Scenes?—** Come and join us for an exciting opportunity to see a cyber-competition in progress. Coastline Community College, a designated CyberPatriot Center of Excellence

(CCOE), is the second largest CCOE in the country and a designated Center of Academic Excellence in Cyber Defense by the National Security Agency. This three-hour pre-conference tour/workshop will allow you to observe a practice competition in action with live students while giving you a chance to sit down and experience first-hand the tasks students are asked to do in a competition setting. Coastline staff and faculty will also share best practices and practical information for setting up, running and participating in CyberPatriot and other cyber competitions.

• **Disney—**Spark creativity and unlock the potential within your students! Disney Youth Programs are valuable learning experiences that harness the power of Disney storytelling and the magic of Disney parks. Take a peek behind the curtain by experiencing an interactive showcase of some of the most popular Disney Youth Programs, including:

• Disney Culinary Arts
• Careers in Costuming
• Properties of Motion
• Creating a Leadership Legacy

Along the way explore the career pathways of Disney Cast Members who work in these fields and bring the magic to life every day.

• **Increasing Completers in High School CTE Courses by Creating Robust Middle School College and Career Readiness Courses: Orange Unified School District Labs—**Join us for three unique site visits in Orange Unified School District, Orange, CA, to learn about CTE programs in middle and high school programs.

1st stop: Yorba Middle School, touring a unique lab classroom setup:

• College and career ready labs feeding pathways across all 15 Industry sectors in CA (Career Clusters in other states).

2nd stop: Orange High School, touring:

• Public Service Academy classroom
• Health Science Careers lab classroom

3rd stop: El Modena High School, touring:

• Academy of Media Arts classroom
• Academy of Computer Science classroom
• Construction lab classroom
• Foundations of Technology & Engineering lab classroom

Both tours are sponsored by Paxton/Patterson

• **Knott's Berry Farm—**See first-hand a successful education-business collaboration through Knott's Berry Farm's model partnership with the North Orange County Regional Occupational Program (NOCROP). You will also take a behind the scenes tour of Knotts' food and beverage division and operations area, showcasing their work with the NOCROP culinary/hospitality program and other educational programs and opportunities.

• **Roadtrip Nation—**Take a tour of Roadtrip Nation's HQ with special stops at the production department where events, web design and more motivate students to pursue careers based on their passions. You will have the opportunity to:

• See the original motorhome (aptly named "The Legend") that started it all.
• Tour the RVs that take our "roadtrippers" around the country exploring careers.
• Talk with the education team about our approach to career exploration inside and outside of the classroom.
• Take a tour of Roadtrip Nation's resources, content and tools for educators and students.

• **Samueli Engineering Academy—**Take a unique tour of the Samueli Academy, a charter school that provides engineering and design pathways for all students delivered in an integrated, holistic environment. Samueli Academy's mission is to serve foster and underserved youth in a technology-rich environment, featuring project-based learning with a STEAM focus and a commitment to college and career success for all its students. In only six years Samueli Academy has maintained a 99% high school graduation rate, 96% college attendance rate and a college persistence rate at more than twice the national average for its student demographic.

• **Tustin T-Tech/ATEP—**Explore Tustin High School's 6-12 CTE programs, featuring the award-winning T-Tech Engineering Academy and the School of Integrated Design, Engineering, and Automation (IDEA) at Irvine Valley College's Advanced Technology and Education Park. Learn how Tustin's program successfully combines academic instruction with cutting edge project-based learning and is recognized as one of the best CTE programs in the state. Participants then visit Irvine Valley College's new School of IDEA, which serves as a catalyst for the college's CTE programs, offering innovative and effective technical education in a state-of-the-art environment.

Knott's Berry Farm Amusement Park

Opinion

Three Reasons That Career and Technical Education Doesn't Preclude College

Confronting some misconceptions about future learners

By Kimberly Green and Kate Kreamer

A NUMBER of recent articles have highlighted the value of career and technical education (CTE) at the individual and system levels. It is truly wonderful to see these programs finally celebrated for all that they can do for students and communities. However, it's hard not to notice that many of these stories choose to emphasize a disconnect between career and technical education and "college," positioning the former as a pathway for students not bound for college. As advocates of these programs, we believe it's important to address this misconception head on.

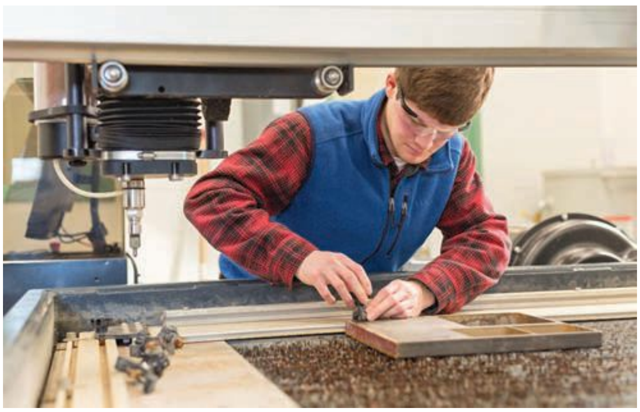
First things first: College, while often synonymous with a four-year institution, encompasses much more than that. Community college and technical college are both "college," as are most institutions that award postsecondary credentials or degrees.

Even the line between apprenticeships and college is being blurred, with apprentices increasingly earning postsecondary credits and community/technical colleges serving as education providers for industry partners. And let's not forget about the 3.7 million students in federally supported postsecondary career and technical education programs.

Second, college is still incredibly important, as are bachelor's degrees. According to Georgetown's Center on Education and the Workforce, a bachelor's degree is still the best bet for lifetime earnings, but it's also true that there is growing value in associate degrees, industry-recognized credentials, and long-term postsecondary certificates.

At the same time, our overreliance on bachelor's degrees as a proxy for workforce readiness has some serious consequences, with $1.4 trillion in national student debt, half of U.S. adults regretting the degrees they earned, the institutions they attended and/or their fields of study, and about 6 million jobs at risk for so-called degree inflation by employers.

Third, career and technical education students do go to college! About three-quarters of these students enroll directly in two- and four-year institutions, and research



Wes McEntee works on a manufacturing machine at Vermont Technical College.

Oliver Parini for The Hechinger Report

Kimberly Green is the executive director of Advance CTE, a national nonprofit representing state CTE leaders. Kate Kreamer is the deputy executive director of Advance CTE. This article was produced by The Hechinger Report *and originally published on* The Hechinger Report *website, www.hechingerreport.org. The Hechinger Report is a nonprofit, independent news website focused on inequality and innovation in education.*

shows that these students are now as likely to go onto postsecondary education after graduation as their peers.

So what's the way forward? It's time that we flipped the script and focused less on ensuring "all kids go to college" and more on "all kids should choose a post-high school path that aligns with their career goals."

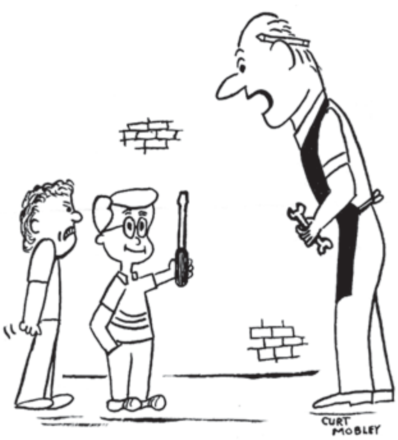
> **"At the end of the day, career and technical education is about preparing learners for the careers of their choice and supporting them on whatever paths they may take to get there. Our language shouldn't get in the way of that goal."**

For this to happen, we must invest as a country in more career exploration and experiences, particularly through more career advising and career and technical education pathways. Students need more exposure, more support, and more direction, starting as early as elementary school.

We also must ensure that all students take a college- and career-ready program of study, including rigorous academics and career and technical education. States and communities must find a balance among academic, technical, and professional knowledge and skills so that all students are prepared for a lifetime of success.

Finally, and perhaps most importantly, we—policymakers, parents, students, advocates, members of the media, and all other stakeholders—must broaden our language, our advocacy, and our understanding of what college is. From a messaging and recruitment perspective, it's inaccurate and harmful to frame career and technical education as a pathway for students not headed to college.

At the end of the day, career and technical education is about preparing learners for the careers of their choice and supporting them on whatever paths they may take to get there. Our language shouldn't get in the way of that goal. td



"No, I did not say to bring me Phillip's screwdriver."

More than Fun Answers

Cross Math

6	+	5	-	9	= 2
×		-		+	
(4	-	3)	÷	1	= 1
÷		+		-	
(8	-	7)	×	2	= 2
= 3		= 9		= 8	

What Next!

The word is PACKET

1 2 4 6 10 12 16
(one less than the prime numbers)

169 121 81 49 25 9 1
(odd squares, descending)

36 28 21 15 10 6 3
(subtract 8, then 7, then 6,...)

14 15 13 16 12 17 11
(add 1, subtract 2, add 3, subtract 4,...)

44 51 17 24 8 15 5
(add 7, divide by 3, add 7, divide by 3,...)

2 5 8 11 14 17 20
(repeatedly add 3)

You're How Old?

Bob is 21 years old now.
Let x = Bob's age now
Then x + 15 = 3 (x - 9)
x + 15 = 3x - 27
2x = 42, x = 21

Entertainment Inventors

1. D
2. H
3. F
4. I
5. B
6. C
7. E
8. A
9. G
10. J

monthly marketplace

more than fun

Cross Math

Place each digit from 1 through 9 in the empty squares of the grid so that the three rows across and the three rows down form correct arithmetic statements. All calculations (which involve only positive integers) should be performed using the correct order of operations. Parentheses have been provided where needed.

	+		-		= 2
×	■	-	■	+	■
(	-	)	÷		= 1
÷	■	+	■	-	■
(	-	)	×		= 2
= 3	■	= 9	■	= 8	■

Puzzle devised by David Pleacher, www.pleacher.com/mp/mpframe.html

What Next!

Determine the next logical number in each sequence. When you've finished, convert each of the six final numbers to a letter (1 = A, 2 = B, etc.) to form a six-letter word reading down.

What is this word?

1 2 4 6 10 12 ____

169 121 81 49 25 9 ____

36 28 21 15 10 6 ____

14 15 13 16 12 17 ____

44 51 17 24 8 15 ____

2 5 8 11 14 17 ____

Puzzle devised by David Pleacher, www.pleacher.com/mp/mpframe.html

You're How old?

Bob makes the following statement:

"In 15 years, I will be three times as old as I was 9 years ago."

How old is Bob now?

Puzzle devised by David Pleacher, www.pleacher.com/mp/mpframe.html

See answers on page 29.

We pay $25 for brainteasers and puzzles and $20 for cartoons used on this page. Preferable theme for all submissions is career-technical and STEM education. Send contributions to vanessa@techdirections.com or mail to "More Than Fun," PO Box 8623, Ann Arbor, MI 48107-8623.

Entertainment Inventors

Each of the inventors listed below made our lives more entertaining in one way or another. See if you can match the inventors with their inventions.

1. Guglielmo Marconi
2. Alexander Cartwright
3. George Eastman
4. George Pullman
5. George Ferris
6. Vladimir Zworykin
7. Alexander Graham Bell
8. Galileo Galilei
9. Thomas Edison
10. Walt Disney

A. Invented one of the first telescopes

B. An expert in the properties of steel, he designed an amusement park ride

C. Invented the electronic television system

D. Developed a practical wireless telegraphy system commonly known as the radio

E. Invented the telephone

F. Introduced the first mass-produced camera intended for use by the public

H. Invented the game of baseball

I. Designed the train sleeping car

J. Created the multiplane camera

G. Invented the phonograph

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Celebrate Black History Month!

Inspire your students with posters of African Americans who have had a major impact on the course of American history, from the research lab to the battlefield to the courtroom.

These posters will help educate your students as well as perk up dull classroom walls.

Each poster provides brief biographical information and a timeline of key life events—all designed around a stunning image of these notable black Americans.

18” × 24" glossy poster stock **$12.95 each!**

Black Technologists posters–set of 3
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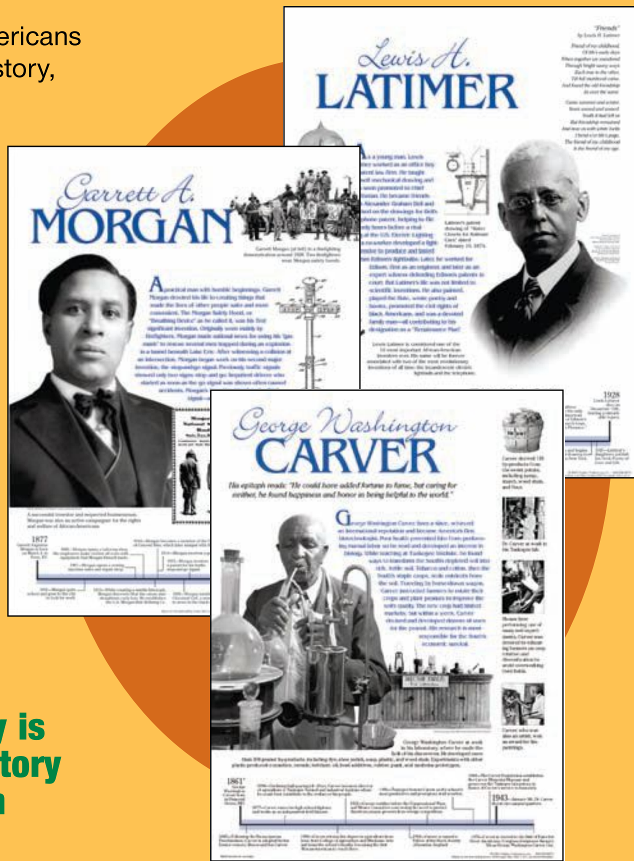
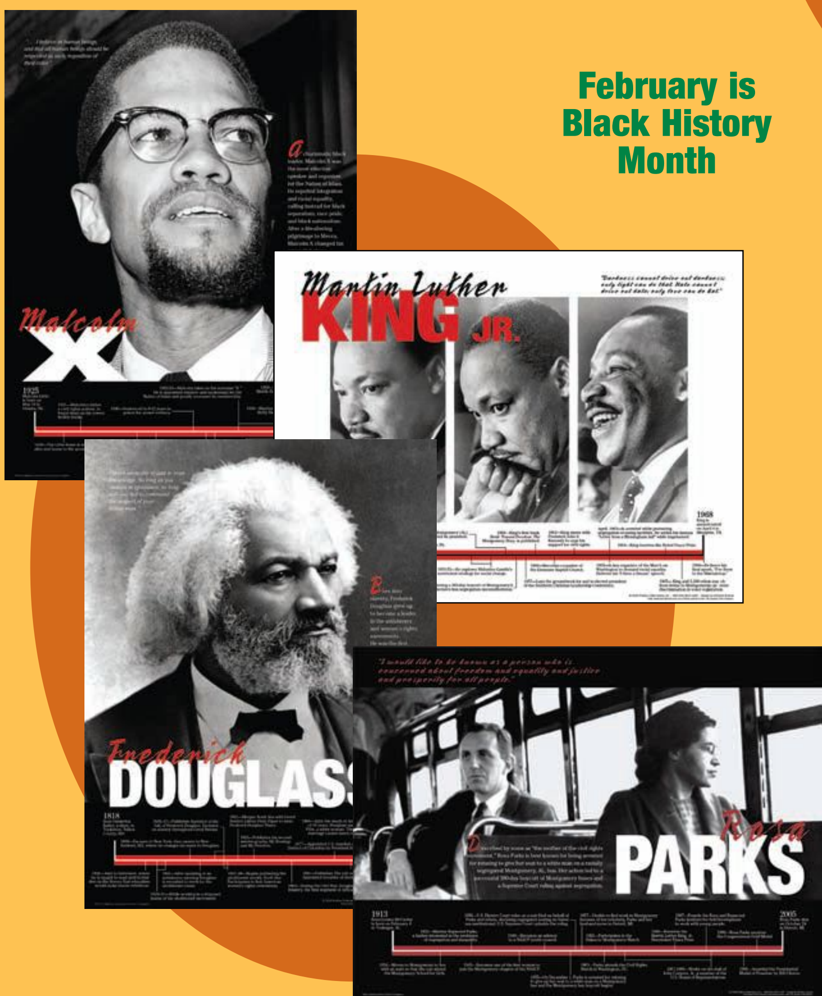
Black History Pioneers posters–set of 14
Only $119.95! Save $61.35!



February is Black History Month



Black Technologists from the Technology’s Past series:
George Washington Carver
Lewis Latimer
Garrett Morgan

Black History Pioneers series:
W.E.B. DuBois
Frederick Douglass
Martin Luther King, Jr. (Portraits)
Martin Luther King, Jr. (March)
Thurgood Marshall
Rosa Parks
Sojourner Truth
Harriet Tubman
Booker T. Washington
Malcolm X
The Buffalo Soldiers (Plains)
The Buffalo Soldiers (Uniform)
Montgomery Bus Boycott
The Tuskegee Airmen

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