Shooting for the Sun

Brave Thinkers

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The JTEC Invention

From his childhood in segregated Mobile, Alabama, to his run-ins with a nay-saying scientific establishment, the engineer Lonnie Johnson has never paid much heed to those who told him what he could and couldn't accomplish. Best known for creating the state-of-the-art Super Soaker squirt gun, Johnson believes he now holds the key to affordable solar power.

In March 2003, the independent inventor Lonnie Johnson faced a roomful of high-level military scientists at the Office of Naval Research in Arlington, Virginia. Johnson had traveled there from his home in Atlanta, seeking research funding for an advanced heat engine he calls the Johnson Thermoelectric Energy Converter, or JTEC (pronounced "jay-tek"). At the time, the JTEC was only a set of mathematical equations and the beginnings of a prototype, but Johnson had made the tantalizing claim that his device would be able to turn solar heat into electricity with twice the efficiency of a photovoltaic cell, and the Office of Naval Research wanted to hear more.

Projected onto the wall was a PowerPoint collage summing up some highlights of Johnson's career: risk assessment he'd done for the space shuttle Atlantis; work on the nuclear power source for NASA's Galileo spacecraft; engineering help on the tests that led to the first flight of the B-2 stealth bomber; the development of an energy-dense ceramic battery; and the invention of a remarkable, game-changing weapon that had made him millions of dollars - a weapon that at least one of the men in the room, the father of two small children, recognized immediately as the Super Soaker squirt gun.

Mild-mannered and bespectacled, Johnson opened his presentation by describing the idea behind the JTEC. The device, he explained, would split hydrogen atoms into protons and electrons, and in so doing would convert heat into electricity. Most radically, it would do so without the help of any moving parts. Johnson planned to tell his audience that the JTEC could produce electricity so efficiently that it might make solar power competitive with coal, and perhaps at last fulfill the promise of renewable solar energy. But before he reached that part of his presentation, Richard Carlin, then the head of the Office of Naval Research's mechanics and energy conversion division, rose from his chair and dismissed Johnson's brainchild outright. The whole premise for the device relied on a concept that had proven impractical, Carlin claimed, citing a 1981 report co-written by his mentor, the highly regarded electrochemist Robert Osteryoung. Go read the Osteryoung report, Carlin said, and you will see.

End of Meeting

Concerned about what he might have missed in the literature, Johnson returned home and read the inch-thick report, concluding that it addressed an approach quite different from his own. Carlin, it seems, had rejected the concept before fully comprehending it. (When I reached Carlin by phone recently, he said he did not remember the meeting, but he is familiar with the JTEC concept and now thinks that the "principles are fine.") Nor was Carlin alone at the time. Wherever Johnson pitched the JTEC, the reaction seemed to be the same: no engine could convert heat to electricity at such high efficiency rates without the use of moving parts.

Johnson believed otherwise. He felt that what had doomed his presentation to the Office of Naval Research - and others as well - was a collective failure of imagination. It didn't help that he was best known as a toy inventor, nor that he was working outside the usual channels of the scientific establishment. Johnson was stuck in a Catch-22: to prove his idea would work, he needed a more robust prototype, one able to withstand the extreme heat of concentrated sunlight. But he couldn't build such a prototype without research funding. What he needed was a new pitch. Instead of presenting the JTEC as an engine, he would frame it as a high-temperature hydrogen fuel cell, a device that produces electricity chemically rather than mechanically, by stripping hydrogen atoms of their electrons. The description was only partially apt: though both devices use similar components, fuel cells require a constant supply of hydrogen; the JTEC, by contrast, contains a fixed amount of hydrogen sealed in a chamber, and needs only heat to operate. Still, in the fuel-cell context, the device's lack of moving parts would no longer be a conceptual stumbling block.

Indeed, Johnson had begun trying out this new pitch two months before his naval presentation, in a written proposal he submitted to the Air Force Research Laboratory's peer-review panel. The reaction, when it came that May, couldn't have been more different. "Funded just like that," he told me, snapping his fingers, “because they understood fuel cells - the technology, the references, the literature. The others couldn’t get past this new engine concept.” The Air Force gave Johnson $100,000 for membrane research, and in August 2003 sent a program manager to Johnson’s Atlanta laboratory. “We make a presentation about the JTEC, and he says” - here Johnson, who is black, puts on a Bill-Cosby-doing-a-white-guy voice - “‘Wow, this is exciting!’” A year later, after Johnson had proved he could make a ceramic membrane capable of withstanding temperatures above 400 degrees Celsius, the Air Force gave him an additional $750,000 in funding.

The key to the JTEC is the second law of thermodynamics. Simply put, the law says that temperature differences tend to even out - for instance, when a hot mug of coffee disperses its heat into the cool air of a room. As the heat levels of the mug and the room come into balance, there is a transfer of energy.

Work can be extracted from that transfer. The most common way of doing this is with some form of heat engine. A steam engine, for example, converts heat into electricity by using steam to spin a turbine. Steam engines - powered predominantly by coal, but also by natural gas, nuclear materials, and other fuels - generate 90 percent of all U.S. electricity. But though they have been refined over the centuries, most are still clanking, hissing, exhaust-spewing machines that rely on moving parts, and so are relatively inefficient and prone to mechanical breakdown.

Johnson’s latest JTEC prototype, which looks like a desktop model for a next-generation moonshine still, features two fuel-cell-like stacks, or chambers, filled with hydrogen gas and connected by steel tubes with round pressure gauges. Where a steam engine uses the heat generated by burning coal to create steam pressure and move mechanical elements, the JTEC uses heat (from the sun, for instance) to expand hydrogen atoms in one stack. The expanding atoms, each made up of a proton and an electron, split apart, and the freed electrons travel through an external circuit as electric current, charging a battery or performing some other useful work. Meanwhile the positively charged protons, also known as ions, squeeze through a specially designed proton-exchange membrane (one of the JTEC elements borrowed from fuel cells) and combine with the electrons on the other side, reconstituting the hydrogen, which is compressed and pumped back into the hot stack. As long as heat is supplied, the cycle continues indefinitely.

“Lonnie’s using temperature differences to create pressure gradients,” says Paul Werbos, an energy expert and program director of the National Science Foundation. “Only instead of using those pressure gradients to move an axle or a wheel, he’s forcing ions through a membrane.” Werbos, who spent months vetting the JTEC and eventually awarded Johnson’s team a $75,000 research grant in 2006, describes the JTEC as “a fundamentally new way, a fundamentally well-grounded way, to convert heat to electricity.” Regarding its potential to revolutionize energy production on a global scale, he says, “It has a darn good chance of being the best thing on Earth.”

Johnson is a member of what seems to be a vanishing breed: the self-invented inventor. Born the third of six children in Mobile, Alabama, in 1949, he came into the world a black male in the Deep South during the days of lawful segregation. His father, David, who died in 1984, was a World War II veteran and a civilian driver for nearby Air Force bases. According to his mother, Arline, who is 86 and still lives in Mobile (in a house remodeled with Super Soaker profits), the family was poor but happy. All eight lived in a three-bedroom, one-bathroom house near Mobile Bay, in a neighborhood then being bisected by the construction of Interstate 10.

As a boy, Johnson was quiet and curious, and early on, he developed a fascination with how things worked. “Lonnie tore up his sister’s baby doll to see what made the eyes close,” his mother recalls. As he grew older, he began making things, including rockets powered by fuel cooked up in his mother’s saucepans. At 13, he bolted a discarded lawn-mower engine onto a homemade go-cart and took it atop the I-10 construction site - only to have a bemused policeman escort him back down. It was around then that Johnson learned that “engineers were the people who did the kind of things that I wanted to do.”

It was hardly an obvious career path: then, as now, the profession was dominated by whites. (As recently as 2004, only 1.6 percent of the engineering doctorates awarded in the United States went to blacks.) In high school, a standardized test from the Junior Engineering Technical Society informed Johnson that he had little aptitude for engineering; but he persevered and, as a senior, became the first student from his all-black high school ever to enter the society’s regional engineering fair. The fair was held at the University of Alabama at Tuscaloosa, just five years after then-Governor George Wallace had tried, in 1963, to physically block two black students from enrolling there. Johnson’s entry in the competition was a creation he called Linex: a compressed-air-powered robot assembled from electromagnetic switches he’d salvaged from an old jukebox, and solenoid valves he’d fashioned out of copper tubing and rubber stoppers. The finished product wowed the judges, who awarded him first prize: $250 and a plaque. Unsurprisingly, university officials didn’t trumpet the news that a black boy had won top honors. “The only thing anybody from the university said to us during the entire competition,” Johnson remembers, “was ‘Goodbye, and y’all drive safe, now.’”

Johnson went on to win math and Air Force ROTC scholarships to Tuskegee University, where he received a bachelor’s degree in mechanical engineering and a master’s in nuclear engineering. He joined the Air Force in 1975 and subsequently held jobs at the Air Force Weapons Laboratory, NASA’s Jet Propulsion Laboratory, and the Strategic Air Command - solid, respectable positions that made him a part of the scientific establishment. But at each stop, he felt that his creativity was stifled, and in 1987, at the age of 38, he could take it no longer. He would go into business for himself, he decided, focusing on his own projects, which included a thermodynamic heat pump, a centrifugal-force engine, and a pressure-action water gun. “All I needed was one to hit,” he says, “and I’d be fine.”

The idea for the water gun had come to him one weekend afternoon in 1982, while he was tinkering with an idea for an environmentally friendly heat pump that would use water instead of Freon. He’d built a prototype pump, attached some rubber tubing, and brought it into a bathroom. Aiming the nozzle at the tub, he turned it on, and produced a blast of water so powerful that the mere wind from the spray ruffled the curtains. This, he thought, would make a great water gun. It took Johnson seven uncertain and stressful years, but he acquired the patents and eventually found a company interested in manufacturing his Super Soaker: the Larami Corporation, which licensed the rights to the gun in a deal that would ultimately make Johnson rich.

Hoping to offer society something more significant than enhanced squirt-gun firepower, Johnson began plowing his Super Soaker profits into energy-related R&D. While continuing to work on mechanical devices such as his heat pump, he also studied battery technology. When what he taught himself about electrochemistry collided with his longtime obsession with the second law of thermodynamics, Johnson had his eureka moment: why not use temperature differences rather than a chemical reaction to force the flow of ions through a cell? The JTEC concept was born.

Today, Johnson and his family live in Atlanta’s upscale Ansley Park neighborhood. The business he launched more than two decades ago, Johnson Research and Development Company, now employs two dozen people, including designers, marketers, and research scientists. Once again, however, Johnson faces financial worries. “There was a time in my life,” he says, “when I was independently wealthy.” But that time has passed: Super Soaker profits have eroded thanks to a host of knockoffs, and now bring in only about a third of his company’s operating budget. For the rest, he relies on grants and commissions - and in the aftermath of the dot-com bust and the recent economic crisis, they’ve been drying up. He’s begun borrowing money to keep his research going - and he’s betting much of it, millions of dollars in all, on the JTEC.

In the winter of 2008, Johnson received a promising call from Karl Littau, a materials scientist with the Palo Alto Research Center (known as PARC), a subsidiary of Xerox. PARC, which gave the world the laser printer, Ethernet, and many other groundbreaking technologies, had expanded into alternative-energy research, and this had led Littau to the JTEC. Like Paul Werbos, Littau initially feared that the device sounded too good to be true, but he and several other PARC scientists set up elaborate three-dimensional computer models to analyze fluidics and heat-flow behavior in the JTEC under various conditions, and they came away from those experiments, he says, "really impressed." Littau, like Werbos, is now a convert. The JTEC, he says, is "a very clever way to extract energy from a heat engine … It's incredibly elegant."

When I spoke to Littau, he ticked off the potential advantages of the JTEC over typical heat engines: no moving parts, which means the engine is more reliable and virtually silent; the safety of hydrogen, which is essentially benign (unlike, say, Freon); and the lack of waste produced (the JTEC gives off no carbon or - unlike a fuel cell - even water, which, although environmentally harmless, can corrode equipment). All of these advantages mean longer-lasting performance and potentially higher energy-conversion efficiencies.

Commercial photovoltaic solar cells convert approximately 20 percent of received solar energy into electricity. The best solar-energy systems today - thermal-power plants that concentrate the sun's heat to drive turbines - operate at a rate of about 30 percent efficiency. The JTEC, Johnson claims, could double that figure, cutting the cost of producing solar power in half from its current average of 25 cents per kilowatt-hour, and making it competitive with coal.

"There's a lot of debate in Washington about carbon emissions and energy," Paul Werbos says - "about coal, nuclear power, and oil, what I call the three horsemen of the apocalypse. If we can cut the cost of solar energy in half, it becomes possible to escape from the three horsemen. The importance of this is just unbelievable."

But having wowed PARC, Johnson is now wrestling once again with the difficulties of working within the confines of the scientific establishment. PARC wants to publish a paper about the JTEC in a peer-reviewed scientific journal, both to provide legitimacy and to encourage members of the scientific community to advance the technologies involved. But Johnson is unconvinced. "Peer review is fine," he says, "as long as you're making incremental improvements to a technology." But Johnson dreams of advancing by leaps and bounds.

Adding to Johnson's worries is tension with PARC over intellectual-property rights. Only recently did Johnson, with much reluctance, give PARC permission to file for patent protection for the problems solved in its lab. After more than two decades as his own boss, Johnson isn't sure how much ownership interest - and potential profit—he is willing to give up. "All of a sudden, I have other people inventing stuff that I don't have control over anymore," Johnson says. "They could put patents in place for things I would need to implement in my engine. I'd have to pay them for my own idea!"

Last year, I visited the four-acre commercial property that Johnson owns on the south side of downtown Atlanta. Wearing pleated khakis and a long-sleeved polo shirt with a turtleneck underneath, Johnson took me on a tour of a meticulously refurbished three-story brick loft space featuring soaring ceilings and antique wood floors. Johnson intends to transform the building into a high-tech manufacturing center that will train and employ workers from the area; however, because of research delays and the recent economic downturn, those plans are on hold.

Until he can scale up, Johnson is instead leasing his beautiful loft space to a city agency, while he and his employees - including a handful of scientists with doctorates in chemistry, materials science, and engineering - hunker down in a low-slung, windowless warehouse across the parking lot. It’s a no-frills space, with galvanized electrical conduit descending from the ceiling through gaps where acoustic tiles are missing. On one wall of his office is a promotional poster created by the retail chain Target that features Johnson’s face amid a pantheon of 19th- and 20th-century African American inventors. Along another wall is a row of plaques commemorating a dozen of Johnson’s 100-odd patents, including those for his water-pressure heat pump, his ceramic battery, hair rollers that dry and set without heat, a diaper that plays a musical nursery-rhyme alarm when the baby is wet, and the electrochemical conversion system at the heart of the JTEC. And hanging crooked above his desk is a cheap black frame that contains an inspirational quote that has been attributed to Calvin Coolidge. Under the heading Press On, it reads:

Nothing in the world can take the place of persistence. Talent will not; nothing is more common than unsuccessful men with talent. Genius will not; unrewarded genius is almost a proverb. Education alone will not; the world is full of educated derelicts. Persistence and determination alone are omnipotent.

After we toured the office cubicles, Johnson swiped a card to unlock a door, and we entered a cavernous laboratory abuzz with fluorescent fixtures and thrumming with high-tech equipment. We stepped across a sticky mat, meant to grab dust from our shoes, and followed a yellow-paint path across the warehouse floor, past shelves of chemicals, airtight glove boxes, and banks of machines bristling with wires, charging and discharging batteries. Technicians in long blue lab coats and protective goggles milled about. Some of the equipment stations were housed beneath plastic clean-room tents topped with large fans and aluminum ductwork that snaked off toward the ceiling. The lab looked like a disheveled, family-garage version of a computer-microchip factory, and the resemblance wasn’t coincidental: to develop his proton-exchange membrane and ceramic batteries, Johnson has borrowed processes developed by the semiconductor industry for depositing materials, often atom by atom, onto various substrates. Beaming as he showed me his latest acquisition - a pricey-looking X-ray photoelectron spectrometer that lets him analyze a material’s atomic makeup - Johnson was clearly in his element.