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The Fusion Illusion

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Sun in a Bottle:
The Strange History of Fusion and the Science of Wishful Thinking
By Charles Seife
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To hear President Barack Obama tell it, we need to fundamentally overhaul the way we produce, deliver, and consume energy. After the House of Representatives passed the Waxman-Markey cap-and-trade bill in June, the president said it would "spark a clean energy transformation in our economy. It will spur the development of low carbon sources of energy—everything from wind, solar, and geothermal power to safer nuclear energy and cleaner coal. It will spur new energy savings, like the efficient windows and other materials that reduce heating costs in the winter and cooling costs in the summer. And most importantly, it will make possible the creation of millions of new jobs." He repeated those sentiments before the G-8 in Italy several weeks later when he stated, "One of my highest priorities as president is to drive a clean energy transformation of our economy."

That's pretty ambitious, if not audacious. Transforming our energy economy would require replacing the massive infrastructure and production and supply mechanisms that power our lives. Moreover, the renewable energy technologies that the president prefers—like wind, solar, and biomass—now make up only three percent of our electricity use, and an even smaller share of our overall energy consumption. This negligible portion of America's energy economy comes despite the fact that many tens of billions of dollars in state and federal subsidies have been pumped into renewables for roughly three decades.

It is these sources that the president proposes should overtake and replace the fossil fuels that dominate our current energy economy. He is engaged in a staggering exercise in wishful thinking. The limitations of these technologies and fuels are well known by now: they are prohibitively expensive, they are intermittent power providers, and they have a low energy density compared to fossil fuels. Renewables will one day play a somewhat larger part in our energy economy—a majority of states have passed laws in recent years mandating that utilities supply power from them, costly as they are—but because of their severe limitations, the contribution from renewable sources will be marginal.

Curiously, the Obama administration has been lukewarm in its supposed support for nuclear energy, which is the one proven technology capable of generating large supplies of reliable power while emitting no greenhouse gases. For instance, the president appears to be pulling the plug on the proposed Yucca Mountain nuclear waste repository, without providing an alternative method for dealing with spent nuclear fuel. For all President Obama's talk about a post-carbon society, there appears to be little place in his thinking for nuclear power.

Is it really possible that we can transform our energy economy, phasing out the system that has grown more or less organically over the course of a century and replacing it with one powered by the clean, green sources the president endorses? We would be wise to consider a similar exercise in wishful thinking about energy that has frustrated scientists and dreamers for more than half a century. The pursuit of fusion energy—essentially, harnessing the force that powers the sun—provides a cautionary tale for those who would remake today's energy economy. It should be heeded by those who so casually put their faith in government's ability to foster scientific breakthroughs that will render the current global energy infrastructure obsolete.

Fusion has been the Holy Grail of energy since long before anyone ever worried about global warming or strategic dependency on OPEC. Since the dawn of the atomic age, armies of scientists and researchers and government officials have invested billions of dollars and countless hours of toil and labor to replicate, in a controlled environment, what the sun is constantly doing: converting matter into energy through a fusion reaction. To figure this out would be to solve humanity's energy needs once and for all. The development of successful fusion power plants would put an end to all the economic, environmental, and foreign policy troubles that plague the current global energy regime. Unlike windmills and solar panels, the potential of fusion energy is virtually limitless.

This vision has spurred a movement of would-be discoverers lighting out for the fame and glory that would accompany the breakthrough of controlled fusion. A recent book chronicles this wild, oft-contentious scientific pursuit. Charles Seife, a former *Science* magazine writer and the author of the heralded 2000 bestseller, *Zero: The Biography of a Dangerous Idea*, has written a lively account of the history of fusion research—"a tragic and comic pursuit that has left scores of scientists battered and disgraced."

Sun in a Bottle is an engrossing, accessible work that tells a fascinating story about the quest for fusion.

It is a story that covers the heights of man's knowledge of physics as well as the depths of his vainglory—a tale of great scientific achievement as well as the maneuverings of charlatans, frauds, cranks, and modern-day alchemists. And it is a story of false hopes; the promise of fusion has forever been just a decade or two away. Yet today the faith in fusion is, in some quarters, as strong as ever.

Fusion is, essentially, the opposite of nuclear fission, which is the process used by our commercial nuclear power plants to generate electricity. With fission, atoms are split and energy is released. With fusion, atoms are made to stick together, and the process converts a tiny portion of the mass of these atoms to produce gargantuan amounts of energy. That's what happens on the sun, where hydrogen nuclei in the very hot plasmas that make up its center constantly slam into each other to produce helium as well as energy. This is the nuclear furnace at the heart of any star. It's what makes the sun shine, and also threatens to blow it up, but the sun does not explode because the intense force of its own gravity holds it together.

While science and industry have been successful at producing power from fission, fusion appeals to us because it is quite a bit more powerful than fission. More than that, fission requires rare plutonium or uranium for its fuel, while fusion requires common atoms like hydrogen. Fusion's supplies would be as inexhaustible as the oceans.

Enrico Fermi conducted the first self-sustained nuclear fission reaction in December 1942 under a squash court at the University of Chicago. Both the bombs at Hiroshima and Nagasaki were fission devices, and a fission bomb turned out to be relatively simple to build; the key is just having enough fuel. A fusion reaction would be far trickier, both to start and to keep going for more than an instant. But if a fusion reaction could be sustained for just a few fractions of a second, it was soon realized, the energy it could produce would be immense.

In just seven years, researchers had figured out how to build fusion bombs dwarfing those that ended the war with Japan. The Ivy Mike blast on the South Pacific island of Elugelab in November 1952 was ten megatons, or roughly the equivalent of exploding seven hundred Hiroshima bombs. In 1961, the Soviets detonated a weapon (the "Tsar Bomba") that was five times more powerful than Ivy Mike. "With Ivy Mike and its successors," writes Seife, "the fusion bomb scientists had succeeded at creating a tiny star on Earth."

Uncontrolled nuclear fusion had been achieved. The challenge was to figure out how to produce a controlled and sustained fusion reaction. The energy potential from fusion for civilian purposes promised to dwarf civilian fission power just as the

H-bomb had dwarfed Fat Man and Little Boy.

This material is well-plowed ground, though Seife does an excellent job distilling complicated questions of physics into something the lay reader can easily understand. The real value of *Sun in a Bottle* begins at this point, when Seife takes readers on a journey over the numerous attempts to create that sustained, controlled fusion reaction. It is a story that goes to the heart of how science is done, and it drips with drama, double-dealing, and politics.

In early 1951, Argentine President Juan Perón made a startling announcement: he claimed to have solved the world's energy problems. A group of scientists under his sponsorship, headed by the Austrian Ronald Richter, had supposedly created controlled nuclear fusion in their lab on the island Huemul. Perón's announcement touched off an international frenzy, but the physics community was rightly skeptical. It was clear that Perón had no idea what he was talking about when he said the Huemul discovery might lead to energy being sold in liter-sized bottles similar to milk bottles used by Argentines. Attempts to validate the experiment independently were met with stonewalling, and what details did emerge convinced the international scientific community that the claim was fraudulent. (One Manhattan Project physicist said the material they were using was "baloney"; the *New York Times* dubbed it the "Baloney Bomb.") It soon became apparent even to Perón that Richter had not produced a controlled fusion reaction. He was a crank who had conned Perón into believing they had saved the world—a huge international black eye for Perón and Argentina.

Meanwhile, real physicists were pursuing fusion with great zeal. Lyman Spitzer worked on a figure-eight shaped reactor at Princeton he called the Stellarator that would exploit the properties of plasma (a hot phase of matter that makes up the sun's core) rather than trying to exactly replicate the hydrogen fusion of atomic weapons. The trick was to confine the plasma yet still get it hot enough. Scientists at the Lawrence Livermore National Laboratory began work on a "magnetic mirror" fusion reactor that used a straight tube for its magnetic bottle to contain plasma. British scientists, meanwhile, toyed with a similar device that would "pinch" the plasma—a so-called "pinch machine." A visiting Los Alamos physicist took this idea back to the United States and built a device cheekily dubbed the "Perhapsatron."

Despite the Argentine farce, legitimate scientists believed that the fusion breakthrough was just around the corner. In 1955, the president of the United Nations Conference on the Peaceful Uses of Atomic Energy said, "I venture to predict that a method will be found for liberating fusion energy in a controlled manner within the next two decades. When that happens, the energy problems of the world will truly have been solved for ever, for the fuel will be as plentiful as the heavy hydrogen in the oceans."

It looked to have happened not in two decades, but two years. In 1957, British scientists appeared to have won the race with a machine called the Zero Energy Thermonuclear Assembly, or ZETA. Several weeks later Japanese researchers made the same claim. The media was wild with claims about "unlimited energy from seawater" and an end to worries about energy supplies. The Brits announced plans to build on the success of ZETA by constructing a reactor that would heat plasmas to a hundred million degrees and, most importantly, would produce more power than it consumed. That, after all, was the ultimate goal for civilian nuclear fusion.

But these researchers had miscalculated. They had not achieved fusion. Within a year of their announcement, they were forced to retract their claim, suffering a humiliation similar to that of Richter and Perón.

After several false starts, public cynicism began to grow, including among the government officials who held the purse strings that had supported so much fusion research. In 1958, not long after the British fiasco, American scientists finally were able to produce a tiny controlled thermonuclear fusion reaction with a pinch machine called the Scylla. But nobody noticed. It was not announced to great fanfare, or even officially announced at all until 1960, when it was buried in a government report to Congress.

Still, the research continued. Soviet scientist Andrei Sakharov made breakthroughs with a donut-shaped machine called a tokamak, which combined features of the Stellarator and pinch machines to contain plasma. Collaborating with British and American researchers, Sakharov began to apply light from lasers, which could concentrate an incredible amount of energy into a tiny space. The tokamak represented a great advance over the earlier Stellarator, and reinvigorated the fusion community. By the early 1970s, government scientists from a number of countries were routinely achieving small-scale fusion with lasers.

These efforts, however, all consumed vastly greater amounts of energy than they were yet capable of producing. Fusion would be a pointlessly expensive proposition if it ran an energy deficit. But in 1974, a private company called KMS Industries, headed by a man named Keeve M. Siegel, claimed to have demonstrated "laser fusion." He promised to deliver efficient fusion power "within the next few years."

He didn't, of course; in fact, he died of a stroke in 1975. Still, news of his announcement helped persuade Congress to ramp up federal spending on fusion. In the late 1970s, Livermore scientists were talking about having a workable fusion power plant in operation by the early 1990s. In the decade and a half after Siegel's celebrated announcement, government scientists would spend hundreds of millions of dollars on laser fusion research, none of which really seemed capable of solving the most pressing dilemma of fusion: how to ignite and sustain a fusion reaction that would produce more energy than it consumed.

Then came a stunning announcement from the University of Utah in 1989. Two chemists, Martin Fleischmann and Stanley Pons, announced that they had figured out how to generate a fusion reaction at room temperature: "cold fusion." They were claiming to have made an end run around everything the scientific community knew about fusion. Their announcement sparked a huge media storm, fueled in part by boosterism from the president of the university, who said their discovery "ranks right up there with fire, with the cultivation of plants, and with electricity."

Curiously, Fleischmann had made his mark in the 1970s with a scientific discovery regarding the detection of trace amounts of a chemical on silver that the conventional wisdom held was impossible. He had defied the scientific consensus before, and had been proved correct.

But like the Brits in 1957, and Richter before them, Fleischmann and Pons hadn't achieved what they said they had. Within two months, they were a laughingstock, their reputations in tatters.

The ensuing years would reprise this familiar storyline: Researchers would make a grand announcement heralding a new advance in fusion, potentially solving many of the world's energy-related problems, only to have their claim wither under the harsh light of rigorous scientific scrutiny. Japanese researchers in the mid-1990s insisted they had achieved "break-even plasma conditions" and that their tokamak was producing five watts for every four that it consumed. Turns out it was not. About the same time, researchers manning JET, a large tokamak operated by a European consortium of researchers, gained attention for their bid to achieve break-even conditions. In reality, they were only producing six watts for every ten put into it. Writes Seife: "It was a record, and a remarkable achievement, but a net loss of 40 percent of energy is not the hallmark of a great power plant."

In 2002, scientists at the Oak Ridge National Laboratory in Tennessee claimed to have created fusion in beakers of acetone at a temperature of tens of millions of degrees. This "bubble fusion" approach was scheduled to be announced in *Science*, the prestigious journal that was then Seife's employer. In the run-up to publication, it became clear there were real problems with bubble fusion: several other Oak Ridge scientists were convinced that their colleagues had failed to produce a fusion reaction. Oak Ridge officials ordered other scientists to attempt to replicate the experiment; that effort, using more finely tuned equipment, evinced no sign of fusion. An internal tug-of-war broke out at *Science* over whether or not it should publish the paper. Ultimately the journal did, giving its imprimatur to the Oak Ridge claims even as those claims were being disproved. Seife was in the curious and uncomfortable position of being a reporter covering the bubble fusion story that intimately involved his employer; his detailing of the awkward controversy is among the real treats of *Sun in a Bottle*.

Despite the cold fusion and bubble fusion debacles, not to mention Richter's fraud, there actually have been a number of successful tabletop fusion reactions. When teenager Thiago Olson made a homemade tabletop fusion device in his Michigan basement in 2006, he became the *eighteenth* amateur to pull off the stunt. (The first to accomplish it, strangely enough, was Philo T. Farnsworth in the 1960s; Farnsworth is much better known as one of the inventors of television.) Seife notes that the idea of tabletop fusion would seem "impossible—a pipe dream sought after only by cranks.... But in fact, tabletop fusion—fusion reactions carried out cheaply in a small piece of laboratory equipment—is real. It just isn't yielding any more energy than it consumes, so it is useless as a source of power."

The future of fusion now seems to lie with the International Thermonuclear Experimental Reactor (ITER), an enormous long-term multilateral effort to build a tokamak reactor in Cadarache, France. The ITER idea has been around since Mikhail Gorbachev proposed it at a summit in 1985. These efforts went nowhere until the United States took an active lead during the administration of George W. Bush, and construction on the massive reactor is slated to begin soon.

Will it work? It will still take decades to find out. Though generally optimistic about ITER, Seife is still skeptical that it will ever achieve ignition and sustained burn. But that sort of skepticism is the exception among fusion enthusiasts, despite the numerous setbacks over the years. "The fusion community clings to the hope that fusion energy is just thirty years away—and that it will solve *all* our energy problems," Seife notes. "The promise of a fusion reactor a few decades away has been a cliché for a half century."

And it will continue to be so. After all, says Seife, "there's something uniquely powerful about the promise of fusion energy. It harks back to the ancient quest to build a perpetual motion machine, but this time the source of unlimited energy doesn't violate the laws of physics."

Which brings us back to today's energy debates, and how and whether we can reduce or eliminate the carbon emissions produced by our primary energy sources. President Obama would have us do so with renewables; for him, to believe we *should* is to believe we *can*. But as the story of fusion shows, wishing a project's success is not enough to make it so. The laws of physics make it very unlikely that renewable sources will ever provide the reliable power needed to replace our current carbon-based sources, no matter how much money we throw at them.

We would be wiser instead to turn to the technology we know can provide such reliability and capacity, and that we already have: nuclear fission. But if we insist on looking to the horizon, let us focus our hopes and our investments not on the windmills and solar panels that we know will always remain a small part of our energy supply, but on the fusion reactors that at least hold the potential for unlimited power.

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