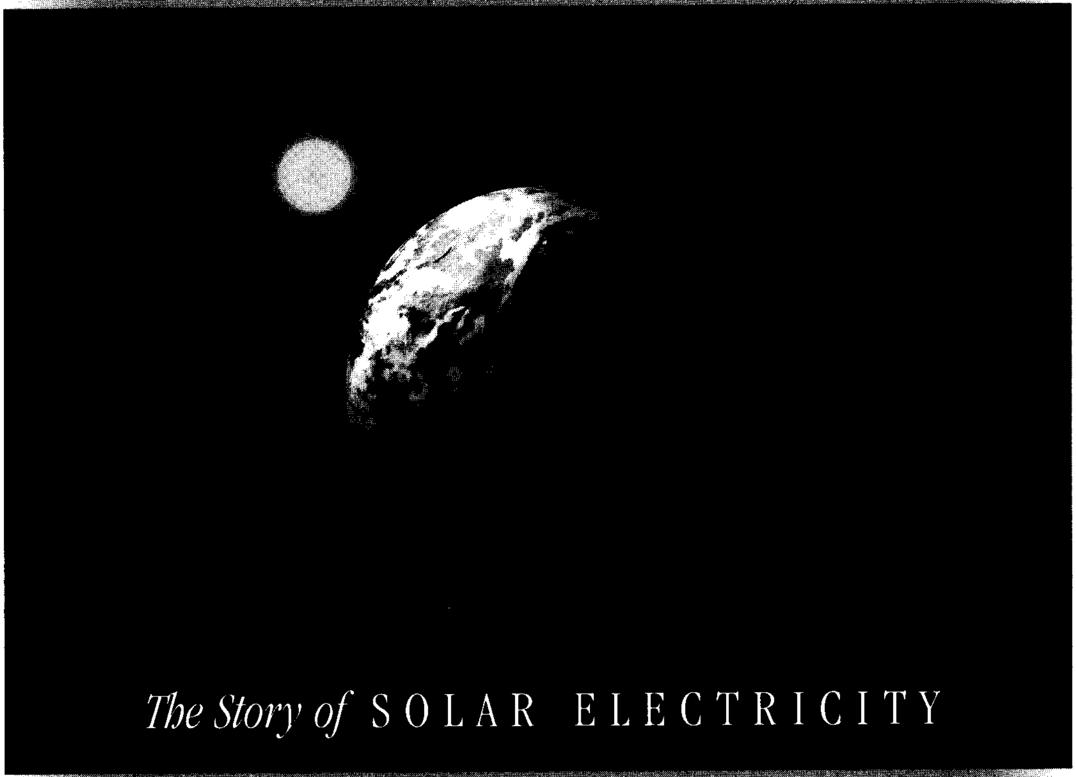
From SPACE TO EARTH



The Story of SOLAR ELECTRICITY

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Co-author of A Golden Thread

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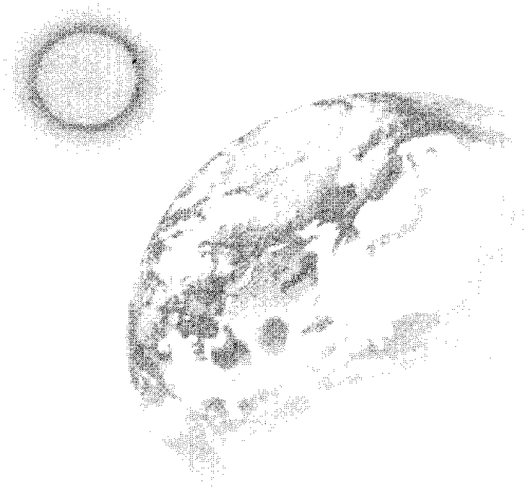


Chapter One

Photovoltaics: The Great Solar Hope

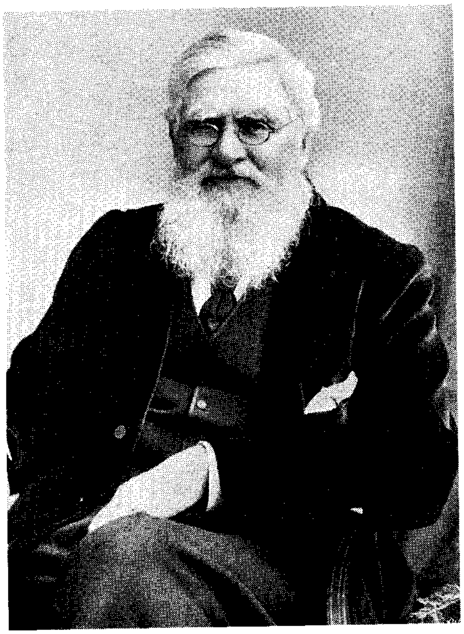
Alfred Russel Wallace, along with Charles Darwin, gained great fame and respect as a co-discoverer of the theory of evolution. In his book *The Wonderful Century*, Wallace described the important technological developments that occurred during his lifetime, which spanned almost the entire nineteenth century. He believed that these changes significantly separated his period from the rest of world history. For example, Wallace noted that from the earliest times until the mid-nineteenth century, land transportation had not changed at all. People either walked or relied on animals to carry them and their goods overland. "The speed for long distances must have been limited to ten or twelve miles [sixteen to nineteen kilometers] an hour" at best, Wallace contended. Whether "ancient Greek or Roman, Egyptian, or Assyrian, [or early nineteenth-century] Englishman," all traveled about "as quickly and as conveniently." Then what Wallace termed an "entirely new departure" in transportation occurred. "Railroads raised the speed of transport to fifty or sixty miles [eighty to ninety-five kilometers] per hour," revolutionizing travel and the conveyance of goods."[1]

"In . . . navigation," Wallace saw, "a very similar course of events." For thousands of years, people had to depend on oars and sails. He judged even "the grandest three-decker or full-rigged clipper ship but a direct growth . . . from the rudest sailing boat of the primeval savage. Then, at the very commencement of the present century, the totally new principle of steam propulsion began to be used," hailed by nineteenth-century observers as "without parallel in the history of man as regards to commerce and rapidity of communications."[2] Indeed, prior to the steamboat, the best way to navigate from Pittsburgh to New Orleans was by keelboat. A round trip took six to seven months. The steamer reduced the voyage to a little over three weeks.[3]

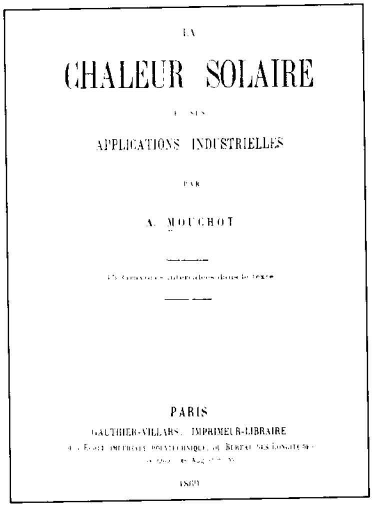
Likewise, engines propelled by steam unleashed industry. No longer tied to water power, factories proliferated, producing for mass consumption a plethora of goods hitherto confined to the wealthy.

These great steps, heralded as "man's increased power over nature," came with a steep price.[4] Most of the engines that propelled these locomotives, ships, and machines burned coal—and the amount of coal they consumed was alarming. In the late 1800s, one leading French engineer worried, "We are currently spending the supplies of energy accumulated over the millions of centuries. Industry is devouring this savings account . . . and one wonders how much longer we can borrow against it."[5] Another nineteenth-century Frenchman, Augustine Mouchot, a professor of mathematics at the Lycée de Tours, expressed even greater anxiety over the situation, prophesying, "Eventually industry will no longer find in Europe the resources to satisfy its prodigious expansion. . . . Coal will undoubtedly be used up. What will industry do then?"[6]

Mouchot thought that perhaps the sun's heat could replace the burning of coal to run Europe's industries. He therefore first studied what had already been done to put solar energy to use. When he learned that the excavators of Pompeii had unearthed window glass similar to that used in his



Alfred Russel Wallace



LA

CHALEUR SOLAIRE

ET SES

APPLICATIONS INDUSTRIELLES

PAR

A. MOUCHOT

PARIS

GAUTHIER-VILLARS, IMPRIMEUR-LIBRAIRE

1869

The frontispiece of Augustine Mouchot's ground-breaking book that described solar applications past and present to his nineteenth-century audience.

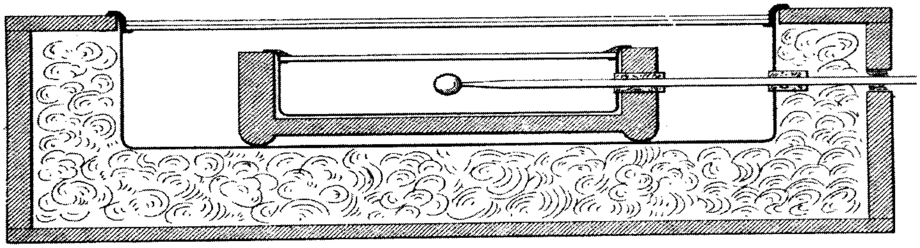
own time, he speculated that the Romans had discovered that clear glass exposed to the sun acts as a solar heat trap. Ancient texts have proven Mouchot correct. The Romans found from experience that when sunlight enters a structure and strikes the floor and walls, it transforms into heat, which cannot easily exit through glass. They named these sunspaces *heliocamini* or "sun furnaces."[7] Scientists today use the term "greenhouse effect."

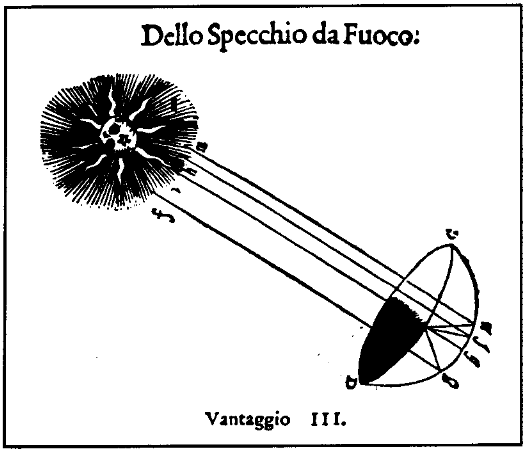
A large Roman window facing south to collect solar heat.

Like so much the ancients had developed, window glass did not survive the fall of Rome. It was not until the Renaissance that glass became as common as it had been in ancient Rome. People then again realized, as Horace de Saussure, one of eighteenth-century Europe's foremost naturalists, observed, "that a room, a carriage, or any other place is hotter when the rays of the sun pass through glass."[8]

Because no one really knew just how much solar heat glass could trap, Saussure took it upon himself to find out. In 1767, he built a miniature greenhouse by stacking five glass boxes of increasing size one inside the other on a black wooden table. Despite the mild weather the day of his experiment, the bottom of the innermost box heated to 190°F (88°C). By replacing the glass sides with wood insulated by black cork, the bottom box heated to 228°F (109°C)—16°F above the boiling point of water.

A simplified version of Saussure's glass-covered boxes. In the early 1880s, Samuel Pierpont Langley, secretary of the Smithsonian Institution, carried the device to the top of Mt. Whitney to study the sun and its effects in high altitudes.

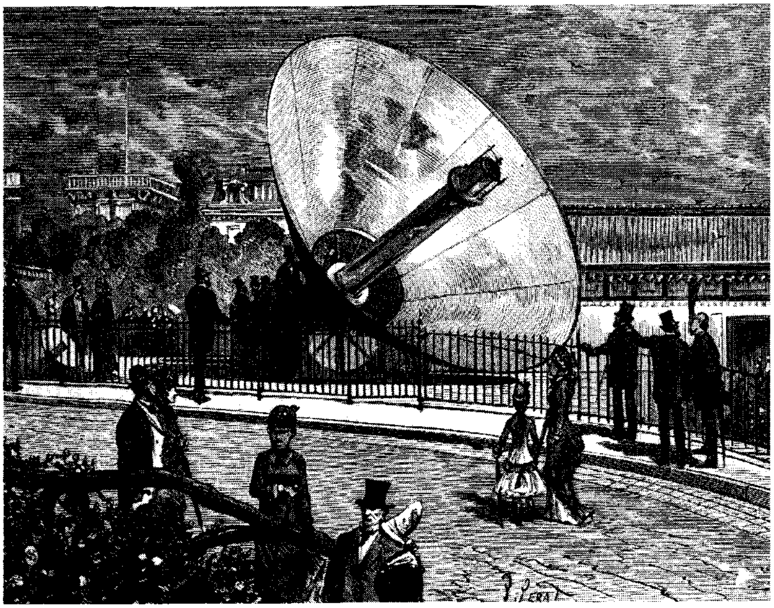




A Renaissance drawing of a concave mirror focusing the sun's heat.

The simplicity of Saussure's device, combined with the fact that it could collect more than enough heat to boil water, fit with Mouchot's ambition to drive industrial steam engines by the sun. However, after much calculation and analysis, Mouchot concluded that to produce enough electricity to actually power machinery, his solar plant would have to be so large that it would not be feasible, either in cost or practice.

But he did not give up. Further studies showed that concave reflectors could optimize solar heat collection. The ancients had called such reflectors "burning mirrors" because they focused the sun's rays to an intensity that could burn wood and melt metals. Through reading old texts, Mouchot learned that two hundred years earlier a fellow Frenchman named Villette had made a burning mirror that, as one eyewitness reported, created a flame "most forcibly of any fire we know."[9] The observer, an English traveler, thought that if these powerful mirrors were redesigned, they "would be of great use," especially to England's iron industry, whose potential was



One of Augustin Mouchot's solar reflectors drove a steam engine at the Universal Exposition in Paris in 1878.

held back for lack of wood fuel. Mouchot's work with mirror technology led him to develop the first sun motor, which produced sufficient steam to drive machinery. One journalist described it as a "mammoth lamp-shade, with its concavity directed skyward."[10]

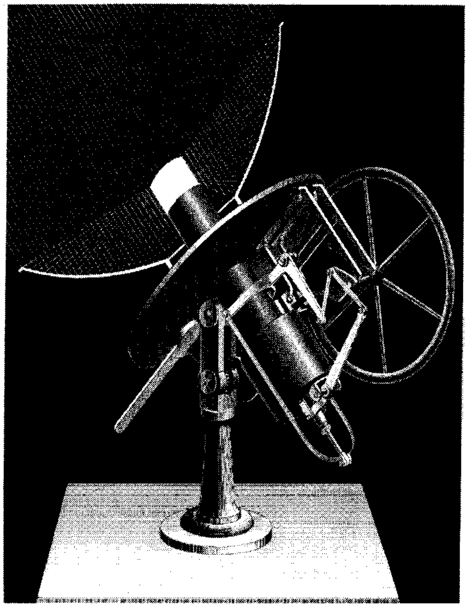
Mouchot's success aroused much debate in France during the 1870s and 1880s. Many were convinced that solar energy could produce unlimited power at almost no cost. Others dismissed his device as nothing more than a toy. To resolve the controversy, the government set up a commission to investigate the matter. After a year of testing Mouchot's sun machine, the commission ruled, "In France, as well as in other temperate regions, the amount of solar radiation is too weak for us to hope to apply it . . . for industrial purposes."[11]

However, the report did leave hope for future solar inventors by adding, "Though the results obtained in our temperate and variable climate are not very encouraging, they could be much more so in dry and hot regions where the difficulty of obtaining other fuel adds to the value of solar technologies. . . . [Hence,] in certain special cases, these solar apparatuses could be called upon to provide useful work."[12]

The nineteenth-century Swedish–American engineer John Ericsson, who probably contributed more to the ascendancy of steam power than any other individual on earth, also argued that the sunny areas of the world were the place for sun-driven machinery. In his words, "The application of the solar engine [in these regions] is almost beyond computation while the source of its power is boundless."[13]

John Ericsson, the inventor of the Monitor, *the first iron-clad vessel.*

Although Ericsson's screw propeller had assured the supremacy of steamship over sail, and the locomotive he built, one of the first, helped to usher in the age of railroading, the steam engine's huge appetite for coal came to haunt him. He feared, as had Mouchot, that "the time will come when . . . Europe must stop her mills for want of coal."[14] Furthermore, Ericsson shared Mouchot's belief that solar power offered the only way to avert an eventual global economic paralysis that would result in putting "a stop to human progress."[15] The inventor felt such an urgency to develop solar engines that he devoted the last two decades of his life to this pursuit.



One of John Ericsson's sun machines.

Ericsson was elated when he completed his first working model, telling a friend, "It marks an era in the world's mechanical history."[16] But three years and five experimental engines later, Ericsson's enthusiasm had been tempered. His experiments taught him that "although the heat is obtained for nothing, so extensive, costly, and complex is the concentrating apparatus" that engines powered by solar energy were actually more expensive than coal-fueled motors.[17]

The failure of Mouchot and Ericsson to come up with economical solar machinery did not dampen everyone's enthusiasm for solar power. In fact, one energy specialist wrote in 1901, "The solar engine is [still] exciting special interest."[18] The truth of that statement could be seen in Frank Shuman's career. Described in a 1909 issue of *Engineering News* as a "man of large practical experience,"[19] Shuman felt, as had Mouchot and Ericsson, the dire need for solar-run machinery if the world were to continue its industrial development. But he did not wish to repeat their mistakes.

After studying the sun machines invented by his predecessors, he found that cost was "the rock on which, thus far, all sun-power propositions were wrecked."[20] He therefore turned his back on reflectors and focused his attention on glass, just as Mouchot had originally done.

In his backyard in the Philadelphia suburb of Tacony, Shuman laid over one thousand square feet (ninety-three square meters) of glass-covered blackened pipes in which a liquid with a low-boiling point circulated. The solar-heated vapor operated an engine, which demonstrated "[t]he practical possibility of getting power from sun heat by the 'hot bed' plan."[21]

The "thousands of barrels of water" that his plant pumped under Pennsylvania's summer sun gave Shuman confidence that one day his sun machines would make agriculture and industry possible in the fuel-shy but sunny regions of the world.[22] However, first he had to cross the same Rubicon that had held Mouchot back: A glass-covered solar plant needed a much greater surface area than the comparatively compact coal-fired engine to produce the same amount of power.

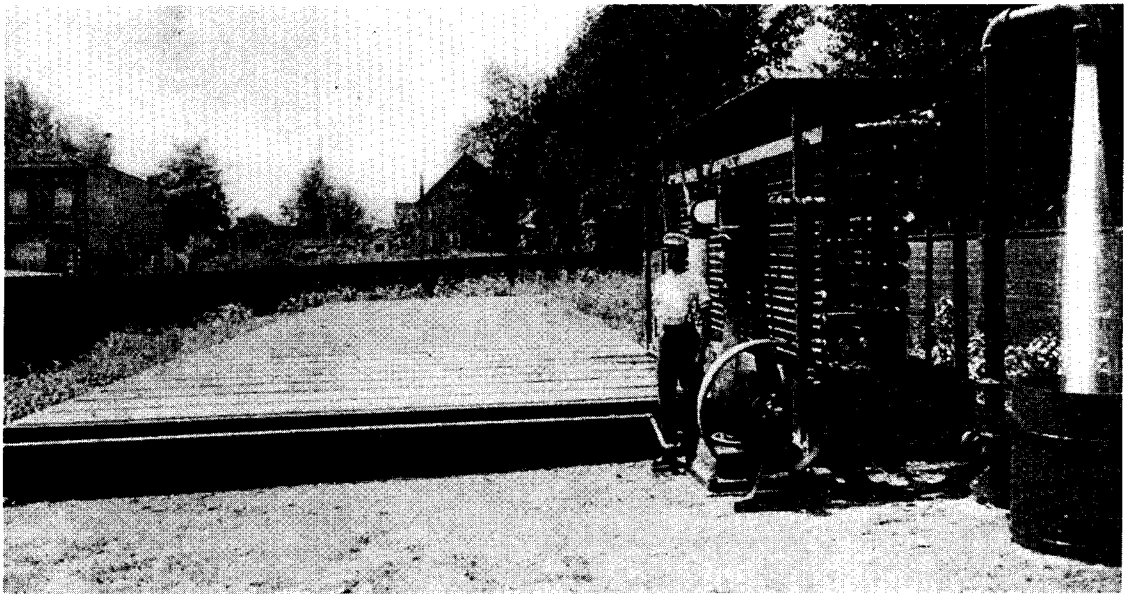
Frank Shuman, solar inventor.

But Shuman found a way to cleverly avoid past pitfalls. First, he chose to locate his commercial solar motor in Egypt, where land and labor were cheap, sun plentiful, and coal costly. Second, to increase the amount of heat generated by the solar motor, the glass-covered pipes were cradled at the focus of a low-lying troughlike reflector. A field of five rows of collectors was laid in the Egyptian desert. The solar plant also boasted a storage system, which collected excess sun-warmed water in a large insulated tank for use at night and during inclement weather. In contrast, solar systems that lacked storage, like those designed by Mouchot and Ericsson, that "go into operation only when the sun comes out from behind a cloud and go out of action the instant it disappears again can hardly be expected to pay dividends," an engineer familiar with early solar machinery stated.[23] For industrialists, Shuman's solution eliminated a major obstacle to solar's appeal.

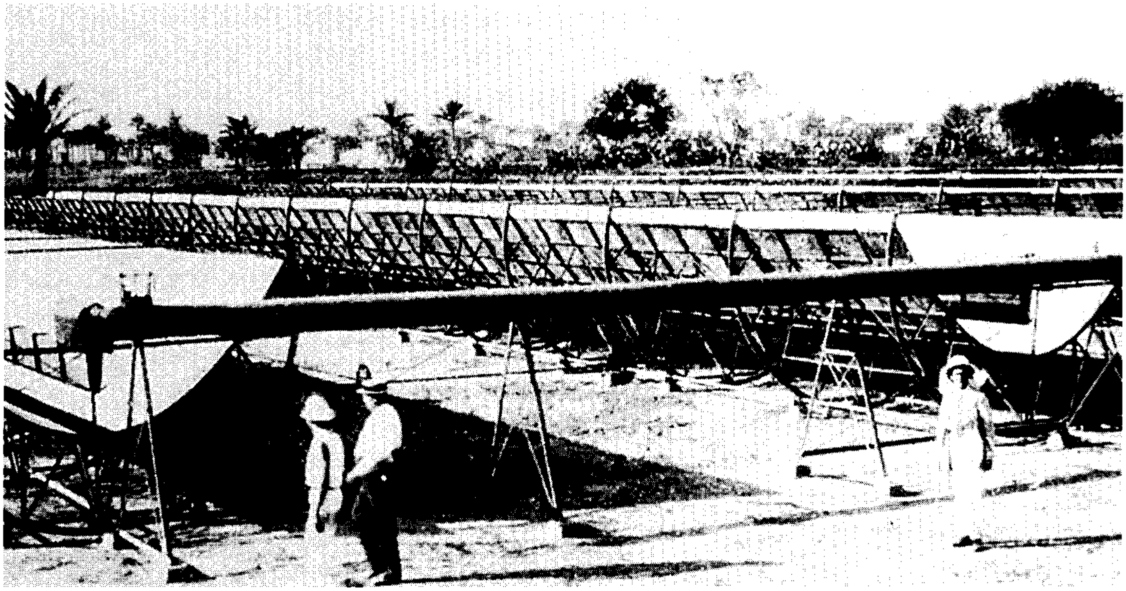
Shuman's solar plant far surpassed the performance of all previous solar engines and, in Egypt, proved more economical than a coal-fired plant. Engineers recognized that Shuman's breakthrough demonstrated that "solar power was quite within the range of practical matters."[24] Even former skeptics, like those at *Scientific American*, now praised Shuman's solar engine as "thoroughly practical in every way."[25]

But all the hopes and plans of solar engineering disintegrated with the outbreak of World War I. The staff of the Egyptian plant had to leave for war-related work in their respective homelands. Shuman, the driving force behind large-scale solar development, died before the war ended. Worse yet, after the war the world turned to oil to replace coal. Oil and gas reserves were found in sunny, coal-shy regions like southern California, Iraq, Venezuela, and Iran—places that had been targeted by Shuman, as well as Mouchot and Ericsson, as prime locations for solar plants. With oil and gas selling at near-giveaway prices, scientists, government officials, and businessmen became complacent over the world's energy situation. Interest in sun power came to an abrupt end.

In the fifty years that followed, oil's low price and seemingly endless supply kept any serious commercial solar activity at bay. Then came the



Shuman's first solar motor, which used glass to trap solar heat, ran this pump in suburban Philadelphia.

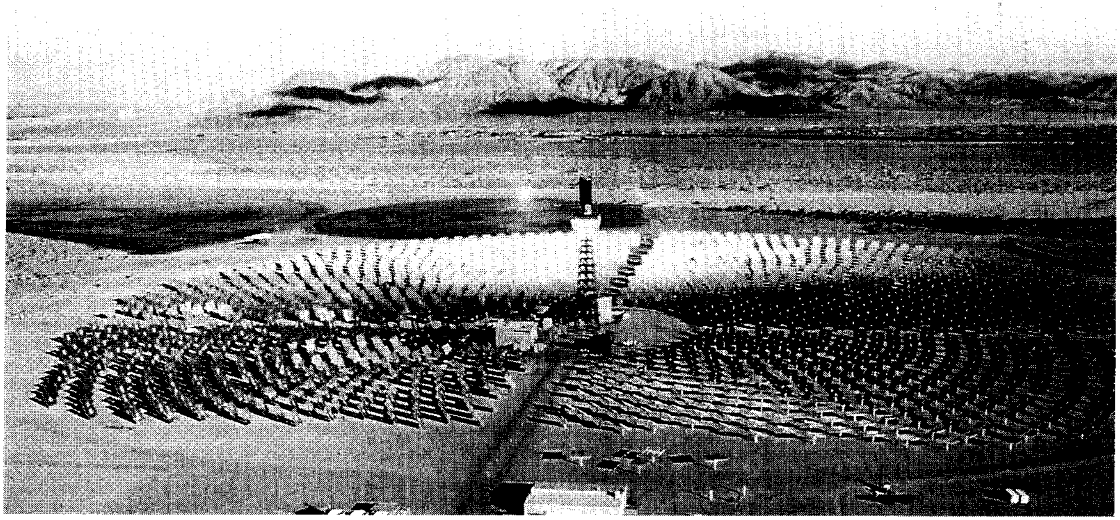


Rows of trough reflectors powered Shuman's successful sun machine located in Egypt.

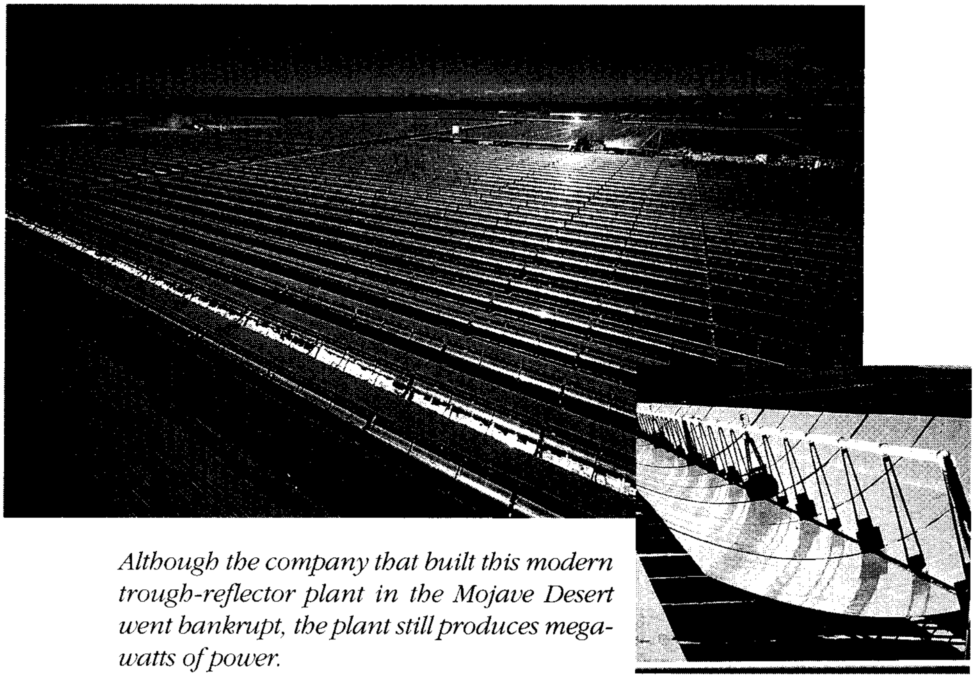
great wake-up call, the oil shock of late 1973. As a result of the embargo imposed by the Arab oil-producing states, the price of oil quadrupled and supplies dwindled. For the next seven years, it continued to climb. In 1980, a barrel of oil cost $32, a 25-fold increase from 1970.[26] Once again, more costly and increasingly scarce conventional fuel supplies made the world look to solar energy. Since it was feared that the utilities would "be severely affected by any ensuing shortfall in gas and oil supplies," work began in earnest to harness the sun for electrical power.[27] The power tower was one option considered.

The power tower concept resembles the use of solar heat that ancient writers ascribed to the mathematician Archimedes. To defend his native Syracuse from the ravages of the invading Roman fleet, Archimedes arranged a number of flat mirrors so that they concentrated the incoming sunlight upon the wooden hulls of the enemy ships "to kindle a fearsome fiery heat . . . [which] reduced them to ashes."[28] Power towers also rely on the proper placement of a number of flat mirrors. For example, a one hundred-megawatt plant would require twenty-five thousand mirrors on four hundred acres of land! But instead of trying to burn ships, these mirrors would move throughout the day to focus sunlight onto a boiler atop a 735-foot tower.[29] The heat produced by the concentrated sunlight would reach around 1000°F (538°C) and so run a conventional turbogenerator.

However, power towers have yet to emerge from the government-funded demonstration-project stage to the commercial market, despite the hundreds of millions of dollars spent on their research and development. And, too, the introduction of a simpler, less futuristic alternative took the wind out of the power towers' sails. This technology uses trough-shaped reflectors that look hauntingly similar to the parabolic troughs Frank Shuman built in Egypt seventy years earlier. Its story has eerily paralleled Shuman's Egyptian experience, too. Experts at first called the Luz trough-reflector plant, built in the California desert, "cost competitive with conventional fuel power stations" and declared its "potential . . . virtually unlimited."[30] Savvy investors confidently signed a contract which guaranteed that the local utility would buy solar-generated electricity at the same price it would have had to pay for fossil fuels. With oil close to $40 a barrel in the early 1980s, and additional escalations in price predicted, it is no wonder that they had expected to make a lot of money. But just like Shuman, the investors were in for a surprise. The price of fossil fuels hit rock bottom in the late 1980s and,



A field of flat mirrors focuses sunlight onto a tower to produce steam for a conventional turbogenerator.



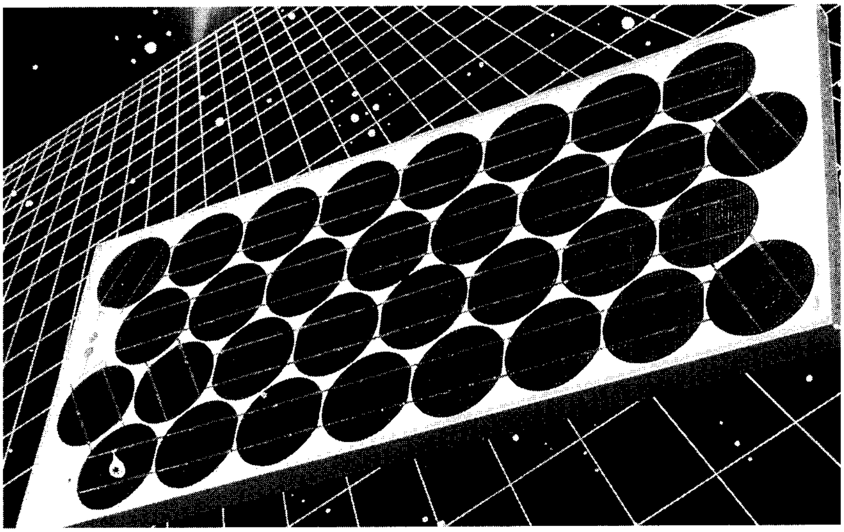
Although the company that built this modern trough-reflector plant in the Mojave Desert went bankrupt, the plant still produces megawatts of power.

again, it appeared there was no end to the supply. As a consequence, the company responsible for building the plant went bankrupt.[31]

"This looks like the end of the story," to quote Beatrix Potter at the moment Old Brown took out his knife to skin Squirrel Nutkin. However, just as Potter let her readers know, ". . . it isn't."[32] Scientists have devised a radically different technology for exploiting solar energy for power, one that casts aside the notion of using the sun's heat. The technology is photovoltaics, the direct conversion of the sun's energy into electricity via fragile-looking solar cells, no more than several hundred microns* thick. Hardly the rugged stuff utility people are accustomed to, photovoltaics does away with the bulky paraphernalia—boilers, turbines, pipes, and cooling towers—required by all other electricity-generating technologies. In fact, solar cells operate without moving parts. Within those few microns, photons, packets of energy from the sun, silently push electrons out of the cells and so make electricity. As Markus Real, who in the late 1970s began his engineering career searching for ways to transform solar heat to electricity, recalled, "For me it was clear when I saw the two technologies [solar reflectors and photovoltaics]. I realized that solar cells were something new, something special. I was convinced we had here a revolution in power generation."[33]

*micron = 10^{-6} meter

Real was not the only person excited by photovoltaics. Around the same time, staff writers for *Science* magazine declared, "If there is a dream solar technology, it is photovoltaics—solar cells . . . a space-age electronic marvel at once the most sophisticated solar technology and the simplest, most environmentally benign source of electricity yet conceived."[34]



These disks are solar cells. Interconnected and framed, they form a photovoltaic panel or module. Despite their ethereal appearance, when exposed to the sun, solar cells produce electricity that is no different than that generated by huge turbines.

Notes & Comments

1. A. Wallace, *The Wonderful Century: Its Successes & Failures* (London: Swan Sonnenschain, 1898), 2, 3, 6–7. Dr. Jay Stephen Gould's column, "The View of Life," in the September 1998 issue of *Natural History* led me to look at Wallace's book.
2. Ibid., 8; H. Tudor, *Narrative of a Tour in North America* (London: J. Duncan, 1834), 2.36.
3. J. Perlin, *A Forest Journey* (Cambridge, MA: Harvard University Press, 1991), 342.
4. Wallace, *The Wonderful Century*, 2.
5. M. Crova, "Rapport sur les Experiences Faites a Montepellier pendant l'Anne 1881 par la Commission des Apparelis Solaires," *Académie des Sciences et Lettres de Montepellier, Section des Sciences* 10 (1884): 289–90.
6. A. Mouchot, *La Chaleur Solarie et ses applications industrielles*, 2nd ed. (Paris: Gauthier-Villars, 1879), 256.
7. E. A. Andrews, *A Latin Dictionary* (Oxford: Clarendon Press, 1879), 845.
8. H. de Saussure, "Lettre de M. de S aux Auteurs du Journal," *Le Journal de Paris*, Supplement, au #108, (17 April 1784), 475. *Also see* H. de Saussure in M. Achille Comte de Buffon, ed., *Oeuvres Completes de Buffon, Tome Premiere* (Paris: Bazouge-Pigoreau, 1839), 183n.
9. "An Account from Paris Concerning a Great Metallin [sic] Burning Concave. . ." in *Philosophical Transactions* V, no. 47 (19 July 1669): 986–87.
10. L. Simonin, "L'Emploi Industriel de la Chaleu Solaire," *Revue des Deux Mondes* (1 May 1875): 204.
11. Crova, "Rapport sur les Experiences," 323.
12. Ibid., 325–26.
13. John Ericsson, in W. Church, *The Life of John Ericsson*, vol. 2 (New York: C. Scribner and Sons, 1890), 266.
14. J. Ericsson, *Contributions to the Centennial Exposition* (New York: Printed by the author, 1876), 577.
15. Ericsson, in Church, *The Life of John Ericcson*, 191.
16. Ericsson, *Contributions to the Centennial Exposition*, 564.
17. Ericsson, in Church, *The Life of John Ericcson*, 271.
18. R. Thurston, "Utilizing the Sun's Energy," *Smithsonian Institution Annual Report* (1901) 265.
19. "Power from the Sun's Heat," *Engineering News* 61, no. 19 (13 May 1909): 509.
20. F. Shuman, *The Generation of Mechanical Power by the Absorption of the Sun's Rays* (Tacony, Philadelphia: By the author, 1911), 2.
21. "Power from the Sun's Heat," 509.
22. Ibid.

23. Thurston, "Utilizing the Sun's Energy," 268.
24. H. Jenkins, in A. Ackermann, "The Utilisation of Solar Energy," *Journal of the Royal Society of Arts* 63 (1915): 564.
25. F. Shuman, "The Feasibility of Utilizing Power from the Sun," *Scientific American* 110 (25 February 1914): 179.
26. J. Lindmayer, "Industrialization of Photovoltaics," in *Third E.C. Photovoltaic Solar Energy Conference* (Cannes, France) (Dordrecht: Kluwer Academic Publishers, 1981), 179.
27. A. Hilderbrandt and S. Dasgupta, "Survey of Power Technology," *Journal of Solar Energy Engineering* 20 (20 May 1980): 91
28. Diodorus Siculus, *Diodorus of Sicily* (Cambridge, MA: Harvard University Press, 1933–1967), XXXVI.18.1.
29. "How Solar Technologies Will Work," *Business Week* (9 October 1978): 96.
30. "The Luz Projects," *Sunworld* 9, no. 4 (1985): 111–12.
31. The Luz plant remains in operation and still generates electricity.
32. Beatrix Potter, *The Tale of Squirrel Nutkin* (New York: F. Warne & Co., 1903), 50.
33. Markus Real, 1994, videotape. (Courtesy Mark Fitzgerald.) Markus Real was not the only defector from power towers to photovoltaics. Bernard McNelis, managing director of IT Power, one of the world's foremost renewable energy consulting groups, spent several years in the late 1970s working on the first European power tower. Although he described his involvement as "very exciting from an engineering/scientific viewpoint, and dealing with European Community officials and French, German, and Italian contractors challenging," the shortcomings of the technology "convinced [him] that [he] had to get back to photovoltaics," where he had begun his solar career. Correspondence with Bernard McNelis.
34. A. Hammond, "Photovoltaics: The Semiconductor Revolution Comes to Solar," *Science* 197 (23 July 1977): 444.