sequence of its age and loose wording in the 1956 agreement. Canadian officials explain that the agreement came into force before the establishment of international safeguards and before the idea that nuclear explosives might have peaceful applications became widely popular.

In the late 1950's, when Canada supplied the fuel for Cirus, India was required under terms of the agreement to keep a close accounting of the resulting plutonium. But that requirement is said to have lapsed in the mid-1960's when India began making its own fuel and extracting what it considered to be its own plutonium. The "peaceful uses" injunction still pertained to the reactor and its products, but, by 1966, as Indian scientists began talking about building a "peaceful bomb" in emulation of the U.S. Plowshare program, it dawned on Canadian officials that the 1956 agreement contained a loophole.

In a futile effort to plug the loophole, Canada's representative to the Geneva disarmament talks, General E. L. M. Burns, put his government on record in the summer of 1966 as defining "peaceful uses" explicitly to exclude explosions of all kinds. Indian representatives are said to have rejected this interpretation. And Prime Minister Pierre Trudeau apparently fared no better when he wrote to Mrs. Gandhi in 1971 to remind her of Canada's definition. Indian officials say the decision to build an explosive device was made that July.

A year later, in July 1972, the United Nations Association of the United States, a private policy-study and fund-raising group, released a report on nuclear safeguards that singled out a Canadian research reactor in India (without mentioning its name) and a French reactor in Israel as being the only two "unsafeguarded" reactors known to be operating in nonnuclear countries that had not signed the Non-Proliferation Treaty. The report estimated India's plutonium stockpile at 95 kilograms and Israel's at 40 kilograms, enough for 19 and 8 bombs, respectively, of Nagasaki-size.

The political repercussions of the Rajasthan explosion are still largely a matter of speculation, with the tone ranging from grim to mildly positive.

In arms control circles, the Indian test is widely viewed as a serious but not lethal blow to completion of the Non-Proliferation Treaty. India's action, and the generally mild international reaction, are seen as stiffening the resistance of already resolute holdouts—notably Pakistan, Israel, South Africa, and Brazil. To some analysts, a more immediate concern is that India may have strengthened the hand of right-wing elements in Japan opposed to ratification of the treaty.

On the positive side, India's newly acquired power (and perhaps prestige among poorer nations) may improve its chances of negotiating a détente with China. And the test puts new pressure on the United States and the Soviet Union to come up with a conciliatory countermove at the June summit, perhaps in the form of a broader test ban agreement (*Science*, 17 May).

Even if India's disavowal of military intent is discounted entirely, the military significance of the Rajasthan test is no larger than India's supply of unsafeguarded plutonium. Its stockpile is small now—probably not larger than 100 kilograms, and some of this is committed to fuel two fast-neutron test reactors—but there is a great deal of growth potential just over the horizon. In April 1972 the Indian atomic energy agency began designing a new 100-megawatt production reactor modeled on Cirus. And near Madras, at Kalpakkam, India is building two 200-megawatt power reactors that one Canadian official describes as "almost carbon-copies" of the CANDU units in Rajasthan state.

To build the Kalpakkam reactors India is using technology purchased from Canada as part of the Rajasthan deal. But because no foreign help is being used in the design and construction of the power plant, the plutonium it produces will not be subject to international control. Under normal operating conditions the three new reactors will make a total of about 118 kilograms of plutonium each year.

In providing India with the nuclear technology that has made all this possible, Hurst explains that "We were trying to help a country that desperately needs energy. They could hardly be expected to stop with one reactor."

From the Canadian point of view, it has begun to look like a case of technological charity gone sour.

—ROBERT GILLETTE

# Windmills: The Resurrection of an Ancient Energy Technology

The windmill seems fair set to make a comeback from the trash heap of technical history. Once a derisible symbol of archaic technology, the environmental reawakening and the sudden wane of the cheap energy era have left the windmill looking more like the feasible alternative power source that its enthusiasts claim it to be.

A recent sign of the windmill's potential as an unfueled provider of electricity was to be tilted at by the oil industry. "But what do you do when the wind dies down?" one company's television ad asked its audience last year. To advocates of the windmill, the question misstates the problem. The basic technology, they believe, is already there. The remaining task is primarily economic: to make the capital costs of windmill energy competitive with what the oil industry and other rivals have to offer. With that achieved, for an energy device that runs on air and doesn't pollute, it should be plain sailing.

Interest in windmills is picking up fast. Two years ago only a dozen or so people in the United States were studying the devices; now there are a few hundred, working at universities, in large companies such as Boeing or Grumman, and in smaller firms such as R. Buckminster Fuller's Windworks. A few weeks ago the National Science Foundation (NSF) asked the research community for proposals on how best to use and construct windmills. The agency plans to spend $7 million on windmill research in the next fiscal year (this fiscal year's budget is $1.5

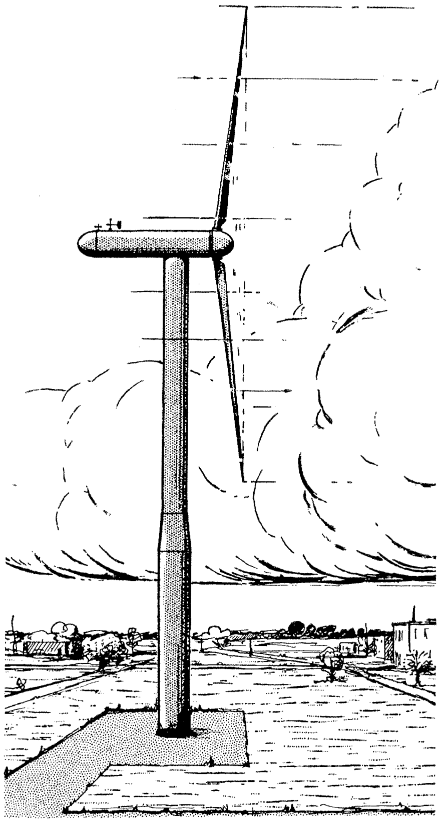

Fig. 1. NASA windmill to be built at Sandusky, Ohio.

million, last year's was $200,000).

NASA also intends to harness the winds with a giant mill to be built at Sandusky, Ohio (Fig. 1). The NASA machine, a pair of blades measuring 125 feet from tip to tip and mounted on a tower 125 feet tall, will be capable of generating 100 kilowatts of electricity. The rivalry between the two bureaucracies is being contained by making NSF keeper of the budget and NASA the chief beneficiary.

Large scale generation of electricity is the principal use envisaged for the windmills of the future. NASA predicts that mills "could supply between 5 to 10 percent of the country's total electric power needs by the year 2000." William E. Heronemus, a former designer of nuclear submarines who will be recognized as the prophet of windmill power if his visions ever come true, believes that by 2000 windmills could be pumping an annual 1.5 trillion kilowatt-hours of electricity into national power grids, which is nearly as much as the total yearly amount of electricity generated in the United States at present.

The estimate depends on the fruition of no Lilliputian a scheme. Heronemus, now a civil engineering professor at the University of Massachusetts, envisages chains of windmills stretching up across the Great Plains from the Texas coast to the Canadian border. An earlier version would have consisted of some 300,000 towers, each 850 feet tall and bearing 20 turbines. Now, to conserve land, he would build 800-foot-tall kingposts straddling the highways at half mile intervals with the turbines slung from cables in between. Two or three years ago few would have given such a conception serious thought. Today Heronemus has an audience, and his ideas are embodied in a recent study of solar (and wind) energy prepared by the NSF and NASA.

The windmill seems to be Persian in origin but the ancient form—still in use today in the eastern provinces of Khurasan and Seistan—has a vertical axis instead of the more familiar horizontal arrangement. The wind is caught by sails rigged between the spokes radiating from the top and bottom of the shaft, which itself is attached to a stone for grinding wheat (see Fig. 2).

The vertical windmill spread throughout the Islamic world after the Arab conquest of Iran, and to China during the world peace imposed by the Mongols. When the windmill appeared in Europe, during the 11th century, the axis was no longer vertical but inclined at an angle of 30° to the horizontal. Some historians cite this as evidence for independent European invention; others consider that, as with so much other technology at the time, the windmill was a transfer from the Islamic world.

By the 17th century the Netherlands had become the world's most industrialized nation by extensive use of wind power in ships and windmills. The machine continued to be improved and refined. The sails gave way to hinged shutters, like those of venetian blinds, and the shutters in turn gave way to the propeller or airscrew.

Windmills helped in the development of the western United States, being used for pumping water and running sawmills. Up until 1950, some 50,000 small windmills converted wind energy into electricity in the Midwest. These backyard generators were put out of business by the activities of the Rural Electrification Administration.

As for large scale generators, giant windmills have at various times in the last 60 years been built in Britain (see Fig. 3), the Soviet Union, and

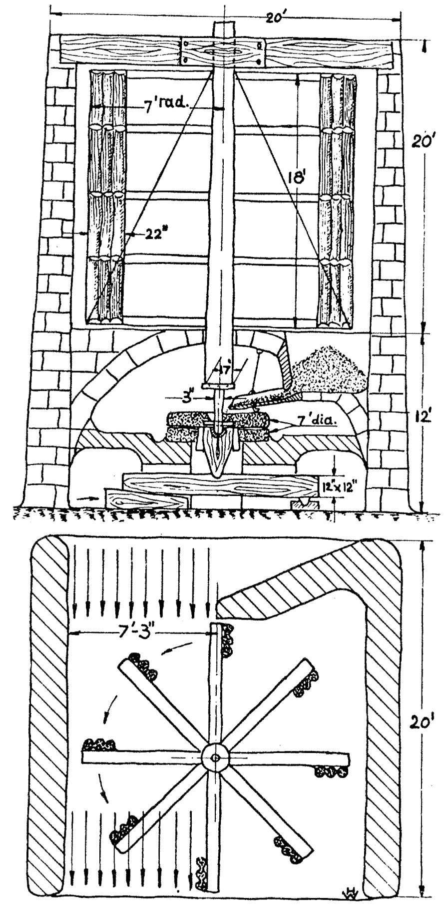


Fig. 2. Persian vertical windmill with grindstone, in sectional views. This version has bundles of reeds instead of cloth for its sails. [From *Traditional Crafts of Persia*, Hans Wulff (MIT Press, Cambridge, Mass., 1966)]

the United States, but none has proved a commercial success. The American windmill, 110 feet high and with blades 175 feet from tip to tip, was built in 1941 on a hill called Grandpa's Knoll outside Rutland, Vermont. The machine cost about $1 million at prevailing prices and provided power on a commercial basis for less than 1 month before one of its 8-ton metal blades snapped off from metal fatigue in 1945.

Though the Grandpa's Knoll machine was in many ways a technical, if not a commercial success, the company that constructed it decided not to persevere, and the development of large scale windmills in the United States—despite the personal interest of science power broker Vannevar Bush—came to a fairly conclusive halt.

Application of the technology of the last two decades in a large scale research effort should produce a much improved windmill, says NSF windmill project manager Louis Divone.

The perfect windmill has not yet

been found, but the laws of physics and economics dictate many of its features. An ideal windmill could extract a theoretical limit of 16/27, or about 59 percent, of the kinetic energy of the wind passing through the area swept by its blades. Windmills of good aerodynamic design in fact generate about 75 percent of the theoretical maximum. The power developed by an ideal windmill is

$$\frac{16}{27} \times (\frac{1}{8}\pi\rho D^2V^3)$$

the interest of which expression is its demonstration that a windmill's power depends on the square of $D$, the diameter of the swept area, and the cube of $V$, the velocity of the wind ($\rho$ is the wind's density). For greatest power, therefore, a windmill should have blades as long as material strength will permit and stand in the fastest winds available. The greatest length envisaged for a blade is at present about 100 feet, giving a diameter of 200 feet, and the best wind regimens in the United States are found on the Great Plains, the eastern seaboard, and the Aleutian chain.

Wind speed increases in strength and constancy the higher up you go; so too does the cost of tower construction. Trade-offs envisioned at present suggest a tower height of 100 to 150 feet. For efficient power generation the windmill shaft must rotate at constant speed, a condition achieved by feathering the blades so that they present a flat face to low winds and turn more edgewise as wind speed increases.

Electric power in the United States is generated at a frequency of 60 cycles per second, which means that to avoid a large number of efficiency reducing gears, the windmill should rotate as fast as possible. In practice this means having two, or at most three, slender blades.

Controlling the pitch of windmill blades, ensuring protection in gale-force winds, and choosing the right material for the blades are among the problems that make windmill design three times more difficult that that of helicopters, says Wayne Wiesner, an aeronautical engineer with Boeing Vertol in Philadelphia. Boeing Vertol and the Southwest Research Institute of San Antonio plan to build a windmill system in which during off-peak hours the windmill would pump air into an abandoned mine; in periods of high electricity use the compressed air would be released through gas turbines.

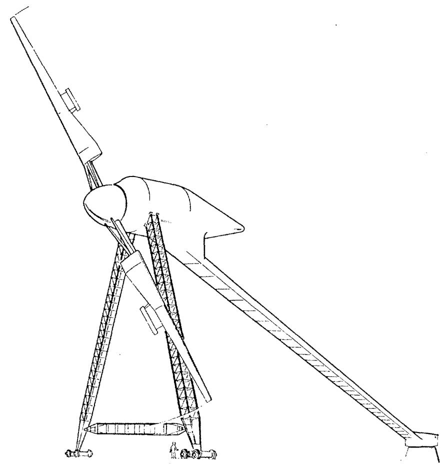

Fig. 3. British design, 1950, for a 1500-kilowatt windmill generator. [From *Wind Power Development in the United States*, Robert K. Swanson *et al.* (Southwest Research Institute, San Antonio, 1974)]

Probably the most formidable problem in designing an economic windmill system is that of coping with the consequences of the wind's variability. The windmill can be used just as a supplementary adjunct to a large power system, or it may provide the whole power, in which case a means must be found of storing energy for delivery when the wind fails. In either case, or in any intermediate situation, the capital costs of the system include considerably more than just those of the windmill and its generator. Nonetheless, capital costs seem to be within striking distance of those of competitive systems. According to Robert K. Swanson of the Southwest Research Institute, large scale wind generators (excluding a back-up system) could be constructed now for about $350 to $400 per installed kilowatt, compared with costs of $250 for gas fired steam turbines, $400 for nuclear plants, and $400 for coal plants with air pollution scrubbing equipment. Divone considers the $400 per installed kilowatt estimate could be reached in 2 years' time.

Besides the compressed air system, other suggested means of storing windmill energy include pumped hydraulic storage (for example by using Lake Superior as an upper reservoir), superflywheels made of light composite materials instead of steel, conventional batteries, and the electrolysis of water to create hydrogen for use as fuel. The hydrogen fuel concept is favored in particular by Heronemus, who would have farms of windmills set up along the Aleutian chain with tankers to carry the liquefied gas to California.

If the economics of such systems have yet to be proved, there are already some applications for which windmill generators are cheaper than any alternative. When Henry M. Clews moved to a remote house in Maine, the local power company quoted $3000 to run him a line. A domestic diesel generating set would produce electricity for 30 cents per kilowatt-hour, or about ten times the power company rate. So Clews invested in a windmill system which, together with batteries and inverter, ran him a total of $2800 and, assuming a 20-year life for the windmill, provides electricity for a total cost of 15 cents per kilowatt-hour. Winds in the location average only 8 to 10 miles an hour.

Clews's system consists of a Quirk's wind generator, manufactured in Australia, with 19 lead-acid storage batteries. He has formed an agency, the Solar Wind Company in East Holden, Maine, to distribute the Quirk's generator in the United States, as well as a range of windmills made by the Swiss company Elektro GmbH.

Another small scale windmill, still in the development stage, is the Sailwing, a propeller-type device but with semisolid blades that deform in the wind, thus providing a self-regulated feathering function. Designed by Princeton aeronautical engineer Thomas E. Sweeney, the Sailwing is licensed to the Grumman Corporation which expects to market the system complete with batteries and generator for between $3500 and $4000.

Other types of windmills under development include two modern adaptations of the Persian vertical windmill, the Darrieus rotor and the Savonius rotor. The special advantage of vertical machines is that they operate equally well regardless of wind direction and don't need extra devices to keep them facing into the wind.

Improvements in the design of cheap, locally made windmills could be a godsend to oil-short countries of the third world. A 25-foot sailwing windmill for use in rural India has been devised by the New Alchemy Institute, of Woods Hole, Massachusetts, in collaboration with the Indian Institute of Agricultural Research and the Wind Power Division of the Indian National Aeronautical Laboratory. A prototype, used for pumping water, was constructed last year on an Indian farm. The machine is made of locally available materials such as a bullock cartwheel for the hub, cloth and a bamboo frame for the sails, and an automobile axle for the shaft.

Present systems of energy production are for the most part massive machines, dependent on man for their fuel and active embodiments of the dominion over nature. Windmills, by contrast, are passive devices, often made with natural materials, and expressive of external forces that represent nature's dominion over man. Their ecological chic is antithetical to the materials consuming style of western economies. As that style shifts, the windmill is moving back into its rightful place in the sun.

—NICHOLAS WADE

# HeLa Cells: Contaminating Cultures around the World

In February 1951, a woman named Helen Lane was being treated for cancer of the cervix at the Johns Hopkins Hospital in Baltimore. Although she ultimately died of her cancer, Helen Lane achieved an unusual measure of immortality—cells derived from her tumor are still very much alive and with us.

Helen Lane was a patient at Hopkins when an investigator named George O. Gey was also there. Gey was a pioneer in the tissue culture field that was then in its infancy. Even today, growing human cells in culture is, in many instances, as much an art as a science. In the 1950's, growing human cells in culture was a revolutionary accomplishment. Gey and his colleagues managed it. They obtained cells from Helen Lane's cervical tumor and cultured them in a blood clot. There, they thrived. Indeed, HeLa (for Helen Lane) became the first human cancer cells to proliferate well in tissue culture. And proliferate they did. For reasons that apparently are still unclear, HeLa cells are particularly vigorous. For years, they were the most standard of all human cell lines, and today they remain a staple laboratory item. HeLa cells are, for example, an excellent medium in which to grow viruses. They have played an important role in cancer research and are among the most studied of all human cell lines.

But HeLa cells, for all the use they have been to science, can also be quite a nuisance, and worse. They have so adapted to life in the laboratory that they thrive and, at times, take over, even where they are unwelcome. If a non-HeLa culture is contaminated by even a single HeLa cell, accidentally introduced through a nonsterile pipette for example, that cell culture is doomed. In no time at all, usually unnoticed, HeLa cells will proliferate and take over the culture. Unfortunately, if this happens, it is not readily apparent. The only way to detect HeLa cell contamination is to monitor cultures by chromosomal and biochemical means. Most laboratories go to great lengths to preclude contamination and many make efforts to monitor their cell lines but, apparently, it is not enough. HeLa can still take over.

According to a California biologist who has for years been responsible for "certifying" the identity of cells for the National Cancer Institute's multimillion dollar Virus Cancer Program, there are a lot more HeLa cells in the world than most scientists recognize. Walter Nelson-Rees of the cell culture laboratory at the University of California, School of Public Health, Naval Biomedical Research Laboratory, Oakland, says that many human cell cultures are not what they seem. On the basis of chromosomal analyses and other data from his laboratory, Nelson-Rees reports that many human tumor cell lines being studied here and abroad, including Russia, are misidentified. In particular, he maintains that certain cultures of human breast tumor cells, prostate tumor cells, bladder tumor cells, liposarcomas, and others are not what they are thought to be. In truth, he says, they are all HeLa cells.

If Nelson-Rees is right—and there are those who dispute his data or are, at least, not thoroughly convinced—a lot of people may have been spending a lot of time and money on misguided research. If, for example, you are studying the properties of human breast tumor cells, hoping to find features that distinguish breast cells from others, and are, all the while, dealing unknowingly with cervical tumor cells, you've got a problem.

Almost 2 years ago, American and Russian scientists entered into a collaborative exchange of information and material related to cancer research. As one of the principal items of that cooperative program, American researchers sent the Russians cell cultures containing what they suspected to be human tumor viruses and Russian investigators returned the favor in kind. American scientists received six separate cell cultures, each said to have been derived from a different human tumor and each containing what might have been a human tumor virus.

After extensive analysis of the "Russian viruses," by immunochemical and other techniques said not to be available in the Soviet Union, it was concluded that the viruses were very similar to the Mason-Pfizer monkey virus (*Science*, 6 July 1973). Previously, this virus had been found only in a rhesus monkey that had monkey mammary adenocarcinoma. The virus was isolated in 1970. Following the observation about the Russian viruses—which was reported formally by American and Russian virologists jointly earlier this year—Nelson-Rees says it became necessary to study the cells from which the viruses came to check the species of origin. Authorities with the Virus Cancer Program sent the cell cultures to California for evaluation. Nelson-Rees and his colleagues examined the cells' chromosomes by a variety of techniques including Giemsa staining, quinacrine-fluorescence analysis, and a trypsin-Giemsa banding system in which individual chromosomes show distinct, identifiable patterns. They found several marker chromosomes common to HeLa cells. They also looked at what is known in the trade as the G6PD (glucose-6-phosphate dehydrogenase) mobility pattern of the cells. A genetically determined enzyme, G6PD, is found in a form called the type A variant in Negroes and persons of part Negro ancestry. In Caucasians, it is present in the form called the type B variant. Helen Lane