ELECTRICITY AND MAN

BY ISAAC ASIMOV

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Our whole industrial civilization depends upon cheap energy streaking out in all directions and under fingertip controls—and that would be very difficult without electric current. It would take enormous ingenuity to find substitutes. If all electricity were shut off, then all electronic devices would be dead. Electric lights would darken. Aluminum would become a rare metal. All factories would have to develop power sources on the spot and would have to switch to primitive, mechanical controls. Every house and every farm would have to give up items we have come to take for granted—not only electric lights, but electric irons, electric toasters, electric water pumps, electric control of furnaces, and so on.

In short, more than a century of technological advance would vanish and much of it could not be replaced.

Isaac Asimov

Nuclear energy is playing a vital role in the life of every man, woman, and child in the United States today. In the years ahead it will affect increasingly all the peoples of the earth. It is essential that all Americans gain an understanding of this vital force if they are to discharge thoughtfully their responsibilities as citizens and if they are to realize fully the myriad benefits that nuclear energy offers them.

The United States Atomic Energy Commission provides this booklet to help you achieve such understanding.

The Author

Isaac Asimov received his academic degrees from Columbia University and is Associate Professor of Biochemistry at the Boston University School of Medicine. He is a prolific author who has written over 150 books in the past 25 years, including about 20 science fiction works, and many books for children. His many excellent science books for the public cover subjects in mathematics, physics, astronomy, chemistry, and biology, such as *The Genetic Code, Inside the Atom, Building Blocks of the Universe, Understanding Physics,* and *Asimov's Biographical Encyclopedia of Science and Technology.* In 1965 Dr. Asimov received the American Chemical Society's James T. Grady Award for his major contribution in reporting science progress to the public. He received the Nebula Award for the best science fiction novel of 1972 for *The Gods Themselves.*

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Introduction

All that men do requires energy; the very existence of life in his tissues, and in the tissues of all living things, requires energy. And the greatest and most overwhelming single source of this necessary energy is the sun.

Every minute the sun radiates 5.6 billion billion billion calories of energy in all directions. This is about the energy 4 million billion billion 100-watt light bulbs would produce. Less than a two-billionth portion of this reaches the earth and over one-third of this is promptly reflected back into space—making our planet visible to astronauts, satellites, and our unknown neighbors in other worlds. Still, the small fraction that reaches earth and remains is enough to power all the life on the planet from single-celled creatures to man himself.

The direct users of the solar energy are the green plants, although they use only about a twentieth of 1% of the sunlight that falls on the earth. Thanks to the chlorophyll they contain, they can use the energy of sunlight to convert the small molecules of low-energy compounds such as carbon dioxide and water into the large molecules of high-energy starches, sugars, fats, proteins, cellulose, and other compounds. In the process, plants liberate oxygen. Plants then use some of these high-energy compounds as fuel to power their life processes, but they form more than they need for this purpose and store the excess in various parts of their structures.

Animals, including man, live on the store of high-energy compounds manufactured by plants. They eat the plants (or they eat other animals that have eaten the plants) and combine the starch, fat, and other compounds with the oxygen also produced by plants. In this way, they release the energy for use in their bodies and form carbon dioxide and water again. The plant world keeps building up the high-energy compounds and the animal world keeps tearing them

down. There is a balance and through that balance the energy of sunlight has kept all life in being for perhaps as long as 3,000,000,000 years.

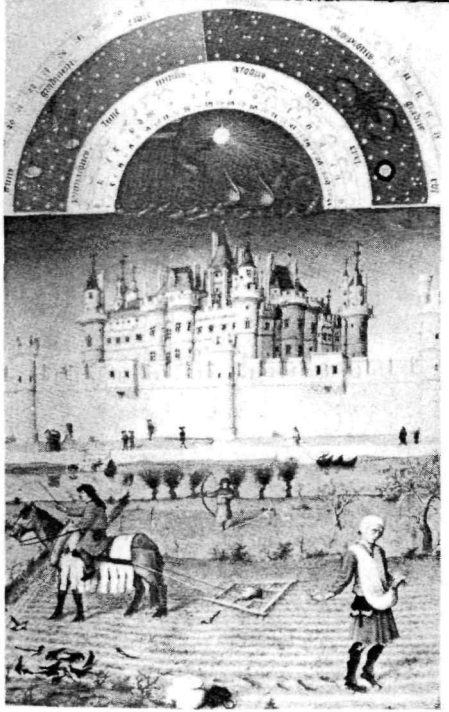
The history of mankind is, to some extent, the tale of the discovery of new and more efficient ways of handling energy. Through most of his history, man could do no more than other animals could—make use of the energy of his own straining muscles. Even when he devised ingenious inventions such as needles, axes, and bows, it was his own muscular effort that had to force them into motion (and without motion, all such devices are useless).

It was an important step forward when man learned to take animals stronger than himself and put *their* muscles to work. Oxen could be used to pull a plow more easily than a man could. Donkeys or horses could draw a chariot. Camels could carry loads. Elephants could push over trees. It may have been as early as 4000 B.C. that animals first became the servants of man, but even 5000 years later, inventions involving animals succeeded in producing great effects on human civilization.

About 1000 A.D., horse collars and horseshoes came into use in Europe. It became possible for the first time to use horses on farms in place of slow, stolid oxen, and to have them pull plows efficiently through the moist and heavy soil of Northern Europe. The food supply increased and this was as large a single contribution as any toward the end of the Dark Ages in that region of the world.

But there are inanimate sources of energy also. Fire always existed and prehistoric man must, on many occasions, have fled in desperate terror (along with other animals) from forest fires started by lightning. On some long-forgotten day in prehistory, though, man learned not to fear a controlled fire and even learned how to start a fire.

Just how he came to learn this we can only speculate, but once he was able to set wood on fire, he had a little sun of his own. He could give himself light in the darkness and warmth in the winter. He could hold his own against animals who dared not approach the fire. He could cook food and make it easier and tastier to eat. In the dawn of civilization, he



A horse plows a field in this illustration from a medieval French prayer book.

learned to use the energy of fire to form metals out of rock, glass out of sand, brick out of clay.

All this was important, and, even in ancient times, man realized that the use of fire marked a turning point in his history, raising him once and for all above the level of the beast. And yet, as we now realize, the potentialities of fire were barely touched right down into modern times. Indeed, man did little more with fire in 1750 A.D. than he had in 1750 B.C.

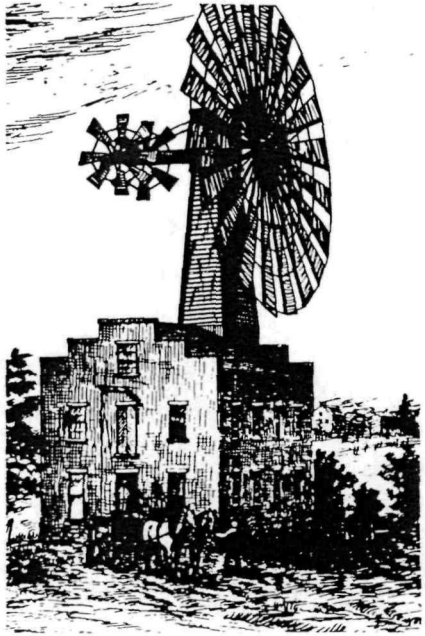
The energy of fire comes from the combination of substances in fuel with oxygen in the air. The first fuel was wood, which consisted of high-energy cellulose and other compounds formed by plants at the expense of solar energy. Animal fat was a less extensively used fuel, but had its convenience because it could be handled as a liquid. In later centuries man learned to use coal as a fuel, then various petroleum fractions and natural gas.

Coal, petroleum, and natural gas are all remnants of plant life that dwelt on earth many millions of years in the past. They are fossil fuels and, in using them, mankind is drawing

on the capital that was laid down by countless generations of plants that had drawn on solar energy. We are consuming the sunlight of the geologic ages when we burn the fossil fuels; consuming the energy "bank account" slowly put away during half a billion years of flourishing plant life and doing it all in just a few centuries.

There are energy sources that have nothing to do with life, but are drawn from the sun in other ways. Solar energy heats up the earth's atmosphere and gives rise to the winds. It evaporates ocean water by the cubic mile and produces the rain and all the flowing rivers. Man learned to use the wind to blow his ships over the waters, and the river currents to float them down stream. He even used wind and water to turn wheels that would grind his grain. The wind, however, is erratic, and waterpower exists in quantity only in certain parts of the world, and not always in the most populated parts.

There are even energy sources that have nothing to do with the sun at all. The earth's own internal heat powers such catastrophes as earthquakes and volcanoes but, in the gentler



In 1745 an Englishman named Edmund Lee invented a fantail that automatically kept windmills facing in the direction of the wind.

form of hot springs, can supply useful heat. The earth's rotation and the moon's gravitational pull combine to produce the ebb and flow of tides that can contribute endless water power along certain seacoasts.

As late as 1750 A.D., however, man's use of energy was still very largely that of muscles—his own and those of animals—and the heat given off by wood fires.

This placed a limit on how far human ingenuity could go in devising clever machinery to do man's work for him. The machinery would have to be set in motion, and, if that meant the use of straining muscles, the gains to be made were small.

Was there any way that the limitless energy of a wood or coal fire could be used to do more than just broadcast heat and light in all directions? Could its energy be trapped and channeled and made to move machinery?

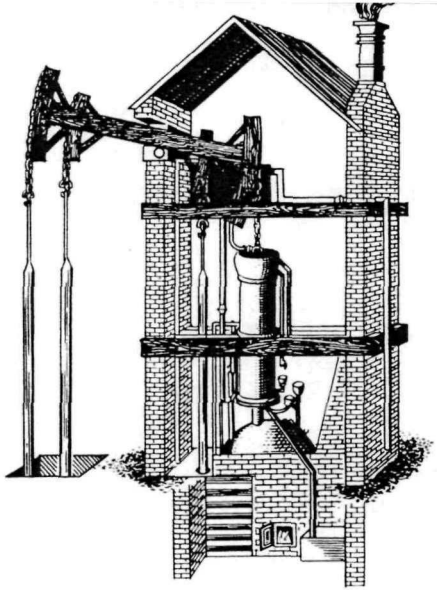
The Steam Engine

If the heat of the fire were used to boil water in an enclosed space, steam would form and would develop high

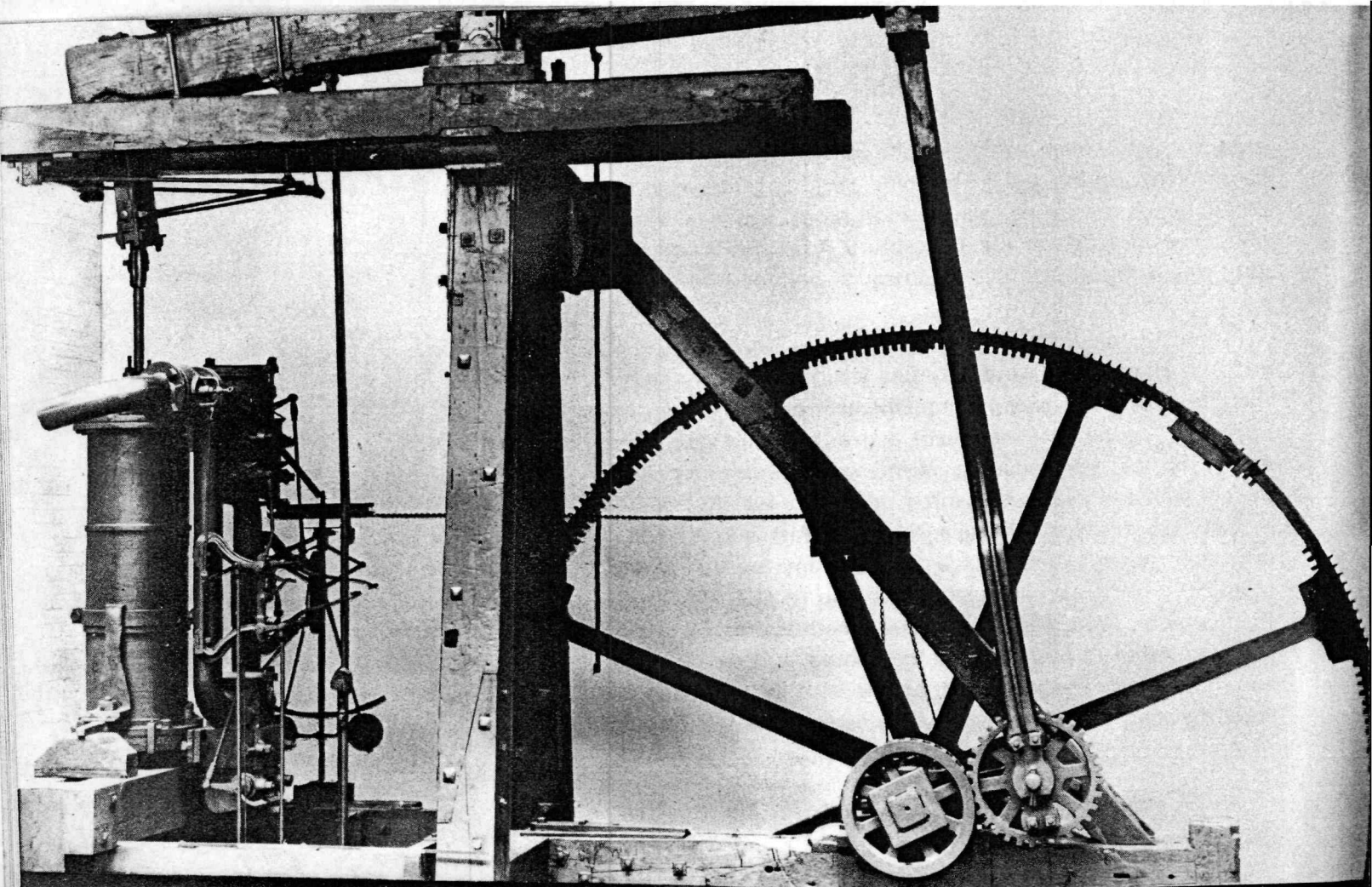
pressures. This steam could be made to force its way out of a constricted opening and in so doing could produce motion. Some Greek engineers played with small steam-powered objects as long ago as the 1st century A.D., but it was not until the 18th century that the energy of confined steam was put to real mechanical use.

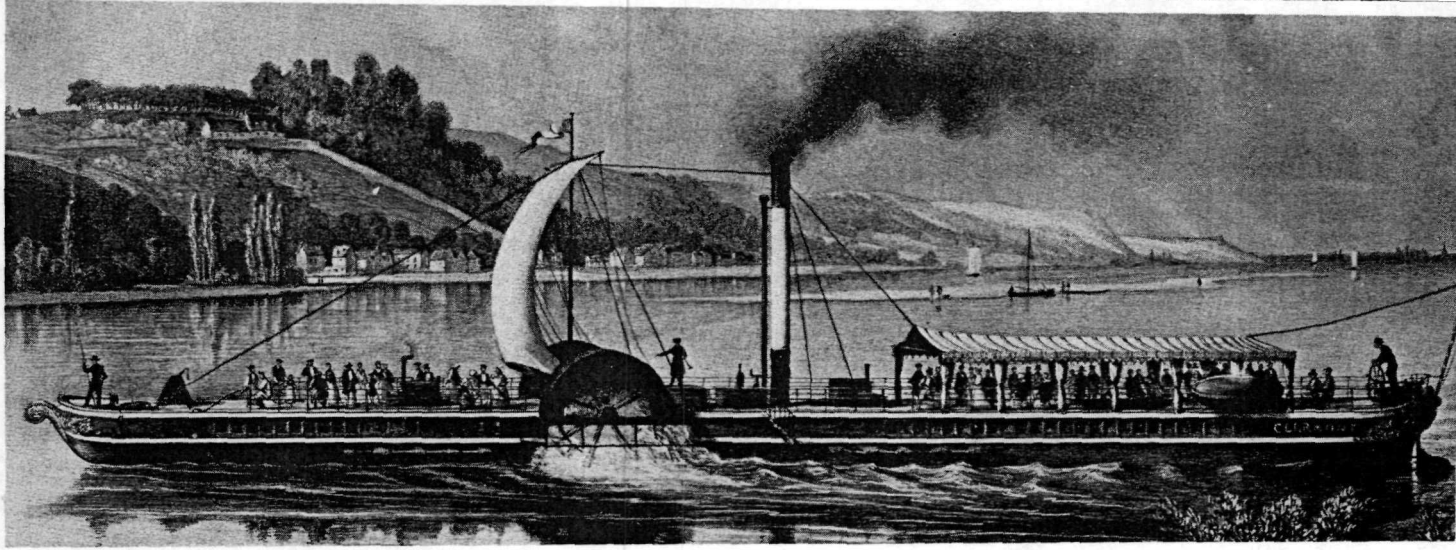
In 1712, an English engineer, Thomas Newcomen, devised an engine that would confine steam and then use its forcible escape to power a pump designed to lift water out of mines. It was terribly inefficient and only about 1% of the energy of the fire ended up doing work. The other 99% merely served to heat up the surrounding air uselessly.

In 1775, the Scottish engineer, James Watt, improved the efficiency greatly and made the "steam engine" truly practical. (Today, such engines can be up to 40% efficient.) Furthermore, Watt went on to devise methods for using the escaping steam to push a piston that would, as it moved back and forth, turn a wheel. By the time Watt was through, a wood or coal fire could, by way of steam, power the motion of almost any type of mechanical machinery.



Thomas Newcomen's heat engine used steam to move a piston, which worked a giant horizontal rocking beam (top left) that pumped water from Cornish tin mines. Because it needed large amounts of coal to produce a small quantity of power, it was replaced by Watt's more efficient steam engine.





The steam engine came to be used to power factories. It introduced what was called the "Industrial Revolution", and utterly changed the economy and way of life first of Great Britain, then of Europe and the United States, and finally of the world.

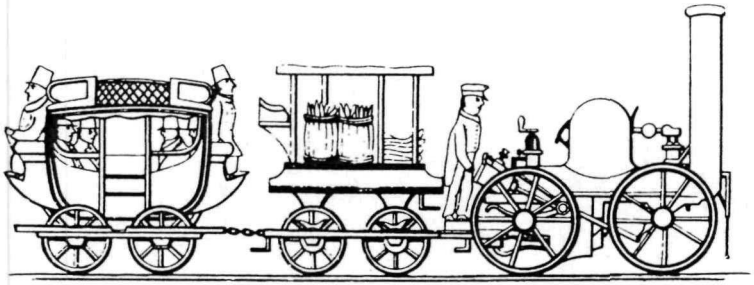
Steam not only powered machinery, it could move objects bodily. A steam engine mounted on board ship could turn a paddle that would move the ship against wind and current. A steam engine mounted on wheels on metal rails

Opposite page, Watt's steam engine. Above, Robert Fulton's steamboat The Clermont. *A surprised witness of its trial run shouted that the devil was going upriver to Albany in a sawmill.*

could turn those wheels and could pull a long train of cars across country much more quickly and tirelessly than any team of horses could pull any coach.

The Internal Combustion Engine

In a steam engine, the source of the energy in the burning fuel is outside the engine. A hundred years after Watt, men began to develop "internal combustion engines" in which the fire was inside the engines. Gasoline vapors were used. When this was mixed with air inside the cylinder and allowed to



One of the first train trips occurred in 1831 between Albany and Schenectady, New York. The DeWitt Clinton, *a wood-burning locomotive, jolted most of the passengers out of their seats as it started off. During the trip, sparks from the smokestack set fire to the umbrellas the travelers had raised as shields.*

burn rapidly, the force of the expanding gases drove a piston that made wheels turn.

The internal combustion engine could be made much smaller and lighter than the steam engine. Where lightness was really essential, as in an airplane, a steam engine would not have worked. The internal combustion engine, working with vapors, could start at once, whereas a steam engine must take time to heat up a large mass of water and produce a head of steam. It was this that made automobiles powered by internal combustion engines preferred over those powered by steam engines.

Both types of engines share certain limitations. In the first place, they must be on the spot where the work is to be done. There is no direct way to transport the energy produced by steam under pressure, or by vapor explosions, over long distances. Every ship or locomotive must have its own steam engine; every automobile must have its own internal combustion engine.

Secondly, both steam engines and internal combustion engines can perform only mechanical work. They can push

Alessandro Volta

levers and turn wheels, and thus do only what human muscles can do, though of course much more powerfully.

This means that if mankind had only the direct use of such engines, there would still be a sharp limit to what could be done. The world would be changed from what it was in 1750, but most technological developments since 1850 would have remained impossible, or, at best, would have been brought about in a manner that was not readily adaptable to mass utilization.

The Electric Battery

What happened to push mankind still farther ahead was the development of current electricity in the 19th century. In 1800, an Italian physicist, Alessandro Volta, devised a combination of metals and solutions that would produce a steady electric current. He had invented the electric battery.

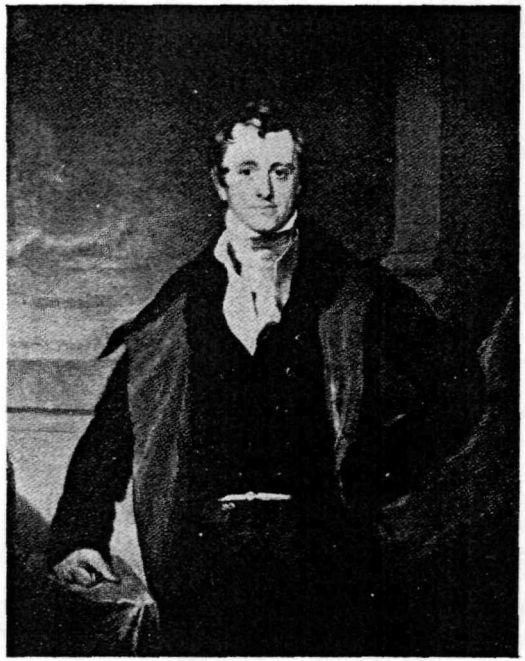
In the decades that followed, scientists and inventors made enormous use of the electric current. By 1807 the

English chemist Humphrey Davy was using powerful batteries to isolate new elements such as sodium and potassium.

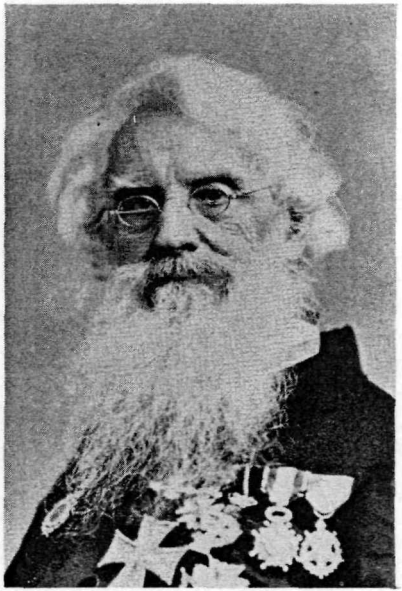
Electricity

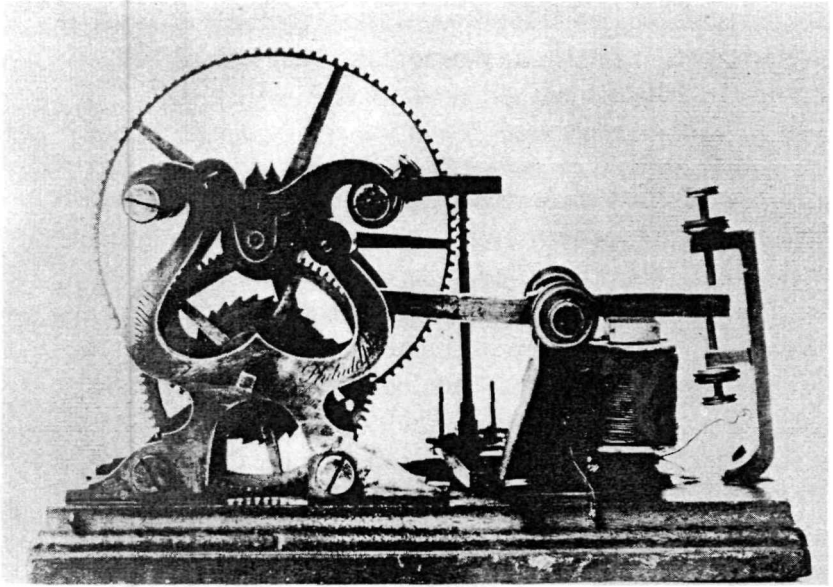
Nineteenth-century theoreticans worked out the laws governing electric currents. In the 1860s the Scottish mathematician James Clerk Maxwell worked out a set of equations that linked electricity and magnetism and showed the relationship of these phenomena to light. The Croatian-American engineer Nikola Tesla devised the transformer that made it possible to transport electricity efficiently over long distances, and the German-American engineer Charles Proteus Steinmetz worked out the theory of alternating currents.

Nineteenth-century inventors applied electricity to devices that gave mankind surprising new power and new comforts. The American artist Samuel F. B. Morse produced a practical telegraph in 1844, and the Scottish-American inventor Alexander Graham Bell presented the world with the telephone in 1876. The greatest inventor of all time,



Humphrey Davy





On the left is Samuel Morse. On the right is a later model of his original telegraph, which, on May 24, 1844, tapped out in a dot-and-dash code: "What hath God wrought!" The main features of the telegraph were developed by two contemporaries, Joseph Henry and Leonard Gale, but it was Morse who successfully synthesized their ideas.

Thomas Alva Edison, electrified the world (literally as well as figuratively) with inventions, of which the electric light in 1879 was the most magnificent.

And yet all these marvelous advances took place without scientists really understanding what was happening in the battery or what the current was all about. Not until the opening of the 20th century, did they come to realize that the electric current was accompanied by a flow of electrons, which were tiny particles much smaller than atoms. However, 19th century scientists did not wait to understand the electric current before learning to use it.

Electrons can exist under a kind of pressure just as steam can, and electrons can be made to move and to produce motion just as steam can.

There were important differences, however. Steam can be made to move along pipes slowly for short distances, but soon loses its heat and therefore its energy. The electric current, however, can be moved along wires at the speed of light for much longer distances without losing too much energy. In fact, by the 20th century methods were developed

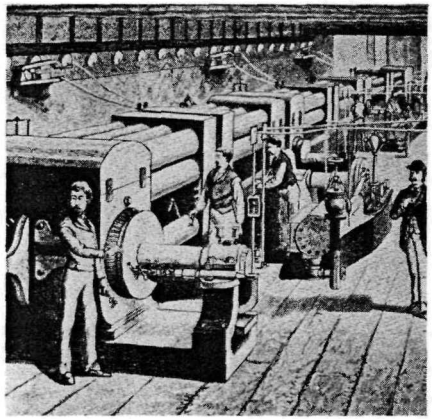
Thomas Edison and his phonograph were photographed in 1878 by Matthew Brady. Previously Edison had worked with electric lights but had then turned to the more promising phonograph. In the year that this photograph was made, however, he resumed his work on lighting.

for transporting electric current, with only minor losses, for great distances.

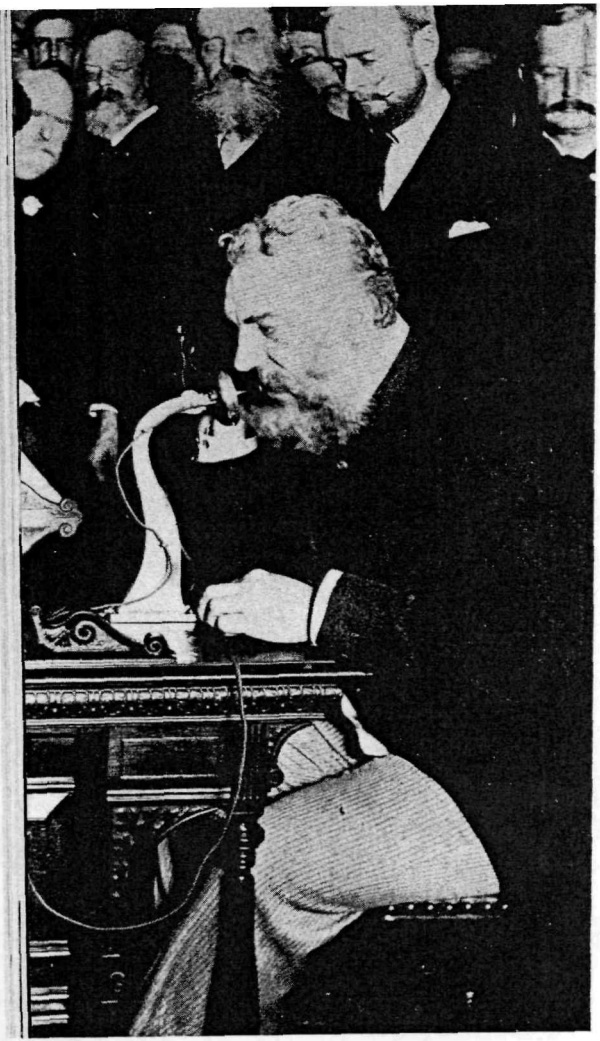
Then, too, associated with electric currents were magnetic fields. As a result, electric equipment could be used to move objects by magnetic forces more delicately and quickly than could be managed by more grossly mechanical forces.

Finally, electrical devices could be used to produce streams of free electrons in a vacuum or in certain solids, or beams of radiations in any medium. These could move from place to place without wires and could be controlled with great delicacy. As a result, electronic devices could be constructed that not all the brute power of ordinary engines could service. No steam engine or internal combustion engine, however powerful and however perfect, could run a television set (in the absence of electricity) with the direct simplicity that electricity makes available to us.

But if electricity has its conveniences as a means of transporting energy over long distances at great speed, and as a way of producing new and very useful forms of energy such as magnetic fields and long-wave radiation, it must still have



After devising his incandescent lamp, Edison built a central power station in New York City. At its peak in 1884, the station serviced 10,164 lamps and 508 customers. Its steam engines drove six jumbo dynamos (above) weighing 62,000 pounds each.



its origin somewhere. There is no direct supply of electricity in quantity on earth—no electricity mines anywhere. Some other form of energy, which *is* present, must be turned into electrical energy; and the electrical energy must be produced as fast as it is consumed, for it can be stored in only very small amounts.

The key substance in the batteries of the type Volta invented were metals such as zinc. In such batteries, men were "burning" zinc to get electricity. Zinc is much less common and much more expensive than wood or coal, so as long as chemical batteries are the only source of electricity, then however convenient and useful the electric current might be, it could not be used in great quantities.

Was there any way of turning mechanical energy into electricity?

Alexander Graham Bell spoke the first words on the new telephone connection between Chicago and New York on October 18, 1892.

The Electric Generator

In 1831, the English physicist, Michael Faraday, found that if a conducting object, such as a copper wheel, were made to turn between the poles of a magnet, an electric current would be set up in it. What's more, an electric current formed as long as the copper wheel turned. The electric current could be bled off the wheel indefinitely as long as the wheel revolved. Faraday had invented the first "electric generator".

But what is to keep the copper wheel turning? Human muscles? A much better alternative is a steam engine. The steam engine can keep a wheel turning between the poles of a magnet, just as it can keep a wheel turning on a railroad track, or a paddle turning in the water. Thus, the energy of burning wood or coal is converted into an electric current.

An internal combustion engine can do it, too, and does do it in an automobile. It keeps a generator going that produces the electricity you use to keep the windshield wiper working and the car radio and the automatic fans and

Michael Faraday

cigarette lighter and so on. Electricity is also stored in the car's storage battery, so that the automobile can be started at the turn of a key rather than by a hard-working mechanical crank as in the old days.

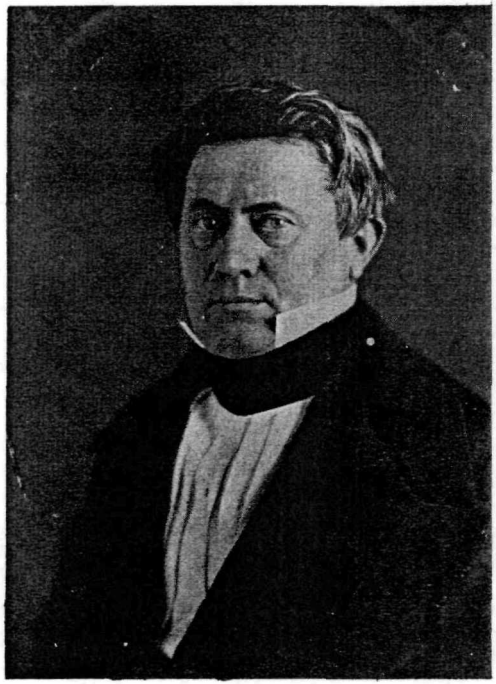
Water power can do it, too, by turning a wheel that will produce electrical energy, and Niagara Falls is a prodigal source of this power.

All this stems from Faraday's invention of the electric generator that, for the first time, made electricity available cheaply and in quantity.

The Electric Motor

In 1831, the year of Faraday's invention, a companion invention was devised by the American physicist Joseph Henry. Faraday had shown how a turning wheel could produce electricity and Henry showed how electricity could be made to turn a wheel. He had invented the first electric motor.

The result was that by the end of the 19th century, the world was well on its way to being electrified. A huge wheel at some central generating plant could produce vast quantities of electricity, which would pour out over myriad wires to myriad places, near and far. In some places it might turn a magnetic field on and off to work a bell or a telegraph. In other places it might heat a wire to produce bright light. In still other places it might rise and fall in time to sound waves or light waves in order to carry sound and pictures over great lengths by telephone and telephoto. And in yet other places it would turn the wheels of 100,000 motors, small wheels



Joseph Henry

and large, run tiny devices of great precision, or huge and ponderous machinery.

And in the 20th century, the electric current was made to produce streams of free electrons and of long-wave radiation to give us radio, television, recording instruments, computers, and a thousand other things that would be altogether impossible without electricity.

Electricity, then, is not a luxury item. It isn't just something to run an air conditioner and an electric toothbrush. It isn't something that can be replaced with fans and ordinary toothbrushes to be powered by a little bit of muscle.

Technology and Electricity

Our whole industrial civilization depends upon cheap energy streaking out in all directions and under fingertip controls—and that would be very difficult without electric current. It would take enormous ingenuity to find substitutes. If all electricity were shut off, then all electronic

devices would be dead. Electric lights would darken. Aluminum would become a rare metal. All factories would have to develop power sources on the spot and would have to switch to primitive, mechanical controls. Every house and every farm would have to give up items we have come to take for granted—not only electric lights, but electric irons, electric toasters, electric water pumps, electric control of furnaces, and so on.

In short, more than a century of technological advance would vanish and much of it could not be replaced.

In the last century, some 2 billion people have been added to the earth's population, partly because an electrified technology could support many more people than a non-electrified one could. Without electricity, how many of those 2 billion people would have a drastically shortened life-span?

And yet the convenient miracles of electricity do have their price in terms of damage to the ecology. Until now, the price has been low enough for mankind to be willing to pay it, but it is going higher each year and we must ask ourselves

what we must do to lower it again before it climbs too high to pay, and before irredeemable catastrophe results.

The price can be described in the form of two questions: (1) How badly is the production of electricity polluting our environment? (2) How soon will we run out of energy sources with which to form electricity?

First, the matter of pollution.

Electric Power Production and the Environment

Most electricity is produced through the burning of fossil fuel—coal, gas, and oil. The products of burning are poured into the air. Most of this is carbon dioxide and water, which are normal components of the atmosphere. There are also minor products—soot, carbon monoxide, sulfur dioxide, and so on—that are unpleasant or dangerous or dirty or all three.

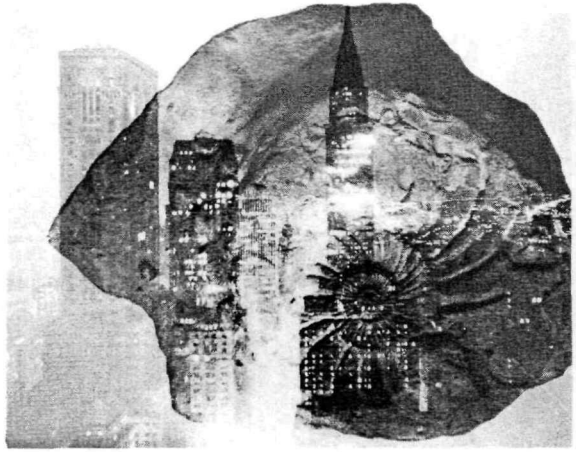
Of course there have been fires for thousands of years, but the 20th century has seen an enormous increase in the rate at which fossil fuels are burned and that rate is still

increasing as the demand for energy in the super-convenient form of electricity keeps rising even faster than the population. The result is that though pollution is not new, it has never been so great in rate of production, and it is now beginning to worry many people.

To keep combustion products from fouling the environment, killing plants, increasing respiratory disease, and generally damaging the quality of life, it would help to burn fuel more efficiently and completely. It would also help to select varieties of coal and oil that are low in those elements which are particularly prone to produce undesirable combustion products—low in sulfur, for instance.

Of course, we live in a world in which improvements are usually to be had only at a price. To develop more efficient methods of combustion means investment in special devices. To make use of low-sulfur fuel means competing for smaller supplies. Both of these changes would make electricity become more costly.

Then, too, even if coal and oil are burned perfectly and produce nothing but carbon dioxide and water vapor, carbon



Most electricity is produced through the burning of fossil fuel—coal, gas, and oil.

dioxide itself becomes something of a pollutant in quantity. With an entire atmosphere in which to dump carbon dioxide, however, its concentration is not likely to rise very much above its normal level of 0.03%, and surely never to the point where it will interfere with breathing.

But even small rises in carbon dioxide content increase the efficiency with which the atmosphere retains heat. This so-called "greenhouse effect" helps raise the earth's average temperature. Some have speculated that even an increase of only a couple of degrees could melt the polar ice caps and raise the sea level high enough to flood vast coastal areas of the continents.

Even if this does not happen* there is the problem of what would happen once the readily available coal and oil are used up.

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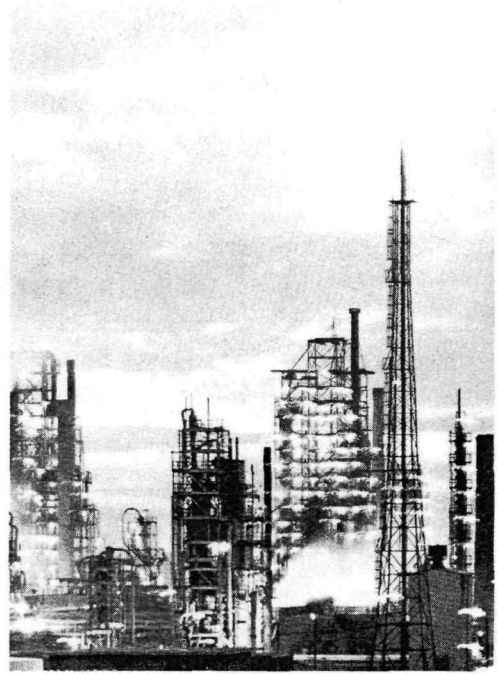
*One reason it may not happen is due to the dust level in our atmosphere. This level, which has increased because of our industrial civilization, cuts down on sunlight slightly and cools the earth. This balances the effect of the carbon dioxide.

Fuel Consumption

We are now consuming coal and oil with such abandon that, at the present rate of consumption, known reserves of oil will be gone in less than a century and the coal in 3 or 4 centuries.

There may be ways of increasing the efficiency with which the fuels are used. At present, fuel must be burned, the heat must boil water to steam, the steam must turn a wheel, and the turning wheel must generate electricity. At each stage, there is loss of energy, and, in the end, the electricity formed represents only 30 to 40% of the energy present in the fuel to begin with.

It is possible to use the fuel to heat gases to high temperatures of 5000° and send them through a magnetic field that generates a current directly. This is a "magneto-hydrodynamic generator". This would eliminate a great deal of the hardware needed for the boiling of water and the turning of wheels. Given further development of such a system, it may be that up to 50 to 60% of the energy of burning fuel would be converted to electricity. The efficiency



Part of an oil refinery.

would be some 5 to 7% greater if electricity were transported through wires held at temperatures near absolute zero. At those ultra-frigid temperatures some metals become "superconductive" and transport electricity with zero loss.

But even at 100% efficiency, fossil fuels would still last only 2.5 times as long as we now expect them to and would disappear in 5 centuries or so. This is to be regretted not only because of their value as fuel, but also because they would no longer serve as a source for innumerable chemical products: lubricants, dyes, medicinals, and so on.

Energy Options

It would be nice if we had some energy source for the production of electricity that would not involve the burning of fuel at all. We have the energy of falling water, the energy of hot springs, and the energy of the tides. These produce no chemical pollutants, not even carbon dioxide, and cannot be permanently used up; for falling water will continue to fall, hot springs to flow, and tides to surge, as long as sun, moon,

and earth exist. These noncombustion sources of energy, however, are located only here and there on the earth.

Solar Power

One might create electricity directly from sunlight. One could conceivably cover 300,000 square miles of the Sahara Desert with special batteries that would yield electric current on exposure to sunlight. Even at 1% efficiency, that quantity of largely useless desert would suffice to support the world's electrical needs at their present level. Or perhaps satellites far out in space might collect sunlight and beam its energy to earth in the form of microwaves that could be converted to electricity.

Such sunpower would produce no pollution and would ensure a copious electric supply as long as earth and sun are in their present form.

Unfortunately, the direct use of solar heat would require enormous investment in the form of both initial cost and upkeep, and the state-of-the-art is not yet advanced to the

point where the giant engineering schemes required to make it practical can be realized. Nevertheless, it would certainly be desirable to keep the possibility of the practical use of solar energy in mind.

Nuclear Power from Fission

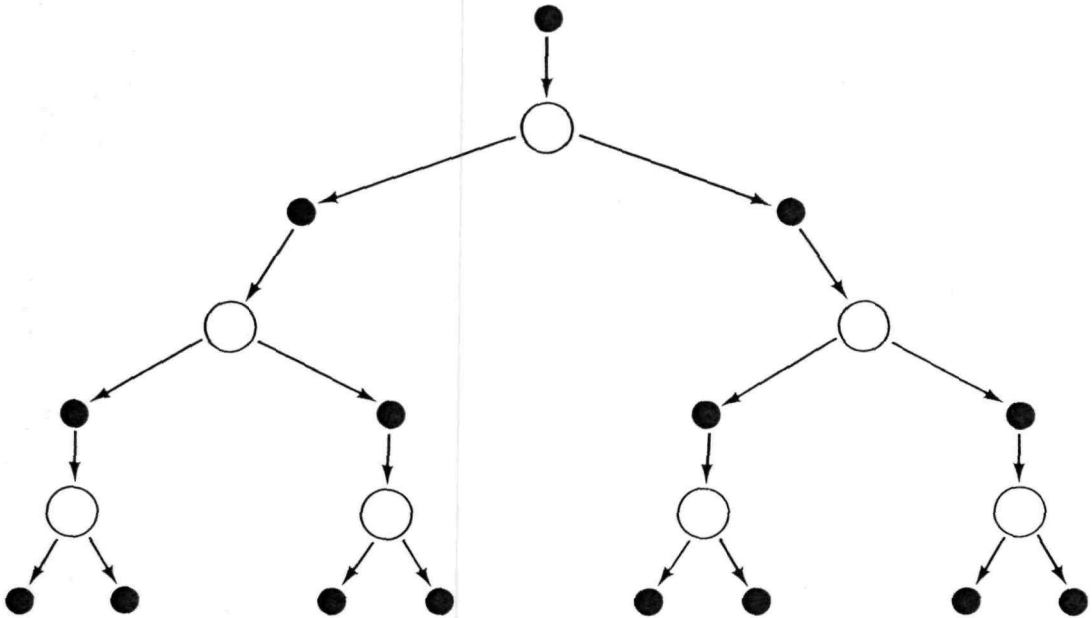
At present, though, it appears that, for the near future, the best bet for obtaining larger supplies of electricity than are currently available, lies in making more use of nuclear energy.

The burning of fossil fuel in ordinary fashion makes use of the energy that lies among the electrons on the outskirts of the atoms. This supply is relatively small, only a tiny fraction of the energy that is concentrated in the atomic nucleus—the tiny structure in the heart of each atom. Unfortunately, it is not easy to get past the cloud of electrons that surround the nucleus and reach the nucleus itself.

The first real success in this respect came in 1942, when scientists learned how to split the nucleus of uranium-235 and begin a chain reaction that would cause other nuclei of uranium-235 to split apart in their turn. This energy was more than a million times greater per weight of material than that produced in the burning of coal or oil.

Of course, uranium-235 is an exceedingly rare material, and no matter how energetic its "fission" might be, its use for the production of energy in quantity would be limited. Fortunately, it is possible to devise fission reactors that will convert the more common uranium-238 (140 times as common as uranium-235) into a form capable of undergoing fission. Reactors can also convert the even more common thorium-232 into a form that will fission.

In such reactors the neutrons released in the fission process enter a surrounding shield of uranium-238 or thorium-232 and convert some of that material into fissionable atoms. Such a reactor forms more fuel in the shield than it consumes in the core. It actually breeds fuel, rather than using it up. It is a "breeder reactor".



Nuclear Fission of Uranium: A neutron hits the nucleus of an atom of uranium. The neutron splits the nucleus into two parts and creates huge amounts of energy in the form of heat. At the same time other neutrons are released from the splitting nucleus and these continue the fission process in a chain reaction.

The feasibility of such a reactor has been scientifically demonstrated by the construction and successful operation of a number of them on an experimental basis. A strong effort is now in progress to produce a breeder reactor on a commercial scale by 1980.

As a result, present-day technology is perfectly capable of making use of all the readily available supplies of uranium and thorium on earth as a source of electrical energy. It is estimated that the total amount of electricity that would be made available through fission by way of breeder reactors is over 500 times as great as that which would come from the burning of the present supply of fossil fuels. It would supply mankind with all the energy it needs for centuries to come.

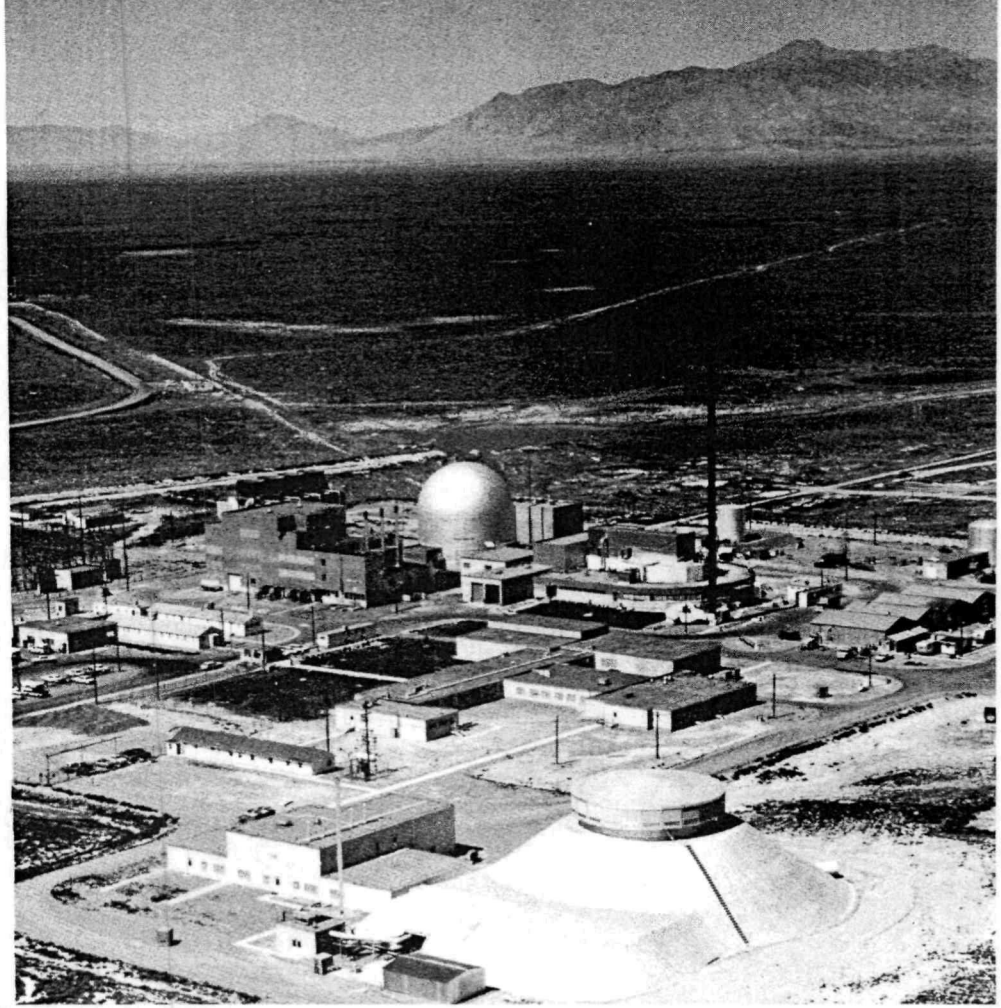
Yet though the nuclear fission power plants do not produce the usual type of pollutants that the combustion of fossil fuels does, they produce something that has another kind of danger. The fission of the uranium or thorium nucleus produces new atoms that are highly radioactive and that, if not carefully controlled, can be very dangerous to life.

Nuclear scientists have labored to make fission plants as safe as possible and, indeed, their safety record is enviable. Much effort is put into the safe handling and disposal of the radioactive products. Liquid wastes from nuclear power plants are processed by evaporation and ion exchange. The resulting end products are solidified in concrete, sealed in drums for safe disposal by land burial on AEC or commercial radioactive waste burial grounds.

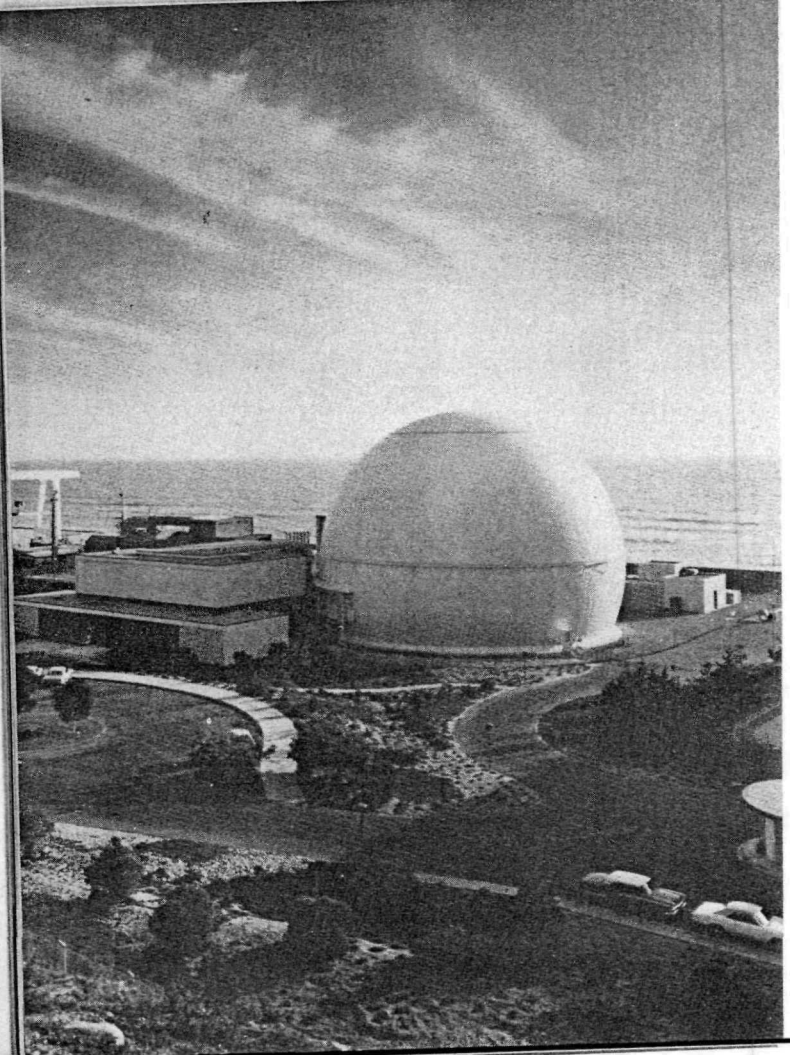
Nevertheless, the safe disposal of the radioactive ash is a difficult problem and grows more difficult each year as the plants produce more electricity—and more ash.

There are also fears among some laymen of accidents that may spread deadly radioactivity over a wide area. The chances of this are small, but so dreadful are the possible consequences, that any chance, however small, disturbs people. In some cases there has been difficulty in gaining acceptance of proposed sites for nuclear fission power plant construction.

But though fission is the easiest way of utilizing nuclear energy, it is not the only way.



Exterior view of the Experimental Breeder Reactor No. 2 complex in Idaho. The reactor is housed in the dome-shaped building.



The San Onofre Nuclear Generating Station near San Clemente, California, has a net electrical capacity of 430,000 kilowatts and began commercial operation in 1967.

Nuclear Power from Fusion

It is also possible to smash small nuclei together and have them fuse into larger nuclei. Hydrogen nuclei can be fused to helium, for instance, and in so doing will produce 7 times as much energy per pound as fission does.

It is hydrogen fusion that produces the vast explosion of the hydrogen bomb. It is hydrogen fusion that keeps the sun and the other stars shining and giving off energy for billions of years.

Producing a controlled hydrogen fusion reaction on earth (and not just an uncontrolled hydrogen bomb explosion) is difficult, however. It requires temperatures of 100,000,000° and more. It also requires at this super-hot temperature a supply of hydrogen nuclei that is held in place by magnetic fields long enough for the fusion reaction to be initiated.

Scientists of all nations have been working in cooperation now for 20 years and they have been making progress in the direction of controlled fusion.

If fusion power plants become practical some day (and that day we hope will not be too far beyond the turn of the century, for the need is increasing yearly) then the chief fuel is likely to be deuterium, which is hydrogen-2, an isotope of hydrogen. Deuterium fuses with considerably greater ease than ordinary hydrogen.

Deuterium is only $1/6000$ as common as ordinary hydrogen, but even so the ocean is so rich in hydrogen atoms that it contains about 35 thousand billion tons of even the rare variety, deuterium.

What's more, it isn't necessary to dig for that deuterium or to drill for it. If ocean water is run through separation devices, the deuterium can be extracted without very much trouble. In fact, for the energy you could get out of it, deuterium from the oceans (even by using present-day techniques and not counting future improvements) would be only one-hundredth as expensive as coal.

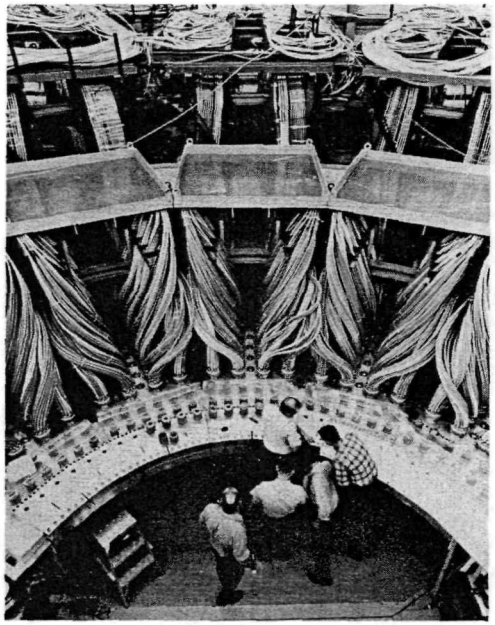
The deuterium in the world's oceans, if allowed to undergo fusion little by little, would supply mankind with enough energy to keep going at the present rate for billions of years. If we are careful, hydrogen fusion will supply

man with all the energy he will need for as long as he exists on earth.

Then, too, fusion reactors will be incapable of "runaway" accidents. Unlike the fuel in a fission reactor, the gaseous fuel of a fusion reactor is continuously renewed. At any given time the actual quantity of fuel present will be so small that there just won't be enough available for serious trouble.

Yet, on the other hand, all is not rosy. There are bound to be some problems. A fusion reaction involving deuterium only is not likely to prove practical. The rare metal lithium may be involved or an even rarer radioactive form of hydrogen called tritium. In either case, the total potential for controlled fusion energy will be greatly reduced though it will still be far greater than that available by fission alone. The use of tritium will make it necessary to guard against radioactive damage. In addition, neutrons will be formed in the process and these will have to be absorbed in some way.

In summary, while we work toward, and wait for, the advent of practical fusion reactors, we hope that the breeder fission reactors will keep us going comfortably.



Enormous machines and complex equipment such as this Scyllac machine are required for nuclear fusion research.

Well, then, suppose we manage to solve the technical problems standing in the way of practical fusion power plants and take care of any obvious dangers involved, will there be any problems at all remaining? Will we then finally have reached that Eden where, with an abundant supply of cheap energy, we can make of the earth anything and everything we want?

Thermal Effects

Unfortunately, there still remains a problem—"heat pollution". Even though fusion power plants produce no chemical pollutants, they still produce heat, and this must be disposed of.

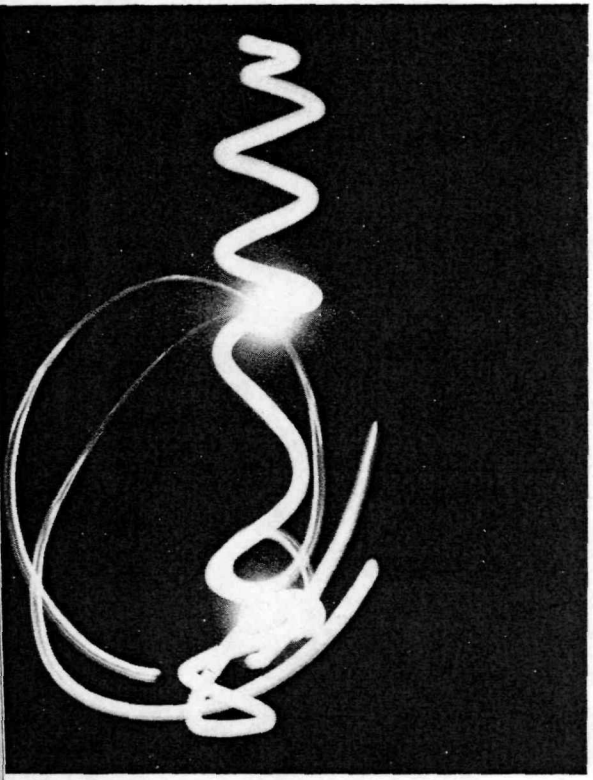
The sun is constantly heating one half of the earth, while the other half radiates heat away into space. The energy received from the sun on one side is just balanced by the energy radiated away on the other side so that the average temperature of the whole earth never changes.

But what if man-made energy over and above that of the sun is produced in such quantity that the earth cannot radiate away the extra energy as fast as it is formed? In that case, the temperature of the earth would have to reach a new and slightly higher level.

At the present time, earth receives heat from the sun at a rate 100,000 times as great as that which it receives from man-made energy. The small quantity of man-made energy makes little difference therefore to earth's temperature.

If, however, earth's man-made energy were to increase to 1% of the total solar supply, that might produce enough of an increase in the earth's average temperature to cause the ice caps to melt and so on. It might be, then, that we would have to be careful never to exceed that rate.

Of course, that represents the utilization of energy at 1000 times the present rate, and, if we control our population and increase the efficiency of our devices, that much energy may be sufficient for our needs forever. Or we can learn how to help earth radiate heat more quickly.



Conclusion

Let's summarize, then—

(1) Every aspect of earth's economy now depends on a copious supply of cheap energy transported in the convenient form of electricity. It is only our industrial economy, of which electricity is so important a part, that makes it possible to support earth's 3.6 billion people even at the present unsatisfactory level.

(2) To abandon electricity, and to cut our use of energy quickly, in some idealistic attempt "to return to nature" cannot be done without sacrificing much of earth's population to famine.

(3) To stand still at the present technological point will result in accumulating pollution and in the depletion of energy resources at an unacceptable rate, leading again to an inevitable catastrophe of colossal dimensions.

(4) To move forward in the search for more, better, and safer energy supplies is the only possible way of avoiding such catastrophe. Technology isn't the whole answer, for mankind must avoid nuclear war, prevent social chaos, and solve its population problems. But from the strictly technological standpoint, the goals we must aim for are those of developing breeder reactors, going on to make fusion power plants practical at the earliest possible date, developing other energy options, and of holding down pollution to an acceptable level until that date arrives.

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