ARTIFICIAL LIVING PLANTS

Proposed here is a design for self-reproducing machines that would be harvested for the materials from which they construct themselves. They might prove more feasible than spaceships and more profitable

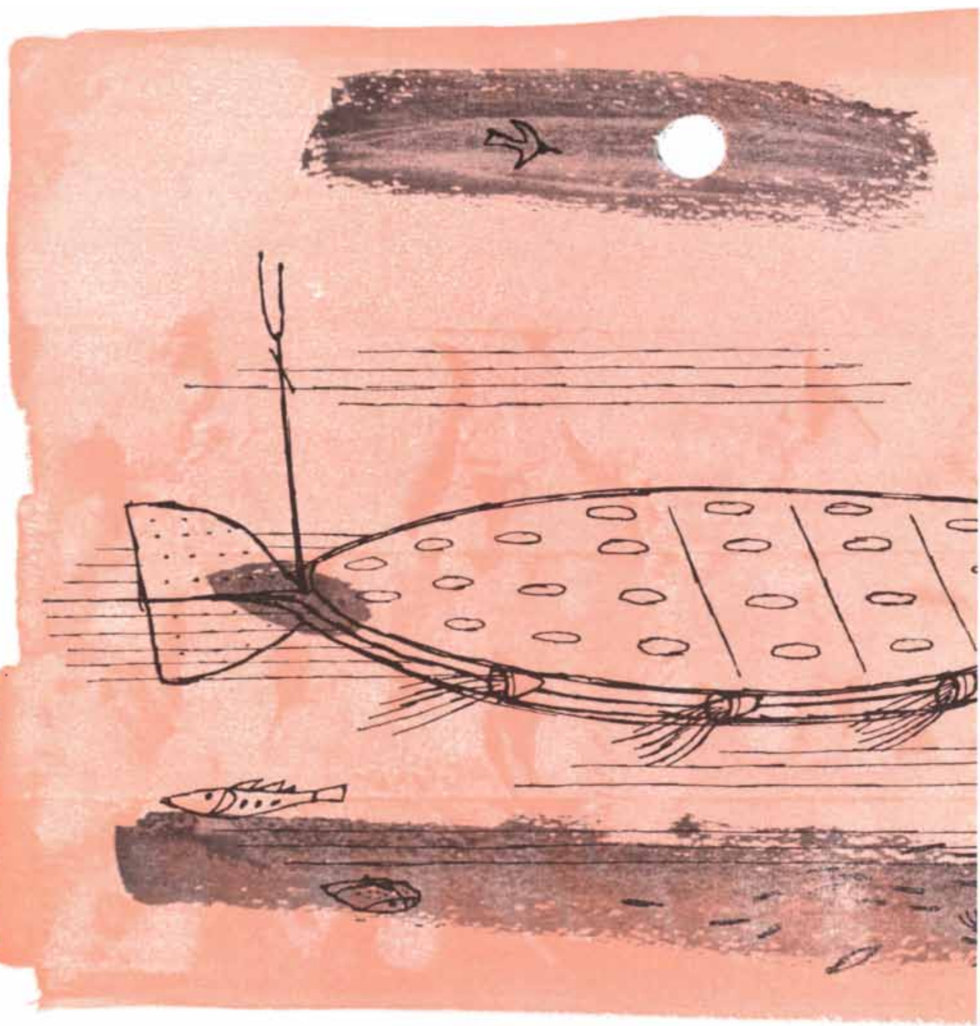
by Edward F. Moore

In the growing profession of designers of automatic machines, discussion goes on at two levels. One is the immediate business of building machines for given purposes. The other is the more theoretical, but in some ways more enjoyable, occupation of speculating about machines of the future. These visions sometimes seem fantastic, but they rest on something more solid than fantasy. Engineers join with philosophers in the speculation. Even practical men know that it is from such dreams that the machines of tomorrow will spring.

Several years ago the mathematician John Von Neumann, who has been a pioneer in designing computers, demonstrated as a proposition in logic that it would be possible to build a machine which could reproduce itself [see "Man Viewed as a Machine," by John G. Kemeny; SCIENTIFIC AMERICAN, April, 1955]. Von Neumann's machine would be made of wires, relays, batteries, devices for doing mechanical manipulation, and so on. Set up in a stock room well supplied with these parts, the machine would assemble them into a copy of itself. The machine and its offspring could go on building duplicates as long as the supply of parts lasted.

It is unlikely that the machine Von Neumann described will ever actually be built, because it would have no useful purpose except as a demonstration. I would like to propose another type of self-reproducing machine, more complicated and more expensive than Von Neumann's, which could be of considerable economic value. It would make copies of itself not from artificial parts in a stock room but from materials in nature. I call it an artificial living plant. Like a botanical plant, the machine would have the ability to extract its own raw materials from the air, water and soil. It would obtain energy from sunlight—probably by a solar battery or a steam engine. It would use this energy to refine and purify the materials and to manufacture them into parts. Then, like Von Neumann's self-reproducing machine, it would assemble these parts to make a duplicate of itself.

For the first model of such a machine, a good location would be the seashore, where it could draw on a large variety of available materials. The air would provide nitrogen, oxygen and argon; the sea water would provide hydrogen, chlorine, sodium, magnesium, sulfur, calcium,



This artificial living plant is jet-propelled, on the model of the squid.

potassium, bromine and carbon; the beach would provide silicon and possibly aluminum and iron. Other elements would be available in smaller quantities. From these elements the machine would make wires, solenoids, gears, screws, relays, pipes, tanks and other parts, and then assemble them into a machine like itself, which in turn could make more copies. If the model designed for the seashore proved a success, the next step would be to tackle the harder problems of designing artificial living plants for the ocean surface, for desert regions or for any other locality having much sunlight but not now under cultivation. Even the unused continent of Antarctica might be brought into production.

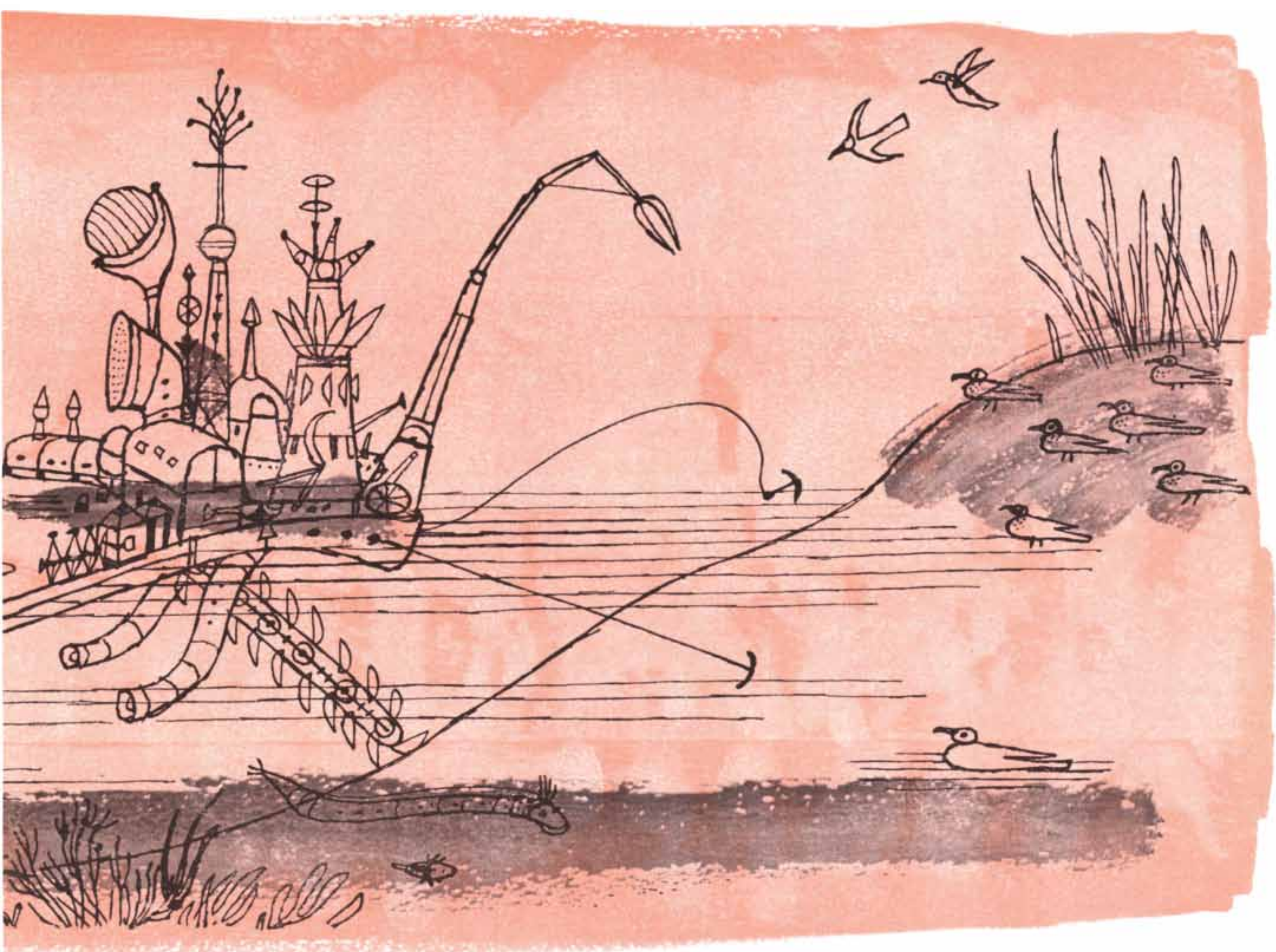
It is easy to see that a plant of this kind could have considerable economic value. It could be harvested for a material it extracted or synthesized, just as cotton, mahogany and sugar cane are now harvested from plants in nature. Thus an artificial plant which used magnesium as its chief structural material could be harvested for its magnesium.

The problems to be solved in the design of such a plant would be problems in logic, electrical engineering, mechanical engineering, chemistry and chemical engineering. The main problem in logic has already been solved by Von Neumann, and the additional tasks in logic posed by this machine would be no more difficult than those solved regularly by the designers of digital computers, automatic elevator controls and telephone central offices. In electrical and mechanical engineering the problems would be somewhat more complex than those handled so far in automatic factories, but they could certainly be solved by the expenditure of enough time and money. Most difficult of all would be the problems in chemistry and chemical engineering; their solution might not be possible without advances over present-day technology.

The first chemical problem is to decide what materials would be required for the plant. For the electrical part of the machine they would have to include a conducting material, an insulating material and a ferromagnetic material. For containers in which to carry out the necessary chemical operations and processes, the machine would need refractory materials—to line a smelter if metal smelting is one of the operations, or to resist sulfuric acid if the manufacture of sulfuric acid is one of the processes.

Once the list of needed materials was chosen, engineers would have to design a flow scheme for the automatic manufacture of all of them. It would be very desirable to keep the list of materials as short as possible, and the manufacturing operations and processes as simple as possible. Since not all the materials would have to be made at once, much of the apparatus could be used for different purposes at different stages.

The operations chosen would not



When securely moored, it will begin the process of reproduction.

Like lemmings, a school of artificial living plants swims into the maw of the harvesting factory.

necessarily be the most economical ones available, for it might be advisable to use somewhat inefficient methods to cut down the complexity of the machine and maximize its over-all effectiveness. In designing such a machine it would simplify matters to adopt some criterion as a general guide for choosing between possible processes or materials. The most reasonable general criterion is the time factor—how long it would take, say, for a population of artificial living plants to double itself. If this time could be made as short as six months or a year, the artificial living plants would be very successful, but if it were as long as the time it takes for money to double at compound interest, the machine would be a poor investment.

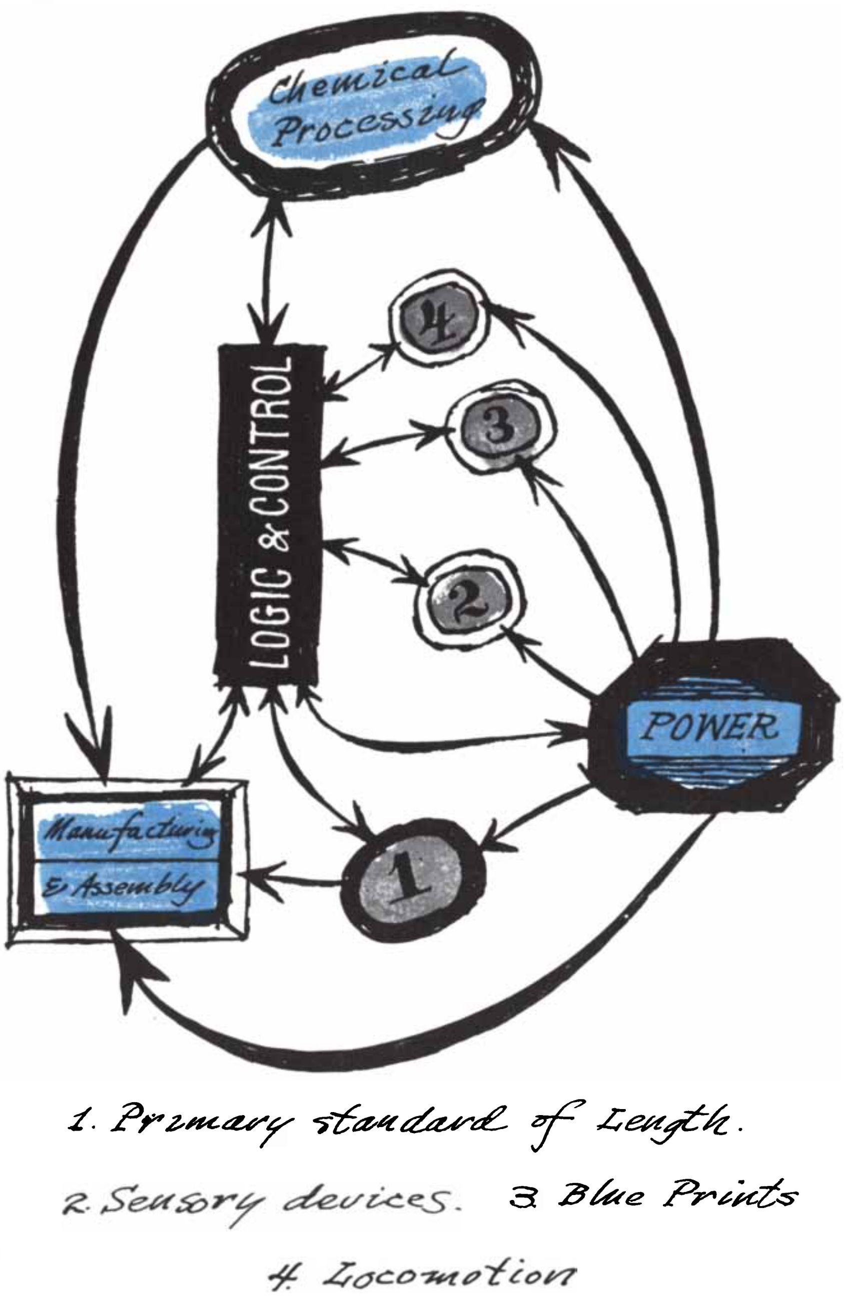
The calculation of net reproduction time of course would have to take account of mortality among the artificial living plants: a certain fraction of each generation would "die" because of internal failures, degeneration or natural catastrophes such as earthquakes or hurricanes.

To use energy effectively and reproduce itself in a reasonable time the machine should be small, or at least very thin. The energy required to manufacture materials would be proportional to their mass (*i.e.*, roughly the cube of the linear dimension), but the machine would receive energy from sunlight only in proportion to area, or the square of linear dimension. A population of algae, spread on the surface of a pond or tank, takes less than a week to double itself, but a sequoia tree may take centuries.

Why make an artificial plant out of ferromagnetic materials, electric motors, machine tools, gears, screws, wires, valves and lubricating oil? Why not make it of organic materials, such as amino acids and chlorophyll? The answer, of course, is that we do not yet understand organic chemistry well enough. Biochemists have not even identified all of the chemical substances in the simple blue-green alga. They are still far from being able to synthesize substances such as chlorophyll. On the other hand, the chemistry of electrical insulators, ferromagnetic materials, lubricating oils and so on are so well known that they can easily be synthesized from materials in nature. Moreover, engineers are on familiar ground in operating machinery by electrical and mechanical methods, but we would not know how to begin to design a system operated by hormones and enzymes.

Similarly we would have to be content with a plant that reproduced itself from the same blueprints, or "genes," in every generation. We have a somewhat better understanding of theoretical genetics and evolution than we do of biochemistry, but it is still not complete enough to enable us to endow a machine with evolutionary abilities. In any case, the ability to mutate would be a doubtful benefit: it seems safer, at least at the beginning, to let the plant reproduce itself exactly in successive generations, lest it take on undesirable characteristics.

If the object is to manufacture a specific product, would it not be much simpler to design an automatic factory to make it, rather than to go to all the trouble of creating an artificial living plant? It would indeed be simpler, but obviously the returns would not be as great. Where a factory turns out products at a constant rate, the production of the artificial living plant would grow exponentially. If its net reproduction time were one year, after 30 years there would be more than a billion of these



Feedback circuits (double-pointed arrows) *ensure coordination of principal organs.*

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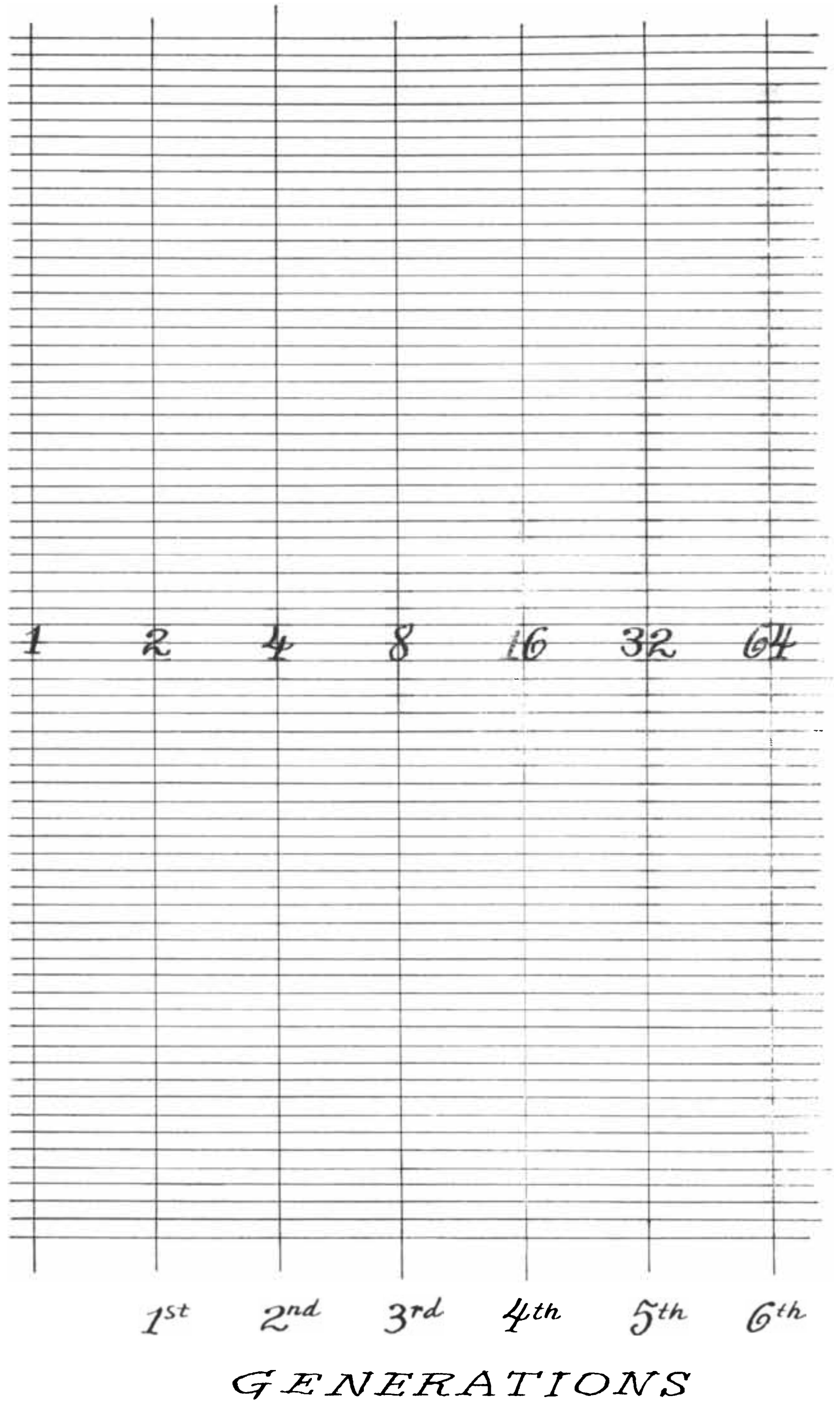
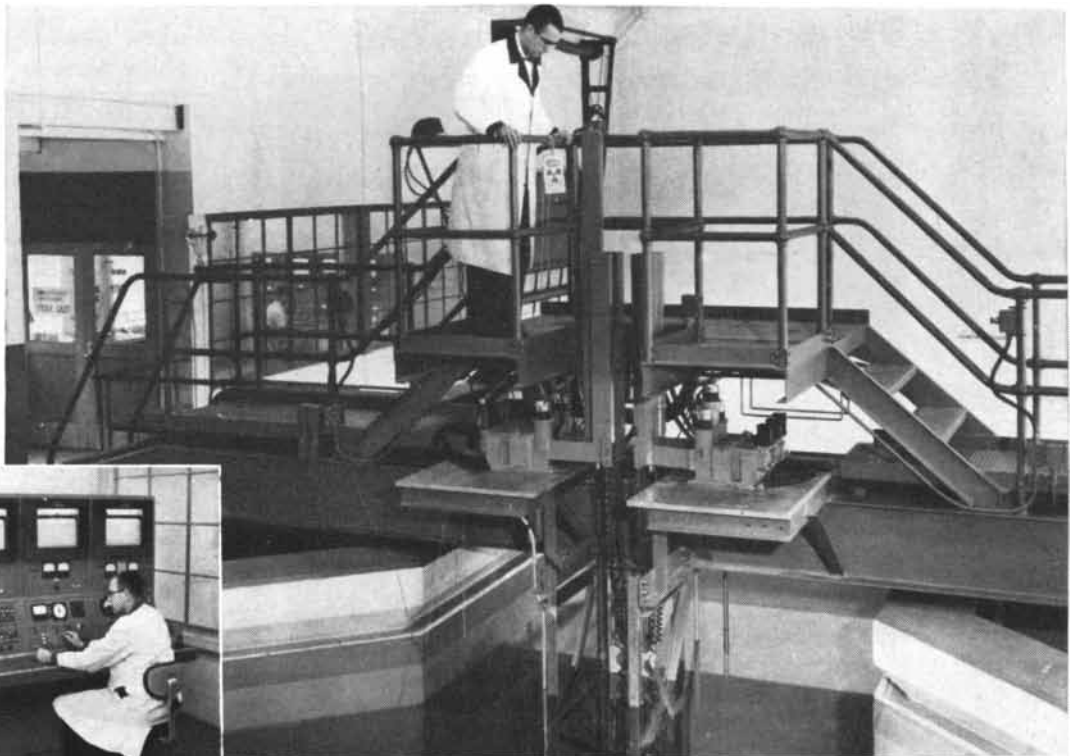


In six generations one plant would have 63 descendants and 1,048,575 in 20.

plants! Needless to say, they could not be allowed to reproduce indefinitely, for they would soon fill up the oceans and the continents. And the artificial plant would have to be provided with a means of locomotion to move out of the way as it was produced; if not, the multiplying population would cut off sunlight and choke itself to death. As the counterpart of the seed-dispersing mechanisms whereby plants are distributed in nature, the artificial plant would need wheels or a propeller. It might be worth while to build into these plants a tendency to migrate, like lemmings, to preassigned locations where they could be harvested conveniently.

Clearly there would be need for international controls and allocation of areas for production and harvesting. This



Scientist at Battelle Memorial Institute observes reactor core prior to startup. Control console at left includes Honeywell *ElectroniK* strip chart instruments to record nuclear radiations and power level; and Honeywell safety amplifier for simplified emergency shutdown of reactor.

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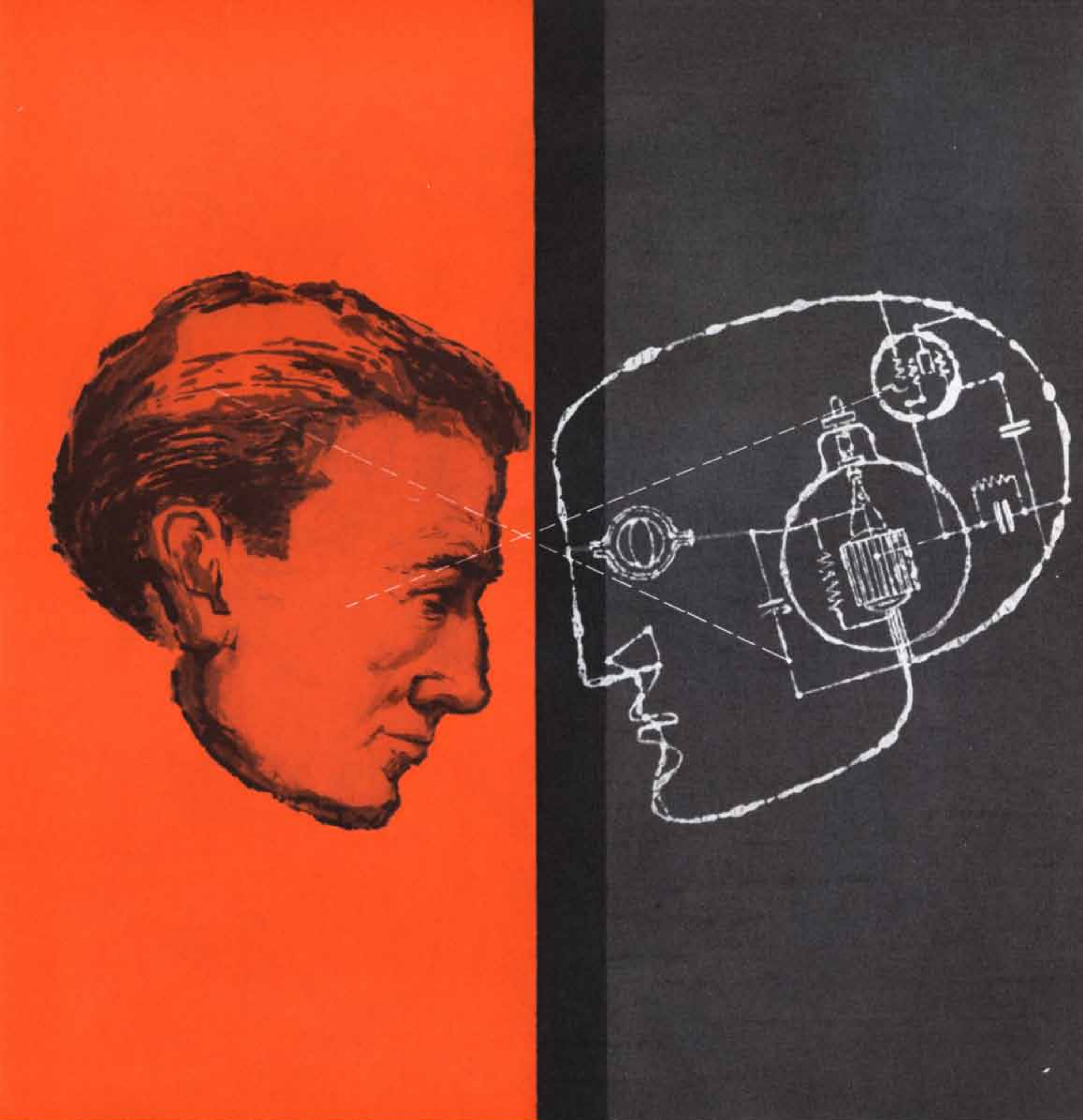
would involve not only the political rights of nations but also questions of natural conservation. Ecologists would be concerned about the artificial plant's competition with natural plants for sunlight and the possibility that it might upset the balance of nature in the areas where it was allowed to multiply.

Social problems would also arise in connection with the selection of products to be manufactured. An artificial plant might be designed to make a product which was not useful to the plant itself. For instance, it might extract gold from sea water, refine it and cast it into an ingot, which would be harvested as the crop from the plant. But it would certainly be shortsighted to select this crop for manufacture. Multiplying at an exponential rate, the gold-making plant would soon produce so much of it that gold would lose its scarcity value and probably end up being worth very little, for gold does not directly fulfill any essential human need. On the other hand, an example of an excellent candidate for production by an artificial plant is fresh water, which is needed in great quantities in various parts of the world.

In short, the artificial living plant has tremendous possibilities, if we can solve the problems in designing it. Such machines would free mankind's agriculture from dependence on the natural characteristics of plants. They would make it possible to produce any desired crop, instead of only those that nature happens to have provided. They would be a long step forward in man's control of his environment.

How much would such a project cost, and how soon could it be successful? That depends on the difficulties encountered in chemistry and chemical engineering. My guess is that if, on the basis of present-day chemical knowledge, a scheme could be found for a machine to reproduce itself from a short list of materials made by simple and efficient processes, the whole design problem could probably be solved in five or 10 years, for as little as $50 million to $75 million. But if new chemical processes must first be found, and if the machine would require a long list of materials producible only at low yield in complicated fashion, it might cost hundreds of millions of dollars and take decades to develop such a machine. I think the achievement would be more easily attainable than human flight to other planets in a spaceship, but it is obviously not going to be accomplished by a lone inventor working in his basement.



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