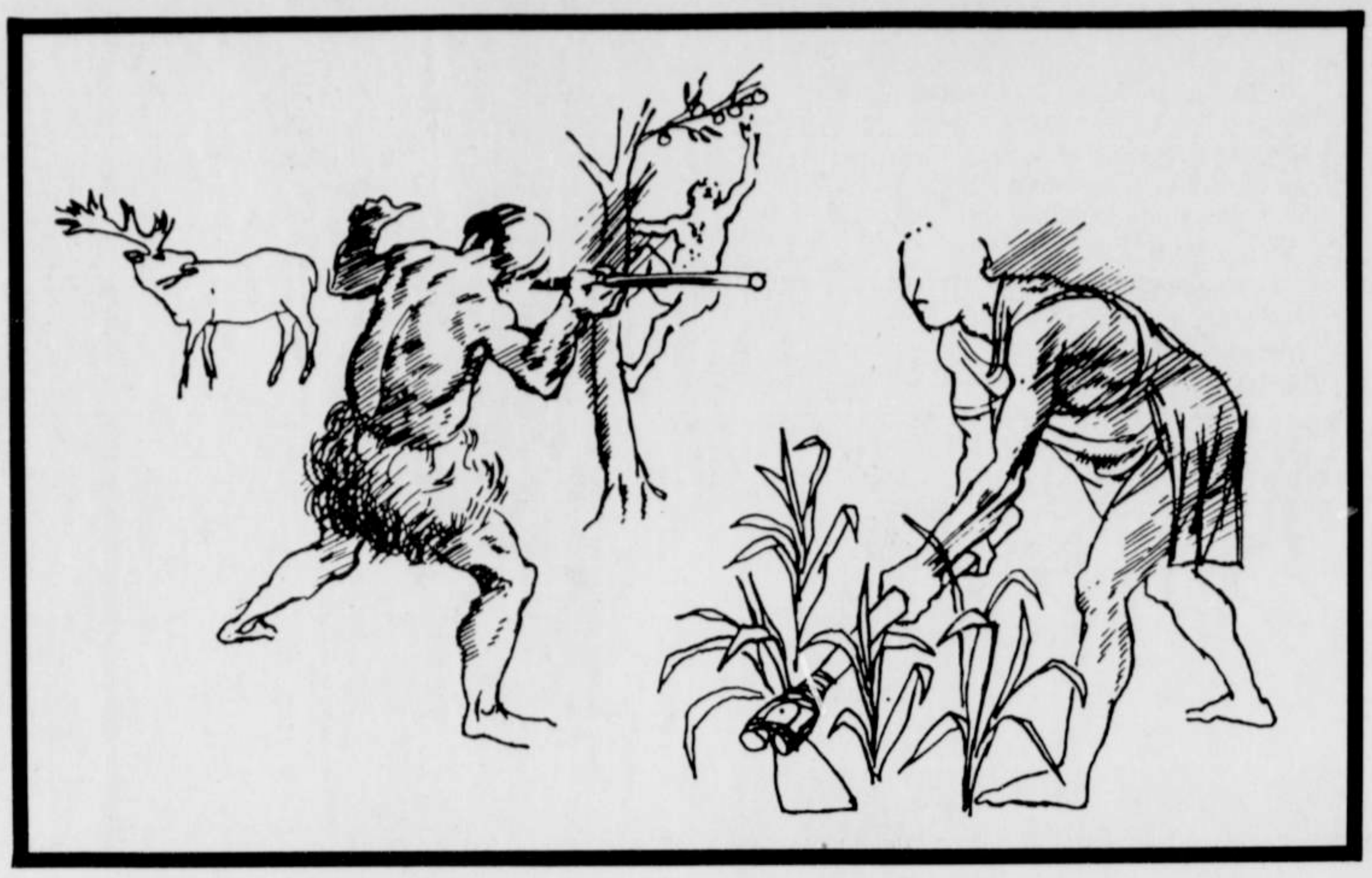
THE FUTURE OF



As the earth's easily available resources are used up, our industrial order is nearing a point of no return. Barring disaster, it can prosper on little more than seawater and granite. But if it should be destroyed in a world cataclysm, it might never rise again.

BY HARRISON BROWN

Harrison Brown was professor of geochemistry at the California Institute of Technology when he wrote the following article for the January 1959 issue of HORIZON, which develops a theme from his book, 'The Challenge of Man's Future'.

Civilized man is coming to the point at which, for his own survival, he will be dependent upon the smooth functioning of his machines. Up to now in human history, this has not been true. Machines have been simply labor-saving devices, rather pleasant luxuries, which enabled us to substitute the energy of coal for the beast of burden or for human muscle. But the role of machines is undergoing a transformation and we shall, in the not too distant future, become their slaves. We must continue feeding them; we must keep them operating; we must build new ones at an accelerating pace. If for any reason they were collectively to fail us, the kind of civilization we know would come to an end and many of us would perish.

Prophets of the future often assume that, even in the event of such a catastrophe, a new industrial civilization would some day rise from the ruins. But this is probably a false comfort. The fact is that we are rapidly approaching a point where such a process of reconstruction would be difficult — if not impossible.

The reason, though seldom given much consideration in discussions of man's future on this planet, is really quite simple. Our present machine civilization was built by making use of the mineral resources easily available on or near the earth's surface. Within a period of time that is very short compared with the total span of human history, supplies of fossil fuels will almost certainly be exhausted. This loss will make man completely dependent upon water power, atomic energy, and solar energy (including that made available by burning vegetation) for driving his machines. There are no fundamental physical laws that prevent such a transition, and it is quite possible that society will be able to make the change smoothly. But it is a transition that will happen only once during the lifetime of the human species.

Once we have crossed the fateful divide, our technology will permit us to continue for as long as industrial civilization keeps functioning. But if for any reason disaster strikes and the industrial network is destroyed, easily available mineral resources — the building blocks of the Industrial Revolution — will not be there for man to use. Without them it seems doubtful that we shall ever again be able to lift ourselves above the agrarian level of existence. Thus man may well be approaching, in terms of industrial civilization, a "point of no return."

Machine civilization as we know it is a manifestation of a new stage of evolution of living matter on earth. Since the dawn of life, the earth has been the abode of innumerable complex interlocking networks of living things, each of which was molded by the combination of the environment and the biological innovations which had appeared up to that time.

Man is the most recent successful arrival on the evolutionary scene. With the help of his machines, he has achieved an unprecedented degree of dominance in the biological environment. But like the amphibians and the reptiles before him, his continued prosperity is not assured by nature.

Man emerged into the world a million or so years ago and for a large part of that time he lived much like the other animals about him. But this new creature possessed a power that was unique to the world scene — the power of conceptual thought. This capability released him from the bondage of being primarily dependent on instinct. He could benefit from the accumulated knowledge of his ancestors. He could transmit his own store of knowledge in detail to his offspring.

With the help of this power, man spread to all parts of the earth where he could eke out an existence. Eventually about ten million human beings inhabited the earth, obtaining their sustenance by hunting and fishing and by gathering varieties of edible plants. That was as far as man could go in terms of numbers until his accumulated knowledge permitted him to obtain more food than was provided by the earth in its natural state. The undeveloped land was then saturated with humanity.

About 7,000 years ago, a dramatic invention appeared that was destined greatly to enhance man's dominance. Man learned that he could cultivate edible plants, and this made it possible for hundreds of humans to live on land that previously supported only one or two. It became possible for an individual to produce more food than he needed for himself and his family, and thus the way was paved for the emergence of towns and civilizations. Human populations increased rapidly. By A.D.1650 there were perhaps fifty times as many human beings as had existed in preagricultural days — about 500 million in all.

Throughout the greater part of the agricultural revolution work was done almost entirely by domesticated animals and by human beings. However, large quantities of wood were consumed for cooking, house-heating, brick-making, and metallurgical purposes. Indeed, the second dramatic "breakthrough" in mankind's history was brought about directly by the fact that the forests in many parts of the world had been cut down.

In England, coal came into widespread use as a substitute for wood. But there was one important process in which wood could not be replaced. Iron manufacture depended upon charcoal, which was made from wood, and repeated attempts to produce an equivalent of charcoal from coal met with failure. Eventually, however, processes were discovered for converting coal into coke, which was a satisfactory charcoal substitute, and the iron industry was liberated from its dependence on woodlands.

The linking of coal to iron was one of the most fateful achievements in mankind's history. It precipitated a series of rapid developments in the course of which a principle that we now call "feedback" exerted profound effect.

As iron became more readily available it came to be more widely used. The demand for coal increased rapidly, with the result that the miners had to dig ever deeper underground. Ground water became a major problem in mining, and efforts to cope with it led to the development of a crude steam engine that could drive a water pump that operated on coal. Further development of this early engine led to its being used for other purposes. It was soon applied in the textile industry, then for transportation. These developments in turn led to increased demands for both iron and coal.The demand for machines grew, as did the demand for machines making machines.

From these early beginnings, industrial civilization emerged in Western Europe. Soon it spread to North America. Later it spread eastward to Russia and westward to Japan. Today we see it spreading to China and India. Barring an intervening catastrophe, it seems inevitable that machine culture, like agriculture, is destined one day to become worldwide.

In the Western world, once machine culture became deeply rooted, developments followed each other with incredible rapidity.The combination of adequate nourishment and the rapid expansion of medical research and public-health techniques raised average life expectancy at birth from fifty years in 1900 to seventy years in 1950. Scientists, inventors, and engineers designed an accelerated flow of new products, devised new production techniques, and greatly increased output per man-hour. Working hours were reduced, and the flow of goods per capita continued to increase rapidly. It began to appear that the combination of science, engineering, and industry might eventually transform the world into a paradise where everyone would have enough to eat, where individuals might own practically all of the material goods they might possibly desire.

However, just as the human body cannot survive on air alone, an industrial machine must be provided with energy and with raw materials if it is to survive. Our industrial civilization feeds on huge quantities or raw materials such as phosphate rock, sulfur, water, and ores of iron, copper, and aluminum. And just as the human body requires energy in the form of food, so our industrial network requires energy in the form of fuels such as coal, natural gas, and petroleum.

As per capita demand for goods continues to grow, as population increases, and as industrialization spreads to other regions of the world, the demand for raw materials will surge upward. Each decade we must produce more materials than were produced the decade before; we must produce more fertilizers, insecticides, machines, and medicines. Correspondingly, we must consume more ores, more coal, more petroleum.

But the ores that feed our machines are not renewable. They are deposited by nature over periods of millions of years and are not being replaced at any appreciable rate today. This means that as time goes by, we will be forced to process ores of steadily lowering grade, and we will be forced to dig ever deeper into the earth. This process of depletion will continue until ores as such no longer exist.

When civilization reaches the point when there are no longer any ores, can it continue to function? We now know that it can, for if necessary our machines could feed successfully on the leanest of earth substances — ordinary rock, seawater, air, sedimentary deposits of limestone and phosphate rock, and sunlight.

We can expect that the industries of the world as a whole will pass through several stages, at the end of which time mineral resources will cease to be important factors in world economy. As high-grade ores diminish in abundance, we will consume our energy resources more rapidly. As coal dwindles and become more expensive, its use will be reserved for premium functions such as reducing iron ore and producing organic chemicals. Eventually iron will be produced entirely without coal, by reduction with hydrogen in electric furnaces, and coal will be reserved entirely for production of chemicals. At some time in the future, aluminum will be produced in the main from anorthosites and clays. Consumption of magnesium will increase, partly as the result of its ready availability in seawater. Sulfuric acid will be produced entirely from calcium sulfate. Increasing emphasis will be placed on the utilization of nitric and hydrochloric acid, largely as a result of the ready availability of raw materials for both. Minor elements such as copper, tin, lead, nickel, and germanium will be extracted from ores containing lower and lower concentrations of the elements, and increasing emphasis will be placed on the extraction of co-products, among which costs can be divided, and on the utilization of substitutes. The mining industries as we know them today will be transformed into enormous chemical industries.

Eventually the time will come when ordinary rocks such as granite will be looked upon as ores.One hundred tons of average igneous rock contain, in addition to other useful elements, 8 tons of aluminum, 5 tons of iron, 1,200 pounds of titanium, 180 pounds of manganese, 70 pounds of chromium, 40 pounds of nickel, 30 pounds of vanadium, 20 pounds of copper, 10 pounds of tungsten, and 4 pounds of lead. Given adequate supplies of energy, these elements could be extracted from the rock, and we now know that the rock itself contains the requisite amount of energy in the form of uranium and thorium.

One ton of average granite contains about four grams of uranium and about twelve grains of thorium. These are admittedly tiny amounts, but the energy content of this amount of