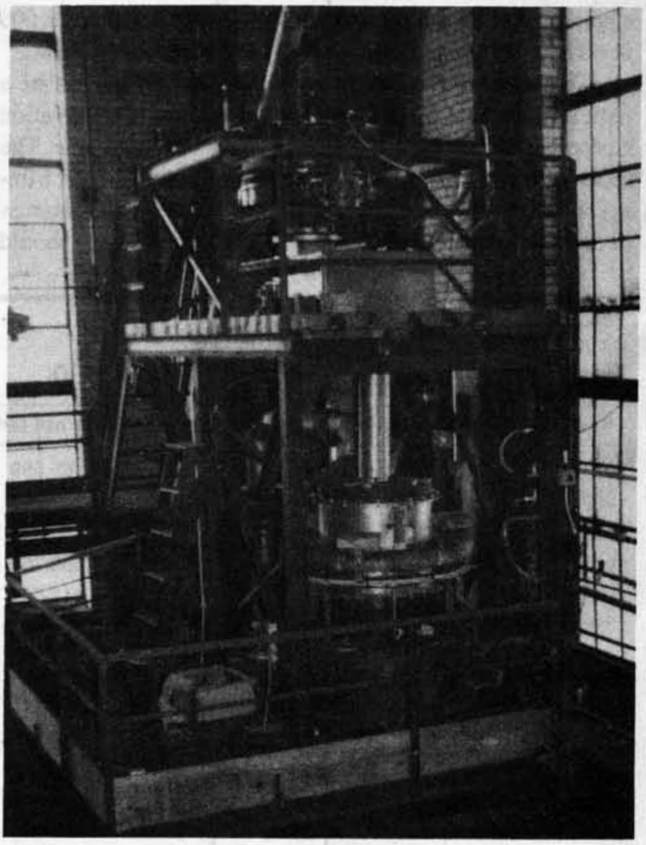
Plasma reactors will end reliance on foreign minerals

Part I in a series by Robert Gallagher on the metal-processing techniques that will have a vital impact on national security.

The United States is today almost completely dependent on foreign sources of aluminum, chromium, manganese, titanium, and other "strategic materials," and our dependence on foreign sources of steel is growing alarmingly. Chromium and manganese are important alloying metals for production of specialty steels, and aluminum is critical today for production of everything from railroad cars to intercontinental ballistic missiles. As **Figures 1 and 2** show, we simply could not build the MX missile without imported metals and metal ores.

Yet as this series will show, the technologies are close at hand to overcome this import dependence in a revolutionary way. We shall examine the new techniques under development for refining metals, such as the plasma reactor, powered by a plasma torch, using in some designs, magnetic processes for the separation of various metals from ores. Not only can these methods produce strategic minerals from low-grade ores; they will also produce enormous increases in productivity and energy efficiency, at lower capital cost than conventional methods.

Particularly crucial today is the bottleneck we face in our capacity to produce steel for defense, for infrastructure projects, and capital goods. *EIR*'s Quarterly Economic Report of June 15, 1985 showed that for the United States to return to 1960s qualities of industrial production, approximately 450 million tons of steel must be produced per annum for metalworking industries alone, without including the huge capacity increase required for construction of bridges, railways, dams, nuclear power plants, irrigation projects and other



The upper portion of the sustained shockwave plasma (SSP) reactor, designed by Jozef Tylko.

needs. Meeting only this 450 million ton figure, would require increasing U.S. steel production five-fold.

This figure is not arbitrary. A capacity requirement of the same order can be derived by looking at the market-basket of steel required by industrial operatives. In 1965 U.S. steel output reached an all-time high of 6.63 tons per industrial operative. Were the United States to go through a high-technology transformation under which 55% of the labor force became industrial operatives, as proposed by economist Lyndon H. LaRouche, Jr., we would require a national steelmaking capacity of 412 million tons to maintain the same output of steel per industrial operative. The mere expansion of the U.S. merchant marine to match the tonnage of the Soviet fleet, requires approximately 20 million tons of steel, over 20% of 1984 U.S. production.

Last year U.S. National Security Adviser George Keyworth initiated the Steel Initiative Program (SIP), to fund research and development in new technologies for steelmaking. However, this fledgling Department of Energy program, under the guidance of the steel companies (who, as we have documented, do not want to produce steel anyway—see *EIR*, March 5, 1985, "Stop the plot to blow up America's blast furnaces"), has rejected acceleration of the development of the one species of technology capable of solving both the bottleneck in steel production and our dependence on foreign sources of minerals: the plasma reactor.

Today we are close to commercialization of plasma reactors that can produce ferrochrome from domestic ores in Montana, aluminum from domestic aluminum silicates, and that can compress the operations of a Greenfield steel plant into a building the size of a small warehouse, producing steel of all kinds at labor productivities over 10 times greater than today's. This same technology can produce cement with the same compression in scale of production, and leap in productivity.

The world's requirement for steel

Just over the horizon lie plasma magnetic separation processes that can produce all the strategic minerals listed in **Figure 1,** from low-grade domestic ores, at higher efficiencies and labor productivities than existing processes in use abroad. Designs exist today for the separation of titanium, aluminum, tin, iron, nickel, and other metals from ores of any quality.

But national security does not mean an autarchical "Fortress America." For the security of the United States itself, it is essential for world metals production as a whole to leap forward. Only by enabling the nations of Africa, Asia, and Ibero-America to industrialize, can we help them become strong republics, the first line of defense for a republican United States in the tradition of Benjamin Franklin.

FIGURE 1

U.S. reliance on imports of strategic minerals (1979)

Material	Imports as percent of consumption
Aluminum ore	93
Beryllium (beryl)	100
Chromium	90
Cobalt	90
Columbium	100
Iron ore	29
Manganese	98
Nickel	77
Titanium (rutile)	100
Tantalum	96
Tin	81
Tungsten	59

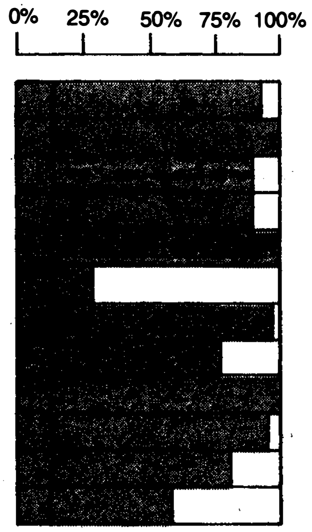
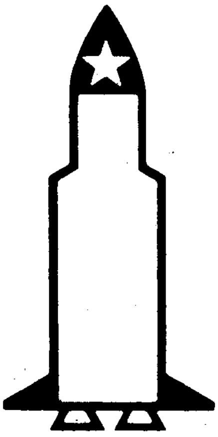


FIGURE 2

Material requirements for one MX missile

Material	Tons
Aluminum	10,000
Beryllium	24
Chromium	2,500
Titanium	150
Steel	890,000
Cement	2,400,000



Were the same formula used above to calculate the U.S. steel capacity deficit, applied to the world—that is, the formula of 6.63 tons per industrial operative, with operatives comprising 55% of the world labor force—the result would be a world steelmaking capacity requirement of 12 to 18 billion tons per annum, depending on how large we assess the world labor force to be. Existing world capacity today is less than 0.8 billion tons per year.

However, according to a University of Chicago study, even these figures are conservative. The report argues that the world requires production of 20 to 50 tons of steel per man, woman, and child, or a worldwide steel-producing capacity of roughly 100 to 200 billion tons per year. As a requirement for a population of engineer-scientists terraforming other planets, these figures are not high.

The great infrastructure projects proposed by Mitsubishi Research Institute require tens of millions of tons of steel. If these projects are going to go through in the next decade, we must see a fantastic leap in U.S. and world production of steel, aluminum, and other metals. This will not be possible, by building more plants along the lines of those currently in use in the United States, Japan, or elsewhere. It is absolutely necessary to take immediate steps to build new steelmaking plants, that can be constructed more quickly and cheaply and that operate at higher efficiencies and higher labor productivities, to meet the challenge of world steel needs.

Furthermore, to make up the world infrastructure deficit, requires more than steel. In the same way that its production must skyrocket, so must that of cement, aluminum, and other products.

Steel, and all these other metals, is now produced with obsolete technology. We must deploy new technologies that

What is a plasma torch?

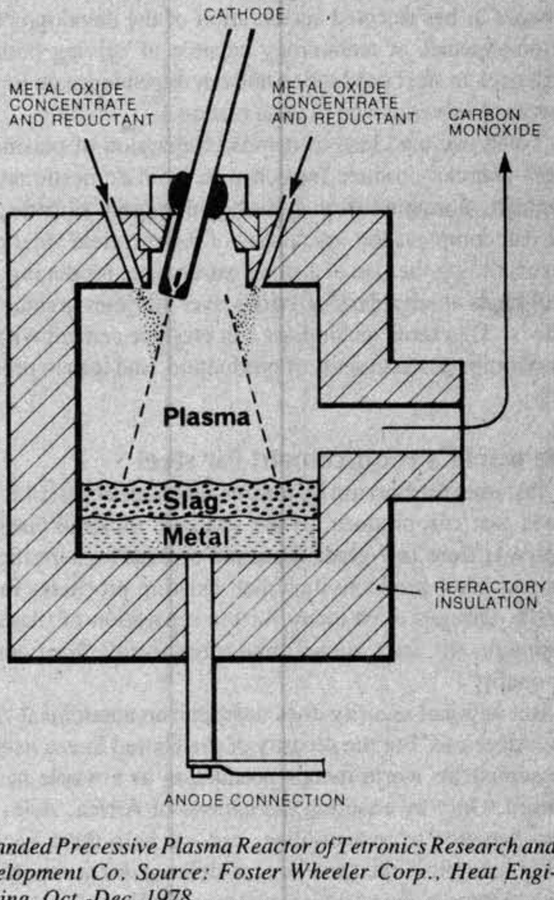
Traditionally, the energy from the combustion of fossil fuels, mainly heat, has been used for raw materials extraction, reduction, and processing. Conventional methods to produce energy generate heat by the combustion of fossil fuels. In 1968, two scientists, William C. Gough and Bernard J. Eastlund, proposed harnessing the unique properties of the ultra-high-temperature fusion plasma to meet the energy, materials, and fuels needs of the future. Fusion, the fusing of isotopes of hydrogen at a temperature of tens of millions of degrees, produces not only heat, but also a full array of electromagnetic radiation, charged particles, and neutral particles at high energy levels, as well as electric power by conventional or advanced conversion methods.

The unique by-products of the fusion process can be used to reduce metal ores, for chemical processes, and bulk materials separation. Unlike the fusion energy of the sun, controlled fusion plants on Earth can be "tuned" to produce more or less of various by-product particles and radiation, depending upon what is required.

But the plasma torch does not require nuclear fusion reactors, as subsequent research and development have shown. The plasma torch produces a flow of ionized gas (a gas with electrons stripped off its atoms), that can be used to reduce metals and perform other useful functions. The species of plasma torch discussed in this article, is powered by conventional electricity. It generates a direct current (DC) arc discharge plasma; the plasma, flows from cathode to anode, as shown in the Figure. It plasma is generated from a neutral gas, such as argon. In a small 40 kilowatt laboratory plasma reactor, there might be an arc voltage of 100 volts between cathode and anode, with the plasma carrying an arc current of 300 amperes. The name "arc discharge plasma" originates from the effective electric discharge that occurs from cathode to anode by means of the presence of the plasma as a conductor. The arc voltage and current ionize the gas and produce the plasma flow.

By pulsating the arc voltage and/or current, it is possible to vary the electrodynamic action of the plasma jet emitted by the cathode, and so tune such action to the specific ore being reduced, as one would a radio.

In addition, rotation of the plasma arc (as is done in the device illustrated) increases the amount of time that solid ore particles are entrained in the plasma.



Expanded Precessive Plasma Reactor of Tetronics Research and Development Co. Source: Foster Wheeler Corp., Heat Engineering, Oct.-Dec. 1978.

can exceed the throughput of the Coke Oven-Blast Furnace-Basic Oxygen Furnace (BOF) combination, in a vessel the size of a small truck. We must compress the functions performed by the old technologies, into a volume equal to a fraction of what they require today.

One example is laser uranium isotope separation, which replaces the huge calutrons and gaseous diffusion plants of Oak Ridge National Laboratory, where uranium hexafluoride vapor is pumped through *miles* of diffusion barriers. The laser process achieves separation in a fraction of the space and time required by conventional technologies.

Low-temperature plasma processes

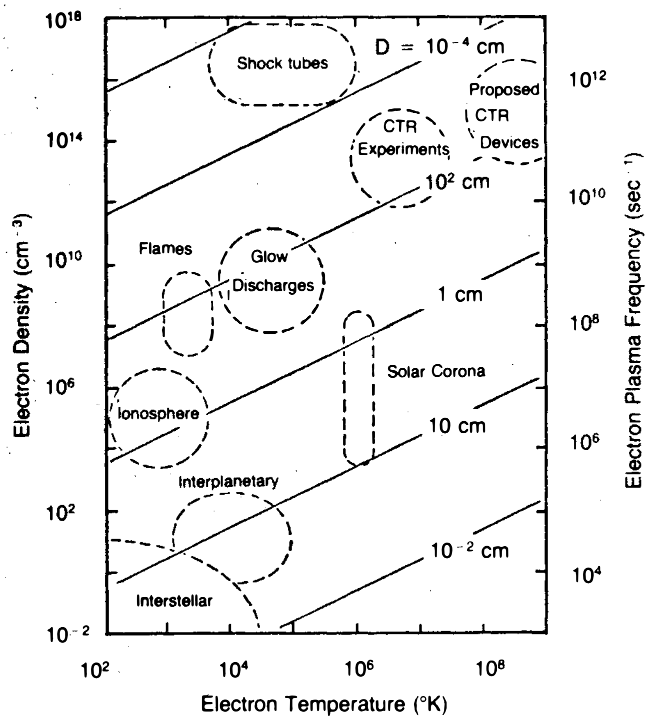
Plasma processes are really not new to industry. The first plasma deployed by man in industrial processes, was the flame. Most existing industrial processes employ the application of the low-intensity plasmas created in flames or other combustion processes. The task of political economy today, is to push through qualitative improvements in the plasmas' available to industry, and in their characteristics of action. For the steel industry, this means replacing the air and oxygen blasts of the blast furnace and BOF with a plasma torch blast. Highly energy dense plasma sources will pay for themselves in the increased throughput and productivity they will make possible.

Figure 3 shows the plasma regimes known to man today. The region labeled "flames," is where most combustion processes now take place, such as those of the blast furnace or basic oxygen furnace. In the case of an open vessel, such as the BOF or a Bessemer converter, the low-temperature plasma is visible in the strong (1,600°C) flame emitted during the "blow" that refines the molten metal to steel.

The region in the figure marked "glow discharges," includes the plasma processes we will use in the next five years, for processing raw materials and performing magnetic separation. Also included in this region are the glow discharge tubes of the electric discharge carbon-dioxide laser. Current

FIGURE 3

Plasmas: laboratory and cosmic



The figure shows the progression from the industrial flame to energy sources with higher electron density, comparing terrestrial and cosmic plasmas in terms of the density and energy of their free electrons. Note that the ordinary industrial flame has a higher electron density and temperature than the ionosphere. CTR refers to "controlled thermonuclear reaction." Source: F. Boley, Plasmas—Laboratory and Cosmic.

FIGURE 4

Process temperatures and plasma free electron energies in various steelmaking processes

	PFE energy (eV)	Process temperature (°C)
Flames	0.1 to 1.0	
Blast furnaces		
Charcoal-fired		1,200
Coke-fired		1,550
Jordan Process		2,200
Basic oxygen furnace		1,660
Glow discharges	1.2 to 65	
Plasma torch sources		3,000–10,000
Ashmont	2 to 3	1,660
Tylko SSP	1 to 7	1,660
Magnetic separation	2 to 4	4,700

The table compares plasma steelmaking with existing combustion-based steelmaking processes in terms of process temperature and the energy of the free electrons of the plasma in the energy source (measured in electron volts). Although process temperatures of existing and plasma processes are about the same (that is, the temperature that the feedstock is heated to), plasma technologies involve approximately an order of magnitude increase in the electron energy. Since flames are plasmas, existing industrial processes may also be assigned a plasma free electron energy.

FIGURE 5

Efficiency of existing and future technologies

	Energy flux density (watts/m²)	Output per unit energy (tons/GWh)
Enriched uranium		
Gaseous diffusion*	10^7	0.424 kg/MWhe
Atomic laser process	10^{15}	18.5 kg/MWhe
Aluminum from bauxite		
Bayer plus Hall Processes	6×10^4	14.5
Magnetic separation	10^8	185-250
Cement production		
Calcining	10^6	2,300
Tylko SSP	10^8	23,000
Iron and steel		
Blast furnace plus BOP	10^7	200
with Jordan Process		2×10^7 3,400
Mesabi Metals	10^7	235
Eketorp	NA	300
Ashmont Metals	10^8	500
Tylko SSP	10^8	600
Magnetic Separation	10^8	730-1000

*Shaded lines indicate existing technologies.

plasma torch technologies have a 90% efficiency of conversion of electricity to plasma. **Figure 4** shows the approximate plasma electron energies associated with some typical present and future plasma sources, and corresponding industrial process temperatures.

Note that recent breakthroughs have lowered the required temperature of operation of a so-called fusion torch magnetic separation device to about 4,700°C, well within the range of existing "low temperature" arc discharge plasma torches.

The table also lists the Jordan Process, a steelmaking technology which uses more oxygen than conventional methods, and whose implementation may present the fastest possible means for almost doubling U.S. and West European steel capacity in the few years, that we await plasma processes to come on-line.

Figures 5 and 6 document the tremendous potential throughputs, economies, and labor productivities of plasma and other advanced processes. They show that the plasma process plants discussed below and in Part II of this series, increase throughput two- to four-fold, raise labor productivity 10- to 100-fold, yet in investment dollars, cost about one-third as much per ton of capacity!

Already, with technologies that will be ready within the next few years, we will be able to eliminate American dependence on some imported strategic materials, such as chromium, and will be able to house a 1 million ton per year

FIGURE 6

Comparison of capacity and cost, existing vs. future technologies

Technology	Capacity (1,000 tons)	Tons output per worker	Capital investment per ton capacity (1985 $)
Steelmaking (300 MW)			
Greenfield plant*	460	1,700	3,000
Mesabi metals	600	16,000	n/a
Eketorp furnace	788	40,000	n/a
Ashmont fetals	1,314	70,000	1,000
Tylko SSP	1,560	87,000	1,000
Magnetic separation	1,920	105,000	n/a
Aluminum (30 MW)			
Hall process	4.5	125	1,000**
Magnetic separation	48	2700	1/2 conv.
Ferrochrome (30 MW)			
Conventional	13	1300	750
Tylko SSP	130	1300	450
Cement (30 MW)			
Portland cement	604	2,860	200
Tylko SSP	6,040	26,000	67

*Shaded lines indicate existing technologies.
**1966

capacity steel plant in a building the size of a moderate warehouse. For steelmaking, all the plasma technologies listed—the hydrogen furnace of Sven Eketorp, the plasma furnace of Ashmont Metals, the sustained shockwave plasma of Jozef Tylko, and the magnetic separation concept of Bernard Eastlund, William Gough, and James Drummond—compress the coke oven, blast furnace, and steel refining furnace into a single machine. Plasma furnaces and reactors can use coal, charcoal, peat, or carbonaceous waste, as reducing agents. Magnetic separation goes even further, eliminating the need for prepared ore, in the feed to the machine, or any reducing agent, if desired. Each of these designs assumes that, for metals, a continuous casting process will be integral to the plant.

The 'universal machine'

For the new industrial revolution, we can no longer be pinned down to machines that are intrinsically useful for one and only one function. We need machines that can be adapted to produce everything from cement to specialty steel to aluminum. This was the dream of Gottfried Leibniz and Lazare Carnot. Today, this dream is becoming reality. We stand on the threshold of an age of *universal machines*.

As one plasma furnace developer told this writer, "Many people across the country are working very hard. We are close to commercialization. We will soon produce steel cheaper, far cheaper than the blast furnace and the BOF."

Several plasma machines which we will describe, appear to be truly universal, and one has to date, in various configurations, successfully produced cement, carbon steel, speciality steel, and ferrochrome, with the potential to produce a wide range of other materials. These machines are within our immediate reach.

The next step, with potential industrial operation in five years, is plasma-assisted magnetic separation machines, by which we can separate elements from low-grade ores and eliminate America's dependence on imports of strategic minerals. This latter technology is *only five years away*, if appropriate research and development funding is put into it.

An excellent example of the machines of the future is the free electron laser, whose radiation emission wavelength is even more tunable than is your radio, to perform a specific industrial-chemical task, such as separation of any isotope, for catalysis of any chemical reaction. The plasma machines now conceived, are approximating this "tunable" characteristic. Perhaps the most advanced example is the Tylko sustained shockwave plasma (SSP).

This comparison of a plasma to a laser is not an analogy. "Lasing" is characterized by a state in which the majority of the lasing medium is "excited" above the ground state. In laser physics jargon, this is called a "population inversion." Inverse to the equilibrium state, where most molecules are unexcited (in the "ground state"), under lasing, most of the population of the medium is excited. Such a population inversion, is precisely the exemplary characteristic of plasmas. One result of this characteristic of a plasma, is an increase in the efficiency of firing metallurgical processes when compared with conventional burners.

Plasma industrial processes divide themselves in two different ways. One distinction that must be made is between:

1) Plasma-fired processes using a reducing agent (such as carbon or hydrogen) for ore reduction (e.g., the Tylko Sustained Shockwave Plasma). The key advance of these machines over existing reducing furnaces, is that the reduction occurs while the feedstock is "in-flight," dropping through the reactor.

2) Plasma-assisted magnetic separation processes, in which an arc discharge plasma acts to partially ionize an element desired for magnetic extraction from a compound for ore.

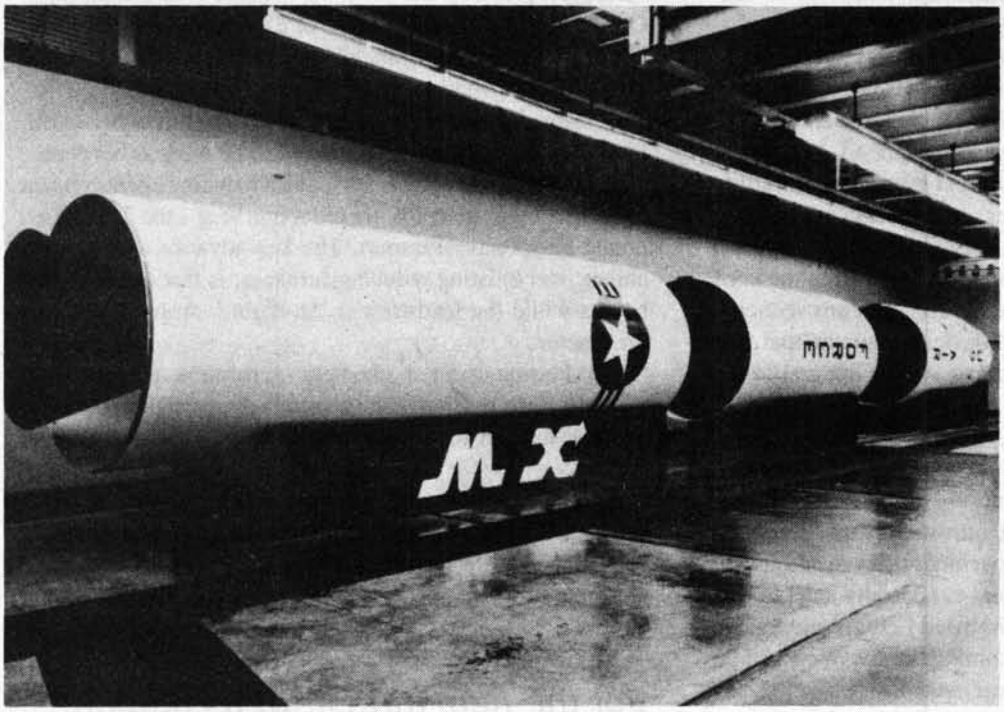
These processes are characterized by having none, or few, moving parts. In addition, existing plasma processes and concepts are based on either thermal or non-thermal concepts of the properties of the plasma. Machines whose action is based on merely the thermal properties of the plasma, are properly called "furnaces." Those whose action is fundamentally non-thermal, are more appropriately called "reactors." Admittedly, there is something artificial about the notion of a purely "thermal" plasma. For example, it has been known for some time that iron reduction does not conform to a purely thermal theoretical treatment. Examples of thermal plasma processes are discussed below.

For the new industrial revolution, we can no longer be pinned down to machines that are intrinsically useful for one and only one function. We need machines that can be adapted to produce everything from cement to specialty steel to aluminum.

On the threshold

Magnetic separation techniques require a couple more years of engineering development. The Eketorp design requires the availability of ample supplies of hydrogen. However, the other techniques discussed here are in or near the pilot-plant stage, and all methods described, are based on available technology.

Ashmont Metals of New York has recently completed construction of a 500 KW-power, 24 ton per day pilot plant in New Jersey, where the company is now trying to get the



A mock-up of the MX missile. Without imports of foreign strategic materials, it cannot be built. Yet the technologies for overcoming this dependence are at hand.

"bugs" out of their process of direct steelmaking from iron ore, into iron and steel powders for powered metallurgy and other products. Up until now, Ashmont has been operating, intermittently, a one ton per day laboratory furnace in its R&D program.

Jozef Tylko of Plasma Holdings, N.V. and of the University of Minnesota Mineral Resources Research Center, has recently completed construction of a 1,000 KW power 'laboratory reactor" for cement production. It stands over 45 feet tall. For metals production, both Tylko's and Ashmont's processes enable precise control over alloying and carbonization of the product.

Tylko's earlier machine, the Expanded Precessive Plasma (EPP), is partially commercialized. Tetronics, the British company holding the EPP patent, has four pilot plants in operation, three at 300 KW and a fourth at 1,400 KW. Reportedly, Mitsubishi Research Institute has obtained an EPP for research (see box).

In Foster-Wheeler's *Heat Engineering* (1978), the company reported that the EPP was suitable for recovery of molten iron from contaminated steelworks dust, and extraction of platinum group metals, as well as production of ferrochrome. In late 1981, Middleburg Steel and Alloys at Krugersdorp, South Africa, awarded Tetronics, a contract for an EPP ferrochrome smelter, planned to have a power of 10.8 MW, producing 50,000 metric tons per year of high carbon ferrochrome, in a plant whose cost per ton of capacity was only $300, versus $500 for conventional processes. The project continued up through the engineering studies required, when the South Africans cancelled the program after the collapse in world ferrochrome demand during the Reagan administration "economic recovery."

Perhaps even more spectacular was the announcement by Tylko and the Rugby Portland Cement Co. of England, of the invention of an EPP process for making hydraulic cement at 10 times the energy efficiency of the existing Portland cement process. The idea of using plasmas to produce relatively cheap, mass-production products like cement, had previously been rejected. In addition, Tylko designed a plant to produce cement precursor products and net energy for electricity production from the combustion of low-carbon industrial wastes or oil shale. The system is capable of producing five times as much energy as goes into the plasma arc discharge firing the machine, in addition to the cement precursor product.

Tylko reports that his new invention, the Sustained Shockwave Plasma, is even more effective than the EPP, and estimates that a million ton capacity cement plant could be built in two years, after initial studies. However, one major advantage of the SSP is that a smaller capacity reactor can be put on wheels and rolled around to where the need for cement (or steel) is!

The EPP has also been used for smelting platinum group metals, and Tetronics granted Texasgulf an exclusive license for that application in 1978.

Part II will present, in summary form, the plasma technologies that are within our grasp, or just over the horizon.