

Information Circular 8529

**Bureau of Mines Research Programs
on Recycling and Disposal of Mineral-,
Metal-, and Energy-Based Solid Wastes**

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UNITED STATES DEPARTMENT OF THE INTERIOR
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BUREAU OF MINES
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This publication has been cataloged as follows:

Kenahan, Charles B

Bureau of Mines research programs on recycling and disposal of mineral-, metal-, and energy-based solid wastes, by Charles B. Kenahan and Einar P. Flint. [Washington] U.S. Dept. of the Interior, Bureau of Mines [1971]

53 p. illus. (U.S. Bureau of Mines. Information circular 8529)

Includes bibliography.

This publication updates Bureau of Mines Information Circular 8460 issued March 1970.

1. Waste products. 2. Scrap metals. 3. Salvage (Waste, etc.)
I. Flint, Einar P., jt. auth. II. Title. (Series)

TN23.U71 no. 8529 622.06173

U.S. Dept. of the Int. Library

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BUREAU OF MINES RESEARCH PROGRAMS ON RECYCLING AND DISPOSAL OF MINERAL-, METAL-, AND ENERGY-BASED SOLID WASTES

by

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ABSTRACT

A summary of Bureau of Mines research on utilization and disposal of solid wastes is presented, accompanied by an extensive bibliography of related publications. The Bureau's Solid Waste and Materials Recycling Program is directed toward four main areas of research, development, and demonstration: (1) extraction of mineral, metal, and energy values from urban refuse; (2) upgrading and recycling of automotive and related ferrous and nonferrous scrap; (3) utilization and stabilization of mine, mill, and smelter wastes; and (4) recovery and reuse of values from industrial waste products. A contract and grant program that supplements the in-house research and aids in the training of manpower in management of mineral-, metal-, and energy-based solid wastes is also discussed.

This publication is an updating of Bureau of Mines Information Circular 8460 issued March 1970.

INTRODUCTION

The Interior Department's Bureau of Mines has always considered the waste products and scrap generated by the mineral and metals industries and the consuming public as potential resources. The Bureau has been active in reclaiming values from byproducts of mineral, metal, and energy processes for over 50 years. This statement is supported by the continuity of publications by Bureau authors on environmental subjects dating back to 1912. The Bureau has pioneered the fields of secondary metals recovery and solid waste reclamation and has laid valuable groundwork in several major solid waste areas, including urban refuse; junk cars; mine, mill, and smelter wastes; and industrial solid and liquid wastes. The authority and responsibility for conducting research on separation, recovery, and recycling of such products, however generated, is inherent in the Organic Act of May 16, 1910, as amended in 1913 and 1915, which established the Bureau of Mines.

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Almost from the date of its founding, the Bureau has been involved in preservation of the environment and conservation of natural resources by recycling. Its activities have encompassed not only solid wastes but also means of alleviating air and water pollution, especially those which originate from industries based on the utilization of minerals, metals, and fossil fuels. Pollution caused by gaseous, liquid, and solid wastes continues to be of major concern to the Bureau. The fact that air and water pollution are excluded from the scope of this report necessitates the elimination from the appended bibliography of the many Bureau publications on these subjects.

Although this summary is devoted to solid wastes, brief reference is made to related Bureau accomplishments that cannot realistically be separated from the solid waste aspect. For example, the acid-mine-drainage problem has occupied a prominent place in the Bureau's work since 1920. Inasmuch as the product of neutralizing acid mine waters is a solid waste sludge, its direct relationship to the Bureau's authority for conserving and developing mineral resources is evident.

The case is equally definite for air pollution caused by emissions of sulfur oxides from metallurgical operations and burning of fossil fuels. Means of alleviating such problems were sought by Frederick G. Cottrell, associated with the Bureau of Mines from 1911 to 1921, and Director, 1920 to 1921. More than any other individual, Dr. Cottrell succeeded in finding means for abating air pollution. He invented and developed the electrostatic precipitator which bears his name, now used for almost five decades throughout the world to remove acid fume and particulate matter from stack gases. The Bureau has continued such work uninterruptedly and is presently conducting research studies on removal of sulfur oxides from stack gases with subsequent recovery of elemental sulfur. Other means for abatement of noxious emissions from many types of industrial operations are also in an advanced developmental stage.

One of the more important functions of the Bureau is to conduct programs of inquiry and research that will stimulate the production of an adequate supply of metals and minerals to meet our national needs. The Bureau's authority and responsibility in this area was recently renewed, strengthened, and explicitly restated in the recently passed Mining and Minerals Policy Act of 1970 (P.L. 91-631). The Congress recognized the Bureau's special competence and responsibility in minerals research and supply by assigning a major role to the Department of the Interior in the Solid Waste Disposal Act of 1965 (P.L. 89-272), and more recently in the Resource Recovery Act of 1970 (P.L. 91-512).

The Bureau's Metallurgy Research organization is well equipped to deal with problems relating to metal- and mineral-waste products. Included are the Divisions of Metallurgy and Solid Wastes, which is made up of about 780 full-time employees at eight research facilities strategically located across the country. About half of the personnel are metallurgists, mineral engineers, geologists, chemical engineers, chemists, and physicists. Other members of the Bureau's staff are engaged in coal, petroleum, and mining research and have capabilities to deal with solid waste problems relating to energy recovery, utilization, and disposal of mining wastes.

With passage of the Solid Waste Disposal Act, the Bureau accelerated and expanded its research efforts in separating, recovering, and recycling the values contained in a variety of metal-, mineral-, and energy-laden wastes. Carrying out this program required extensive retraining of a group of its engineers and scientists to cope with the wide range of problems, methods, and materials that characterize the secondary materials industry, but which have traditionally escaped consideration in the curricula of colleges and universities. The approach taken by the Bureau to solve these problems has always been that of improving and expanding the technology of extractive metallurgy and in modifying known techniques to the solution of difficult secondary materials problems. The success of this approach is evident in achievements during 50 years of secondary metals research as detailed in hundreds of publications, patents, and presentations resulting from these studies. Documentation is provided in the bibliography.

Rather than consider metal and mineral wastes as environmental problems, as many do, the Bureau of Mines views them as opportunities to bolster our supply of natural resources. These opportunities exist not only in the processing and recycling of proposed new products but also in processing the present generation of scrap more effectively. Since the scrap materials of tomorrow are being manufactured as durable goods today, we are afforded a real opportunity to examine them for potential future benefits. These materials are accumulating as goods-in-use at a rapid rate and collectively are reaching enormous proportions. We must be prepared to recover them efficiently and completely.

The importance of secondary metals--which represent our only growing metal resource--can best be assessed by comparing the gross production of the major metals with the quantities reclaimed from secondary sources. According to production estimates, on an annual basis, over 50 percent of lead, 40 percent of copper, 45 percent of iron and steel, and 25 percent of zinc and aluminum fabricated into new products last year were derived from secondary sources. Equally important are the estimated quantities of these metals accumulating in the "in-use" channels of the economy. About 40 million tons of copper and 4 million tons of lead and zinc are presently in this category, which represents a constantly growing "man-made mine" of future raw materials.

Since the mineral resources, once mined, are irreplaceable, it is apparent that a primary solution to the problem of scarcity is the development of methods for recovering, recycling, and reusing the values contained in wastes. To some extent, the secondary metal industries have traditionally served this purpose and have done a remarkable job, but the concept must be more widely applied. It is probable that present mine tailings dumps, junk-car graveyards, and possibly even municipal landfills may be looked upon in the future as man-made mines for minerals and metals whose natural ores have been depleted or remain in deposits that can be mined only at greater cost than required for recycling of wastes.

The Bureau of Mines considers solid wastes as resources out of place--we are simply trying to put them back.

IN-HOUSE RESEARCH PROGRAM

Extraction of Mineral, Metal, and Energy Values From Urban Refuse

The Bureau is directing a major research effort toward developing methods to recover metal, mineral, and energy values from municipal incinerator residues and raw, unburned refuse. Specifically, the program seeks to (1) develop and demonstrate new or improved techniques to State and local governments and private industry for the recovery and recycling of values contained in urban refuse; (2) reduce environmental pollution resulting from inadequate treatment and disposal of a major solid waste; (3) develop technology and provide training in solutions to problems involving the use and reuse of urban solid wastes; and (4) alleviate the acute problem of urban solid waste disposal. A conceptual systems approach for managing all urban wastes is presented in figure 1. The principal components of the urban-refuse research program are the following.

Municipal Incinerator Residues

A pilot plant with a capacity of one-half ton per hour, which treats municipal incinerator residues in much the same manner that minerals are separated from their ores, has been operated successfully by the Bureau for over a year (figs. 2-3). The inputs to the plant, consisting of a heterogeneous mixture of tin cans, iron and steel products, aluminum, copper, lead, zinc, glass, and ash, are automatically separated and recovered on a continuous basis. A sophisticated component of the plant equipment separates the glass into clear and colored fractions. The process, in addition to being technically sound, shows favorable economics.

Unburned Municipal Refuse

Also, under development is a process for mechanically separating and recovering the metals, glass, paper, and plastics from raw, unburned refuse on a continuous basis. The initial step in this process is the liberation of all of the materials in the refuse by coarse shredding in a mill with double opposed chains. Various combinations of air classification, magnetic separation, screening, optical sorting, and gravity concentration separate and reclaim the individual values. The major equipment required for pilot plant operation has been purchased, and installation is nearing completion (fig. 4).

Reclamation and Reuse of Waste Glass

Glass, which is the major constituent of incinerator residues and one of the major components of refuse, is being given special attention. Methods to obtain clean separations of clear and colored glass are nearly perfected. The fine-size colorless glass concentrates obtained from the pilot plant are already of a quality acceptable as cullet for making new glass containers by the industry. Research has also been conducted on making such products as bricks, glass wool, reflecting beads, and tile from the waste glass fractions. Attractive colored bricks have been produced that meet ASTM (American Society for Testing and Materials) specifications for "severe weather" facing brick, and high-quality glass wool has also been produced from the waste glass product (figs. 5-6). An optical electronic sorter, which is not yet part of the

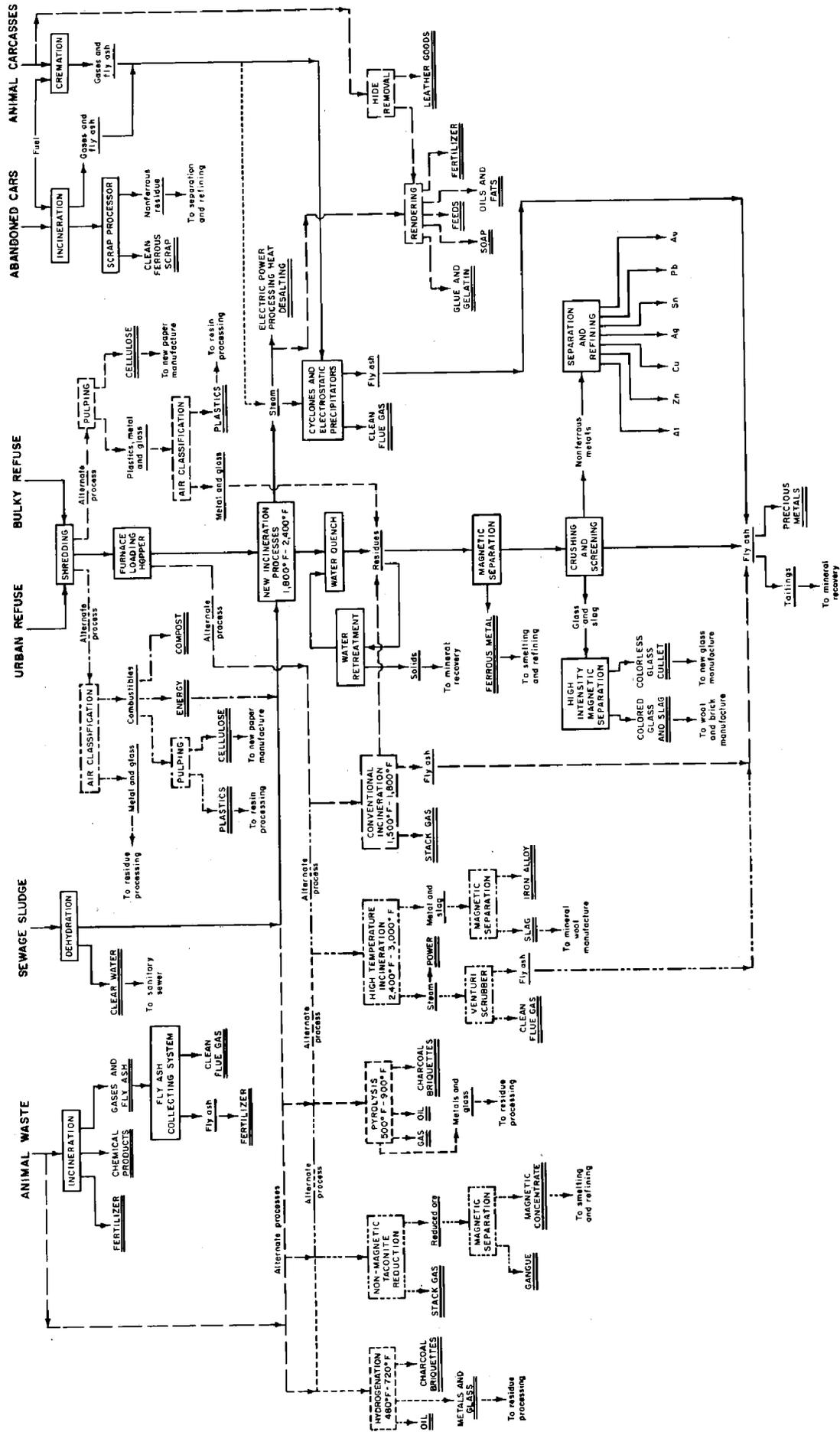


FIGURE 1. - Proposed Environmental Waste Management System—Model Municipal Incineration, Reclamation and Power Complex.

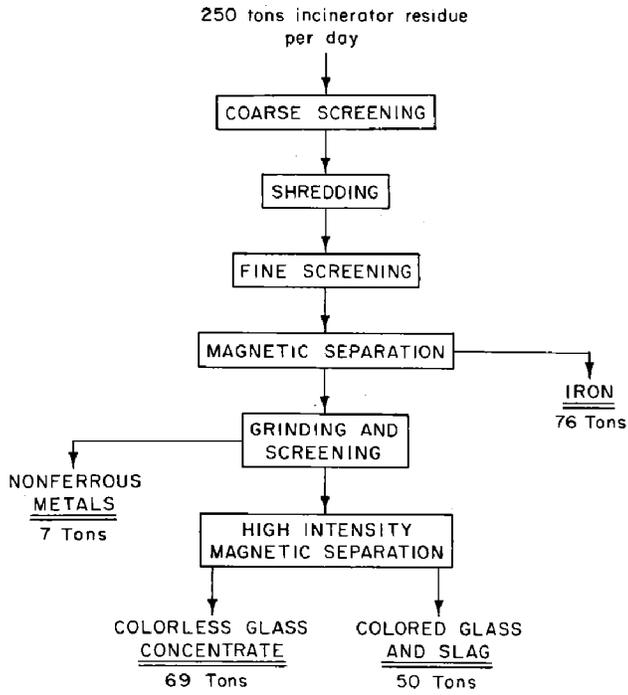


FIGURE 2. - Municipal Incinerator Residue Processing Flowsheet.

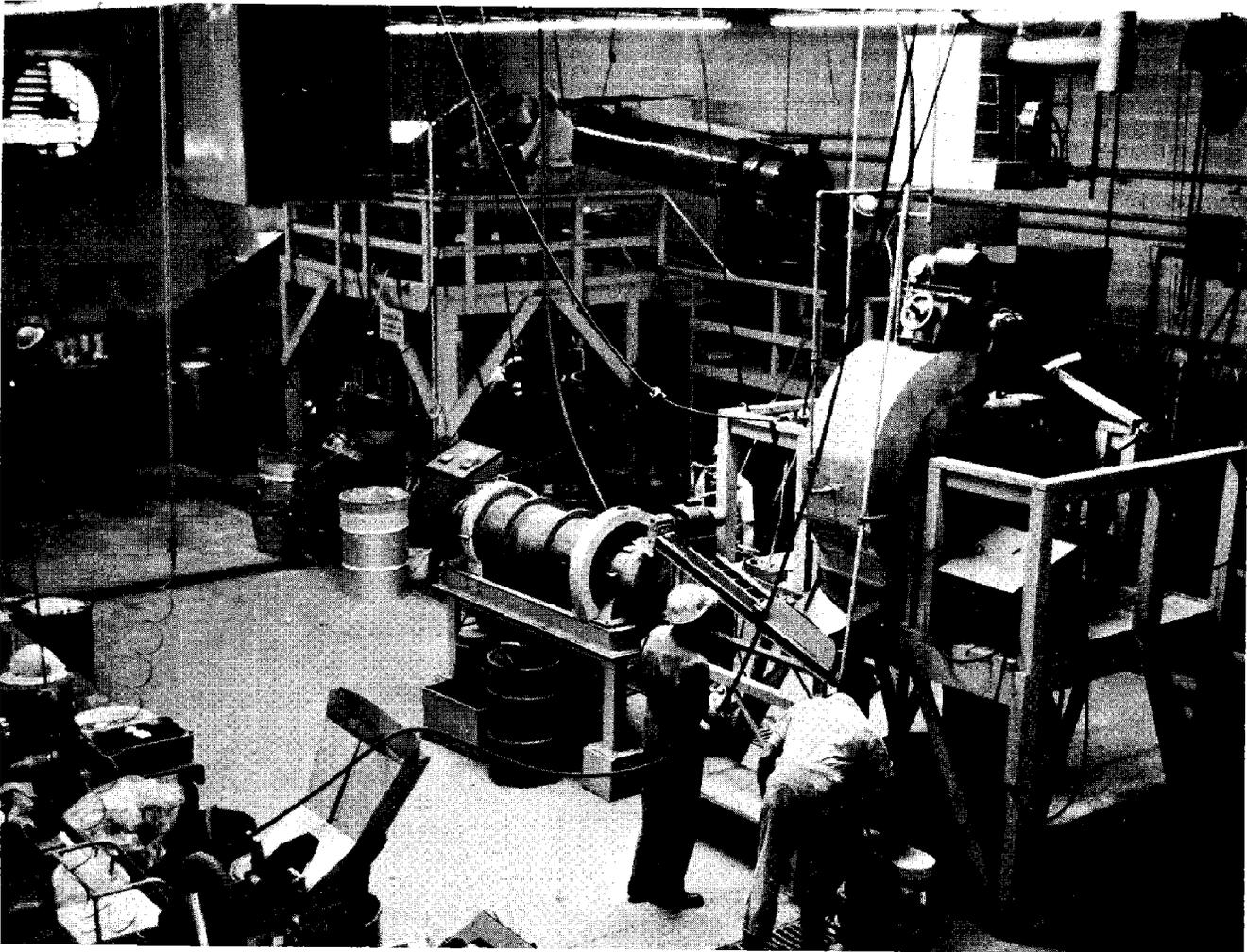


FIGURE 3. - Municipal Residue Reclamation Pilot Plant.



FIGURE 4. - Components of Raw Refuse Processing Plant.

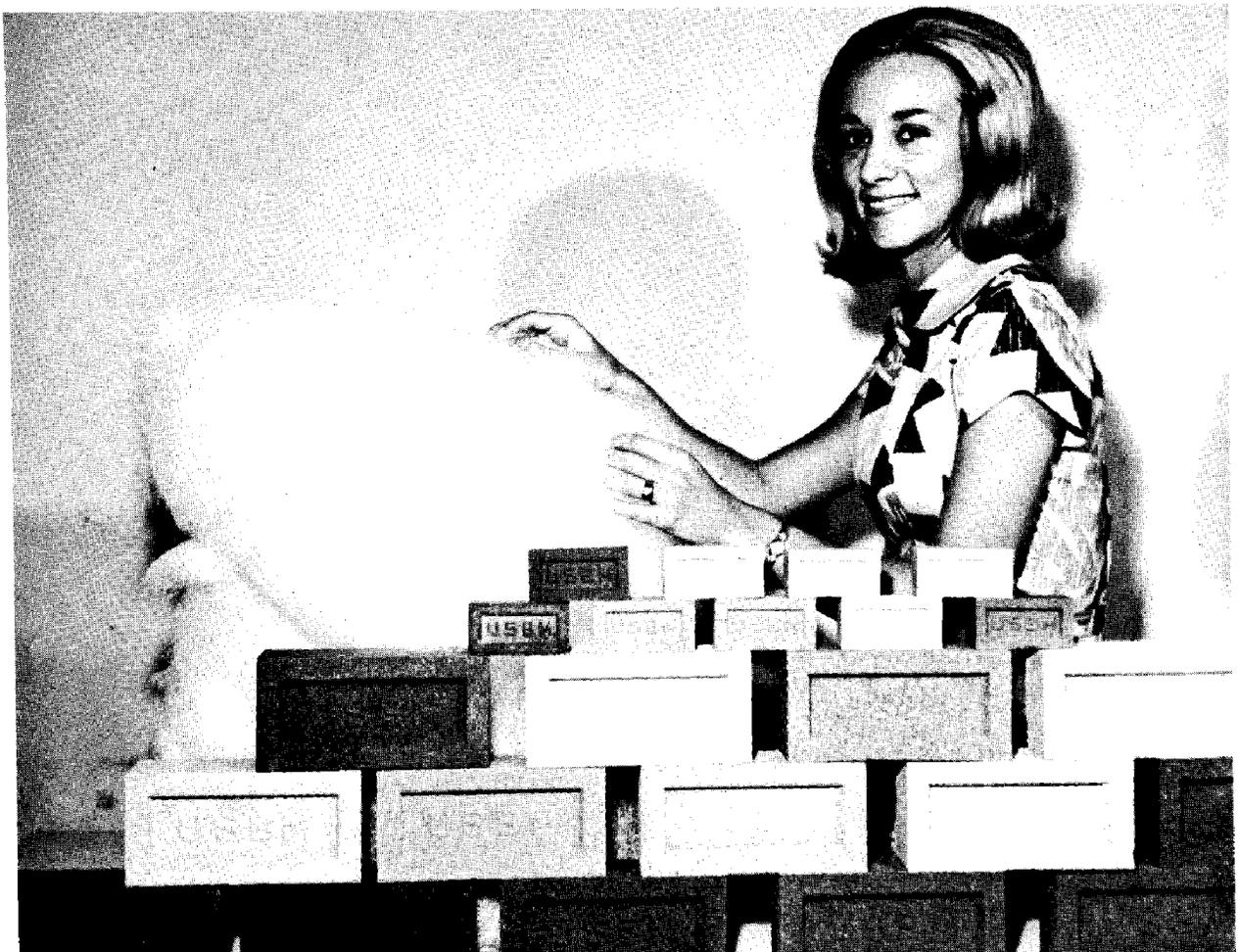


FIGURE 5. - Structural Products of Face Brick and Glass Wool Made From Waste Glass Fraction of Municipal Incinerator Residue.

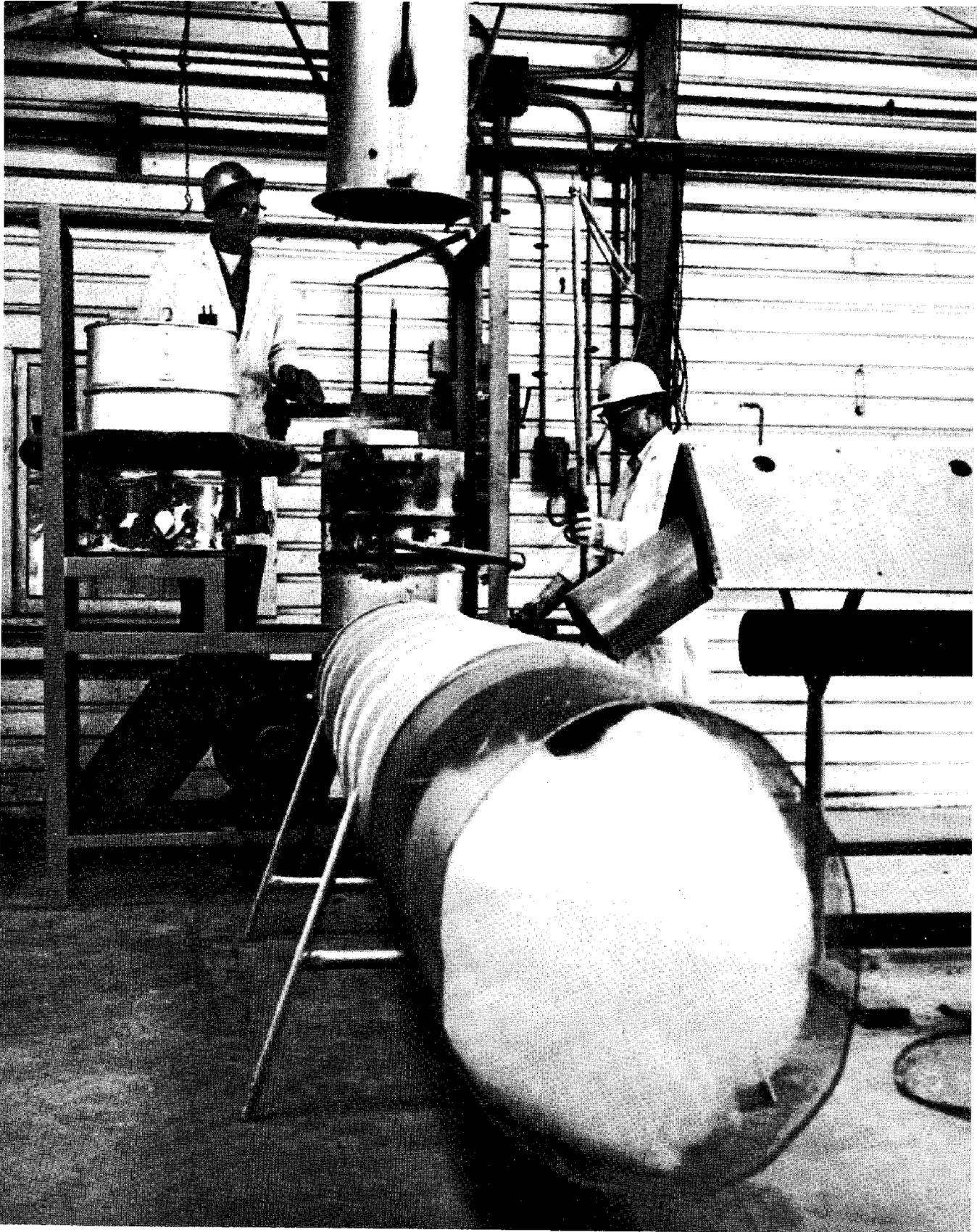


FIGURE 6. - Glass Wool Being Made From Waste Glass Fraction of Municipal Incinerator Residue.

flowsheet, has been successfully employed in batch tests to preconcentrate the colorless glass.

Refining of Metals From Refuse

Emphasis is being placed on refining and utilizing the ferrous and non-ferrous values recovered from incinerator residues and raw refuse (fig. 7). Conversion of the metallic fractions of refuse into marketable products is another of the prime objectives of the urban refuse research.

Several methods developed by the Bureau for refining the iron fractions that contain small amounts of copper and tin have shown considerable promise. Preliminary tests indicate that an excellent separation of high-quality aluminum product from the mixed nonferrous metals can be made by using heavy media techniques. The sink fraction of the separation is a copper-rich product containing zinc, lead, tin, and small amounts of stainless steel. The lighter aluminum is collected in the float fraction. Other techniques including vacuum refining, intermetallic compound formation, and flux refining are also being applied to the separation of the complex nonferrous metal fraction of the residues.

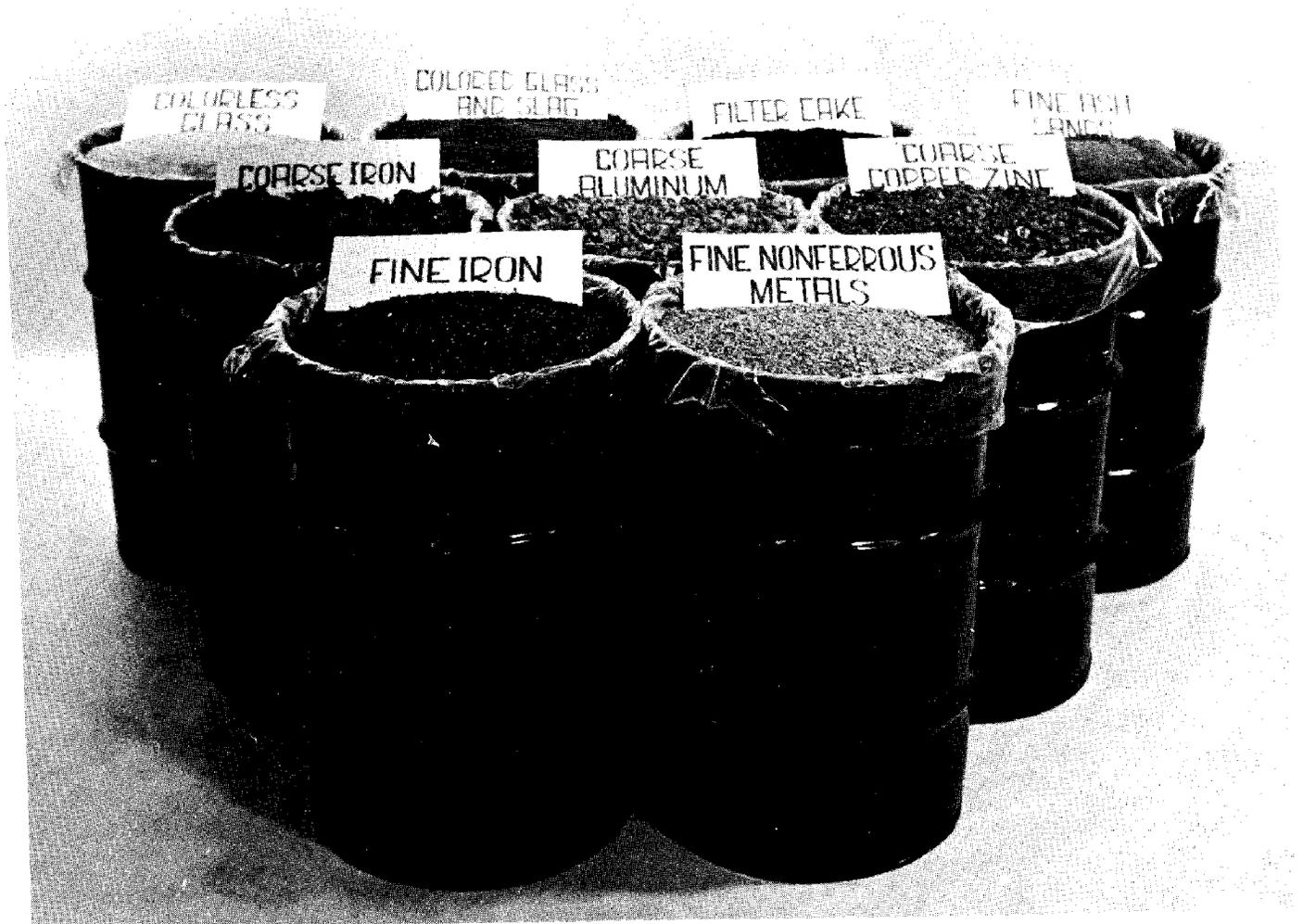


FIGURE 7. - Products From Municipal Incinerator Residues.

Other utilization research is focused on developing uses for the fines and ash products. Grants have been awarded to the Universities of Missouri, Stanford, Alabama, and Wisconsin to seek ways of utilizing these and other values contained in refuse.

Utilization of Discarded Plastics

The Bureau is investigating methods to utilize the vast tonnages of plastics discarded annually. Preliminary tests have shown that polyethylene, polystyrene, polyvinyl chloride, and polypropylene, which represent over 95 percent of waste plastics, can be separated and reshaped by application of heat and pressure (fig. 8). Characteristics of the reshaped plastics are comparable to those made of virgin materials. It has also been discovered that polyvinyl chloride can be broken down into anhydrous hydrogen chloride by heating at 300° C (fig. 8). Half the weight of this polymer is made up of hydrogen chloride gas which is released on destructive distillation, yielding a residual char suitable for use as a fuel.

Pyrolysis of Solid Wastes

The Bureau is applying the process of pyrolysis, the destructive distillation of materials in the absence of air, to the disposal of a variety of waste products including refuse. This process involves the thermal conversion of materials into usable forms of char, oil, and gas. It can be applied to a variety of waste materials such as municipal refuse, wood bark, sawdust, scrap tires, mulch, and plastics (fig. 9). The process generates enough byproduct fuel gas to supply the required heat for the reaction. The Bureau's work on pyrolysis originated more than 50 years ago when it was applied to the destructive distillation of coal.

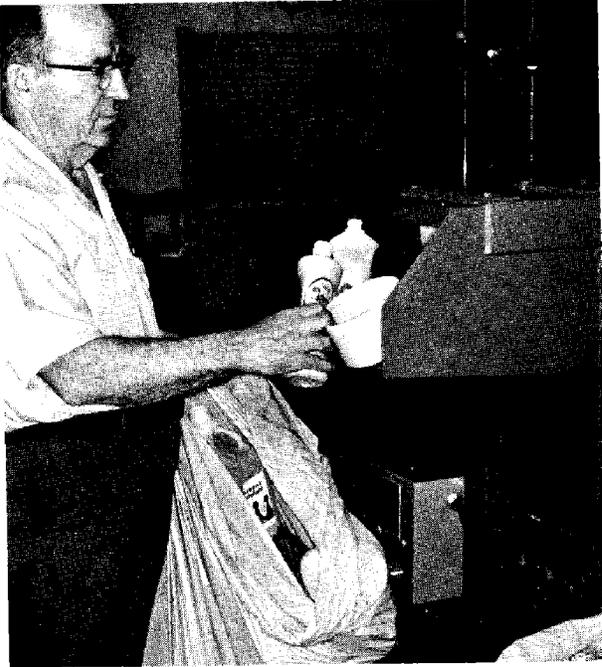
Conversion of Organic Refuse to Oil

A novel process for converting the organic material contained in refuse (garbage and cellulose) into crude oil is also being investigated (fig. 10). The process involves the reaction of carbon monoxide and steam at 500° F and at 1,500 psi. The technique can also be applied to sewage sludge, manures, and wood byproducts. One ton of dry refuse, minus the glass and metal content, will produce 2 barrels of oil with a sulfur content of only 0.1 percent. Even higher yields are recoverable from manures. The Bureau is presently operating a continuous laboratory process for treating waste organic materials by this method.

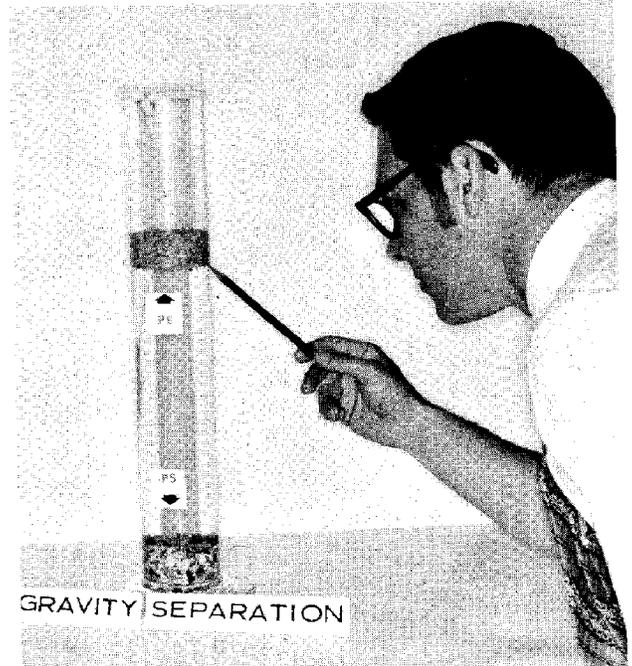
Upgrading and Utilization of Automotive and Related Ferrous Scrap

The Bureau of Mines has been conducting research on problems relating to ferrous scrap for many years. The primary objective is to devise economic methods to recover and upgrade the values contained in junk cars and related ferrous scrap in order to increase the utilization of this commodity and maintain traditional markets.

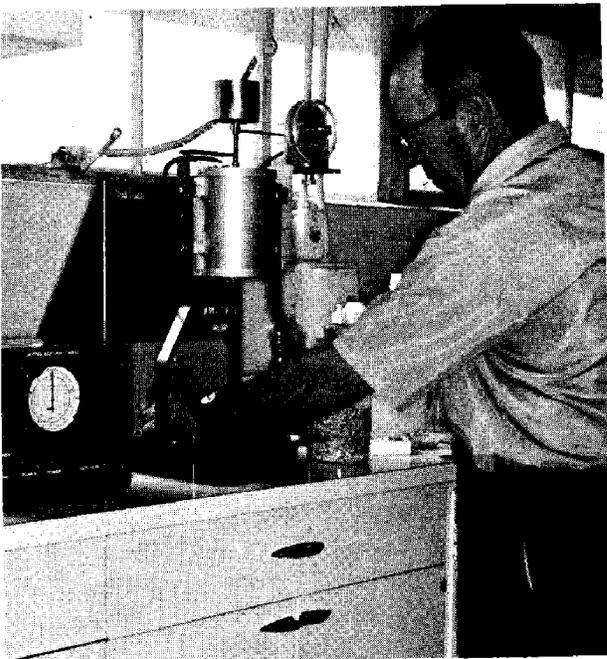
The total inventory of junk cars in the United States has been estimated at about 15 million cars, and is still growing, so that a substantial loss of



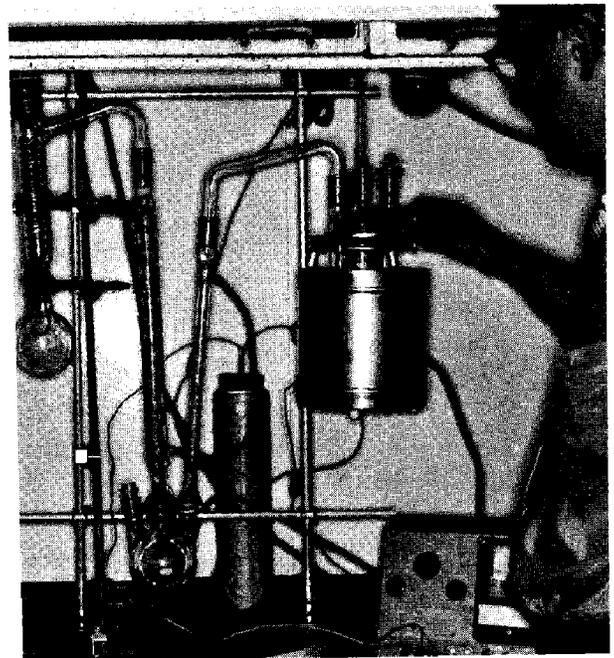
Granulation of Waste Plastics Found in Urban Refuse Reduces the Volume and Is a First Step Toward Reclamation Processing.



Differences in Density of the Plastic Types Found in Urban Waste May Be the Key To Separating Relatively Pure Fractions, as Shown by Separating Polyethylene From Polystyrene in Water.



The Extrusion Plastometer Is Used To Measure the Melt Index of Waste Plastics, One of the Specific Properties That Characterize Them for Industrial Uses.



Controlled Thermal Dissociation of Polyvinyl Chloride To Release and Recover HCl as a Resource Is One Approach To Solving the Problems That Arise When This Plastic Is Incinerated.

FIGURE 8. - Utilization of Waste Plastics.

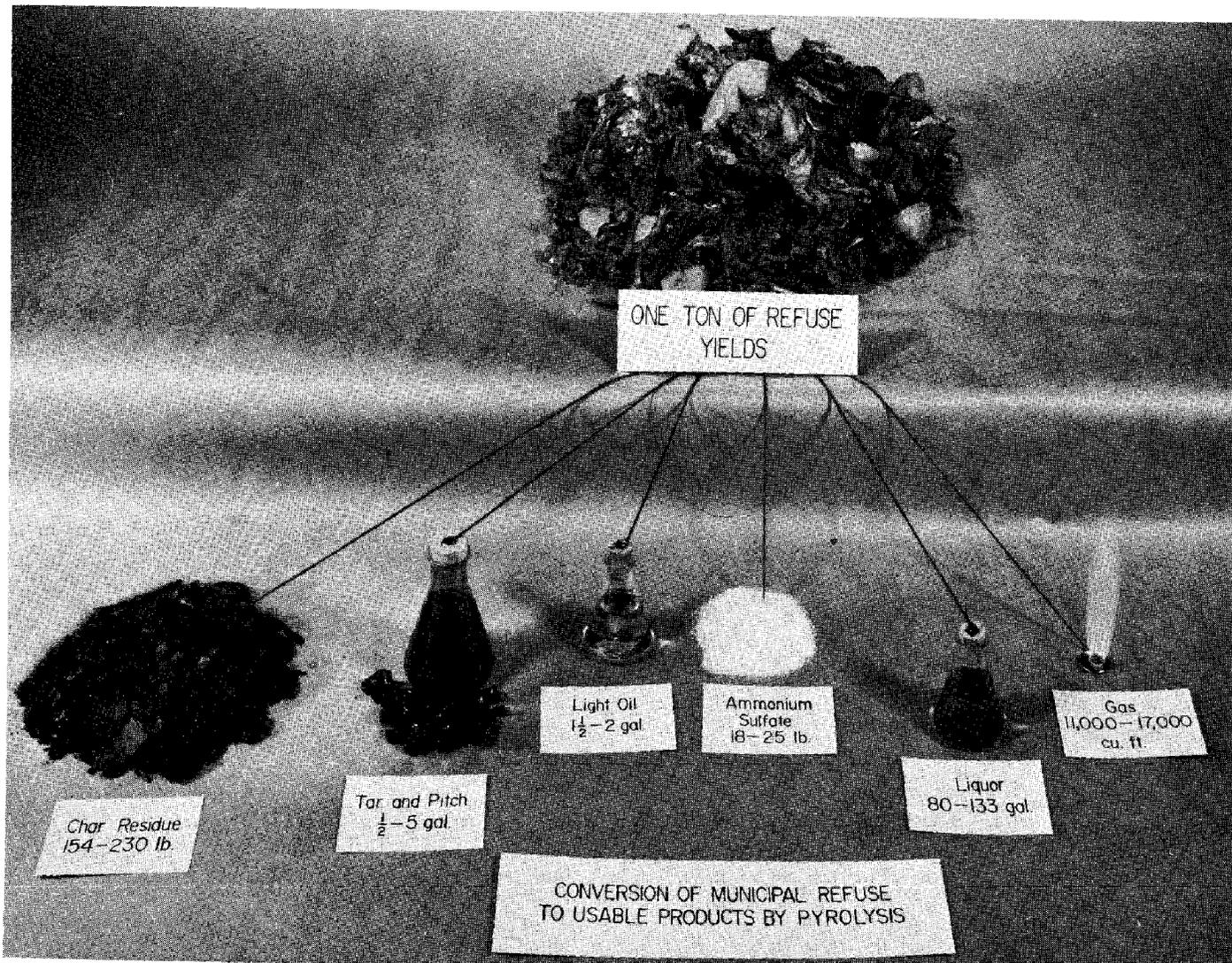


FIGURE 9. - Pyrolysis of Municipal Refuse.

valuable metals results. Even when a car enters the normal scrap cycle, much of its aluminum, copper, and zinc content is not recovered, but is discarded in dumps along with nonmetallic components of the vehicle.

The Bureau is conducting an in-house research program directed toward expanding the market for junk auto and large-appliance scrap, as well as the 7 million tons of tin cans generated annually, by improving the preparation of these scrap materials for conventional markets, and increasing the recovery of nonferrous metals associated with such scrap. Research efforts are underway on (1) an improved junk car and railroad car incinerator; (2) increased use of ferrous scrap in electric furnace steelmaking; (3) production of synthetic pig iron from ferrous scrap; (4) removal of contaminants from molten ferrous scrap; (5) development of an air separator for junk car shredder residue; (6) recovery of copper from copper-containing ferrous scrap by cryogenic techniques; (7) recovery of copper from starters, generators, and alternators by a molten salt method; and (8) high-temperature, oxidation-reduction studies aimed at producing iron oxide and clean scrap products that can be used as sources of iron in the steel industry. Current Bureau research in this area is as follows.

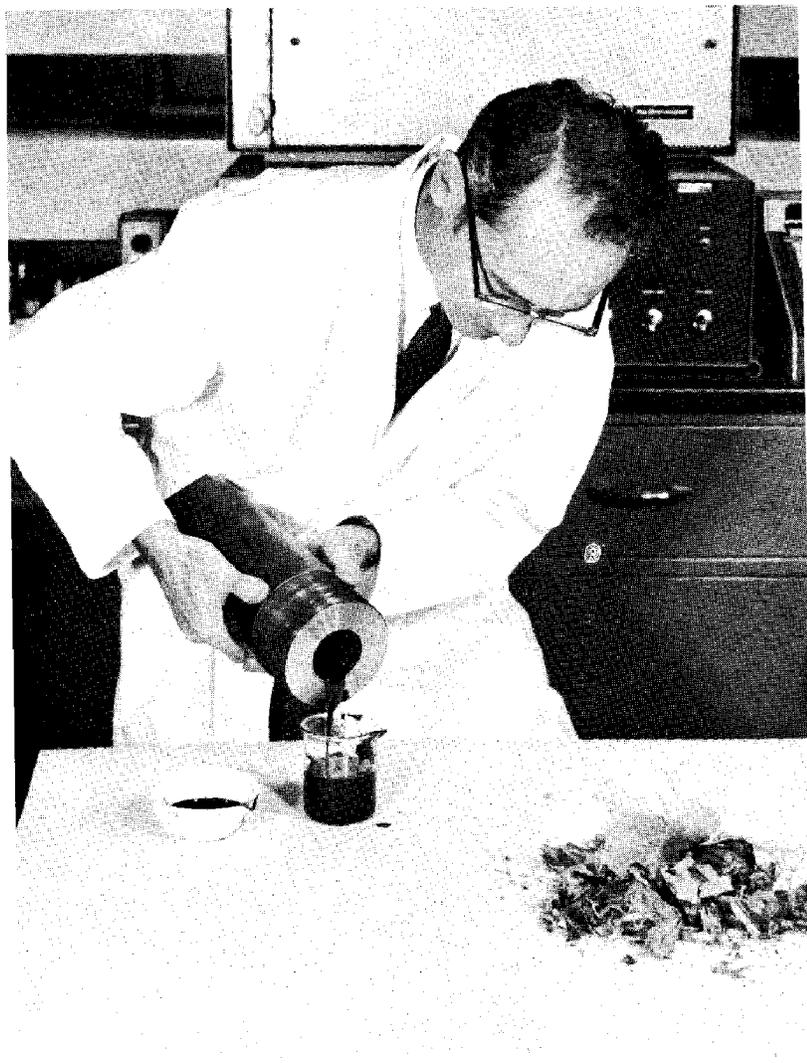


FIGURE 10. - Oil From Garbage
by Carbon-Monoxide-
Steam Treatment.

Junk Car Incinerator

The Bureau has developed and has been successfully operating for over a year a prototype low-cost (estimated at \$22,000), smokeless, junk car incinerator (fig. 11). The facility was constructed in cooperation with a scrap processor in Utah and operated as part of the scrap yard equipment. Over 20,000 scrap cars have been processed in the facility without adverse air pollution effects. Work is continuing on the unit to (1) determine amounts of non-ferrous metals melted during incineration, (2) increase the capacity of the incinerator, and (3) lower operating costs. Burning of old railroad cars, trucks, and buses prior to final processing is another area in which the Bureau-designed incinerator has potential and on which research is underway. The prototype incinerator is capable of burning four cars every 20 minutes with a particulate emission discharge of less than 0.01 grain per cubic foot. The cost of burning, including fuel for the afterburner, has been reduced to less than \$2 per car.

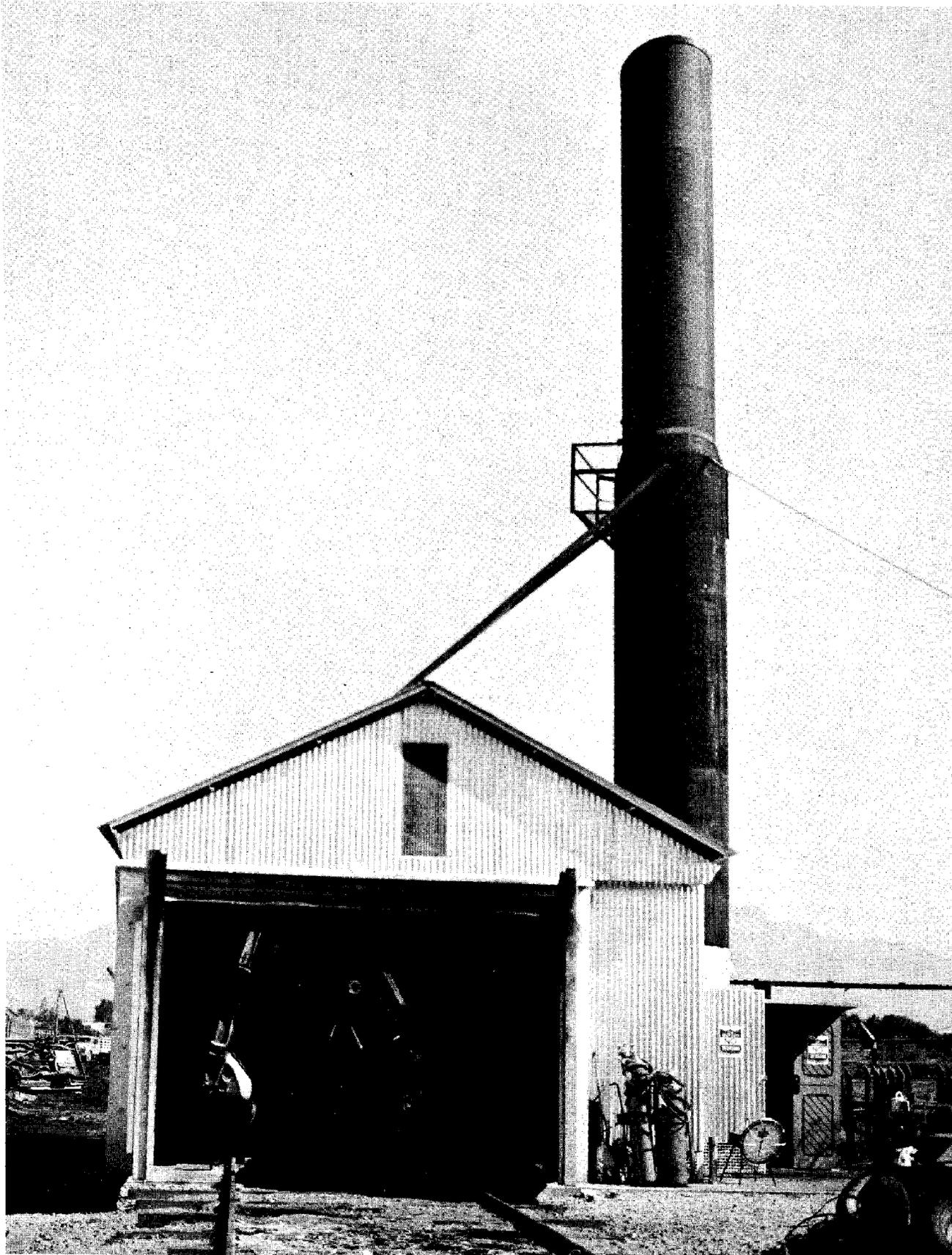


FIGURE 11. - Bureau's Smokeless Junk Auto Incinerator.

Increased Use of Ferrous Scrap in Electric Furnace Steelmaking

The electric-furnace steelmaking industry is one of the major consumers of purchased scrap. However, growing competition from pelletized iron ore, which can also be fed to these furnaces, may drastically reduce the auto-scrap market for such purposes because prereduced iron pellets can be charged continuously to furnaces whereas much of the present scrap cannot. This fact gives the pellets an advantage over scrap even when prices are equal. Bureau engineers believe that properly prepared auto and large appliance scrap, as well as tin cans, can also be charged continuously to electric furnaces, and that a mixture of scrap and pellets would be a suitable charge in most cases. Current research on this project has emphasized (1) the effects of continuous charging of ferrous materials at low and elevated temperatures to a conventional, tilt-able, open-arc furnace; (2) the technical feasibility of continuous steelmaking in a stationary open-arc furnace; and (3) process evaluation for production of secondary pig iron from fragmented auto hulks in a submerged-arc furnace. Preliminary tests in which prereduced iron ore in various forms and shredded autos were added continuously at a controlled rate to a bath of molten auto scrap showed that, compared with conventional batch practice, the duration of heats and energy consumption can be substantially lowered and tramp metal content can be reduced to levels acceptable for most steel products. Further improvement in the efficiency of electric furnace steelmaking appears practical by utilizing the sensible heat in furnace offgases during continuous charging to preheat feed material.

Production of Foundry Pig Iron From Junk Car and Other Ferrous Scrap

The objective of these studies is to determine the optimum charges and processing variables required to make specification-grade foundry iron from auto scrap and subcommercial scrap iron at commercially attractive costs. This research is being conducted in a modified size "0" hot-blast cupola having an 18-inch inside diameter (fig. 12). The cupola can accommodate 330 pounds of scrap, together with coke and fluxes, to produce approximately 300 pounds of metal. Preliminary tests have shown that the copper content of metal produced in the cupola, using prepared scrap, meets the specifications for gray iron but not for malleable iron. The tests also indicated that specifications for sulfur content for gray iron can be achieved.

Destructive Oxidation of Ferrous Scrap

Work is progressing on a process for converting junk-car and other low-grade scrap in a rotary kiln at 1,000° C (fig. 13) to yield coproducts of high-grade iron oxide and dense residual steel scrap of high purity. Destructive oxidation need not be limited to treatment of automobile hulks but can accommodate other low-value ferrous scrap such as refrigerators, stoves, tin cans, turnings, and borings. The light-gage material yields only one kiln product consisting of high-grade iron oxide. Heavier ferrous scrap charges are 70 percent oxidized in one pass through the kiln and can be either removed as a usable product or recycled through the kiln. Recovery of the heavier members of automotive scrap from the kiln roast product not only provides feed suitable as heavy melting stock for electric furnace or foundry use, but also gives a material that is substantially more valuable than the original auto scrap.

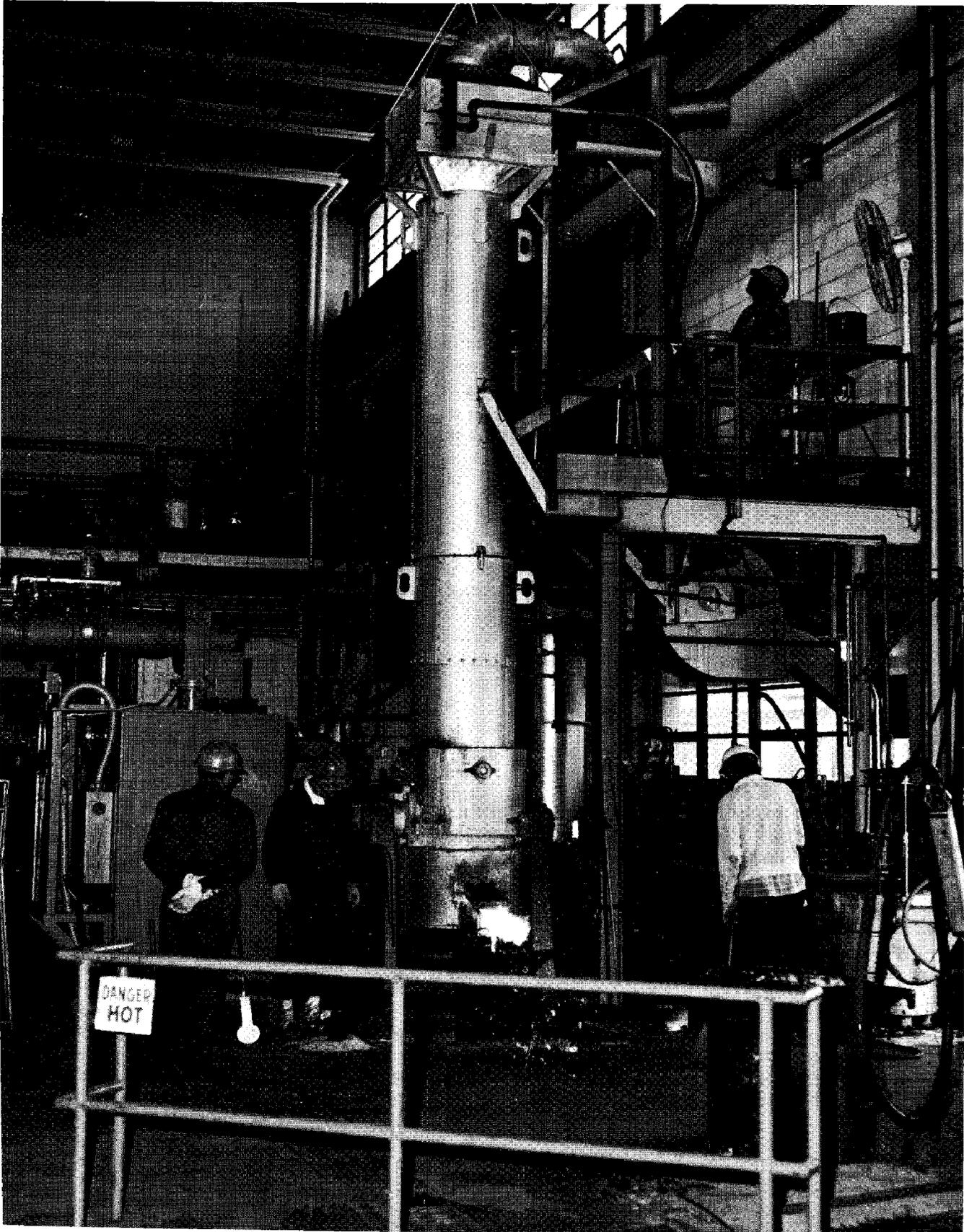


FIGURE 12. - Experimental Hot-Blast Cupola.

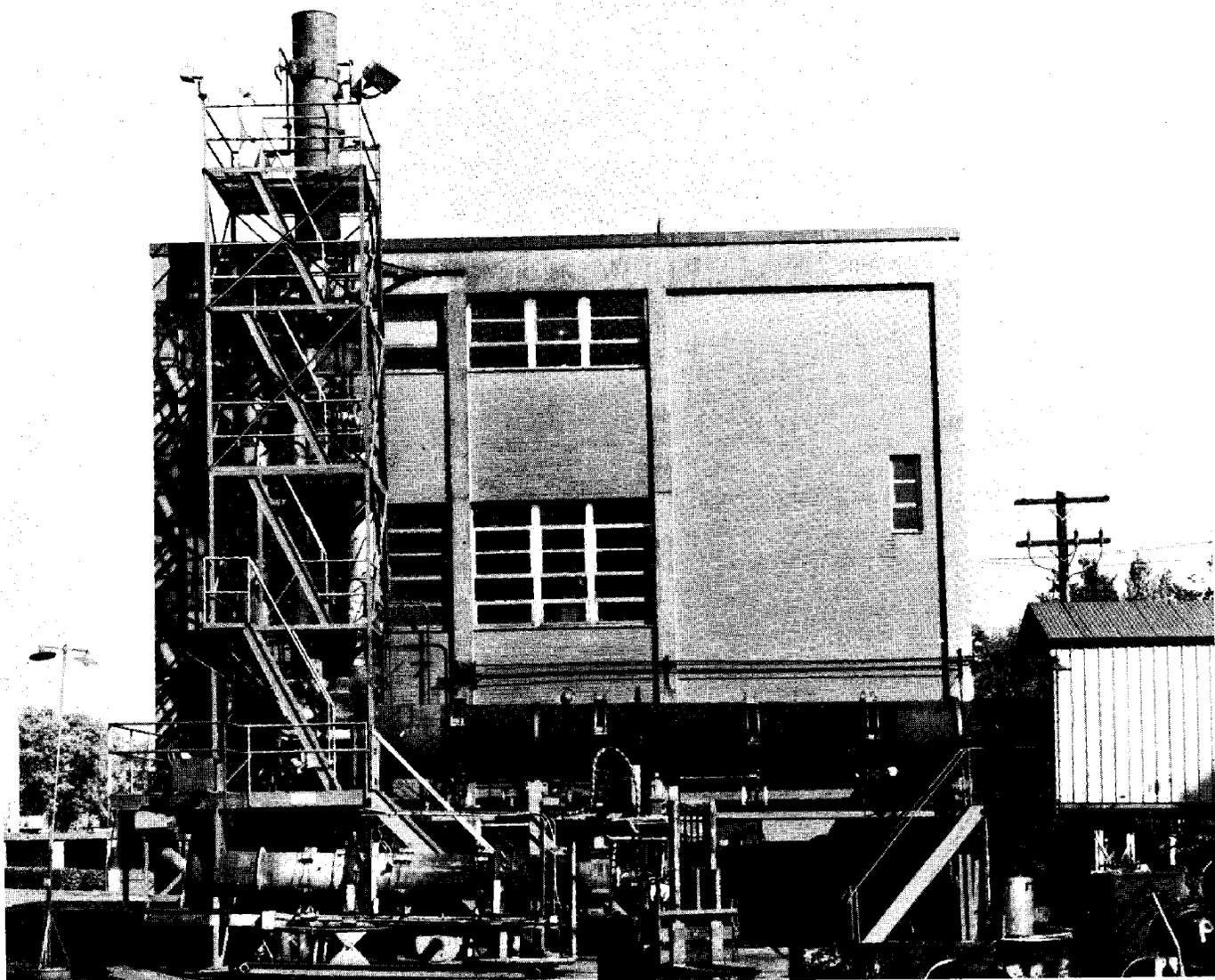


FIGURE 13. - View of Large and Small Rotary Kilns Used in Automobile Scrap Processing Showing Afterburner at Top of Stack.

Utilization of Ferrous Scrap as a Reductant

The Bureau has done considerable work on the utilization of ferrous scrap as a reductant for converting nonmagnetic taconite into a product that can be separated from associated gangue minerals. In the process, the mixture of ore and scrap iron is heated to $1,000^{\circ}\text{C}$ in a rotary kiln (fig. 13). The scrap is oxidized to iron oxide and the nonmagnetic ore feed is reduced to the magnetic form. Past experience has shown that the best scrap charge is thin-gage auto scrap, tin cans, borings, and turnings. The thinner gage scrap is oxidized more rapidly in the process. Although the heavier ferrous scrap may not be completely oxidized in the kiln, it can be collected and used as high-quality, heavy-melting stock for electric furnace feed. Future work, particularly on the use of auto scrap as a reductant, will emphasize the recovery of valuable nonferrous metals present in the iron oxide concentrate.

Recovery of Copper and Iron From High-Grade Ferrous Scrap

The aim of this work is to recover high-grade copper and iron from copper-bearing ferrous scrap, such as generators, starters, alternators, etc., by a preferential melting technique in molten salts, slags, or other suitable media. Although the basic method was developed some time ago, the Bureau is continuing this work with emphasis on improving the economics of the process. Calcium chloride has been found to be a suitable substitute for the more costly barium chloride salt used in early work. It has also been determined that pretreatment of the scrap with sodium sulfate prior to immersion in the molten bath for sweating off the copper increases the copper recovery.

Removal of Contaminants From Molten Ferrous Scrap

The Bureau is also working on a metallurgical refining method for removing copper and other contaminants from molten junk car scrap and other ferrous materials. One promising approach, currently under investigation, is the use of an alkali slag to remove copper from molten iron (fig. 14). Technical feasibility of the technique has been demonstrated and its possibilities for commercial use are being explored. The process involves the addition of sodium sulfate to a molten iron bath to form copper sulfide, which is removed along with the copper. Work is continuing on means of lowering the sodium sulfate addition to the bath and on increasing the recycling of the sodium salt from the slag. The ultimate aim will be to develop a process that will permit electric furnace melting of low-grade ferrous scrap.

Air Separator for Automobile Shredder Residue

In most junk-car shredding operations, large quantities of nonferrous metals, combined with the other nonmagnetic residues from the shredded vehicle such as glass, plastics, and rubber, are disposed of in dumps or landfills. It is estimated that 300,000 tons of nonferrous metals are lost annually in this manner. The Bureau has designed an inexpensive pilot air classifier with a capacity of 16 tons per hour, in which the nonmagnetic residue from shredding operations can be automatically separated (figs. 15-16). Tests have shown that more than 95 percent of the nonferrous metal of the residue can be collected in a single pass through the device. Methods for physical separation of the individual metals from the nonferrous metal concentrate are being examined.

Recovery of Copper, Aluminum, and Other Nonferrous Metals by Cryogenic Techniques

Preliminary tests have shown that quick freezing of copper-ferrous scrap in liquid nitrogen, or in mixtures of acetone, methanol, and dry ice, greatly enhances recovery of the copper. Copper and aluminum wire can also be cleanly separated from plastic and rubber insulation by freezing and shredding. The method is particularly suited to recovery of copper from small motors.

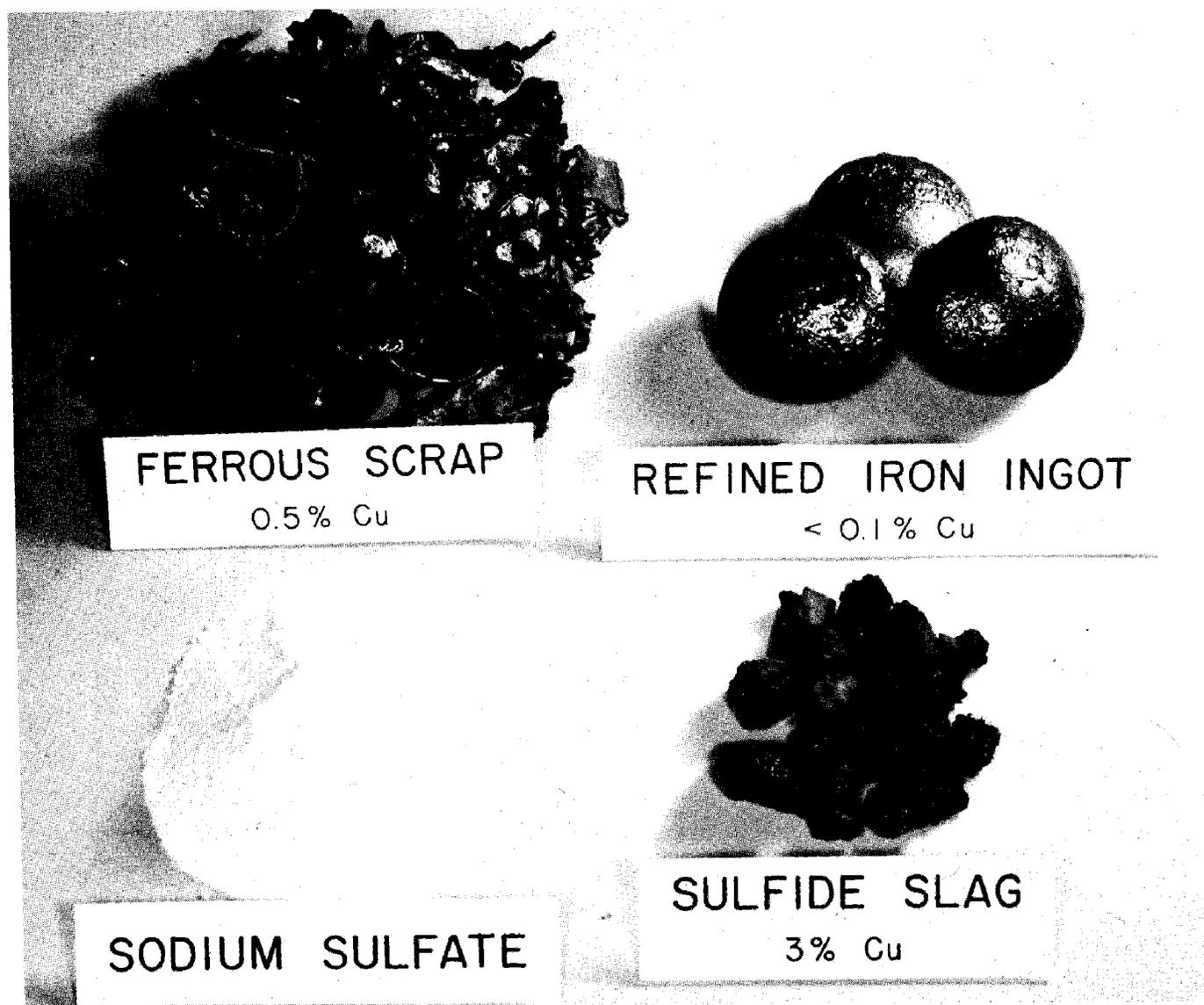


FIGURE 14. - Typical Feed Materials and Products for Recovering Copper From Molten Iron.

Ferrous-Scrap-Operation Surveys

The Bureau, in conjunction with its surveys of mineral industries, has recently conducted an examination of nine representative junk-car shredding operations across the country. The rated capacity of the sample from nine shredders was 21 percent of the total capacity of 89 existing shredders. Collection and dissemination of information will be continued on various types of ferrous scrap operations that include junk cars.

Utilization and Stabilization of Mine, Mill, and Smelter Wastes

Another phase of the Bureau's solid waste program is directed toward the stabilization and utilization of the nearly 25 billion tons of mining and mineral solid waste accumulated across the country. Surveys have identified many of the existing wastes, and characterization studies have provided much information and data on their nature. Many such wastes can be used to make

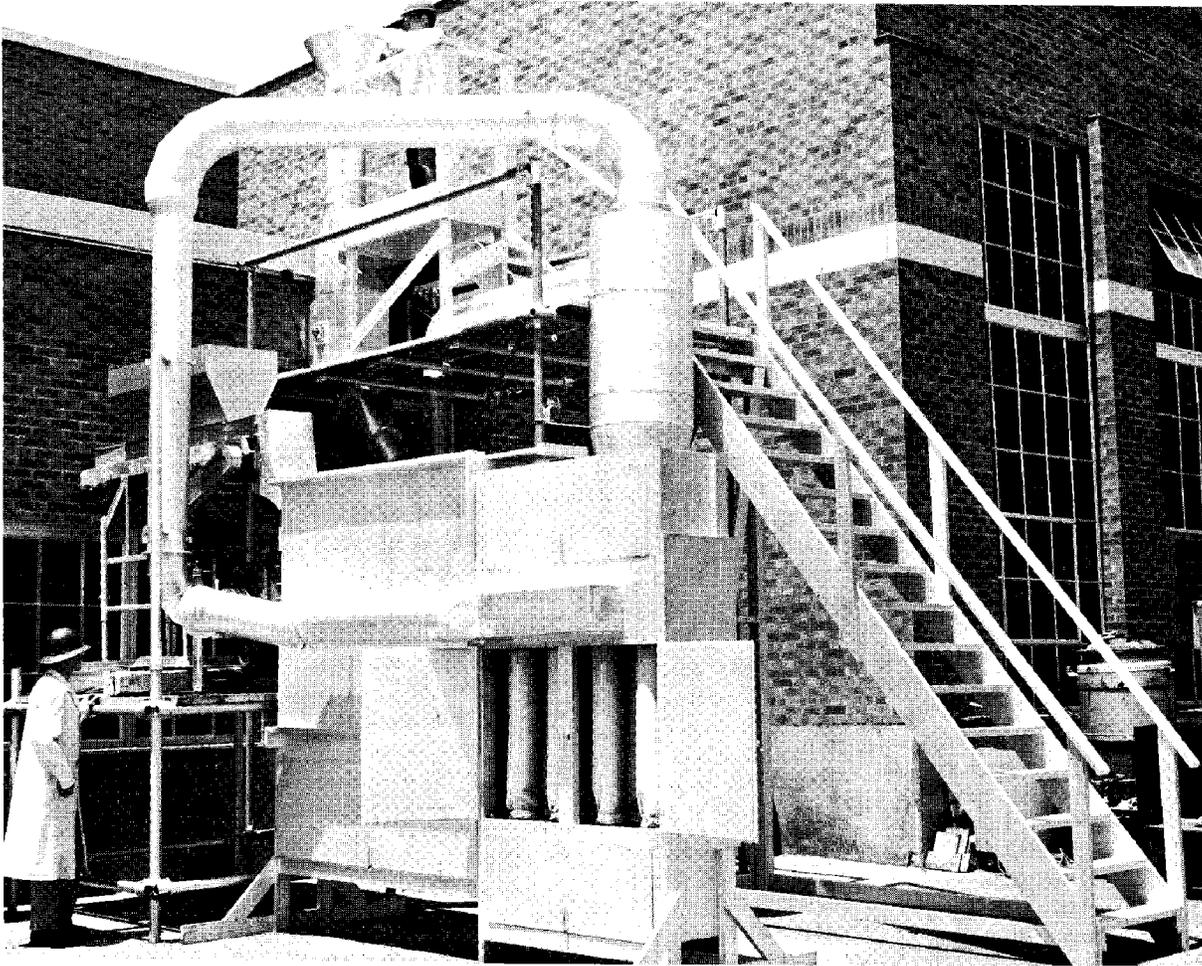


FIGURE 15. - Air Classifier for Processing Junk-Car-Shredder Reject.

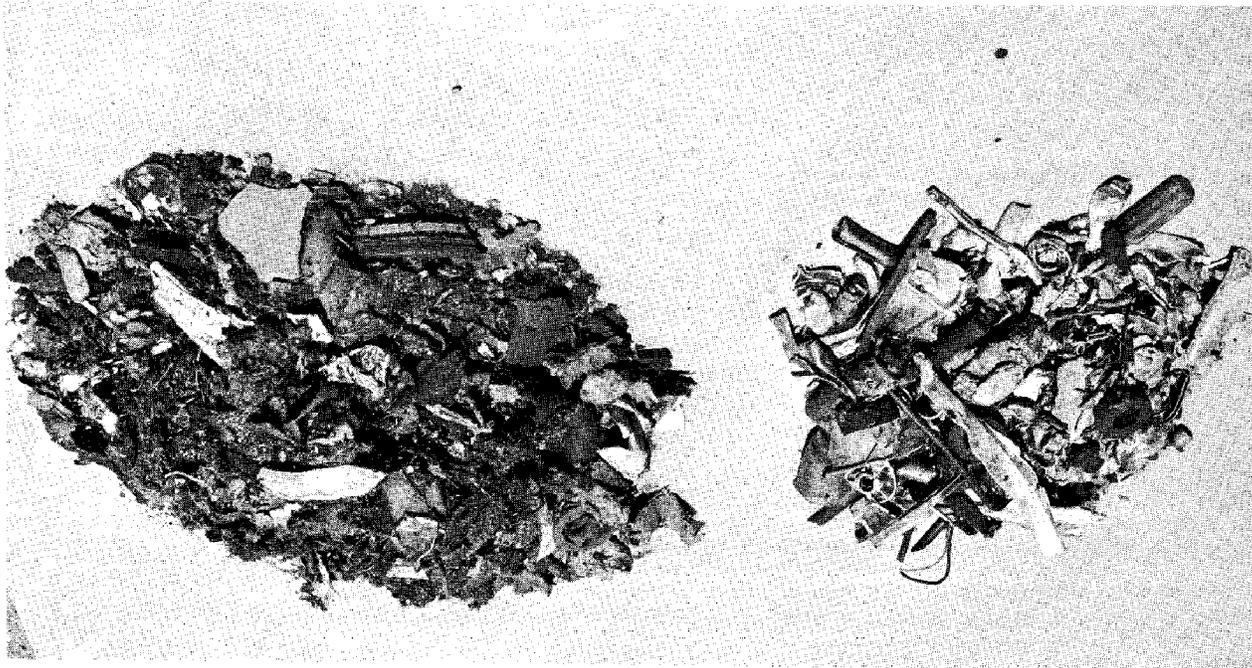


FIGURE 16. - Nonferrous Metal (Left) Recovered From Junk-Car-Shredder Rejects (Right) by Bureau Developed Air Classifier.

attractive structural materials, and others can be stabilized by several promising methods. Excellent progress has been made in the development of low-cost methods to stabilize fine waste such as tailings. Large acreages of uranium, copper, and lead-zinc tailings piles have been successfully stabilized by vegetative and chemical means. The Bureau also has a substantial research and demonstration program on coal mine subsidence and on controlling fires in coal waste banks. Current research on mineral wastes includes the following.

Vegetative Stabilization

Successful vegetation stabilization procedures have been developed for tailings piles from mining of copper, uranium, and lead-zinc ores. Many varieties of grasses, wheats, and ryes have been grown in laboratory tests and on large-acreage tailings plots (fig. 17). Vegetation that shows promise includes sweet clover, winter wheat, rye, and barley; grasses such as sorghum, Kentucky blue, and orchard; and shrubs such as sagebrush, rubber rabbit brush,

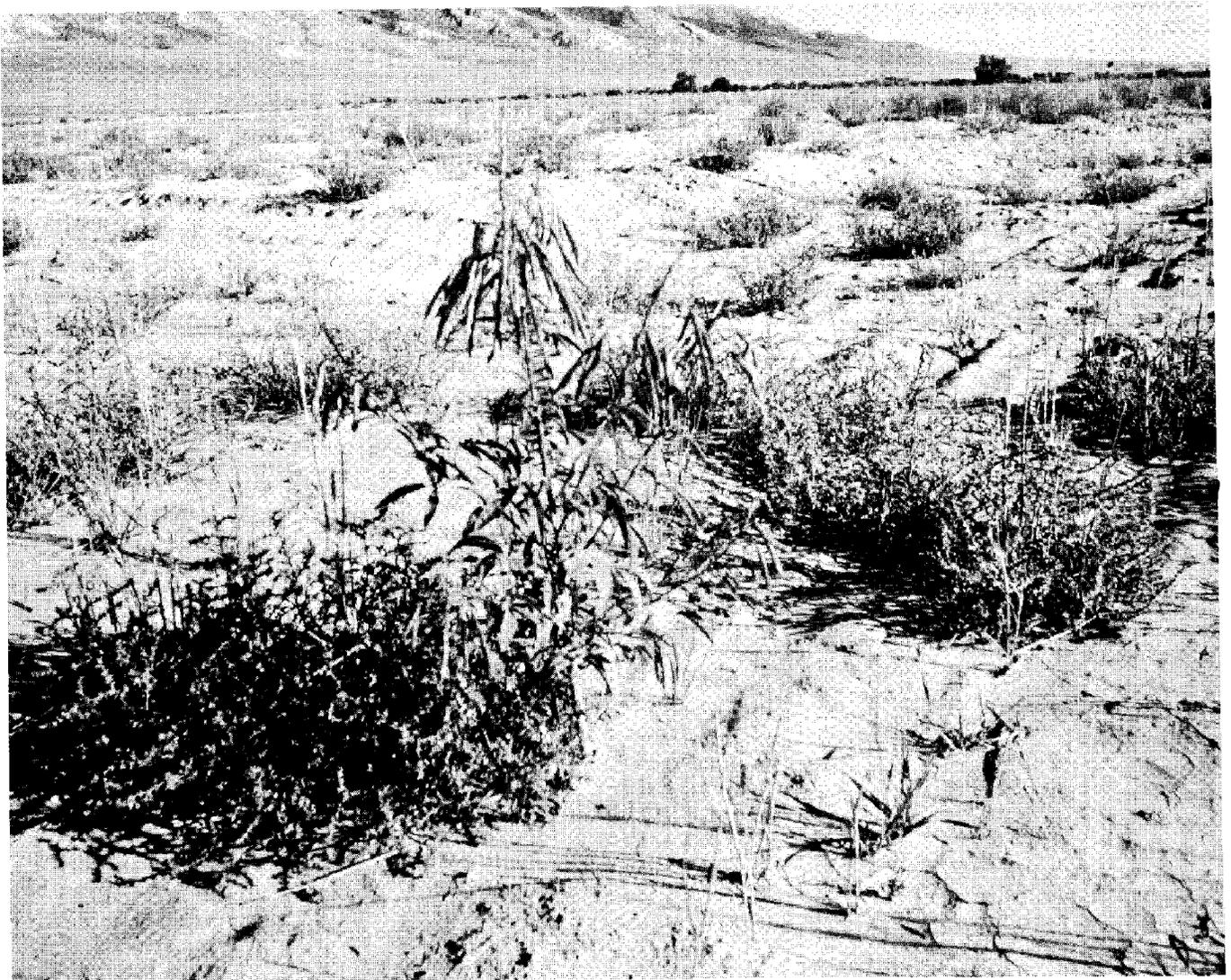


FIGURE 17. - Stabilized Copper Mill Tailings 1 Year After Planting, Showing Encroachment of Native Plant Species.

and Siberian pea tree. A special barley, Charlottetown 80, has been effectively grown in acid wastes at a pH as low as 3.0. Laboratory work is also underway to determine which salts or organic reagents in the tailings most affect plant growth. Considerable research has been conducted to devise means of overcoming the deleterious effects of salts and acids within mill tailings. Both sewage sludge and compost made from municipal refuse were tested as additives to the tailings and proved beneficial to both vegetative germination and growth.

Research is in progress to determine the feasibility of reclaiming and revegetating coal refuse banks and adjacent affected lands. Coal refuse was examined for composition, texture, acidity, moisture content, and plant nutrient levels. Experiments have been conducted by applying various amounts of fly ash and soil conditioners and mixing these components with coal refuse to varying depths to promote plant growth. Grasses and legumes were successfully established on a formerly barren coal refuse bank.

Chemical Stabilization

Chemical stabilization of fine-grained mill tailings is a promising method to reduce pollution from such materials. In many instances the tailings, because of contained chemicals or climatic conditions, are not amenable to vegetative treatment. At costs of 0.01 to 0.03 cent per square yard, some of the additives found to be effective surface stabilizers are Coherex, a resinous adhesive; DCA-70, an elastomeric polymer; calcium, ammonium, and sodium lignosulfonates; and cement and lime. A 34-acre tract of uranium mill tailings in Arizona was effectively stabilized with DCA-70 and calcium lignosulfonate (fig. 18).

Combined Stabilization Methods

One of the most innovative studies of the Bureau in this area has been the development of a combination chemical-vegetative stabilization method. The use of chemicals in conjunction with vegetative growth can have several advantages in (1) preventing sandblasting of plants, (2) helping to retain moisture by decreasing evaporation, (3) aiding in germination by adsorbing heat, (4) adding organics to the wastes, and (5) preventing reflection of the sun's rays back to the plant. A combination system involving vegetation and an application of Coherex was successfully used on a 10-acre copper tailings plot in Nevada. Smaller plots of lead-zinc tailings have also been stabilized with the combination methods.

Work has also been conducted on physical stabilization of fine tailings to prevent air pollution. The most useful materials are rock and soil obtained from adjacent areas. Granulated smelter slag has been employed as an effective stabilizer as well as bark covering, straw, placement of windbreaks such as old tires, and spreading of a mixture of limestone chips and sodium silicate as a coating.

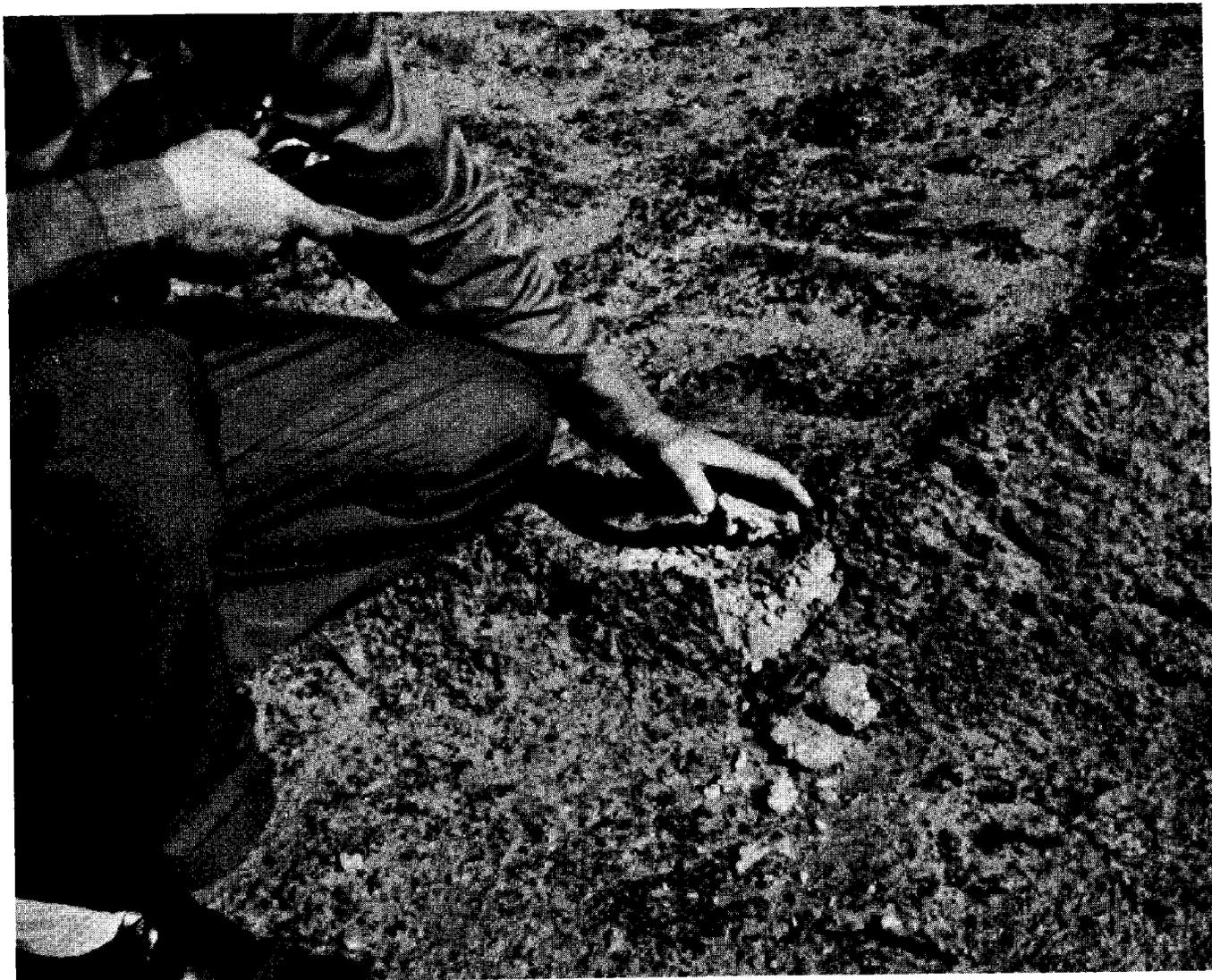


FIGURE 18. - Chemically Stabilized Uranium Mill-Tailings Pile.

Utilization of Mineral Wastes

Research is underway on the use of mineral wastes for producing ceramic and construction materials. As most mineral wastes are usually low in clay and plasticity, the Bureau's work has been directed toward developing dry-pressing and steam-curing methods to produce structural products. The feasibility of using copper mill tailings for making bricks from six different sources by a dry-press method has been demonstrated (fig. 19). Tailings containing 1.5 percent or less sulfides were used as received, mixed with calcium lignosulfonate and water, and subjected to pressure and curing.

Steam-cured, silicate-bonded building bricks have also been made in the laboratory from porphyry copper mill tailings from Utah and Arizona. A method was devised for producing quality wall tile from phosphorus furnace slag.

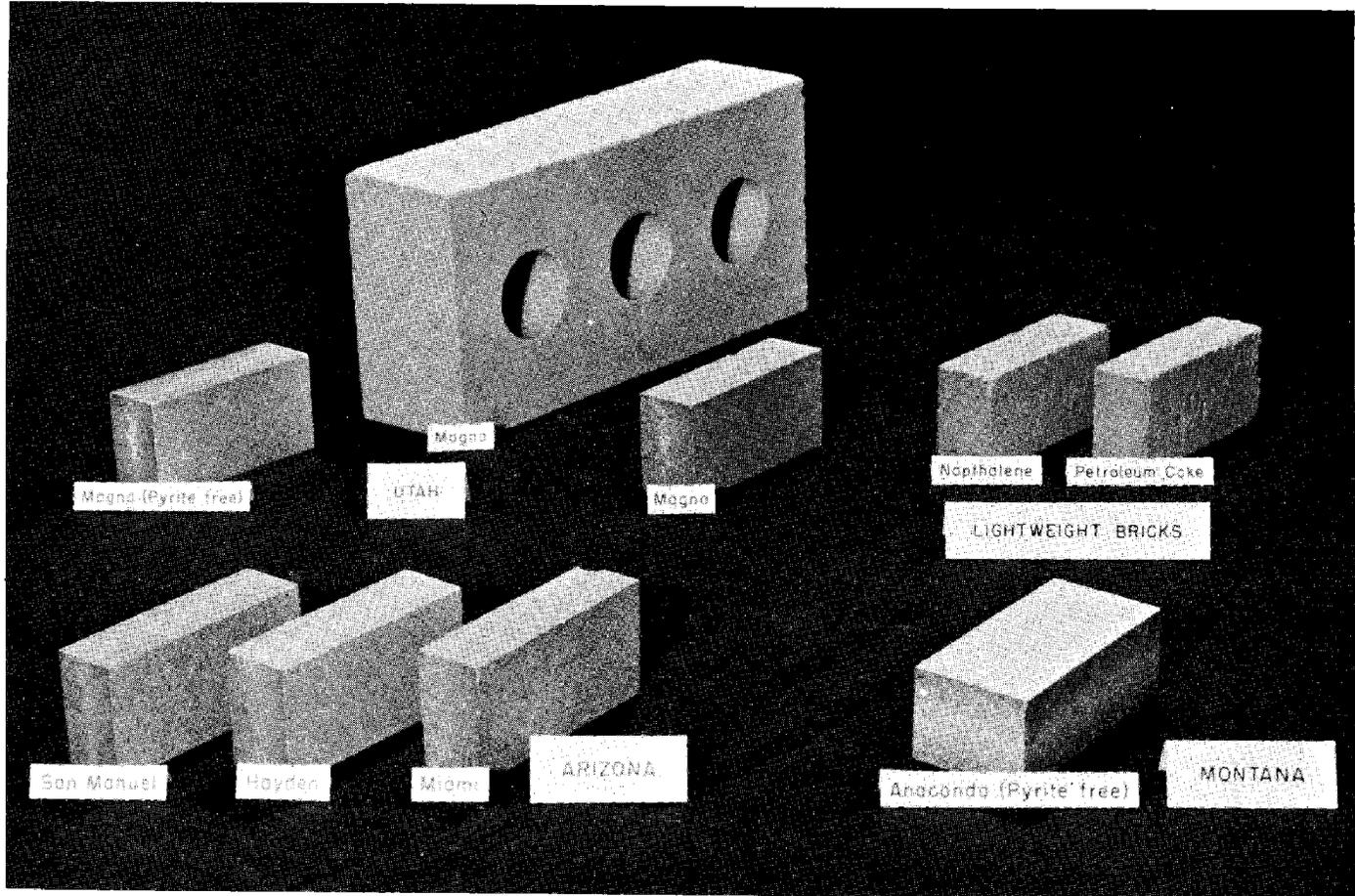


FIGURE 19. - Structural Materials Made From Copper Mill Tailings.

Studies on mineral wastes include development of low-cost methods for recovering copper, as well as molybdenum, gold, and silver from mining and milling wastes. Procedures comprising crushing, screening, and flotation are being employed to obtain rich concentrates. Percolation leaching of coarse, residual, dump material is also being investigated. Improved, low-cost techniques for recovering uranium from wastes such as mill tailings and mine water are under development.

Mine Subsidence Control

Mine refuse from past anthracite coal mining operations is being used to backfill voids in abandoned mines to prevent subsidence of the surface in populated areas (fig. 20). To date, 12 projects have been completed on flushing crushed mine refuse into abandoned underground mine voids to provide surface support under populated areas. Surface water leaches sulfides in the waste banks to form acid drainage; the waste banks contribute silt to adjacent land areas and streams; and, when ignited, the banks contribute to pollution of the air. Thus, three benefits evolve from backfilling operations--disposal of waste, control of subsidence, and elimination of hazardous conditions.



FIGURE 20. - Backfilling of Underground Mine Void With Coal Refuse Slurry.

Control of Burning Coal Waste Banks

Waste accumulations from coal mines contaminate air and water, pose hazards to public health, create scenic blights, and interfere with community development. Because of the carbonaceous content of these piles, they are susceptible to ignition by spontaneous combustion or by irresponsible trash burning. Once ignited, a coal waste bank may burn for decades, polluting the atmosphere with smoke and noxious gases (fig. 21). According to the most recent survey conducted by the Bureau, 292 burning coal waste banks are located throughout the United States.

Two demonstration projects have been completed in Pennsylvania's anthracite region to develop effective methods for extinguishing fires in coal waste banks. One consists of water-quenching and compaction and the other is based on constructing ponds on the leveled surface of the bank. A third project involves testing the effectiveness of using yet another technique--water sprays and a water injection system. In addition, a survey of the ambient air at the project site is being conducted to gather data on emissions of gases, such as sulfur dioxide and carbon monoxide, from the coal refuse fire.

Recovery and Reuse of Values From Industrial Wastes

Industrial wastes present serious disposal problems because each type of waste requires a different solution. In this category are included piles and acres of sludges, slags, scrap plastics, scrap metal, rags, and waste paper, as well as chemicals, oils, solvents, and other liquids resulting from manufacturing processes.

The Bureau has developed methods to recover values from industrial waste products over a period of more than 30 years. However, these have been mostly metal- and mineral-bearing wastes and were directed to reclamation of high-value materials. In fact, many of the procedures used by secondary processors to recover metal values from industrial wastes are Bureau developments. In recent years, the Bureau has also directed its attention to a variety of troublesome low-value industrial waste materials. Current investigations include the following.

Scrap Metal Identification

An important project involves a study on developing rapid, simple identification methods for scrap metals. Although this is a vital step in the reuse cycle, and errors can be serious and cumulative, the methods in common usage are neither scientific nor reliable. Tests that permit rapid identification of the major alloying constituents of aluminum alloys have already been developed. An inexpensive device, (fig. 22) requiring only 15 seconds per test, was designed for electrographic sampling onto filter paper. Current work is directed toward methods for identifying the large number of copper alloys that are collected in scrap processing yards.



FIGURE 21. - Burning Anthracite Refuse Bank.

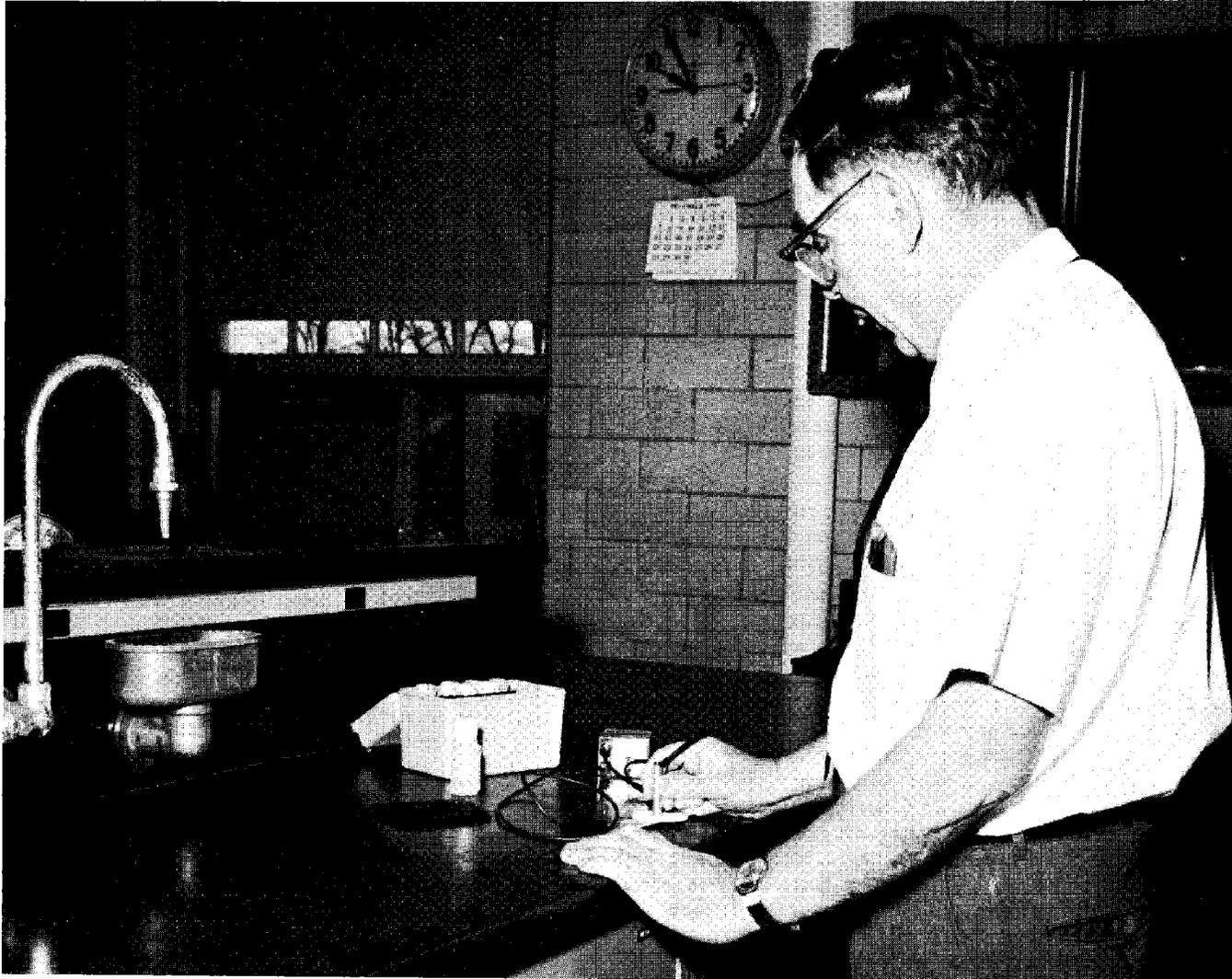


FIGURE 22. - Scrap Metal Identification Test Kit.

Precious Metal Recovery From Scrap

Methods are under investigation to recover and recycle the vast quantities of precious metals that are presently lost when electronic equipment is discarded. Military electronic equipment is presently being scrapped at a rate of 15,000 tons per year. This scrap averages per ton, 100 troy ounces of silver, 5 troy ounces of gold, 1 troy ounce of palladium, and lesser amounts of other precious metals (fig. 23). The most promising approach for recovery of these valuable metals is a smelting process, followed by electrolytic treatment to separate the precious metals from copper (fig. 24).

Reuse of Waste Lubricating Oils

The Bureau has recently initiated research to develop the best methods and techniques for recovery and reuse of the 8 million barrels of automotive and industrial lubricating oils presently dumped onto land surfaces or into streams each year. Further attention is being directed toward the



FIGURE 23. - Assorted Precious-Metal-Bearing Electronic Scrap.

sludge-disposal problem resulting from the re-refining of used oil. The products are being examined for a variety of uses.

Recovery of Sulfur Dioxide From Smelter Gases

Another serious problem is that of collection and recovery of sulfur dioxide emitted from smelters. The Bureau has developed a process for recovering elemental sulfur from smelter stack gases by absorbing the SO_2 in a solution of sodium citrate and sodium carbonate. By reacting the absorbed SO_2 with H_2S , elemental sulfur is precipitated. Stripped citrate solution is recovered for recycle, and part of the sulfur is converted to H_2S for use in the precipitation step. A pilot plant based on the Bureau's process was built and operated for several months in cooperation with Magma Copper Co. to obtain technical and economic data on the process.

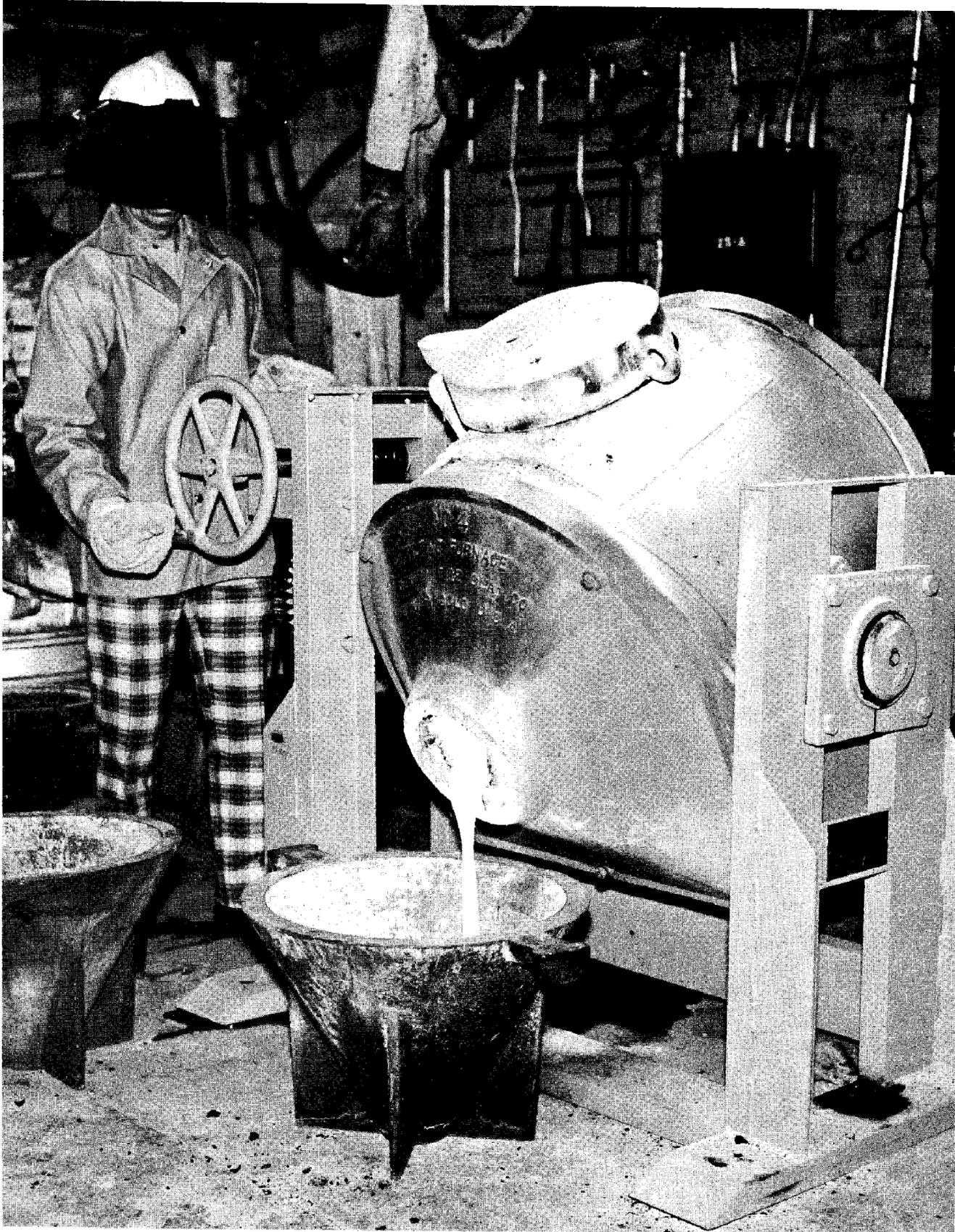


FIGURE 24. - Pouring Copper-Gold-Silver Bullion Recovered From Electronic Scrap by Smelting.

Reuse of Ferrous and Nonferrous Dusts

Studies identifying the nature and magnitude of solid wastes issuing as flue dusts in steelmaking operations are underway. Aside from the loss of iron contained in these wastes, significant amounts of zinc, copper, and lead, originating from the scrap additions to the steelmaking processes, are also present. Techniques such as sulfuric acid extraction of copper and zinc are being used to treat and recover these dusts so they can be returned to the steel furnaces as high-grade pelletized iron ore. Processes to treat flue dusts from brass smelters to form metallic zinc, lead, and copper products are also being investigated. Emphasis is placed on methods that allow the dusts to be treated in the plants where they are generated.

Recovery of Values From Waste Plating Solutions and Sludges

Work continues on recovery of metallic values from waste electroplating solutions by application of the Bureau's waste-plus-waste technique. This method involves the combination of two waste liquids to produce recoverable products. Research has been initiated on recovery of the valuable constituents in the sludges that result from electrochemical machining (ECM) and electrical discharge machining (EDM) of stainless steels and nickel- and cobalt-base alloys. Approaches to be used in solving this problem include selective dissolution, solvent extraction, and controlled-potential electrolysis.

Recycling Titanium Scrap

Attention is also directed toward improved methods of recycling titanium and titanium-based alloy scrap. One procedure employs the use of the Industoslag process for continuous direct feed and melting of scrap titanium.

Another project involves developing a fused-salt, electrorefining process to recover titanium from scrap alloys containing aluminum and tin.

Recycling High-Temperature Alloy Scrap

Methods to recover and recycle the individual components of high-temperature-alloy scrap are receiving attention. Studies include sequential oxidation and reduction of elements from molten salts based on their position in the emf (electromotive force) series.

Treating Aluminum Scrap

Research is continuing on electrolytic processing of aluminum scrap and alloys in a large, single-compartment cell. Emphasis is placed on extraction of aluminum and precious metals from aluminum-base electronic scrap and the nonferrous fraction of municipal incinerator residues. Tests are also being conducted to determine process conditions necessary for effective separation of aluminum and aluminum oxide from high-chloride salt slag by molten slag filtration techniques. Refining slags and fluxes for treating aluminum drosses are under examination.

Lead-Battery Scrap

Work has been initiated on developing a new method for processing lead-battery scrap to allow recovery of lead and sulfur and eliminate the current problem of sulfur dioxide emissions. Optimum conditions for leaching, smelting, sulfur recovery, and regeneration of leaching agents are being examined.

Reuse of Fly Ash, Coal Bottom Ash, and Other Wastes

Other research and development projects include the use of waste glass, coal bottom ash, and fly ash to produce brick by appropriate mixtures of clay and the waste materials.

Research on the production of portland and regulated set-cement from fly ash is proceeding. The use of waste silicofluorides and other mineralizers in the production of cements and refractories appears to be highly promising. Reclamation of iron foundry core sands is under investigation.

CURRENT AND RECENTLY COMPLETED SOLID WASTE RESEARCH GRANTS AND CONTRACTS

The Bureau's work on utilization and disposal of solid wastes is supplemented by grants and contracts to educational and other organizations. The program has two objectives. One is to involve educational institutions in the recovery and recycling of solid wastes. The second is to provide incentives to graduate students and their associates to prepare for industrial and public service careers concerned with environmental and mineral supply problems.

Urban Refuse

SWD-12	Residual Elements in Scrap Iron	\$59,044	Pennsylvania State University
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Objective: To determine the thermodynamic properties of iron-copper solid solutions and use the results to develop sulfidation and/or evaporation processes for removing copper from scrap iron.

Between 1,050° and 1,466° C copper in dilute solution in iron exhibits extreme positive deviation from Raoult's law. The deviation decreases with increasing temperature. At 1,300° C, carbon increases the activity coefficient of copper in iron, but silicon has no effect. Application of the results to copper removal from iron-based alloys is under study.

SWD-29	Utilization of Ferrous Urban Wastes	\$108,445	University of Wisconsin
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Objective: To determine the effect of various concentrations of contaminants, such as copper and tin, on the physical properties of iron reclaimed from urban refuse.

Both tin and copper moderately increase the strength of annealed ductile iron while reducing the ductility slightly. The results are similar with pearlitic ductile iron except that additions of tin in excess of 0.02 percent do not alter the tensile strength. However, tin has a marked effect on properties of cast specimens. The properties of malleable iron are not affected as much by copper and tin as anticipated. A copper-tin heat of about 0.2 percent Cu and 0.88 percent Sn made from ferrous incinerator scrap gave greater chill depths than previous heats made with tin or copper additions alone.

Both copper and tin additions increase the strength of cast steels. The percentage elongation of cast steel decreased to and remained almost steady at 15 percent following addition of either 0.05 percent Sn or 1.0 percent Cu. Addition of 0.12 percent Sn and 0.2 percent Cu produced higher hardness and lower ductility than did the same amount of these elements added singly.

	Use of Waste Glass in Expanded Shale		University of
SWD-28	Aggregate	\$32,928	Alabama

Objective: To determine the technical and economic feasibility of using crushed waste glass from urban refuse in combination with expandable clay or shale to produce lightweight concrete aggregate.

A number of lightweight concrete aggregates have been produced and tested in concrete. The properties of test specimens, made with the aggregates, are comparable to those made from commercial expanded shale.

	Technical Evaluation of Refuse Incineration		University of
SWD-31		\$55,301	Alabama

Objective: To survey current municipal incinerator operation and design, and to make recommendations as to future research needs.

As a result of the study, recommendations are made on development of quantitative information regarding combustion theory and air requirements, materials of construction and grate influence, furnace configuration, combustion emissions, and slag.

	Characterization of Mineral and Metal		University of
SWD-22	Values in Incinerator Residue Gangue	\$50,500	West Virginia

Objective: To characterize municipal incinerator residues and seek means of utilizing all or part of this waste material.

Fly ash and the nonmagnetic residues from incinerators have been analyzed for 24 elements. Concentrations of gallium were found to be unusually high, suggesting that this element might be recovered. Preliminary investigations are underway into methods for recovering gallium and copper. Fly ash has also been utilized as a raw material for making lightweight aggregate. Concrete made therefrom meets ASTM specifications.

<u>SWD-24</u>	<u>Phosphate Slimes as a Soil Amendment</u>	<u>\$8,766</u>	University of Florida
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Objective: To study the effects of phosphate slimes on physical and chemical properties of Florida soils and the growth responses of selected crops.

Experiments conducted with millet plants indicate that increasing the amount of phosphate slimes placed on the soil results in increased plant growth.

Mining and Industrial Wastes

<u>SWD-1</u>	<u>Treatment of Mine Tailings To Enhance Plant Growth and Promote Stabilization of Tailings</u>	<u>\$120,000</u>	Utah State University
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Objective: To determine the best methods for using vegetation to stabilize mine tailings.

Suitable plants were selected and plant growth enhanced by altering the tailings chemistry. In field testing, the major problems encountered were oxidation of pyrites in the tailings pile, decrease in pH, and solubilization of heavy metals from the pile. The severity of these problems increases with time. The plants chosen must be hardy in the climate of the area, but they are usually not indigenous. Native plants become established on the tailings piles when the nonnative plants have been in place for a few years. Decrease in salinity of the tailings and additions of phosphorus and nitrogen are required. Growing of legumes on tailings pile will result in nitrogen fixation. Rarely is there a lack of potash.

<u>SWD-13</u>	<u>Utilization of Mine Waste Tailings</u>	<u>\$58,279</u>	University of Wisconsin
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Objective: To investigate and develop means of utilizing jig and flotation mill tailings from the zinc district of Wisconsin.

Upgraded float tailings yielded a concentrate containing 26.9 percent Fe and 30.3 percent S, which was oxidized in a fluidized bed reactor. A reactor was designed to handle 200 tons per day of 200-mesh pyrite.

<u>SWD-14</u>	<u>Use of Fly Ash as a Soil Conditioner</u>	<u>\$42,267</u>	Virginia Polytechnic Institute
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Objective: To study the potential of fly ash as a supplier of boron, zinc, and other elements to correct nutrient deficiencies in soil.

The boron in fly ash is in a form available to alfalfa plants and is beneficial. Potassium in fly ash can be absorbed by corn seedlings, but high proportions of ash may produce boron toxicity.

	Characterization and Utilization of		Commonwealth of
SWD-15	Anthracite Refuse	\$364,086	Pennsylvania

Objective: To develop uses for refuse from more than 800 anthracite refuse banks that blanket 12,000 acres of land in northeastern Pennsylvania.

The potential of burning the refuse (containing 35 to 40 percent carbon) and using the resulting ash as aggregate is being explored. Other applications are for landfill, highway embankments, road subbases, manufacture of bricks, nonskid highway surfaces, and recovery of carbon. A Pennsylvania utility company plans to build and operate a 300-megawatt steam-generating station using anthracite refuse as a fuel. Anthracite refuse is also being evaluated as an antiskid material by Wyoming and Luzerne County, Pa.

	Recovery of Metal Values From Steel		Georgia
SWD-32	Plant Dust	\$20,514	Institute of Technology

Objective: To investigate the recovery of iron, lead, and zinc from precipitator dust on pilot-plant scale, and to investigate potential techniques for recovering other values such as magnesium, manganese, and aluminum.

In a pilot plant having a capacity of 300 pounds of electric-furnace dust, initial leaching is with acid to remove zinc, followed by caustic treatment to remove lead as sodium plumbite. Oxidation of the residue will follow to convert the iron to iron oxide. Some manganese, magnesium, and aluminum will report in the acid leach solution which must therefore be purified before electrowinning the copper. The remainder of the manganese, magnesium, and aluminum are oxidized with the iron. Process and economic data will form the basis for designing commercial plants.

	Utilization of Mining and Milling Wastes		IIT Research
SWD-C-8		\$104,484	Institute

Objective: To evaluate clays, fly ash, and hydrated iron oxide as additives to foamed taconite blocks.

The properties studied were foam stability, settling from the slurry, shrinkage cracks, and strength of fired specimens. Ball clay additions increased strengths. The effects of adding mixtures of mineral wastes to the taconite are under study.

The Third Mineral Waste Utilization Symposium will be cosponsored in March 1972 by the Bureau of Mines and the IIT Research Institute.

Junk Automobiles and Railroad Freight Cars

SWD-C-10	Incinerator for Scrap Automobiles and Railroad Cars	\$60,000	Luria Brothers and Co., Inc.
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Objective: To construct, operate, and demonstrate the feasibility of a facility to incinerate scrap automobiles and railroad boxcars on a large scale, based on the Bureau of Mines prototype junk car incinerator at Salt Lake City, Utah.

The incinerator is to have a capacity of 20 scrap automobiles per hour or one scrap railroad boxcar every 2 hours. Afterburning of the smoke allows the incinerator to conform to local air pollution standards. In this cooperative project, the controlled burning of scrap cars and the recovery of low-melting junk car components is being studied by the Bureau of Mines. Burned cars are to be shredded by Luria to determine the effects of incineration on scrap quality.

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Bureau of Mines
Information Circular 8529

BUREAU OF MINES RESEARCH PROGRAMS ON RECYCLING
AND DISPOSAL OF MINERAL-, METAL-,
AND ENERGY-BASED SOLID WASTES

by

Charles B. Kenahan and Einar P. Flint

ERRATA

Page 20--Caption of figure 16 should read as follows:

FIGURE 16.--Nonferrous Metal (Right) Recovered From Junk-
Car-Shredder Rejects (Left) by Bureau-Developed
Air Classifier.

Page 22--Paragraph on Chemical Stabilization, third sentence should read
as follows: "At costs of 1 to 3 cents per square yard..."

The bibliography on pages 37-46 should read as follows:

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- 18--Effect of Lowering the Tin Content of Secondary Red Brass, by L. W. Higley, J. L. Holman, E. R. Cole, and H. Kenworthy. 1969.
- 21--Construction and Testing of a Junk Auto Incinerator, by C. J. Chindgren, K. C. Dean, and J. W. Sterner. 1970.

***May be purchased at the price indicated from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

⁵Copies of reports may be obtained from the Publications Distribution Branch, Bureau of Mines, 4800 Forbes Avenue, Pittsburgh, Pa. 15213, unless indicated as available from the National Technical Information Service.

- **22--Recovery of Heavy Minerals From Alabama Sand and Gravel Operations, by G. B. Sullivan and J. S. Browning. 1970. PB 190 997.
- **25--Conversion of Urban Refuse to Oil, by H. R. Appell, I. Wender, and R. D. Miller. 1970. PB 192 414.
- **27--Recovery of Metals From Electroplating Wastes by the Waste-Plus-Waste Method, by L. C. George and A. A. Cochran. 1970. PB 194 948.
- 31--Recovery of the Nonferrous Metals From Auto Shredder Rejects by Air Classification, by C. J. Chindgren, K. C. Dean, and L. Peterson. 1971.
- 33--Economics of Recycling Metals and Minerals From Urban Refuse, by P. M. Sullivan and M. H. Stanczyk. 1971.
- **34--Preliminary Separation of Metals and Nonmetals From Urban Refuse, by K. C. Dean, C. J. Chindgren, and L. Peterson. 1971. PB 201 900.
- **36--Recovery of Chromite and Silica From Steel Foundry Waste Molding Sands, by P. G. Barnard, R. A. Ritchey, and H. Kenworthy. 1971. PB 203 890.

Bureau of Mines Open-File Reports⁶

- 1--High-Temperature Alloy Scrap in California and Nevada, by G. C. Branner and J. W. Padan. 1962.
- 2--Secondary Base Metals Processing Technology, by A. J. McDermid. 1962.
- 3--Method for Separating Insulation From Scrap Aluminum Copper Wire, by P. M. Sullivan. 1963.
- 4--Radioactive Waste Disposal in Acid Leach Column-Ion Exchange Milling Flowsheets, by K. E. Tame. 1964.
- 5--Recovery of Nickel and Cobalt From High-Temperature Alloy Scrap, by B. E. Barton, R. L. DeBeauchamp, and T. A. Sullivan. 1966.
- 6--Laboratory Development For Process To Remove Undesirable Impurities From Automobile Scrap, by C. E. Armantrout, G. W. Elger, and S. C. Rhoads. 1969.

**May be purchased for \$3 in paperback and 95 cents in microfiche from the National Technical Information Service, U.S. Department of Commerce, Springfield, Va. 22151. Identify report by PB number.

⁶Access to copies of available reports may be obtained by contacting Charles B. Kenahan, Chief, Division of Solid Wastes, U.S. Department of the Interior, Bureau of Mines, Washington, D.C. 20240.

Contract and Grant Publications,⁷ Bureau of Mines-Sponsored Research

- 1--Treatment of Molten Automotive Scrap To Reduce Copper Content, PPG Industries, Glass Research Center, Contract No. 14-09-0070-363. 1967.
- 2--Vegetation and Metal Toxicity in Relation to Mine and Mill Wastes, Circular 148, Utah Agricultural Experiment Station, Utah State University, SWD-1. 1967.
- 3--Copper Control in Vehicular Scrap With Special Emphasis on Component Design, Ralph Stone Company, Inc., Contract No. 14-09-0070-382. 1968.
- 4--Utilization of Red Mud Wastes for Lightweight Structural Building Products, IIT Research Institute, Contract No. 14-09-0070-386. 1968.
- 5--Production of High Pressure Steam-Cured Calcium Silicate Building Materials From Mining Industry Waste Products, Stanford University, Grant No. SWD-11. Part I--Program for Investigation and Report of Field Survey of Siliceous Mine Wastes in California, Technical Report No. 86, 1968; Part II--Preliminary Economic Feasibility Study, Technical Report No. 89. 1968.
- 6--Removal of Fly Ash by Fluidized Bed Techniques, North Star Research and Development Institute, Contract No. 14-69-0070-375. 1968.

⁷See footnote 6.