NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
REPORT 166

WASTE MATERIALS AS POTENTIAL REPLACEMENTS FOR HIGHWAY AGGREGATES

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

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WASTE MATERIALS AS POTENTIAL REPLACEMENTS FOR HIGHWAY AGGREGATES

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AREAS OF INTEREST:
CONSTRUCTION
MINERAL AGGREGATES

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. 1976

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

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FOREWORD

By Staff
Transportation Research Board

This report presents the results of a comprehensive survey of the technical and economic potential for making use of waste materials as alternative aggregates in highway construction and maintenance. Its contents will be of special interest to highway materials engineers and material producers searching for new sources of aggregates, and to those involved in waste management who are seeking economical means for the disposal of waste products. More than 300 relevant documents were reviewed in a formal literature search. This review was supplemented by numerous contacts with individuals and agencies representative of both potential users and suppliers of waste materials. A system for assessing the use potential of all waste materials available in sufficient quantity to receive consideration was devised and applied.

Highway use accounts for a substantial portion of the nearly 2 billion tons of construction aggregates produced in the United States annually. Although the Nation's over-all supply of material for conventional aggregates is sufficient for any forseeable need, and production plant capacity is considered currently to be adequate, unequal distribution has created local and regional shortages. The supply problem is perhaps most critical in urban areas when demand is high and where zoning and environmental regulations often inhibit full exploitation of available conventional materials. Concurrently, the disposal of 3.5 billion tons of solid waste generated annually, much of which is also within or close to highly populated areas, is an even greater problem. Utilization of the waste materials to assist in filling aggregate requirements where supplies are short offers an attractive remedy to be applied to both problems.

NCHRP Report 135, "Promising Replacements for Conventional Aggregates for Highway Use," published in 1972, presents an overview of the aggregate supply situation and points out various possible ways in which the production of conventional aggregates might be supplemented. The potential for converting waste materials into aggregates was noted and further research in the area was recommended. The present project, in assessing the potential of available waste materials for conversion into highway aggregates, has isolated for more detailed examination those waste materials that show the greatest promise. Information is presented on locations, probable quantities, markets, processing requirements, and possible costs. Current uses of waste materials, both as highway aggregates and in more general nonaggregate applications, are reported. The potential for each material is placed in good perspective. Anyone wanting to use, or to exploit the use of, waste materials in the highway aggregate field is given a good background for determining whether further pursuit would be likely to yield favorable results.

Of an initial group of 34 waste materials that attracted the attention of the Valley Forge Laboratories researchers, 31 were deemed to show technical promise. One was later eliminated because of a possibly adverse environmental effect in use. Technical, economic, and environmental evaluations over-all favored blast furnace slag; fly ash, bottom ash, and boiler slag from electric power generating stations; reclaimed paving material; and anthracite coal mine refuse for further development as highway aggregates. Of these, blast furnace slag has already gained wide acceptance.

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The efforts of Brian Cooper of I. U. Conversion Systems in developing economic figures for various processing systems used to beneficiate waste materials were extremely helpful.

Finally, the research team wishes to express its gratitude to the Franklin Institute Research Laboratories, Science Information Services, and particularly to Dorothy Sandoski, for conducting the literature search and review and for assistance in preparation of the bibliography for the final report.

Industrial associations were valuable sources of information. Deserving of special mention are National Ash Association, National Slag Association, Rubber Reclaimers Association, National Tire Dealers, and Glass Container Manufacturer's Institute.

WASTE MATERIALS AS POTENTIAL REPLACEMENTS FOR HIGHWAY AGGREGATES

SUMMARY

Although production of aggregates in the United States totals nearly 2 billion tons per year, many areas are experiencing shortages of conventional aggregates. New material sources are needed to alleviate these shortages, which are most critical in urban areas due to restrictive zoning and environmental regulations. At the same time, 3.5 billion tons of solid waste are being generated annually. Disposal of these solid wastes is also a major problem, especially in most metropolitan areas. Utilization of waste materials as aggregates in highways would be a partial solution to both problems.

This project's two main objectives were to:

1. Inventory types, sources, and quantities of solid wastes potentially suitable for production of aggregates.
2. Assess prospects for the practical use of such aggregates in highways, particularly where conventional aggregate shortages exist.

In order to achieve these objectives:

1. A literature review was conducted to determine locations and quantities of natural aggregates and the locations, quantities, properties, and uses of waste materials. From this review, conventional aggregate shortages were located, and waste materials were listed and inventoried. Current uses were also determined, with emphasis on highway use.
2. A system was established for evaluating the technical, economic, and environmental feasibilities for use of each waste material in highway construction.
3. The potential of each waste material was evaluated in accordance with the developed system.

In all, 31 waste materials were evaluated and classified as either industrial, mineral, or domestic wastes. Huge quantities of these wastes are being generated annually or have accumulated over many years. Many are located within or adjacent to metropolitan areas. Some have been used in highways with varying degrees of success.

Based on the results of the technical, economic, and environmental evaluations, the waste materials most highly recommended for further developmental work as aggregates in highway construction are blast furnace slag, fly ash, bottom ash, boiler slag, reclaimed paving material, and anthracite coal refuse.* All of these materials have been used previously in highway construction. In fact, blast furnace slag has already gained wide acceptance as an aggregate and millions of tons are used annually.

Other waste materials exhibiting some potential for highway aggregate use are steel slag, bituminous coal refuse, phosphate slag, slate mining waste, foundry waste, taconite tailings, incinerator residue, waste glass, zinc smelter waste, gold mining

* Higher levels of use should not be overlooked.

waste, and building rubble. Of these, steel slag, taconite tailings, and building rubble have been found suitable as highway construction aggregates; others, such as incinerator residue and waste glass, have been used as aggregate on an experimental basis.

As a result of this research, a number of conclusions were drawn of which the most significant are that:

1. The basic technology now exists for converting solid wastes into some form of synthetic aggregates.
2. Generally, the engineering properties of these synthetic aggregates are not as good as those of natural aggregates with some exceptions, such as blast furnace slag, fly ash, and boiler slag.
3. Much research and field experimentation must be done to determine the suitability of individual waste materials as highway aggregates. This developmental process usually requires many years.

The following recommendations were considered to be warranted:

1. Waste materials having satisfactory performance records as highway aggregates should be more fully utilized.
2. Future research and development efforts related to waste material use should be coordinated under the jurisdiction of a strong central agency.
3. Existing specification requirements should be thoroughly reviewed for the possibility of being made less restrictive, especially in states where aggregate shortage is a problem.
4. The adoption of performance specifications should be considered on a trial basis to allow more latitude in selecting highway materials.
5. The use of lightweight aggregates in various types of highway applications should be researched and developed.
6. Field experimentation should be conducted on all waste materials recommended for further development which are not already being used in highways.
7. More detailed information is needed on precise locations and magnitude of conventional aggregate shortages. A standard definition of an "aggregate shortage" should be formulated and used throughout the United States.
8. Developmental work should be initiated for a portable processing system, preferably barge mounted, which would be capable of processing such materials as fly ash, foundry waste, coal refuse, and dredge spoil.
9. More research is necessary to determine the most suitable mineral wastes for development as aggregate materials. Cooperative efforts of the U.S. Bureau of Mines and the Federal Highway Administration are suggested.
10. A thorough study is needed to determine transportation rates for the movement of the most highly recommended waste materials from points of origin to probable market areas.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

PROBLEM AND OBJECTIVES

The demand for aggregate materials has outstripped their availability in many parts of the United States. This applies especially in metropolitan areas where the adoption of increasingly restrictive zoning laws and environmental regulations have inhibited the extraction and processing of aggregate within urban boundaries.

Many areas have never possessed an abundance of high-quality natural materials or are not located within reasonable distances of an operating pit or quarry.

At the same time, it is now quite clear that one of the major problems in the U.S. is the disposal of the alarming volumes of solid waste being generated. Each year, as production increases, the space available for economical disposal decreases. As a consequence, the question has been asked: "Can waste materials be used as aggregate in highways?" Doing so would be a partial solution to both the aggregate shortage and the solid waste disposal problem.

Acceptance of the use of new materials, particularly those of marginal quality, in the structural support system of a highway occurs only after a long and tedious period of trial and performance evaluation. This is understandable because of the lack of universally accepted rapid evaluative techniques that will predict long-range performance of such things as new base course materials. Also, the consequences of premature failure of these materials are usually most severe.

If the use of synthetic aggregates produced from waste materials affords a practical solution to the problem of aggregate shortages, it is urgent that the developmental work necessary to gain their acceptance be started very soon. It is hoped that this study will provide direction for programs to develop the use of waste resources in highway construction.

The principal objectives of this project were to:

1. Inventory types, sources, and quantities of waste materials potentially suitable for the production of synthetic aggregates or otherwise replacing the need for conventional aggregates in highway construction.
2. Assess the prospects for practical use of specific waste materials for the production of synthetic aggregates or otherwise replacing the need for conventional aggregates in highway construction, particularly where aggregate supplies are scarce.

Inherent in these objectives are three practical considerations:

1. Determine those areas in which predicted shortages of conventional aggregates are sufficiently severe to necessitate the development of alternative material sources such as waste materials?
2. Determine whether solid wastes can be economically processed so that synthetic aggregates of suitable quality can be produced, or whether the highway industry will adjust to the use of substandard (in accordance with present criteria) materials?
3. Determine whether the quantities of waste materials that have potential use in highway construction will have a significant impact on solving the problems currently associated with the disposal of these wastes?

RESEARCH APPROACH

Tasks necessary to accomplish the objectives included (a) a literature review, (b) a determination of the supply and demand for natural aggregates, (c) an inventory of waste resources, (d) a determination of current uses of waste resources, and (e) an evaluation of the waste materials studied.

At times, the research tasks were carried out concurrently, and frequently information gathered in one task affected procedure in another. Periodic review by members of a control board along with the guidance of a team of industrial consultants gave direction to the work. It was their primary function to critically review procedures and progress according to two basic guidelines to ensure (1) that all significant factors were being considered, and (2) that the results of the study would provide a realistic appraisal of the potential for waste material use.

Literature Search

Published data were the principal source of information. A review of foreign and domestic literature was made. This review focused on publications concerning:

1. Types, quantities, and locations of waste materials.
2. Use of waste materials in highway or building construction.
3. Supplementary uses of waste materials.
4. Research and development related to the conversion of waste materials into useful products.
5. Quantities and locations of natural aggregates.

The information sources that were searched included:

1. Information retrieval services.
2. Technical society and industry periodicals.
3. Industry, government, and technical associations.

The formal literature search was further supported by a solicitation of unpublished reports and commentaries that came to the attention of the researchers.

More than 300 relevant documents were reviewed by the research team. Approximately 270 were abstracted. A bibliography (Appendix E) lists those publications that contributed significant information toward accomplishment of this investigation. References *6, 244, 245, 247, 248,* and *267* were especially useful.*

Conventional Aggregate Supply and Demand

Published data were reinforced by information obtained from materials engineers from each state on the location of areas experiencing shortages, or future potential shortages, of quality natural aggregates.

The research team used an additional guideline to establish potential natural aggregate shortage areas. More than 90 percent of all aggregates are presently transported by truck. This suggested that construction sites beyond an economical truck hauling distance from an existing natural aggregate source could be considered as locations where shortages could develop. Forty miles was selected as the maximum economical truck hauling distance. A haul over this distance would incur an average transportation cost of $2.25 per ton.

Factors concerning the use of aggregates in highway construction during the period 1969-71 and the *1972 National Highway Needs Report,* which identifies highway needs and projects highway construction costs during the period 1970-90, were used extensively to forecast and verify future aggregate requirements.

The end result of this portion of the study was the assessment of those locations in the continental U.S. that either now or in the future will experience a shortage of quality natural aggregates. The practical aspects of this assessment were subjected to a critical appraisal by the research team.

Inventory of Waste Resources

Waste materials were classified as being in one of three major categories—industrial, mineral, or domestic. The classification is given in Appendix B. The data sources were used to determine locations, quantities, chemical compositions, and physical properties of all the waste materials listed. The classification of wastes was particularly helpful in making judgments concerning those wastes about which existing information was sparse.

The basic procedure in this portion of the study involved a compilation of the available published data, verification and amplification of this information by industrial and governmental representatives, and, finally, a resolution of the data into usable form.

It must be mentioned here that, in some cases, detailed information on certain waste materials did not exist. A substantial effort involving a plant-by-plant, or stockpile-by-stockpile, determination of quantities, composition, and the like would be required to obtain complete data. For instance, the team was unable to obtain detailed information on the locations and quantities of sulfate sludge. In these instances the best judgments of informed observers were used in supplying and reporting data.

* These and any other numbered references are keyed to the "Selected Bibliography," Appendix E.

Current Uses of Waste Materials

Emphasis was placed on assembling, evaluating, and reporting on published accounts of the use of waste materials in highway construction and/or general building construction. Attention was given also to supplementary uses of waste materials that would provide an insight into their potential as raw materials for synthetic aggregates.

Equal importance was attached to (a) the determination of the costs and techniques involved in the process of manufacturing useful products from waste materials and (b) the procedures, time, and over-all ramifications of gaining acceptance of these products, particularly in the highway industry.

The significance was determined of each instance of use of a waste material in construction as well as its level of use. Current use generally was found to have attained one of three levels:

1. Laboratory research or pilot plant operation.
2. Experimental applications.
3. Routine acceptance in competition with other conventional materials.

Evaluation System and Evaluation of Waste Resources

The evaluation of the potential of waste materials was divided into five phases:

1. Initial screening.
2. Evaluation of the physical and chemical properties of the wastes (a) as they occur naturally or in combination with other materials, and (b) after processing for comparison with currently accepted standards for aggregate (called the "technical evaluation").
3. Evaluation of the locations, quantities, physical forms in which the wastes occur (slurry, refuse pile, etc.), processing requirements, and adaptability to construction for comparison with the cost and availability of natural aggregates (called the "economic evaluation").
4. Evaluation of the environmental consequences of the use of waste materials (called the "environmental evaluation").
5. "Over-all evaluation" based on the combined results of the technical, economic, and environmental evaluations.

Initial Screening

Eliminated from detailed consideration were those waste materials that for obvious practical reasons offered little or no potential for use as highway aggregate replacements. Four minimum criteria were established:

1. The annual quantity of waste material available at any one location must be at least 50,000 tons. If annual production is less than 50,000 tons, a quantity of at least 500,000 tons must have accumulated.
2. The sources of waste materials must be located within a reasonable distance of potential market areas. For truck

transport, 40 miles was selected as the maximum hauling distance. The maximum hauling distance was considered to be 100 miles for rail and 300 miles for barge.

3. The material must not be highly toxic, especially after being completely processed.

4. The material must not be soluble in water.

Technical Evaluation

A weighted numerical rating system was devised to evaluate the physical and chemical properties of each waste. An explanation of the system is given in Appendix D. The primary purpose of the rating system was to force the research team to focus its attention on each significant property of each waste material and to arrive at a value judgment as to its suitability. Secondarily, the over-all numerical rating of the waste material enabled a gross classification of its potential to be made.

The basic evaluation team consisted of three members—a specialist in portland cement and portland cement concrete, a specialist in asphalt and bituminous mixtures, and a geologist. Each numerical rating of a property was established jointly after an examination of the relevant data and a joint discussion of the significance and dependability of the data.

After a quantitative rating was given to each property (hardness, soundness, particle size, etc.), the results were compared with the known performance record of the few waste materials that have been used as aggregates. This served to either verify the rating or to lend credence to an adjustment of the valuation.

The waste materials were then assigned to one of four groups, Class I to Class IV. Class I materials had maximum potential. They either (a) possessed the best aggregate properties in one or more of their forms (naturally occurring, combined, or processed) or (b) had a record of satisfactory performance in highway applications. Class II contained those materials (a) which required more extensive processing or (b) whose properties were not as adequate as those materials in Class I. Class III included materials (a) which showed less promise than those of Classes I or II and (b) which were recommended for use only in isolated situations. Class IV materials showed little or no promise for use as synthetic aggregates.

Each waste material was also evaluated and classified in terms of its potential use in specific highway applications such as stone base, bituminous mixture, or portland cement concrete. The possibility of using each waste material as an element of a stabilized base was also considered.

Economic Evaluation

Quantitative and qualitative methods were applied in assessing the economic feasibility of converting waste materials into synthetic aggregates.

Some typical costs were available in the literature; others were developed by the research team. The types of costs involved were disposal costs; manufacturing costs for producing aggregate from waste materials (pulverizing, screening, pelletizing, and sintering); and transportation costs by truck, rail, and barge. These figures were used to develop quantitative measures of the ranges of cost involved in reclaiming the waste materials, processing them for use, and then using them in highway construction. It was realized that this type of analysis would serve only to indicate economic feasibility. Exact determinations of unit costs will be obtainable only in a real-life competitive situation.

A semiqualitative approach was used to reinforce the findings of the cost analysis. This approach involved an examination of each waste material with respect to specific economic factors chosen to reflect the economic potential of a material for development as an aggregate. These factors fell into four broad categories:

1. Location and quantity of material.
2. Application potential of the material in highways.
3. Value of the material as a resource.
4. Ecological and social considerations.

A numerical rating system was devised, which was similar to that used in the technical evaluation in which economic factors were weighted according to their relative importance. The research team again was forced to focus on the significance of each factor to each waste material and to make a value judgment.

As a result of the combined evaluations (cost analysis and economic factors), each waste material was categorized according to one of four classes, Class I to Class IV. Class I materials had the highest economic potential; Class IV materials had the least.

A more detailed discussion of the economic evaluation, including a listing of the factors, is given in Appendix D.

Environmental Evaluation

Evaluation of the potential environmental consequences of using specific waste materials for highway purposes considered three environmental effects:

1. Those resulting from the recycling of a specific waste, such as the benefit obtained by removing anthracite coal refuse piles from the landscape.

2. Those possibly developing as hazards, perhaps as a result of the manufacturing operation of producing synthetic aggregates from waste materials.

3. Those being generated by qualities inherently unique to the waste materials, such as dusting and leaching.

Each waste material was examined in light of the environmental factors and rated numerically. The waste materials were rated on the basis of the environmental benefit derived from their use and assigned one of three classes, either recommended, marginal, or not recommended.

A discussion of the environmental evaluation, including a listing of the factors, is given in Appendix D.

Over-All Feasibility

The results of the technical, economic, and environmental feasibility of waste materials were finally combined, and a list of those materials having the best over-all feasibility for development and use as construction aggregate was formulated.

The waste materials finally were grouped into four classes, Class I through Class IV. The final results were weighted more heavily in favor of the technical and economic evaluation, with the materials most highly recommended placed in Class I and those with the least feasibility placed in Class IV.

CHAPTER TWO

FINDINGS

The findings of this investigation are presented in four parts. The first part discusses the status of conventional aggregate supplies, including actual and potential shortage areas; the second contains the over-all findings of the waste resource inventory; the third discusses the status of current and potential uses of waste materials; and the fourth part presents the results of the evaluation of waste materials.

CONVENTIONAL AGGREGATE SUPPLY AND DEMAND

On a nationwide basis, the supply of good-quality natural aggregates is sufficient to meet the present and predicted demands of highway and building construction markets. The total annual production of conventional aggregates was approximately 1.8 billion tons in 1970. Highway consumption during 1970 amounted to over 800 million tons, or 47 percent of the total amount of aggregate produced. An estimated 2 billion tons annually may be needed for highway use by 1985. This is 50 percent of a projected 4 billion tons of total annual aggregate production at that time (*6*). Aggregate supplies on a regional and statewide basis also appear to be adequate.

On a local basis the situation is different. Most urban areas, where demands are high and zoning restrictions often remove acceptable materials from availability, are or will be deficient in the supply of conventional aggregates. Such urban areas, for example, are typified by the standard metropolitan areas of the United States in 1970, as defined by the U.S. Bureau of the Census and shown in Figure 1. Conventional aggregate shortages also occur to a degree in rural areas. Appendix A presents the details on conventional aggregate supplies and shows locations where supplies are deficient (Fig. A-3 and A-4). These areas all lack high-quality materials and are located beyond a 40-mile hauling distance from existing supplies of good aggregate. Because of a current low demand for aggregate in many of the areas, the situation within them is presently not critical. However, even moderate increases in construction and maintenance activities could produce future shortages. The development of ways to upgrade or to modify the use of low-quality aggregates that exist in many of these areas to provide acceptable service could alleviate the shortages.

Serious shortages in highway aggregates that may occur within the next few years are likely to be felt first in AASHTO Regions 1 and 2, for example. AASHTO Region 1, comprised of states in the northeastern part of the U.S., must increase its production of aggregates to a greater extent than most others to meet the material demands anticipated in the next 10 years. The states in AASHTO Region 2, the south and southeastern parts of the country, must also significantly increase aggregate production, although not to so great an extent as those in Region 1.

INVENTORY OF WASTE RESOURCES

An inventory of all the waste materials identified in this study is given in Table 1. Figure 2 shows the 10 study regions into which the U.S. was divided for the purpose of this study. Figure 3 is a key to the map symbols pictured in Figures 4 through 13, which show for each of the 10 study regions (a) locations of potential aggregate shortage areas and (b) locations of available waste materials.

Mineral wastes (Table 1) are available in the largest quantities. For instance, an estimated 1 billion tons of anthracite coal refuse are presently available in stockpiles. If all of this were usable, it would be sufficient to supply the current demand for highway aggregate in the entire U.S. for one year. Somewhat smaller, but still significant, quantities of other wastes such as fly ash, slag, and domestic refuse are available. The estimated annual production of fly ash is 32 million tons. This would be sufficient to meet the current aggregate requirements of such States as New York, Pennsylvania, Illinois, or Michigan. The estimated annually produced quantities of various wastes are given by state in Table 2 and compared with the highway aggregate requirements in Table 3.

Assume that 10,000 tons of aggregate are required per mile of two-lane highway and that 50 percent of the aggregate can be replaced by synthetic aggregate made from waste materials, the required amount of synthetic aggregate would be 5,000 tons per mile. As another example, the amount of glass required to replace 60 percent of the aggregate in a typical bituminous mixture is estimated to be 7 lb per square foot per inch of thickness. A 2-in. layer of resurfacing to be placed over 1 mile of 24-ft-wide roadway would require approximately 900 tons of glass.

Based on the preceding, it is believed that at least 50,000 tons of a specific waste should be available annually at one location for the material to be considered as an aggregate replacement on a continuing basis. This minimum amount might be as high as 100,000 tons per year in or near large metropolitan areas. Accumulations of 500,000 tons of solid

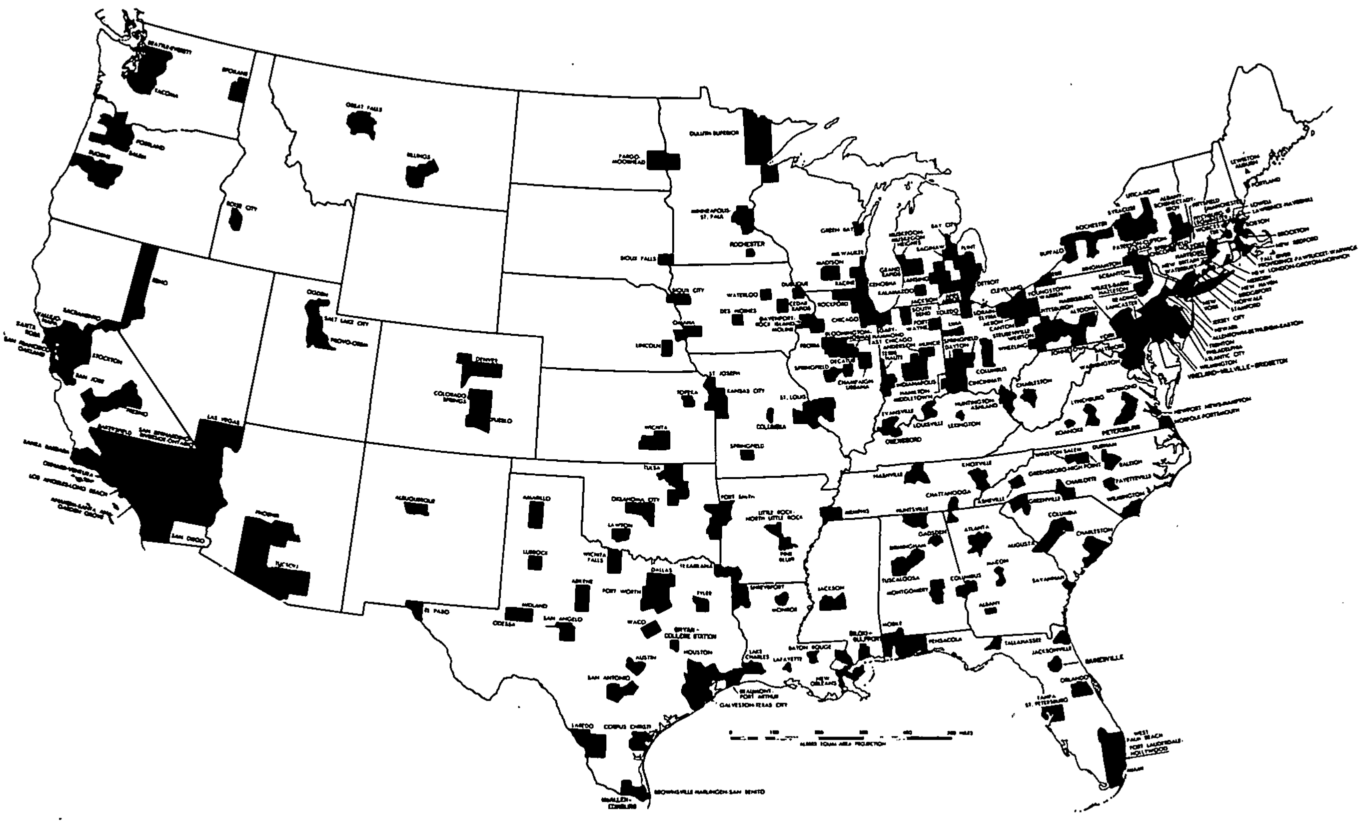


Figure 1. Standard metropolitan areas of the United States in 1970 according to the U.S. Bureau of the Census.

wastes in one area are considered to be minimum in the event that annual production rates are not sufficient. Smaller amounts of waste materials can and have been used in unique local situations. These are considered to be special cases and should continue on this basis.

To meet criteria for minimum quantities of waste materials, it will be necessary to know the amount of accumulated and annually produced wastes available in a specific area.

In summary, waste materials that have potential for the manufacture of synthetic aggregates are available in quantities sufficiently large to provide significant amounts of aggregates to the highway industry. Many of these wastes are located in areas where conventional aggregates are in short supply. This is especially true of urban areas.

CURRENT USES OF WASTE MATERIALS

Table 1 gives the current uses of the waste materials studied in this investigation. Note that blast furnace slag, steel slag, fly ash, bottom ash, boiler slag, waste glass, coal refuse, rubber tires, incinerator residue, and some mine tailings have been used in the construction of highways. The amounts used and the significance of the use have varied widely, as noted in Table 4. A more detailed discussion of current uses of each waste material considered in this study is presented in Appendix C.

Generally, the amounts of waste materials used to date represent only a small percentage of the available quantities. Only blast furnace slag and steel slag have been utilized to a significant extent by the highway industry. Efforts to date concerning most other waste material use in highways have been mostly experimental, involving relatively small quantities of materials.

One reason for such small use of waste materials lies in the fact that the process of gaining acceptance of new materials in highways is a long and tedious one. The natural reluctance of most highway engineers to use unproven materials in a situation where premature failure can cause serious funding dislocation and loss of human safety necessitates extensive testing and experimentation on many levels. Experience in the development of blast furnace slag and fly ash has shown that full acceptance of such materials may take about 20 years.

Although fly ash has been researched and promoted since approximately 1950 and proven suitable for highway application, much greater use could be made of the material.

Historically, private industry has provided the initial stimulus in the research and promotion of better alternatives for the disposal of its waste materials. Efforts by the steel industry on behalf of slag are an outstanding example. Associations formed for the purpose of advancing the use of waste materials are a positive force in pointing out the advantages of and in increasing the consumption of these materials.

TABLE 1

INVENTORY OF WASTE RESOURCES

WASTE MATERIAL	SOURCE	LOCATION	PHYSICAL STATE	ANNUAL QUANTITY (million tons)	ACCUMULATED QUANTITY (million tons)	CURRENT OR POTENTIAL USES
INDUSTRIAL WASTES						
Alumina Red and Brown Muds	Alumina processing plants	Alabama, Arkansas, Louisiana, Texas	Slurry and dried fines	5-6	50	Insulation, pigment, soil conditioner, concrete additive, binder
Phosphate Slimes	Phosphate processing plants	Florida, Tennessee	Slurry	20	400	Lightweight aggregate, brick, pipe
Phosphogypsum	Phosphate processing plants	Florida Tennessee	Slurry	5	N.A.	Plaster substitute
Sulfate Sludges	Chemical plants	Distributed Nationally	Slurry	5-10	N.A.	Road base composition mixtures
Fly Ash	Coal burning power plants	Appalachia Great Lakes	Dust	32	200-300	Fill, lightweight aggregate, road base compositions, cement replacement
Bottom Ash	Coal burning power plants	Appalachia Great Lakes	Fine sand	10	50-100	Fill, lightweight aggregate, road base compositions
Boiler Slag	Coal burning power plants	Appalachia Great Lakes	Black gravel size particles	5	25-50	Fill, highway aggregate, anti-skid material, roofing granules
Scrubber Sludges	Power plants with scrubbings equipment	Generally distributed	Slurry	N.A.	N.A.	Road base composition mixtures
Blast Furnace Slag	Iron and steel production plants	Pennsylvania, Ohio, Illinois, and Michigan	Coarse particles	30	N.A.	Construction aggregate, railroad ballast, fill material
Steel Slag	Iron and steel production plants	Same States as Blast Furnace Slag	Coarse particles	10-15	N.A.	Construction aggregate, railroad ballast, fill material
Foundry Wastes	Iron Foundries	Same States as Steel Slag	Fine dust	20	N.A.	Pigments, colorants, highway aggregate
MINERAL WASTES						
Anthracite Coal Refuse	Anthracite mines	Northeastern Pennsylvania	Coarse and fine particles	10	1,000	Anti-skid material, highway aggregate
Bituminous Coal Refuse	Bituminous coal mines	Appalachia, Midwestern States	Coarse and fine particles	100	2,000	Highway aggregate
Chrysotile or Asbestos tailings	Asbestos mines	California, Vermont, Arizona	Coarse fibers	1	10	Additive to highway mixtures
Copper Tailings	Copper mines	Southwestern States, Michigan	Slurry or dust	200	8,000	Fill material
Dredge Spoil	Dredging operations	Navigable waterways	Slurry	300-400	N.A.	Disposal, fill material
Feldspar Tailings	Feldspar mines	Northwestern North Carolina	Coarse and fine particles	0.25-0.50	5	Highway aggregate

TABLE 1 *(Continued)*

WASTE	SOURCE	LOCATION	PHYSICAL STATE	ANNUAL QUANTITY (million tons)	ACCUMULATED QUANTITY (million tons)	CURRENT OR POTENTIAL USES
MINERAL WASTES						
Gold Mining Waste	Gold mines	California, South Dakota, Utah, Nevada Arizona	Wet sand or gravel	5-10	100	Sand-lime brick
Iron Ore Tailings	Iron mines	Alabama, New York, Pennsylvania	Slurry, fine particles	20-25	800	None
Lead Tailings	Lead mines	Missouri, Idaho Utah, Colorado	Slurry, fine particles	10-20	200	Railroad ballast, road stone
Nickel Tailings	Nickel mines	Southwestern Oregon	Fine particles	N.A.	N.A.	None
Phosphate Slag	Phosphate smelters	Idaho, Montana, Wyoming, Utah	Fine stone chips	4	N.A.	Lightweight aggregate, highway aggregate
Slate Mining	Slate mines	New England, New York, Pa., Maryland, Virginia	Coarse fine particles	N.A.	N.A.	Highway aggregate
Waste Taconite Tailings	Taconite mines	Minnesota, Michigan	Slurry, fine particles	150-200	4,000	Formed block, highway aggregate
Zinc Tailings	Zinc mines	Tennessee	Slurry, fine particles	10-20	200	Highway aggregate
Smelter Waste	Zinc Smelters	Oklahoma	Fine sand	N.A.	N.A.	Highway aggregate
DOMESTIC WASTES						
Building Rubble	Demolition activity	Metropolitan areas	Coarse particles	20	N.A.	Landfill, highway aggregate
Battery Casings	Automobile batteries	Metropolitan areas	Coarse particles	0.5-1.0	N.A.	Highway aggregate
Ceramin Wastes	Brick, pottery, pipe plants	Distributed nationally	Coarse particles	N.A.	N.A.	Landfill
Incinerator Residue	Municipal incinerator	Metropolitan areas	Ash	10	N.A.	Landfill, highway aggregate
Plastic Wastes	Plastic manufacturing plants	Distributed nationally	Containers, particles	2.5-3.0	N.A.	Plastic Manufacture
Pyrolysis Residue	Pyrolysis operations	Metropolitan areas	Char	N.A.	N.A.	Highway aggregate
Reclaimed Paving Material	Highway reconstruction projects	Metropolitan areas	Coarse particles	N.A.	N.A.	Landfill, highway aggregate
Rubber Tires	Automobile and truck tires	Metropolitan areas		3-5	N.A.	Seal treatment, asphalt additive
Sewage Sludge	Sewage treatment plants	Metropolitan areas	Slurry or ash	8-10	N.A.	Stabilized fill material
Waste Glass	Container glass	Metropolitan areas		12	N.A.	Glass production, highway aggregate, glass wool, slurry seal

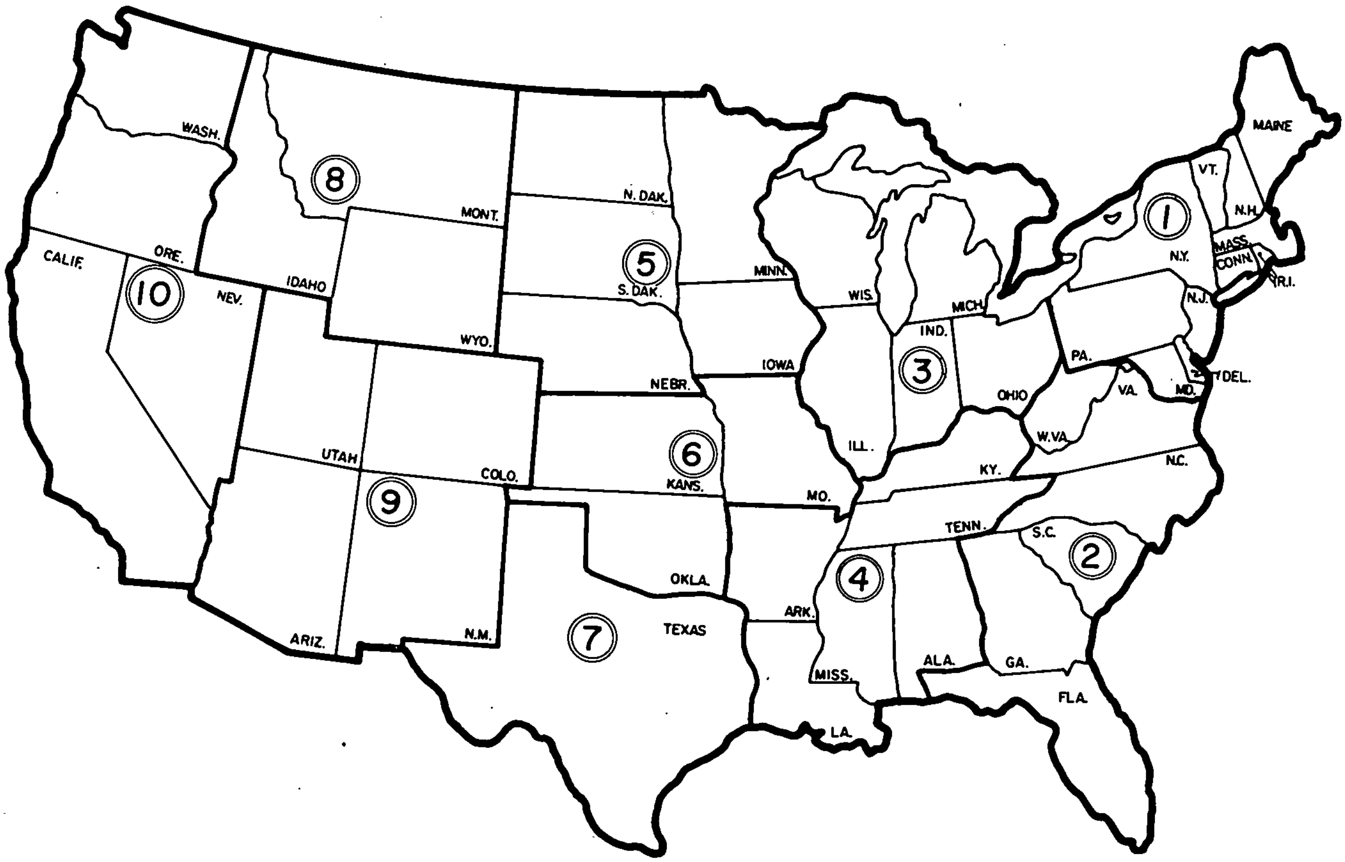


Figure 2. The U.S. was divided into 10 regions established to facilitate the study.

EVALUATION OF WASTE MATERIALS—OVER-ALL FEASIBILITY

Three waste materials were identified as having little or no potential in the initial screening process. These were ceramic wastes, chrysotile or asbestos tailings, and plastic wastes.

Ceramic wastes occur in suitable physical form for use as aggregates. However, the annually produced quantities are relatively small and normally deposited in landfills rather than stockpiled. Due to lack of availability and small quantities, ceramic wastes appear to have very little potential for use as an aggregate and should be considered only on a local basis.

Chrysotile or asbestos tailings exist in limited quantities at only a few mining locations scattered throughout the U.S. In addition, the hazardous nature of asbestos fibers discourages recommending the material to any great extent as an aggregate replacement.

Although approximately 3 million tons of plastic wastes are generated annually in metropolitan areas, these wastes are usually but a small part (3 to 5 percent) of the total refuse mixtures. The need for costly separation to retrieve these materials, together with the small amount available in any specific location, normally renders their use as aggregates impractical.

The categorized results of the over-all evaluation of waste materials are presented in Table 5.

Class I refers to those materials that show the most potential for use as highway aggregate. Nearly all of these materials have received some measure of acceptability for highway use. All possess the desirable properties of aggregates and all are capable of treatment. Generally, they are located in or near metropolitan areas and occur in sufficient quantity to provide a continuous source of supply for highway consumption.

Certain wastes, such as blast furnace slag and fly ash, have evolved as acceptable highway materials over a time period of many years. Because of its desirable properties of hardness and soundness, particle shape, particle strength, abrasion resistance, and gradation, blast furnace slag has developed into an all-around highway and building construction material. In fact, this material is so widely used in highways that it is more often thought of as a conventional aggregate than as a waste material.

Although fly ash has been used in stabilized base course compositions for many years, its pozzolanic properties have not been used to advantage in the manufacture of synthetic aggregate to any great extent. Lightweight fly ash aggregate has been processed and used in lightweight concrete structural applications, but the potential for its use in highways has not as yet been realized.

The performance of other ash wastes in highways has demonstrated their capabilities for certain uses. Bottom ash has been used with good results in base compositions, bi-

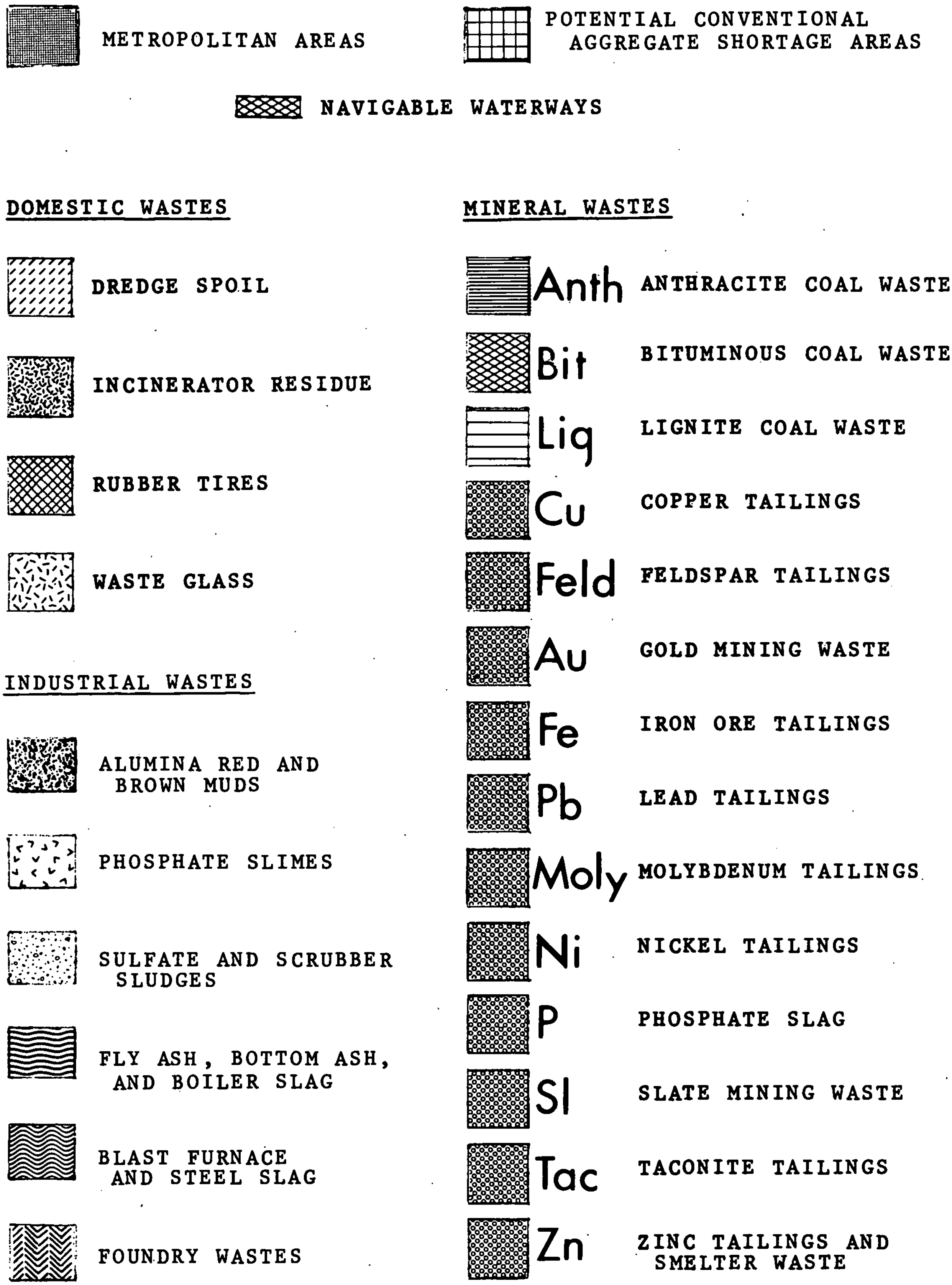
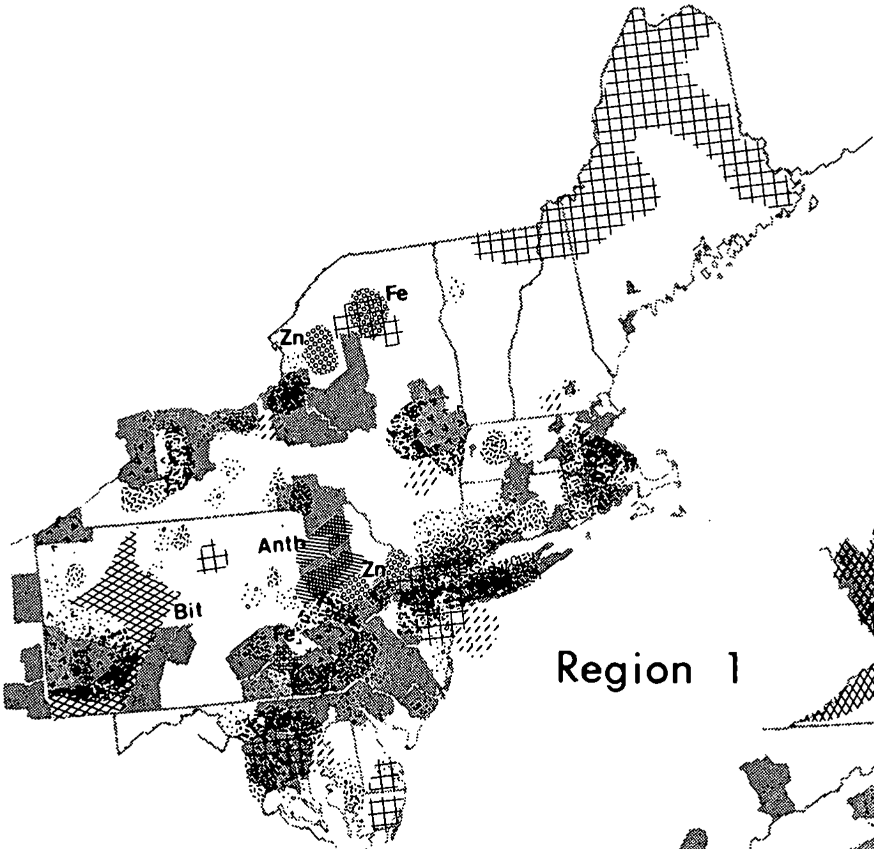


Figure 3. Key to map symbols, Figures 4 through 13.

Figure 4. Locations of potential aggregate shortage areas and available waste materials, Region 1.



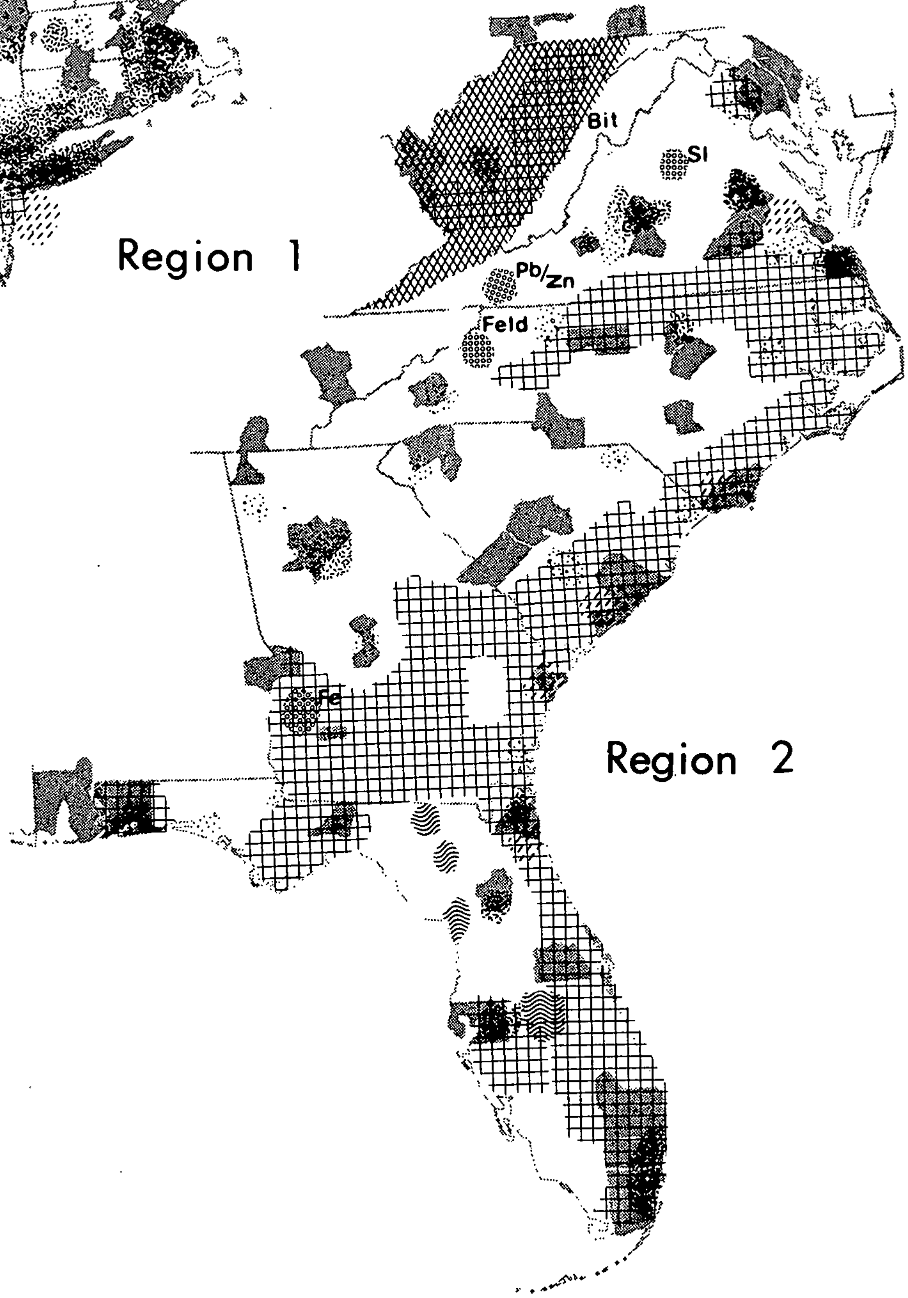


Figure 5. Locations of potential aggregate shortage areas and available waste materials, Region 2.

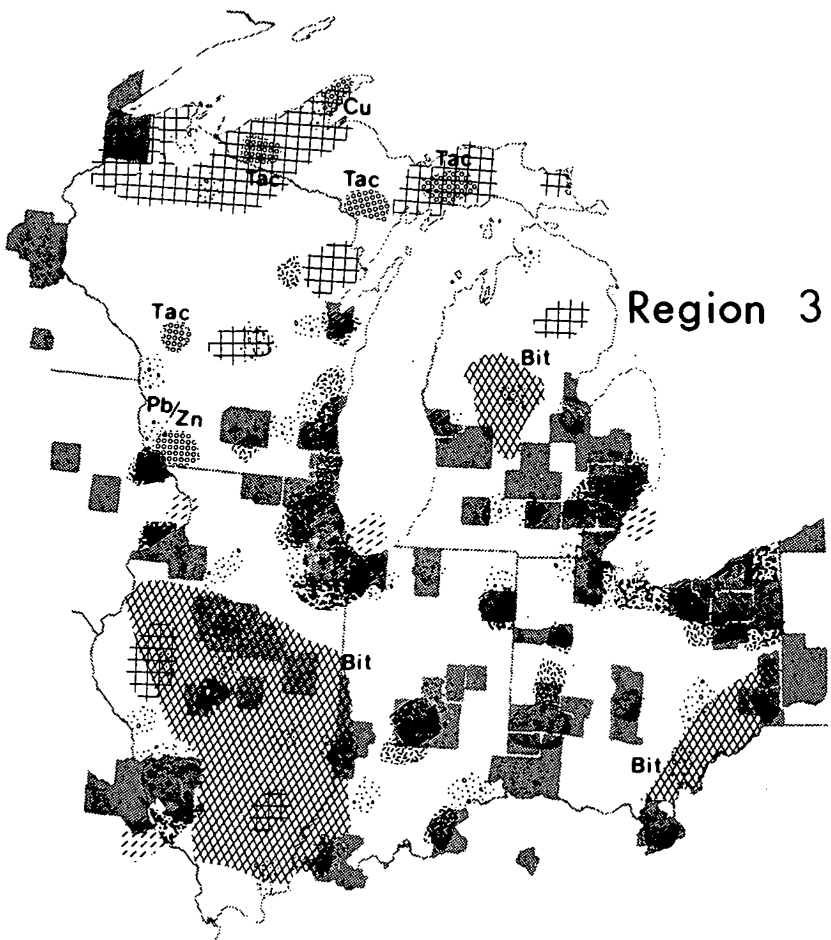


Figure 6. Locations of potential aggregate shortage areas and available waste materials, Region 3.

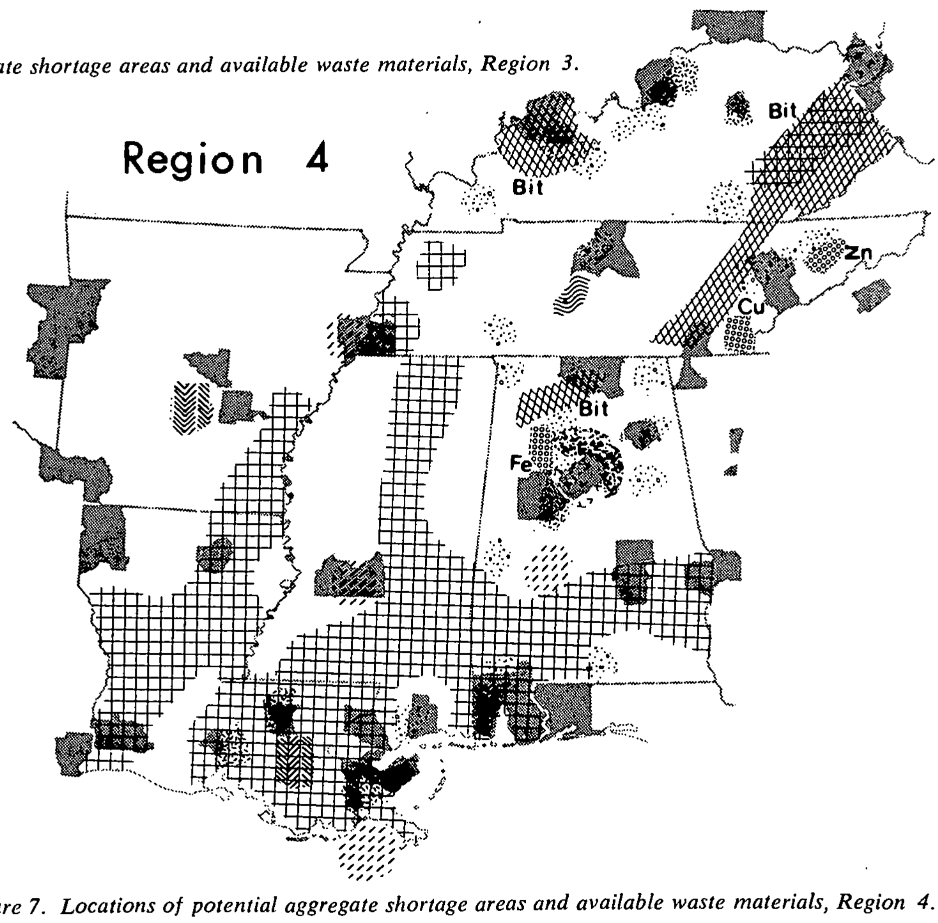


Figure 7. Locations of potential aggregate shortage areas and available waste materials, Region 4.

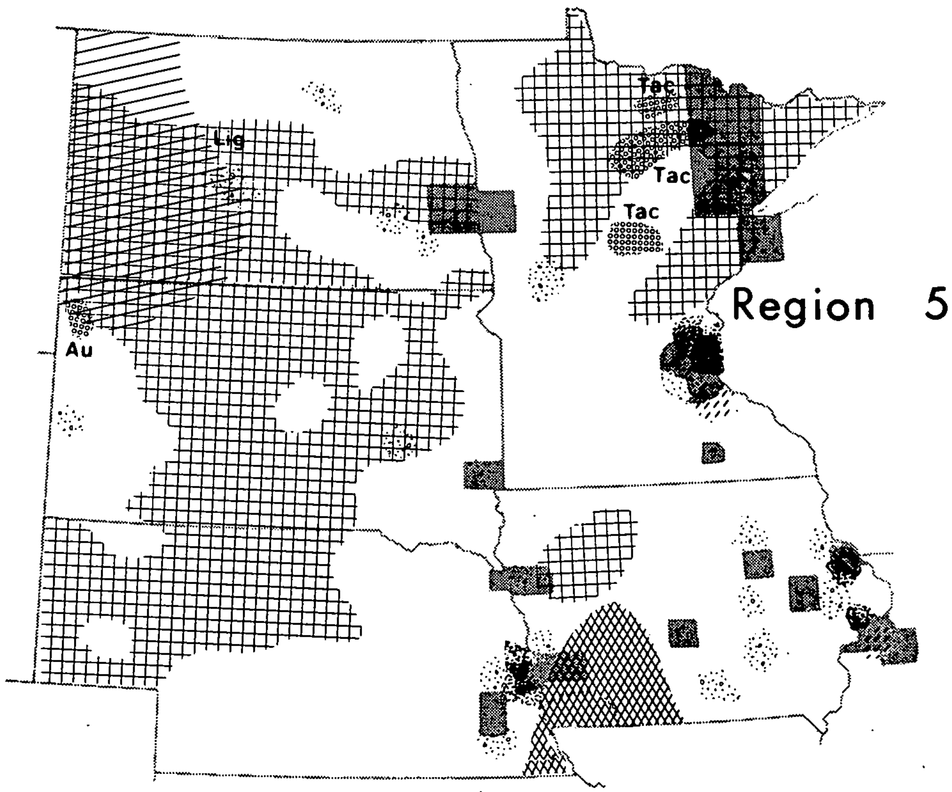


Figure 8. Locations of potential aggregate shortage areas and available waste materials, Region 5.

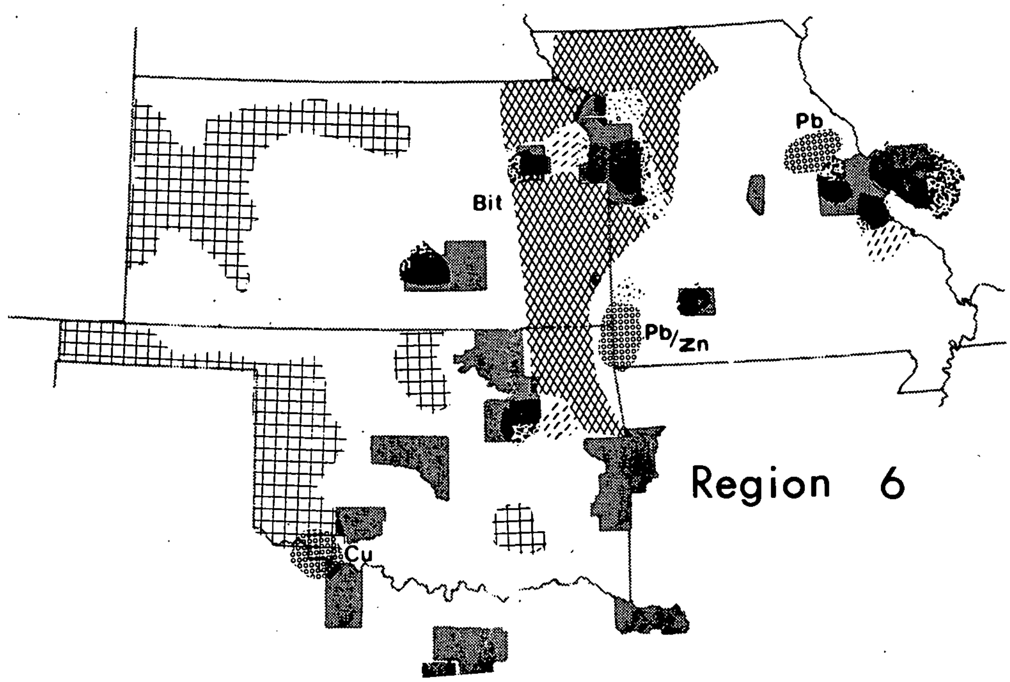


Figure 9. Locations of potential aggregate shortage areas and available waste materials, Region 6.

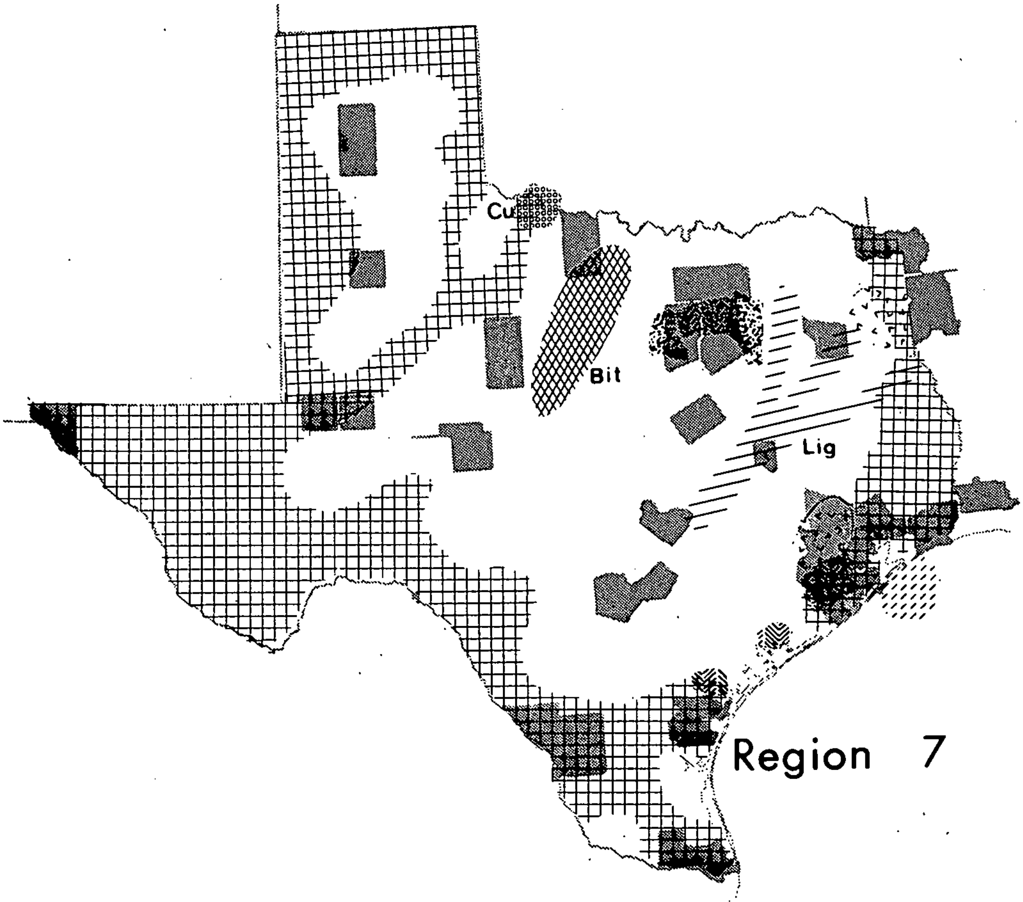


Figure 10. Locations of potential aggregate shortage areas and available waste materials, Region 7.

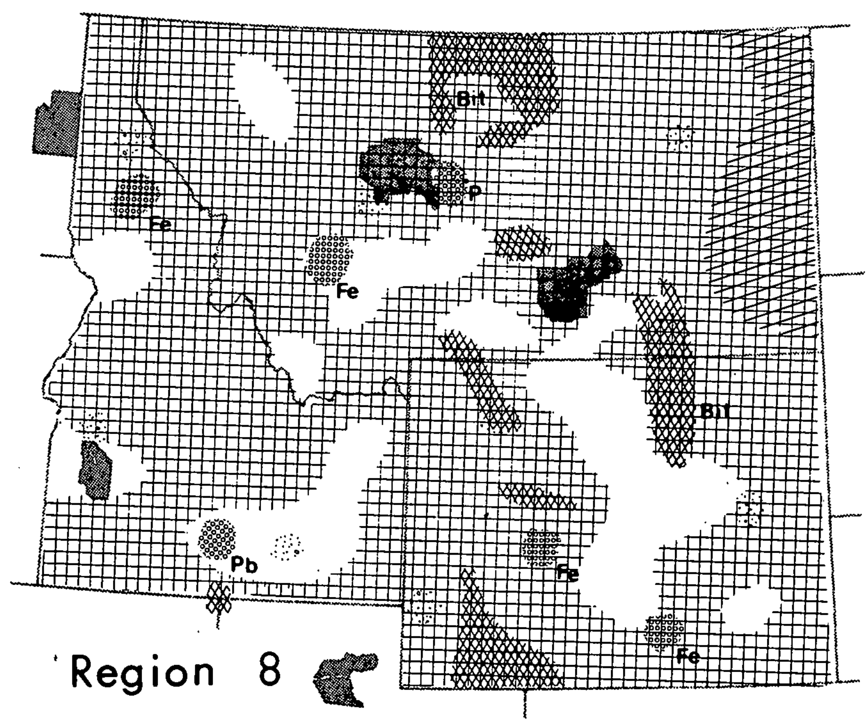


Figure 11. Locations of potential aggregate shortage areas and available waste materials, Region 8.

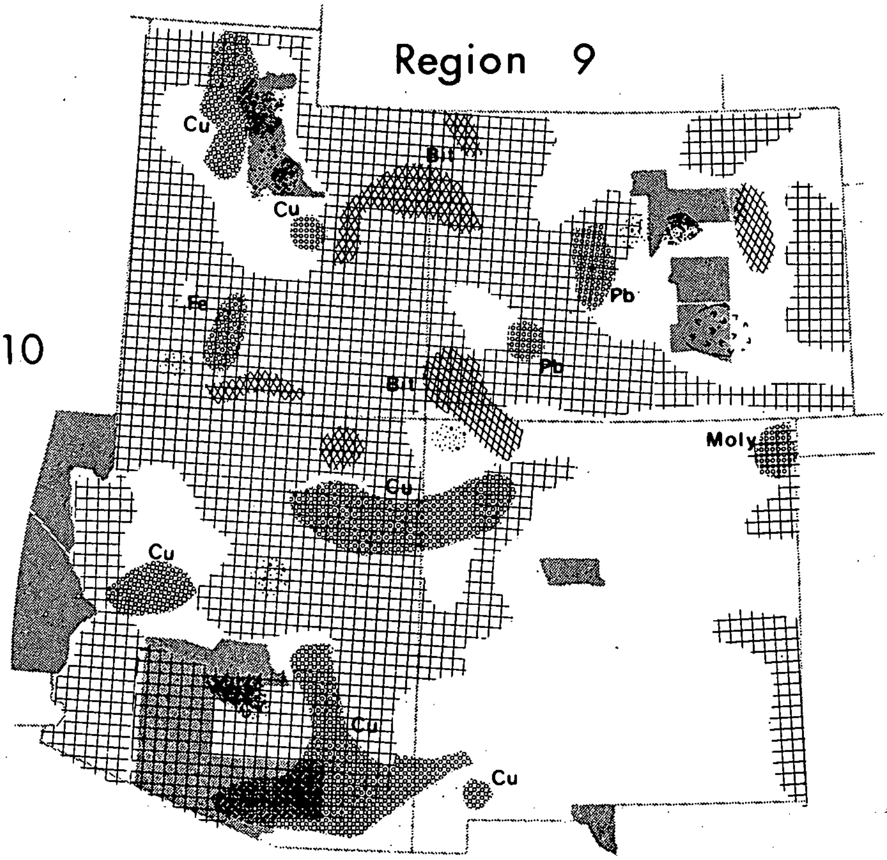


Figure 12. Locations of potential aggregate shortage areas and available waste materials, Region 9.

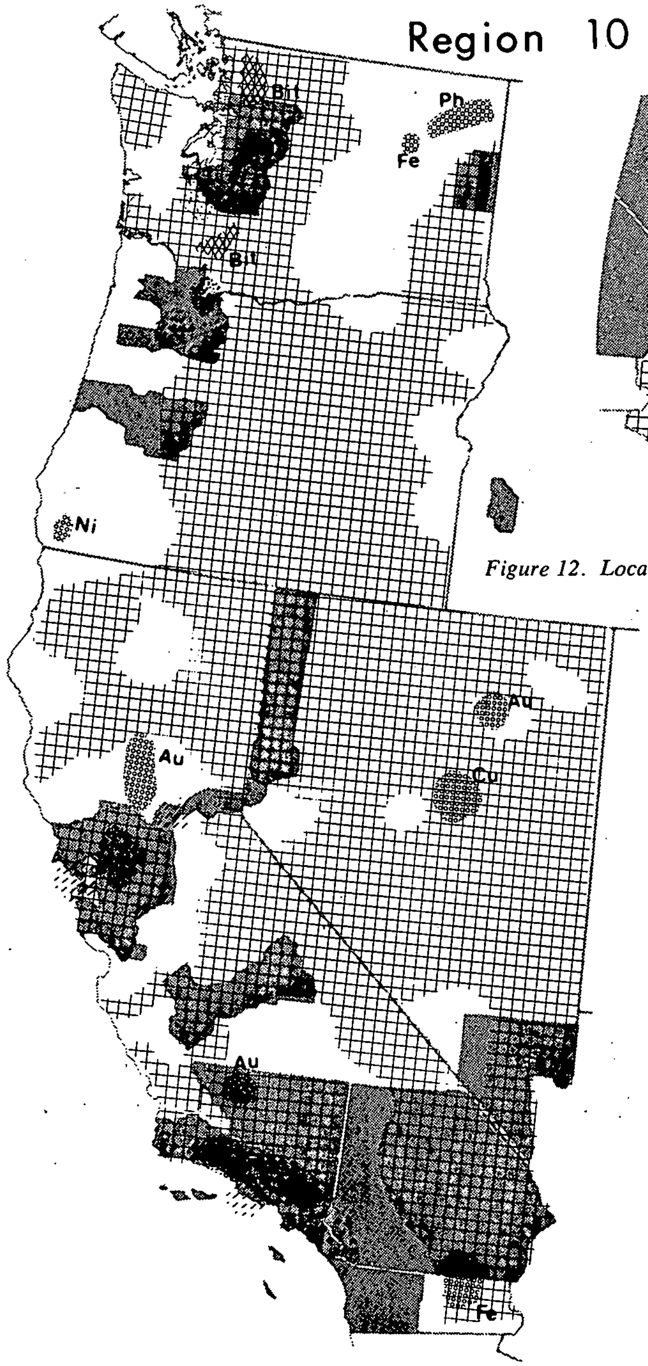


Figure 13. Locations of potential aggregate shortage areas and available waste materials, Region 10.

TABLE 2

ESTIMATED QUANTITIES OF ANNUALLY PRODUCED SOLID WASTE MATERIALS AVAILABLE IN EACH STATE[a]

	MATERIALS AVAILABLE (Thousands of tons)									
STATE	TOTAL WASTE	MINERAL WASTE	ASH WASTE	SLAG WASTE	FOUNDRY WASTE	BUILDING RUBBLE	SEWAGE SLUDGE	INCINERATOR RESIDUE	RUBBER TIRES	WASTE GLASS
Alabama	14,400	7,000	1,750	2,000	2,800	400	140	10	80	220
Arizona	150,710	150,000	50	— — —	100	260	100	— — —	50	150
Arkansas	2,270	2,000	— — —	— — —	— — —	150	60	— — —	50	10
California	18,150	10,000	— — —	1,000	20	3,500	1,200	150	480	1,800
Colorado	5,270	3,200	350	1,000	60	300	120	— — —	60	180
Connecticut	1,765	200	180	— — —	180	500	160	450	70	25
Delaware	505	200	150	— — —	10	100	30	— — —	10	5
Florida	22,220	20,000	180	— — —	10	1,000	360	250	170	250
Georgia	3,410	1,200	1,100	— — —	50	500	180	— — —	100	280
Idaho	5,275	5,000	120	— — —	— — —	50	80	— — —	20	5
Illinois	25,000	13,000	3,200	3,000	2,500	1,750	300	500	200	550
Indiana	10,150	4,500	2,500	500	1,200	600	240	150	110	350
Iowa	2,650	1,200	500	— — —	300	300	120	— — —	70	160
Kansas	2.220	800	650	— — —	400	60	100	— — —	60	150
Kentucky	28,690	25,000	2,600	— — —	350	300	100	120	70	150
Louisiana	3,610	2,600	— — —	— — —	70	450	180	215	70	25
Maine	365	200	— — —	— — —	— — —	100	40	— — —	20	5
Maryland	3,920	300	700	1,500	90	550	210	200	70	300
Massachusetts	2,805	200	15	— — —	180	950	350	500	110	500
Michigan	33,340	22,000	2,250	2,000	3,800	1,300	500	600	190	700
Minnesota	107,090	105,000	900	— — —	100	500	190	40	90	270
Mississippi	630	300	70	— — —	— — —	150	60	— — —	40	10
Missouri	12,525	9,500	1,600	— — —	400	600	225	70	90	40
Montana	17,275	17,000	80	— — —	60	80	30	— — —	20	5
Nebraska	1,165	500	360	— — —	10	150	60	35	40	10
Nevada	4,285	4,000	190	— — —	— — —	50	20	— — —	20	5
New Hampshire	335	200	— — —	— — —	— — —	80	30	— — —	20	5
New Jersey	5,430	2,200	460	— — —	100	1,250	450	120	150	700
New Mexico	13,290	12,200	850	— — —	— — —	150	50	— — —	30	10
New York	15,790	3,700	1,300	1,500	1,050	3,100	1,140	2,000	370	1,630
North Carolina	4,060	500	2,600	— — —	140	300	150	60	110	200
North Dakota	2,600	1,500	1,000	— — —	— — —	50	20	— — —	20	10
Ohio	28,540	11,200	4,500	6,000	3,200	1,500	600	450	240	850
Oklahoma	4,270	3,500	— — —	— — —	400	160	120	— — —	70	20
Oregon	4,625	4,000	— — —	— — —	50	400	100	— — —	60	15
Pennsylvania	38,400	20,000	4,000	6,000	3,400	2,600	620	650	230	900

TABLE 2 (*Continued*)

STATE	MATERIALS AVAILABLE (Thousands of tons) TOTAL WASTE	MINERAL WASTE	ASH WASTE	SLAG WASTE	FOUNDRY WASTE	BUILDING RUBBLE	SEWAGE SLUDGE	INCINERATOR RESIDUE	RUBBER TIRES	WASTE GLASS
Rhode Island	740	200	---	---	---	150	60	100	220	10
South Carolina	2,220	500	600	---	60	200	800	---	50	10
South Dakota	2,095	2,000	---	---	---	50	20	---	20	5
Tennessee	8,300	5,700	1,950	---	---	400	150	---	80	20
Texas	10,270	5,000	---	1,000	700	1,600	600	200	270	900
Utah	50,530	50,000	40	---	240	150	60	---	30	10
Vermont	310	200	---	---	50	20	10	---	10	20
Virginia	11,110	7,700	1,100	500	330	400	490	250	90	250
Washington	5,280	4,000	300	---	60	500	80	---	80	260
West Virginia	31,310	29,000	2,100	---	---	120	50	---	30	10
Wisconsin	10,825	7,000	1,500	---	1,000	500	135	300	90	300
Wyoming	5,130	3,500	1,500	---	60	40	15	---	10	5

[a]Not including Alaska and Hawaii.

tuminous paving mixtures, and cold-mix emulsified asphalt mixes. Boiler slag has been used successfully in bituminous base course and wearing surface applications, especially when blended with conventional aggregates.

Class II includes those materials that deserve consideration for further development as aggregates, which do not at this time appear to have as high a potential as the Class I materials. Class II materials do not always possess so many favorable properties, and they generally require a greater amount of processing to be rendered suitable for use as aggregate. Although most of the materials categorized as Class II exist in significantly large quantities, many are not located within immediate proximity to potential market areas. Several of the materials rated in Class II have been used to a limited extent in highways.

Some Class II materials are recommended for use as highway aggregate with some minor reservations. For example, steel slag has the capability of rendering very satisfactory performance in a number of highway applications, but extreme care must be exercised in its use. A curing period of at least six months and preferably one year should elapse before this material is used because of its expansive nature when undergoing hydration. The aging period for steel slag may possibly be reduced for use in asphalt mixes if the slag is subjected to water sprays and crushing before such use.

Bituminous coal refuse should be incinerated before use as an aggregate to remove unburned carbon and to impart greater strength to the particles. Incinerator residue can also be converted into a better aggregate product after fusion to complete the burning process. Separation of nonrubble components from demolition material is necessary for building rubble to be used successfully as aggregate.

Although waste glass has performed as an aggregate in "glasphalt" experiments to date, the economics of collecting and crushing the material for use need to be given careful consideration. Huge quantities of glass are not normally available and glass companies are willing to pay $20.00 per ton to groups collecting glass for recycling. Theoretically, only the collected glass exceeding the cullet requirements of glass manufacturers is available for glasphalt. With relatively small quantities of glass, processing costs for crushing are likely to be prohibitive in many instances. Perhaps the most practical use of glass would be for bituminous patching, driveways, and other low-volume applications. Use of glass in portland cement concrete is not recommended because particle shape and lack of porosity cause poor bonding and strength development. Another problem of perhaps greater concern with the use of glass in portland cement concrete is the potential alkali-silicate reaction.

Class III refers to those waste materials which do not show great promise for use as a highway aggregate for a variety of reasons. Many of the materials in this category require extensive processing, have nonuniform characteristics, or do not possess many of the properties considered essential for a quality aggregate material. Several of the Class III waste materials are located beyond economical hauling distances from potential market areas. Very few of these materials have any record of previous use as aggregate in highway or related construction.

Many of the wastes in this category require dewatering because of their sludge- or slurry-type consistency. Processing costs can therefore be expected to be much higher. Included are alumina muds, phosphate slimes, dredge spoil, sulfate sludge, and power station scrubber sludge. Fine tailings from many mining operations are also deposited in the form of a slurry.

TABLE 3

COMPARISON OF FIGURES FOR HIGHWAY AGGREGATE CONSUMPTION AND ESTIMATED ANNUAL SOLID WASTE PRODUCTION (Millions of tons)

STUDY REGION	STATE	ESTIMATED HIGHWAY AGGREGATE CONSUMPTION	ESTIMATED SOLID WASTE PRODUCTION	PERCENT HIGHWAY AGGREGATE CONSUMPTION
1	Connecticut	5.15	1.77	
	Delaware	1.14	0.51	
	Maine	6.49	0.37	
	Maryland	12.48	3.92	
	Massachusetts	12.00	2.81	
	New Hampshire	3.64	0.34	
	New Jersey	12.47	5.43	
	New York	35.00	15.79	
	Pennsylvania	38.60	36.06	
	Rhode Island	1.64	0.74	
	Vermont	4.81	0.31	
		133.42	68.05	50.7%
2	Florida	24.60	22.22	
	Georgia	16.16	3.41	
	North Carolina	11.70	4.06	
	South Carolina	6.80	2.22	
	Virginia	19.20	11.11	
	West Virginia	7.95	31.31	
		86.41	74.33	86.0%
3	Illinois	37.90	25.00	
	Indiana	23.60	10.15	
	Michigan	31.50	33.34	
	Ohio	35.70	28.54	
	Wisconsin	29.50	10.83	
		158.20	107.86	68.1%
4	Alabama	13.20	14.40	
	Arkansas	11.90	2.27	
	Kentucky	9.25	28.69	
	Louisiana	19.80	3.61	
	Mississippi	6.69	0.63	
	Tennessee	27.50	8.30	
		88.34	57.90	65.4%
5	Iowa	15.82	2.65	
	Minnesota	31.60	107.09	
	Nebraska	11.62	1.17	
	North Dakota	6.43	2.60	
	South Dakota	8.00	2.10	
		73.47	115.61	157.0%
6	Kansas	9.35	2.22	
	Missouri	17.10	12.53	
	Oklahoma	11.25	4.27	
		37.70	19.02	50.5%
7	Texas	47.70	10.27	21.5%
8	Idaho	7.35	5.28	
	Montana	14.95	17.28	
	Wyoming	7.50	5.13	
		29.80	27.69	92.9%
9	Arizona	18.10	150.71	
	Colorado	17.00	5.27	
	New Mexico	7.75	13.29	
	Utah	6.10	50.53	
		48.95	219.80	450.0%
10	California	98.30	18.15	
	Nevada	5.17	4.29	
	Oregon	14.00	4.63	
	Washington	19.80	5.28	
		137.27	32.35	23.5%
	TOTAL	841.26	731.88	87.0%

TABLE 4

CURRENT USE OF WASTE MATERIAL AS AGGREGATE IN HIGHWAYS

WASTE MATERIAL	ESTIMATED ANNUAL QUANTITIES USED	PRINCIPAL LOCATION OR USE	REMARKS
Blast Furnace Slag	10 Million Tons	Pennsylvania, Ohio, Illinois, Michigan	Routinely used as aggregate in Portland cement concrete, bituminous paving mixtures, stone base, and base course compositions.
Steel Slag	5 Million Tons	Pennsylvania, Ohio, and California	Used as base course material. Experimentally used as aggregate in bituminous paving mixtures.
Fly Ash	150,000 Tons	Illinois and Pennsylvania	Routinely used in highways as a stabilized base with lime and aggregate. Experimental use in pelletized aggregate form.
Bottom Ash	150,000 Tons	West Virginia and Ohio	Used as component of lime-Fly Ash aggregate and cement-treated base base courses. Also used in cold-mix emulsified asphalt resurfacing mixtures.
Boiler Slag	50,000 Tons	Illinois, Indiana, Ohio, West Virginia and Minnesota	Used as aggregate in bituminous base courses and wearing surfaces. Also used as a component of lime-Fly Ash aggregate and cement treated base courses. Investigated experimentally for slurry seal treatment use.
Power Station Scrubber Sludge	50,000 Tons	Transpo'72 Demonstration Project	Experimentally used as a component of a lime-Fly Ash - Sulfate Sludge aggregate base course composition. Also used experimentally with lime and Fly Ash in the manufacture of synthetic aggregate.
Anthracite Coal Refuse	30,000 Square Yards Resurfacing	Pennsylvania	Experimentally used as aggregate in bituminous resurfacing mistures.
Bituminous Coal Refuse	Not Available	Virginia and West Virginia	Used as base and sub-base material in highways. Laboratory experiments at University of Kentucky and West Virginia University on use in bitumious mixtures.
Copper Tailings	Not Available	Utah	Used as embankment material in Utah. Found unsatisfactory for aggregate use in concrete or stone base in Arizona.
Phosphate Slag	Several Hundred thousand tons total use	Montana	Used in highways as a base course material.
Slate Mining Waste	30,000 tons	Virginia	Used as aggregate in concrete mixtures, seal treatments, and in stone base courses.
Taconite Tailings	Not Available	Minnesota	Used as aggregate in stone base. sub-base, and bituminous mixtures.
Incinerator Residue	Not Available	Philadelphia, Pennsylvania Tampa, Florida Houston, Texas	Used experimentally either in fused or unfused condition as aggregate in bituminous mixtures.
Plastic Waste	Not Available	Elgin, Illinois	Used experimentally as partial sand replacement for concrete pedestrian footbridge.
Pyrolysis Residue	Not Available	Baltimore, Maryland	Intends to use as aggregate in bituminous paving mixtures when available.
Reclaimed Paving Material	Not Available	Many states including Texas and California	Used as aggregate in bituminous paving mixtures when available.
Rubber Tires	Not Available	Arizona	Used in hot asphalt - rubber seal treatments and as partial aggregate replacements in bituminous resurfacing mixtures.
Waste Glass	Approximately 3,000 Tons Used to Date	Many locations throughout United States	Used experimentally in glasphalt mixes. Also used experimentally as base material for Interstate highway in Ohio.

TABLE 5

RESULTS OF OVER-ALL WASTE MATERIAL EVALUATION

CLASS I	CLASS II	CLASS III	CLASS IV
Blast Furnace Slag	Steel Slag	Alumina Muds	Phosphogypsum
Reclaimed Paving Material	Bituminous Coal Refuse	Phosphate Slimes	Sewage Sludge
Fly Ash	Phosphate Slag	Sulfate Sludge	
Bottom Ash	Slate Mining Waste	Scrubber Sludge	
Boiler Slag	Foundry Waste	Copper Tailings	
Anthracite Coal Refuse	Taconite Tailings	Dredge Spoil	
	Incinerator Residue	Feldspar Tailings	
	Waste Glass	Iron Ore Tailings	
	Zinc Smelter Waste	Lead-Zinc Tailings	
	Gold Mining Waste	Nickel Tailings	
	Building Rubble	Rubber Tires	
		Battery Casings	

Coarse mine tailings are somewhat more adaptable to aggregate use. However, their mineralogy varies between locations, and the properties of some minerals have been found to be marginal at best when used in highways. Mine tailings source locations are often distantly removed from population centers and economic transportation, and their ecological effects in highway use are questionable.

Class IV waste materials are those not recommended for further consideration as potential replacements for highway aggregates. Such materials do not lend themselves readily to any current use, do require a formidable amount of processing, and have little, if any, potential for future aggregate use.

Phosphogypsum, on the basis of very little available information, does not seem to possess any potential for use as a highway aggregate, although there may be some possibility for its use in cement manufacturing. Sewage sludge by itself also has very little, if any, feasibility for aggregate use, although it may be considered as a possible component of a stabilized base course mixture. Ash from the incineration of sewage sludge may have some potential for use as a highway fill material, but lack of information on its potential as aggregate, coupled with relatively small quantities and high processing cost, make it appear to have little feasibility.

The final recommendation given to a specific waste material was determined mainly by its technical and economic feasibility, with environmental considerations as an additional guide. Appendix D presents a detailed discussion of the system used to evaluate the technical, economic, and environmental feasibility of the waste materials.

Development of the synthetic lightweight aggregate industry over the past 20 years has provided the required technology for processing waste materials having a variety of physical properties. Pelletizing, extruding, and agglomerating processes have been used successfully to form aggregate shapes capable of being fired into bloated or nonbloated materials by a sinter strand or rotary kiln. Temperatures used in these fusion processes normally range between 2,000 and 2,400 F. Additional processing, when required, consists of dewatering or thickening of slurry-type wastes, thermochemical bonding of pozzolanic wastes, neutralization of toxic substances, and crushing and sizing of the finished material to achieve proper gradation.

Generally speaking, some form of aggregate can be produced from nearly all of the waste materials considered in this study; but, the quality (determined by evaluation of individual properties and past performance) of the finished product is the determining factor in measuring its technical value.

Many factors interact when considering the economics of developing a waste material into an aggregate. In most

cases, the cost of processing a waste material is directly proportional to the number of processing steps required. Therefore, wastes existing in sludge or slurry form can be expected to be more costly to process than wastes found as a dust or in fine particle sizes. The most attractive materials from a processing-cost standpoint are those requiring only crushing and sizing prior to their use.

Transportation costs must be determined for each waste material by negotiation with individual carriers on the basis of a specific movement from point A to point B. The most inexpensive form of transport is likely to be barge, followed by rail and truck. Determination of exact rates for barge and rail transport of a particular waste commodity can be a very difficult experience because tariffs are not always established for such materials.

The cost of a synthetic aggregate produced from a waste material is influenced by the cost of obtaining the waste material. For example, locating the owner of a long-abandoned mining operation can be difficult and appreciably increase the cost of obtaining mine tailings. The cost of a mineral or industrial waste will be variable, depending upon the normal disposal cost and the amount of processing remaining. To be competitive with other sources of aggregate, a waste aggregate should range in net cost between $4 and $10 per ton (after deduction of the normal cost of waste disposal), depending upon (a) the scarcity of conventional aggregates, (b) the cost of synthetic lightweight aggregates, and (c) the price structure of these materials. In short, the economics of using a particular waste material can be accurately determined only after a careful market study has been conducted for a specific waste in a specific market area.

Environmental considerations have served as a guideline in the final recommendation of waste materials for development as aggregates. Many of the mineral wastes have been placed in Class III because of their somewhat negative environmental aspects, such as their potential for dusting or leaching of metallic substances. Those waste materials that constitute a blight or pose a significant ecological threat were considered to have a higher priority for reuse when weighing technical and economic factors. However, enhancement of the environment is a positive factor that is very difficult to quantify in an evaluative process.

CHAPTER THREE

CONCLUSIONS AND RECOMMENDATIONS

The following major conclusions have been derived from this study. The ensuing recommendations drawn from the conclusions are designed to aid highway administrators, public works officials, and other interested parties in formulating policy concerning waste utilization in highways.

CONCLUSIONS

1. The basic technology exists at the present time, or can be readily developed, for converting solid waste materials into synthetic aggregate form. The use of sludge thickeners, pelletizing or agglomerating techniques, heat processing using sinter strand or rotary kiln equipment, and thermochemical processing are all adaptable to the manufacture of synthetic aggregates from wastes.

2. Generally, the engineering properties of the synthetic aggregates that have thus far been produced from waste materials are not as good as those of natural aggregates. Notable exceptions are blast furnace slag, fly ash, and boiler slag.

3. Although synthetic aggregates manufactured from waste materials often are not equal in quality to natural aggregates, they may be good enough to use in certain highway applications, such as in shoulders or as embankment material.

4. Much work remains to be done in research and field experimentation to determine the suitability of using many of the waste materials examined in this study as highway aggregates. Such a process is a time-consuming one; it is not unusual for a period of 20 years to elapse between the proposal of a new material and its acceptance for highway use.

5. Up to the present, most efforts expended in research and development of waste material use in highways have been scattered and sporadic. Exceptions have been the programs coordinated by the National Ash Association and the National Slag Association.

6. The requirements of current specifications for conventional aggregates appear to be too severe for many of the synthetic aggregates that might result from the processing of waste materials. As part of the developmental process, it will be necessary to determine the effects, under a total system concept, of some reduction in standards to permit the use of lower-quality aggregate. This is likely to involve also a redesign of pavement sections to compensate for the use of reduced-quality aggregates under the various classes of traffic, climatic conditions, and subgrade support.

7. Areas exist where good-quality natural aggregates are in short supply. Of particular interest is that most metropolitan areas are lacking in both natural aggregates and the sources of large quantities of waste materials.

8. No well-defined idea of exactly what constitutes an aggregate shortage exists at the present time.

9. The existence of a steady, sizeable market is essential to the success of any recycling effort.

GENERAL RECOMMENDATIONS

To aid those interested in the use of waste materials in general and those who view waste utilization as a possible partial solution to the problems of conventional aggregate shortages, the following general recommendations are made:

1. A strong effort should be made to increase the use of waste materials with records of satisfactory performance as highway aggregates. These include slags, ash, incinerator residue, and some mineral wastes.
2. States and municipalities should thoroughly inventory available waste resources and determine the amounts, locations, and physical and chemical properties of such wastes. Cooperative efforts should also be established between interested industries and state and local governments to identify and attempt to alleviate major pollution problems.
3. Quantities of available waste materials should be compared with the amount of aggregate being produced and consumed for highway purposes on a state and municipal basis.
4. A strong central agency should be given the responsibility to coordinate the research and development efforts related to waste material use and to provide the impetus for acceptance of the resulting products by the highway industry.
5. Existing specification requirements for aggregates should be thoroughly reviewed and analyzed with an eye toward relaxation of certain requirements, particularly in areas where shortages of conventional aggregates are now or will become a problem.
6. Consideration should be given to the adoption of performance specifications, even if on a trial basis, in order to allow more latitude in the selection of highway materials.
7. The use of lightweight aggregates in various types of highway applications should be researched and developed.
8. Field experimentation should be conducted on all Class I and Class II materials not already used in highways in some form. This work should be fully coordinated and take the form of pilot programs, demonstration projects, and the like. In this way, materials could be tested and data collected for a wide variety of design, traffic, and climatic conditions.
9. Facilities of both existing pit and quarry operations and lightweight-aggregate producers should be utilized to the maximum extent possible as a logical first step in developing processing locations for waste material.
10. A data retrieval system should be established as part of the proposed study. The system would serve as a storehouse for all information related to waste materials having any sort of potential for use in highway construction, whether as aggregate, fill material, or stabilization material. As new information is received, the system could be updated. Use of an existing information system modified for this purpose would be most practical.

SPECIFIC RECOMMENDATIONS

The following recommendations are directed toward governmental and industry personnel who are faced with the responsibility of deciding whether and in what fashion waste materials may be used in highways:

1. More detailed information is needed on the precise locations and magnitude of conventional aggregate shortages. Each state should gather exact data and assess the extent to which aggregate shortages can be met by using waste materials. A standard definition of "aggregate shortage" should be formulated and used throughout the U.S.
2. Waste resources located within a 100-mile radius of major metropolitan centers and within reach of transportation are optimum candidates for reuse. Any developmental work should give early consideration to these wastes. The most promising from a technical and economic standpoint are ash wastes, incinerator residues, building and paving rubble, slags, and coal refuse.
3. A sponsored program utilizing a portable barge-mounted processing system is recommended for use on navigable waterways. The system should possess the capability for the processing of several different types of waste materials such as fly ash, foundry dust, coal refuse, and dredge spoil. In view of energy requirements, materials with latent heat value should be given prime consideration for supplying energy for processing. In addition, the use of wastes as supplementary fuels will result in energy savings and should be encouraged on that basis.
4. State transportation departments experiencing conventional aggregate shortages and having access to large volumes of fly ash and coal refuse should explore further their possibilities for use. The long-range possibility of using hopper-car unit trains to transport waste materials should be investigated if such materials are to be eventually developed on a large scale involving millions of tons per year over many years. It may also be possible to apply the unit-train concept to the transport of conventional aggregates in some states.
5. Municipal governments should develop or improve programs for recovery and reuse of solid wastes. Separation techniques in larger metropolitan areas will yield significant tonnages of glass and useable rubble from demolition activity. Savings in disposal costs will help to offset the costs of the purchase and transport of conventional materials in a municipal road-building program. Cooperation by Federal agencies, such as FHWA or EPA, probably will be needed for pilot programs to develop the economic feasibility of such policies.
6. Although certain lower grade waste materials under municipal jurisdiction, such as rubber tires and sewage sludge, are not suitable for high-quality aggregate use, they might be capable of displacing a certain percentage of conventional aggregates in lower class applications without a significantly detrimental effect to the performance of the highway system. Research of these type uses might be approached through cooperative efforts at the university level with state and municipal agencies.
7. A study should be initiated toward developing the necessary technology for dewatering, agglomerating, and sintering various samples of dredge spoil material. If usable as an aggregate, the available tonnages of such material located notably in the Gulf Coast region would go far in alleviating some natural material shortages in that area.
8. The U.S. Bureau of Mines and the Federal Highway Administration should reinforce cooperative research ef-

forts toward the goal of defining the most suitable mineral wastes for development as aggregate materials. Much of the work done to date by the Bureau of Mines has been directed towards stabilization or reclamation of metals from mineral wastes.

9. Many waste materials have been used successfully in combination with other waste materials. The possibilities for combining waste materials into a serviceable product are many. Research should be undertaken on the effects of using aggregates from different waste materials in different combinations.

10. Portable processing operations, such as those used successfully to process reclaimed paving material, should be more frequently used for processing such wastes as building and paving rubble and coal refuse.

11. Further study of transportation costs is needed. A detailed study should be made of the cost of moving all waste materials rated Class I and Class II from their points of origin to the nearest market areas. This study should define quantities in terms of tonnage available at each location, types of transport available, names of carriers, and, most important of all, a determination of the probable rates to be charged for each movement.

12. At the present time, tariff rates for many waste materials are discriminatory with respect to corresponding rates for virgin materials. An outstanding example is the rate for scrap iron and steel, which is as much as four times as high as the rate for iron ore. A study of transportation rates mentioned in item 11 should also include comparison, where applicable, with virgin materials. Means should be found, including legislation if necessary, for establishing more favorable rates for transporting waste materials with an eye toward promoting their further use.

13. Thorough inventories of potential sources of conventional aggregates should be conducted concurrently with inventories of available waste resources. Valuable deposits of high-quality natural aggregate materials are known to exist and, whether currently being worked or not, such deposits should be protected and preserved for future use by judicious zoning.

APPENDIX A: CONVENTIONAL AGGREGATE - SUPPLY AND DEMAND

A.1 INTRODUCTION

Development of waste resources for potential use as aggregates requires an examination of the availability of naturally occurring aggregate supplies relative to the demands for aggregate materials. Conventional aggregates are classified as: 1) crushed stone, and 2) sand and gravel.

Prior studies have investigated the status of conventional aggregate supplies (267), as well as the capability of the aggregate producing industry to meet the demands of the highway and building construction industries (6).

A.2 CURRENT AGGREGATE PRODUCTION AND CONSUMPTION DATA

In 1970, the total production of conventional aggregates was approximately 1.8 billion tons. Aggregate production in 1970, by state, is shown in Table A-1 (245). By 1975, the production of conventional aggregate is expected to exceed 2.5 billion tons and will approach 4.0 billion tons by 1985 (139).

Although the annual consumption of aggregates by the highway industry is approaching 1 billion tons, precise records of the quantities actually used are not directly obtainable. The quantity of aggregate used in each state can be estimated, however, by applying appropriate aggregate usage factors to highway construction cost data for various highway classifications in the state (247).

TABLE A-1

TOTAL CONVENTIONAL AGGREGATE PRODUCTION BY STATE IN 1970 (Millions of Tons)

STATE	CRUSHED STONE	SAND AND GRAVEL	TOTAL
Alabama	19.88	6.73	26.61
Arizona	3.51	17.82	21.33
Arkansas	15.28	13.30	28.58
California	46.40	140.26	186.66
Colorado	3.55	22.26	25.81
Connecticut	8.34	6.77	15.11
Delaware	-	1.57	1.57
Florida	43.09	12.48	55.57
Georgia	26.64	3.67	30.31
Idaho	4.24	12.45	16.69
Illinois	55.78	43.93	99.31
Indiana	25.82	23.48	49.30
Iowa	25.31	21.06	46.37
Kansas	15.16	12.47	27.63
Kentucky	29.31	8.76	38.07
Louisiana	9.06	18.16	27.22
Maine	W	12.97	12.97 + W
Maryland	16.02	12.95	28.97
Massachusetts	8.14	17.93	26.07
Michigan	41.69	53.09	94.78
Minnesota	4.58	46.85	51.43
Mississippi	W	10.86	10.86 + W
Missouri	39.73	12.45	52.18
Montana	6.50	19.28	25.78
Nebraska	4.27	12.23	16.50

*Note: W = Information Withheld

TABLE A-1 (Continued)

STATE	CRUSHED STONE	SAND AND GRAVEL	TOTAL
Nevada	1.86	8.57	10.43
New Hampshire	W	6.53	6.53 + W
New Jersey	15.16	16.73	31.85
New Mexico	3.10	10.67	13.77
New York	37.62	35.54	73.16
North Carolina	30.36	12.77	42.63
North Dakota	0.10	8.09	8.19
Ohio	47.24	42.07	89.31
Oklahoma	18.18	5.68	23.86
Oregon	13.44	17.53	30.79
Pennsylvania	66.24	18.50	84.74
Rhode Island	W	2.39	2.39 + W
South Carolina	9.71	5.86	15.57
South Dakota	1.98	16.56	18.54
Tennessee	35.37	6.72	42.09
Texas	45.56	31.44	77.00
Utah	1.65	12.01	13.66
Vermont	1.51	4.05	6.56
Virginia	35.42	11.13	46.55
Washington	13.70	25.09	38.79
West Virginia	9.70	4.46	14.16
Wisconsin	17.58	41.10	58.60
Wyoming	1.27	9.45	10.72
TOTAL	859.05 +W	916.70	1775.75 +W

*Note: W = Information Withheld

SOURCE: Minerals Yearbook, Volume I, pp. 997, 998, and 1045.

Table A-2 indicates the estimated consumption of aggregates for highway construction and maintenance in each state for 1970. A comparison of total aggregate production and highway consumption figures for each state is given in Table A-3. The approximate percentage of total aggregate production used for highways in each state is also indicated. A comparison of these firgures on a regional basis is shown in Table A-4. The use of approximately 48% of the current national production of aggregates by the highway industry at this time is indicated. The percentage of total aggregate production and highway aggregate consumption for each AASHTO Region are compared in Table A-5.

The following observations are based upon a study of the above tables:

1. Total aggregate production on a national basis is geared to satisfy the demands imposed on aggregate producers by the highway and building construction industries.

2. None of the AASHTO Regions appears to be experiencing shortages of highway aggregates at this time, although the percentage of aggregate consumed by highways is somewhat greater than average in Region 4.

3. Several states seem to have a markedly higher than average consumption of aggregates for highway purposes. This does not necessarily mean there is a shortage of highway aggregates in those states.

4. It is impossible to determine with a great degree of accuracy where conventional aggregates are in short supply based upon aggregate

TABLE A-2

ESTIMATED CONVENTIONAL AGGREGATE CONSUMPTION FOR HIGHWAYS BY STATE IN 1970 (Millions of Tons)

STATE	HIGHWAY CONSTRUCTION	MAINTENANCE	TOTAL HIGHWAY CONSUMPTION
Alabama	10.97	2.23	13.20
Arizona	15.42	2.68	18.10
Arkansas	9.81	2.09	11.90
California	81.82	16.58	98.30
Colorado	14.14	2.86	17.00
Connecticut	4.30	0.85	5.15
Delaware	0.95	0.09	1.14
Florida	20.48	4.12	24.60
Georgia	13.34	2.82	16.16
Idaho	6.12	1.23	7.35
Illinois	32.20	5.70	37.90
Indiana	19.62	3.98	23.60
Iowa	13.44	2.38	15.82
Kansas	7.80	1.55	9.35
Kentucky	7.58	1.67	9.25
Louisiana	16.48	3.32	19.80
Maine	5.40	1.09	6.49
Maryland	10.38	2.10	12.48
Massachusetts	10.01	1.99	12.00
Michigan	27.10	4.40	31.50
Minnesota	25.20	6.40	31.60
Mississippi	5.67	1.02	6.69
Missouri	14.52	2.58	17.10
Montana	12.43	2.52	14.95
Nebraska	8.85	2.77	11.62

TABLE A-2 (Continued)

STATE	HIGHWAY CONSTRUCTION	MAINTENANCE	TOTAL HIGHWAY CONSUMPTION
Nevada	4.30	0.87	5.17
New Hampshire	3.04	0.60	3.64
New Jersey	10.59	1.88	12.47
New Mexico	6.40	1.35	7.75
New York	29.00	6.00	35.00
North Carolina	9.95	1.75	11.70
North Dakota	5.47	0.96	6.43
Ohio	30.30	5.40	35.70
Oklahoma	9.35	1.90	11.25
Oregon	11.68	2.32	14.00
Pennsylvania	32.21	6.39	38.60
Rhode Island	1.32	0.32	1.64
South Carolina	5.67	1.13	6.80
South Dakota	6.68	1.32	8.00
Tennessee	22.86	4.64	27.50
Texas	39.73	7.97	47.70
Utah	5.07	1.03	6.10
Vermont	3.94	0.87	4.81
Virginia	15.92	3.28	19.20
Washington	16.25	3.55	19.80
West Virginia	6.59	1.36	7.95
Wisconsin	24.57	4.93	29.50
Wyoming	6.25	1.25	7.50
District of Columbia	1.78	0.47	2.25
TOTAL			843.51

TABLE A-3

COMPARISON OF 1970
AGGREGATE PRODUCTION
AND HIGHWAY CONSUMPTION BY STATE
(Millions of Tons)

STATE	TOTAL AGGREGATE PRODUCTION	ESTIMATED HIGHWAY CONSUMPTION	PERCENTAGE CONSUMED BY HIGHWAYS
Alabama	26.61	13.20	49.6%
Arizona	21.33	18.10	84.9
Arkansas	28.58	11.90	41.6
California	186.66	98.30	52.7
Colorado	25.81	17.00	65.9
Connecticut	15.11	5.15	34.1
Delaware	1.57	1.14	72.6
Florida	55.57	24.60	44.3
Georgia	30.31	16.16	53.3
Idaho	16.69	7.35	44.0
Illinois	99.31	37.90	38.2
Indiana	49.30	23.60	47.9
Iowa	46.37	15.82	34.4
Kansas	27.63	9.35	33.8
Kentucky	38.07	9.25	24.3
Louisiana	27.22	19.80	72.7
Maine	12.97 + W	6.49	50.0
Maryland	28.97	12.48	43.1
Massachusetts	26.07	12.00	46.0
Michigan	94.78	31.50	33.2
Minnesota	51.43	31.60	61.4
Mississippi	10.86 + W	6.69	61.6
Missouri	52.18	17.10	32.8
Montana	25.78	14.95	58.0
Nebraska	16.50	11.62	70.4
Nevada	10.43	5.17	49.6
New Hampshire	6.53 + W	3.64	55.7

*Note: W = Information Withheld

TABLE A-3 (Continued)
(Millions of Tons)

STATE	TOTAL AGGREGATE PRODUCTION	ESTIMATED HIGHWAY CONSUMPTION	PERCENTAGE CONSUMED BY HIGHWAYS
New Jersey	31.85	12.47	39.2%
New Mexico	13.77	7.75	56.3
New York	73.16	35.00	47.8
North Carolina	42.63	11.70	27.4
North Dakota	8.19	6.43	78.5
Ohio	89.31	35.70	40.0
Oklahoma	23.86	11.25	47.2
Oregon	30.97	14.00	45.2
Pennsylvania	84.74	38.60	45.6
Rhode Island	2.39 + W	1.64	68.6
South Carolina	15.57	6.80	43.7
South Dakota	18.54	8.00	43.1
Tennessee	42.09	27.50	65.3
Texas	77.00	47.70	62.0
Utah	13.66	6.10	44.7
Vermont	6.56	4.81	73.3
Virginia	46.55	19.20	41.2
Washington	38.79	19.80	51.0
West Virginia	14.16	7.95	56.1
Wisconsin	58.60	29.50	50.3
Wyoming	10.72	7.50	70.0
District of Columbia	N.A.	2.25	
TOTAL	1795.75	843.51	47.5%

*Note: W = Information Withheld

TABLE A-4

COMPARISON OF 1970
AGGREGATE PRODUCTION AND
HIGHWAY CONSUMPTION BY
AASHTO REGION
(Millions of Tons)

AASHTO REGION 1 STATE	TOTAL AGGREGATE PRODUCTION	ESTIMATED HIGHWAY CONSUMPTION	PERCENT CONSUMED BY HIGHWAYS
Connecticut	15.11	5.15	
Delaware	1.57	1.14	
District of Columbia	N.A.	2.25	
Maine	12.97 + W	6.49	
Maryland	28.97	12.48	
Massachusetts	26.07	12.00	
New Hampshire	6.53 + W	3.64	
New Jersey	31.85	12.47	
New York	73.16	35.00	
Pennsylvania	84.74	38.60	
Rhode Island	2.39 + W	1.64	
Vermont	6.56	4.81	
	289.92	135.67	46.8%

AASHTO REGION 2 STATE	TOTAL AGGREGATE PRODUCTION	ESTIMATED HIGHWAY CONSUMPTION	PERCENT CONSUMED BY HIGHWAYS
Alabama	26.61	13.20	
Arkansas	28.58	11.90	
Florida	55.57	24.60	
Georgia	30.31	16.16	
Kentucky	38,07	9.25	
Louisiana	27.22	19.80	
Mississippi	10.86 + W	6.69	
North Carolina	42.63	11.70	
South Carolina	15.57	6.80	
Tennessee	42.09	27.50	
Virginia	46.55	19.20	
West Virginia	14.16	7.95	
	378.22	174.75	46.2%

TABLE A-4 (Continued)

AASHTO REGION 3 STATE	TOTAL AGGREGATE PRODUCTION	ESTIMATED HIGHWAY CONSUMPTION	PERCENT CONSUMED BY HIGHWAYS
Illinois	99.31	37.90	
Indiana	49.30	23.60	
Iowa	46.37	15.82	
Kansas	27.63	9.35	
Michigan	94.78	31.30	
Minnesota	51.43	31.50	
Missouri	52.18	17.10	
Nebraska	16.50	11.62	
North Dakota	8.19	6.43	
Ohio	89.31	35.70	
Oklahoma	23.86	11.25	
South Dakota	18.54	8.00	
Wisconsin	58.60	29.50	
	636.00	269.37	42.3%

AASHTO REGION 4 STATE	TOTAL AGGREGATE PRODUCTION	ESTIMATED HIGHWAY CONSUMPTION	PERCENT CONSUMED BY HIGHWAYS
Arizona	21.33	18.10	
California	186.66	98.30	
Colorado	25.81	17.00	
Idaho	16.69	7.35	
Montana	25.78	14.95	
Nevada	10.43	5.17	
New Mexico	13.77	7.75	
Oregon	30.97	14.00	
Texas	77.00	47.70	
Utah	13.66	6.10	
Washington	38.79	19.80	
Wyoming	10.72	7.50	
	471.61	263.72	55.8%
TOTAL	1775.75	843.51	47.5%

*Note: W = Information Withheld
NA = Information Not Available

TABLE A-5

PERCENTAGE OF TOTAL 1970 AGGREGATE PRODUCTION AND HIGHWAY CONSUMPTION BY AASHTO REGION

REGION	AGGREGATE PRODUCTION Million Tons	Percentage	HIGHWAY CONSUMPTION Million Tons	Percentage
1	289.92	16.4	135.67	16.1
2	378.22	21.2	174.75	20.7
3	636.00	35.8	269.37	32.0
4	471.61	26.6	263.72	31.2
TOTAL	1775.75	100.0	843.51	100.0

production and consumption figures. The following section of this Appendix discusses the nature of aggregate shortages and a determination of the locations of these shortages.

A.3 CURRENT SHORTAGES OF CONVENTIONAL AGGREGATES

When evaluating the problems caused by shortages of conventional aggregate supplies, several questions arise:

1. What is meant by an "aggregate shortage"?
2. Why are some areas experiencing shortages in aggregates?
3. Where are the areas of aggregate shortage?

The shortages noted in this study refer to a lack of locally available aggregate materials sufficient in quality and quantity to meet the normal requirements of a specific area for highway construction and maintenance purposes.

Several factors can aggravate or cause aggregate shortages:

1. Excessively high quality requirements.
2. Zoning restrictions combined with intensive land development, preventing utilization of aggregate resources.
3. Pollution control regulations that prevent the establishment of new pit and quarry operations, or the growth of existing operations.
4. Expense involved in hauling from distant production operations.
5. Seasonal fluctuations of highway construction compared to more stabilized demand for aggregates from the building construction industry.
6. Unique local conditions, such as frequent freezing and thawing, that create a demand for aggregates with special properties.

Areas beyond economical hauling distance from existing pits and quarries are experiencing shortages of high quality conventional aggregates. These include most urban areas.

A report by Witzcak, et al, (267) shows the locations of crushed stone quarries and sand and gravel pits in the United States. To delineate areas of potential aggregate shortages, forty miles was selected as the maximum economical truck hauling distance.

All areas located farther than forty miles from existing crushed stone quarries are shown in Figure A-1. All areas located farther than forty miles from existing sand and gravel pits are shown in Figure A-2. By superimposing areas deficient in both, a determination can be made of those areas located beyond an economical hauling distance from any supply of natual mineral aggregate. These locations are shown in Figure A-3. Figures A-1, A-2 and A-3 serve only to indicate those areas where the need for conventional aggregates would involve expensive hauling costs. Demand for sizable quantities of aggregates in these areas potentially could result in aggregate shortages.

Locations of synthetic lightweight plants are also shown in Figure A-3. At the present time, approximately 95% of all lightweight aggregate is used by the building construction industry and only 5% is being used for highway and other special uses (122). Aggregate materials with a dry unit weight or less than 55 pounds per cubic foot are considered as lightweight aggregates.

In order to verify locations where difficulties now exist

LEGEND OF MAP SYMBOLS

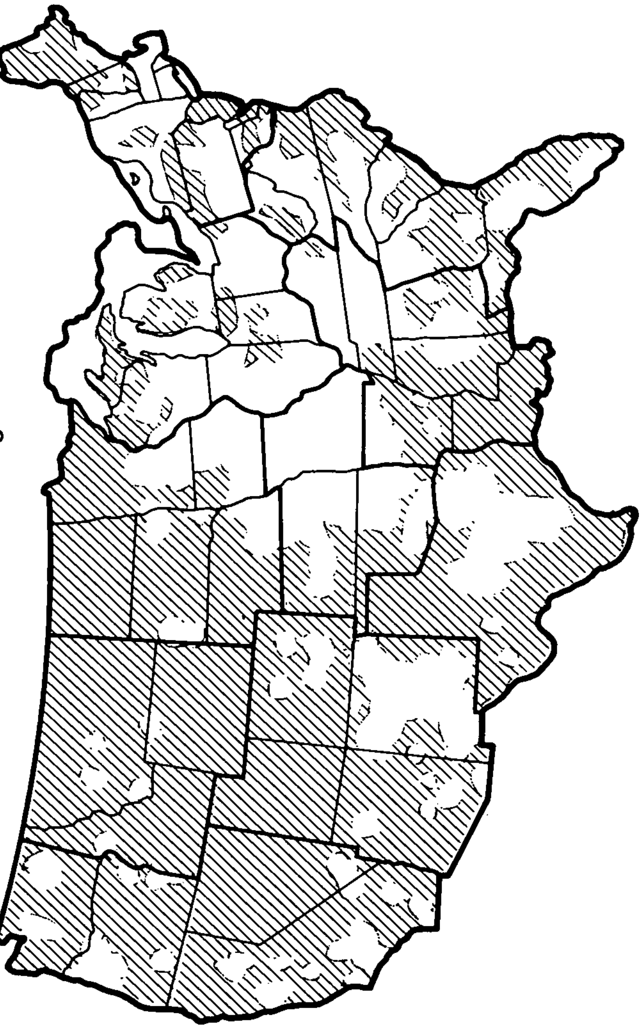
CONVENTIONAL AGGREGATES

POTENTIAL CRUSHED STONE SHORTAGE AREAS

POTENTIAL SAND AND GRAVEL SHORTAGE AREAS

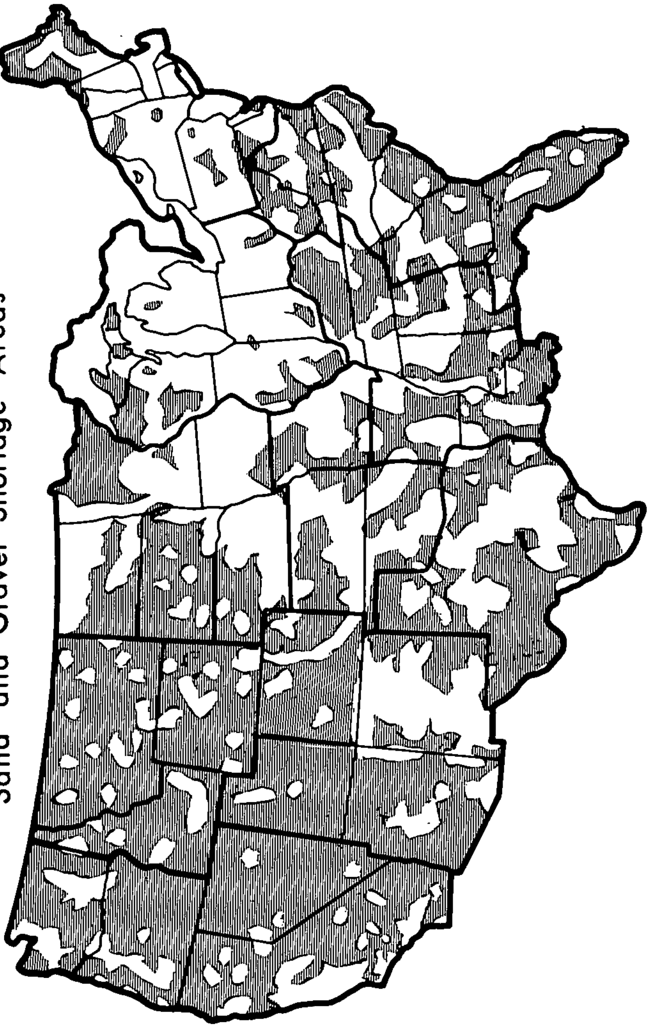
POTENTIAL CONVENTIONAL AGGREGATE SHORTAGE AREAS

STATE HIGHWAY REPORTED AGGREGATE SHORTAGE AREAS



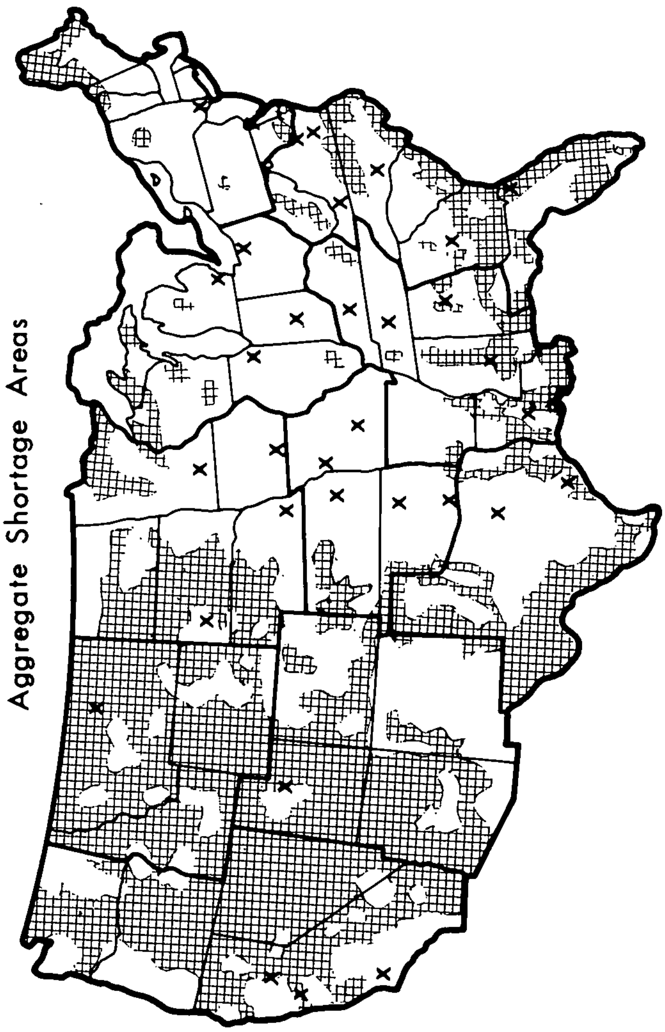
Crushed Stone Shortage Areas

Figure A-1



Sand and Gravel Shortage Areas

Figure A-2



Aggregate Shortage Areas

Figure A-3

in securing adequate supplies of conventional aggregates, a survey was made of all state highway materials engineers. Results of this survey are shown in Figure A-4, which indicates areas that were noted to be deficient in the supply of high quality natural aggregates. These results substantially agree with those of Witzcak, et.al. (267) and are the most accurate representation of where conventional aggregate shortages occur.

In addition to areas shown in the preceding maps, it is reasonable to assume that all major metropolitan areas are experiencing some shortages in aggregates whether or not these have been specifically mentioned by the state highway materials engineers. This, then, is the current status of the availability of conventional aggregates.

A.4 PROJECTED SHORTAGES OF CONVENTIONAL AGGREGATES

What are the prospects for future availability of conventional aggregates? The 1972 National Highway Needs Report projects a total identified highway construction cost for the twenty year period, 1970-1990, of $512 billion, an average of more than $25 billion a year (248). This is the amount of funding necessary to fulfill all needs for highway construction through 1990. These figures do not include necessary maintenance costs. Table A-6 indicates the percentage distribution of total identified construction costs over the twenty year period for each AASHTO Region.

Comparing these projections with 1970 highway construction expenditures of approximately $11 billion (247) indicates that, even with the completion of the Interstate Highway System, much work must be done in improving and extending our present highway

State Highway Departments
Reported Aggregate Shortage Areas

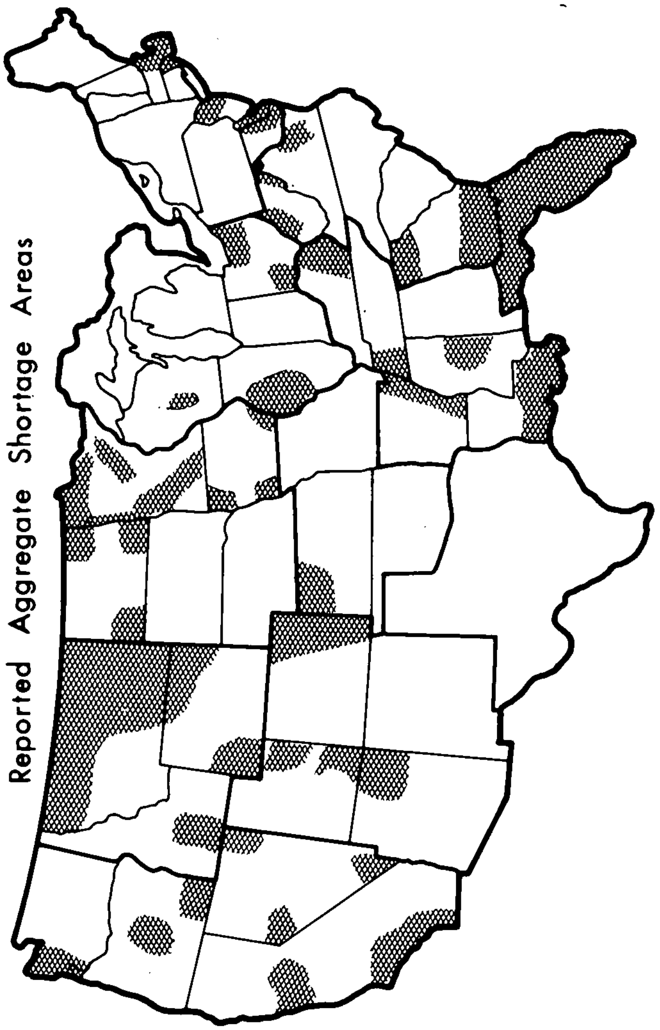


Figure A-4

TABLE A-6

PERCENTAGE OF TOTAL IDENTIFIED HIGHWAY CONSTRUCTION COSTS BY AASHTO REGION (1970 - 1990)

REGION	PERCENTAGE OF TOTAL COSTS
1	24.9
2	24.6
3	27.3
4	23.2
TOTAL	100.00

SOURCE: 1972 National Highways Needs Report, p. IV-11.

system in the future, not to mention the maintenance requirements for these facilities. Therefore, the need for aggregates in highways can be expected to increase rapidly especially in metropolitan areas where highway transportation needs are most pronounced.

CONCLUSIONS

Where will shortages of highway aggregates become most pronounced in the future? According to Table A-6, the projected expenditures for highway construction on the basis of needs will be evenly distributed over the next twenty years for all AASHTO Regions. Figures from Table A-5 show that highway consumption of aggregates is greatest in Regions 3 and 4. Comparison of projected construction cost percentages with current aggregate production and consumption percentages indicates that aggregate production for highways must show the greatest increase in Regions 1 and 2 to meet demands forcast on the basis of highway needs. How will increased highway aggregate demands be satisfied in the future?

1. Production of conventional aggregates will increase to meet demands in those areas where pit and quarry operations are feasible.

2. Longer transport distances will become more acceptable in certain areas, further increasing the construction costs for buildings and highways.

3. Use of synthetic aggregates manufactured from natural clays and shales may be used to a greater extent.

4. Specification requirements may be relaxed in areas experiencing pronounced aggregate shortages, permitting the beneficiation of existing lower grade materials for certain applications in highway work. Specification requirements in the future may be based to a greater extent upon performance.

5. Waste by-products may be more fully utilized in the manufacture of aggregates for use by the highway and building construction industries.

The response to the aggregate supply problem will develop over a period of time. These activities probably will occur at various times and in various ways in different parts of the country. It is even possible that in certain areas all will take place simultaneously.

It appears certain that the use of supplementary materials, such as synthetic aggregates produced from wastes, would help alleviate local shortages while providing some measure of relief for certain ecological problems.

APPENDIX B: INVENTORY OF WASTE RESOURCES

B.1 INTRODUCTION

One of the principal objectives of this study is to inventory types, sources, and quantities of waste materials potentially suitable for the production of synthetic aggregates as replacements for conventional aggregates in highway construction.

The following information is the result of personal contacts, correspondence and an investigation of available foreign and domestic literature. To facilitate further discussion, the waste materials under consideration have been grouped into more specific generic headings.

The absence of a specific waste from the applicable generic listing does not exclude the waste from further consideration as a replacement for highway aggregate. It indicates only that:

1. No reference was made to such a material in any of the literature under review.

2. No reference was made to such a material in any correspondence, personal contact, or project discussions.

3. The material was studied initially but, for reasons such as insufficient quantity, lack of continuous supply, or poor location, was considered to have very low potential.

B.2 CLASSIFICATION OF WASTE MATERIALS

The following classifications were developed for waste resources having potential use as highway aggregates:

1. INDUSTRIAL WASTES

a. Ceramics Industry

Brick Plant Rejects
Ceramic Tile Waste
Clay Pipe Waste
Pottery Waste

b. Chemical Processing Industry

Alumina Red and Brown Muds
Phosphate Slimes
Phosphogypsum
Sulfate and Sulfite Sludges

c. Electrical Power Industry

Fly Ash
Bottom Ash
Boiler Slag
Scrubber Sludge

d. Iron and Steel Industry

Iron Blast Furnace Slag
Steel Making Slags
Foundry Waste Products

2. MINERAL WASTES

Anthracite Coal Refuse
Bituminous Coal Refuse
Chrysotile or Asbestos Tailings
Copper Tailings
Dredge Spoil
Feldspar Tailings
Gold Mining Waste
Iron Ore Tailings
Lead Tailings
Nickel Tailings
Phosphate Slag
Slate Mining Waste
Taconite Tailings
Zinc Tailings
Zinc Smelter Waste

3. DOMESTIC WASTES

Building Rubble
Discarded Battery Casings
Incinerator Residue
Plastic Waste
Pyrolysis Residue
Reclaimed Paving Material
Rubber Tires
Sewage Sludge
Waste Glass

B.3 DESCRIPTION OF WASTE MATERIALS

Proper evaluation of the potential of a specific waste material requires a basic knowledge of the origin, physical state, chemical composition, location, and available quantities of the material. The following descriptions of waste types and sources are derived primarily from a review of cited literature, but are based in part upon visual inspection of waste material samples.

B.3.1 INDUSTRIAL WASTES

The amount of waste generated by American commercial and industrial sources has been estimated at 190 million tons annually.(209) Sources and quantities of industrial wastes are indicated in Table B-1. The geographical locations of wastes from the chemical processing industry are shown in Figure B-1. Electrical power industry wastes are located as shown in Figure B-2. Wastes resulting from the production of iron and steel are located as shown in Figure B-3.

a. CERAMICS INDUSTRY

The rejects, breakage, and waste by-products from

TABLE B-1

SOURCES AND QUANTITIES OF INDUSTRIAL WASTES
(Millions of Tons)

INDUSTRIAL WASTE	SOURCE LOCATION	ANNUAL PRODUCTION	ACCUMULATED QUANTITY
Ceramic Wastes	Clay brick, tile, pipe, and pottery plants	N.A.	N.A.
Alumina Red and Brown Muds	Alabama, Arkansas, Louisana, Texas	5-6	50
Phosphate Slimes	Florida, Tennessee	20	400
Phosphogypsum	Florida	5	N.A.
Sulfate and Sulfite Sludges	Chemical Plants Distributed Nationally	5-10	N.A.
Fly Ash	Coal Burning	32	200-300
Bottom Ash	Power Plants	10	50-100
Boiler Slag	located mainly in Appalachia and Great Lakes Region	5	25-50
Scrubber Sludge	Power Plants equipped with SO_2 Scrubbers	N.A.	N.A.
Iron Blast Furnace Slag,	Iron and Steel producers in	30	N.A.
Steel Making Slags,	Pennsylvania, Ohio,	10-15	N.A.
Foundry Waste Products	Illinois, Michigan and other states	20	N.A.

N.A. = Information Not Available

the manufacturers of brick, ceramic tile, clay pipe, and pottery, are found as coarse, angular particles of varying sizes, possessing a high degree of hardness. These wastes are chemically inert and are composed primarily of silicates tempered by extreme heating.

Locations of brick, ceramic tile, clay pipe, and pottery manufacturing plants are generally distributed nationally. Most manufacturing plants have dumping areas which may contain accumulations of these materials.(139) The quantities of these wastes are not large enough to consider for extensive aggregate use.*

b. CHEMICAL PROCESSING INDUSTRY

Alumina Red and Brown Muds

These wastes are clay-like residues obtained by the extraction of aluminum from bauxite ores. Most bauxite ore used in the United States is imported from Caribbean deposits in the Dominican Republic, Jamaiça, Haiti, Guinea, and Surinam. Domestic bauxite ores are mined in Arkansas. Alumina processing is performed at seven plants located in Alabama, Arkansas, Louisiana, and Texas.

The Bayer process, which is most widely used, yields the so-called "red muds". A combination of the Bayer-sinter process results in "brown muds". These red and brown muds

* Dr. William H. Bauer, Rutgers University - Private Communication.

are issued from alumina recovery plants as slurries containing 20 to 25 percent colloidal solids. When stored over long periods in settling ponds, these slurries will eventually become a dry residue.

The muds themselves are a complex compound of soda, alumina, silica, and water, with iron oxide as the predominant crystallized constituent.(191) Table B-2 indicates the chemical analysis of a typical sample of the residue from Jamaican red mud,(252) and a comparison with the residue from domestic red and brown muds.(191)

Between 5 and 6 million tons of these wastes are produced each year from aluminum processing plants, with red muds comprising 90 percent of the total. Although no information is available regarding accumulations, an estimate of 50 million tons of these wastes is probably realistic.

These waste residues are found in the Gulf Coast Region with the largest concentrations located in Louisiana, Texas, and Arkansas, as shown in Figure B-1. Alumina red and brown muds are concentrated in large holding ponds at specific processing locations. One of the major problems associated with these wastes is the dusting of the dried residues.(252)

Phosphate Slimes

In the production of rock phosphate, the matrix (consisting of one-third phosphate, one-third sand, and one-third clay) is washed with large volumes of fresh water. The

TABLE B-2

REPRESENTATIVE CHEMICAL ANALYSIS FOR ALUMINA RED AND BROWN MUDS

CONSTITUENT	JAMAICAN RED MUD	DOMESTIC RED MUD	DOMESTIC BROWN MUD
Al_2O_3	20.0	26.5	6.4
Fe_2O_3	49.0	10.7	6.1
SiO_2	3.4	22.9	23.3
CaO	6.8	8.1	46.6
Na_2O	2.0	11.8	4.1
TiO_2	4.5	3.3	3.0
SO_3	Trace	2.8	0.5
P_2O_5	0.8	-	-
L.O.I.	13.1	12.9	7.3

SOURCES: Reference No. 169, p. 249.
Reference No. 252, p. 9.

LEGEND OF MAP SYMBOLS

INDUSTRIAL WASTES

ALUMINA RED AND BROWN MUDS

PHOSPHATE SLIMES

SULFATE AND SCRUBBER SLUDGES

FLY ASH, BOTTOM ASH, AND BOILER SLAG

BLAST FURNACE AND STEEL SLAG

FOUNDRY WASTES

resultant wash-water carries the clay content of the original matrix in colloidal suspension and is known as phosphate slime. Slimes are discharged from processing plants into holding ponds at 3 to 5 percent solids. After many years of settling, the slimes thicken to between 25 to 30 percent solids.

Although compositions of slimes from different processing plants will vary somewhat, these wastes are composed principally of oxides of silicon, calcium, aluminum and phosphorous.(254) A typical chemical composition of phosphate slimes is shown in Table B-3.(48) The color of these slimes varies from light gray to reddish brown.(227) More than 70 percent of the mineral matter is less than 1 micron in size.(23)

The principal phosphate producing area in the United States is in central Florida, where nearly 80 percent of the nation's phosphate is mined and processed. Substantial quantities are also produced in Tennessee. Nearly 2 billion tons of phosphate slimes, with a solids content of nearly 20 percent, are estimated to have accumulated as a result of 40 years of phosphate production (254). The total amount of phosphate slime produced annually is indefinite at this time. Figure B-1 also shows the locations of major phosphate processing plants.

The ponding of these slimes poses several potential hazards to the environment. First, the holding dams sometimes break, inundating surrounding areas with the phosphate slimes

Chemical Industry Wastes

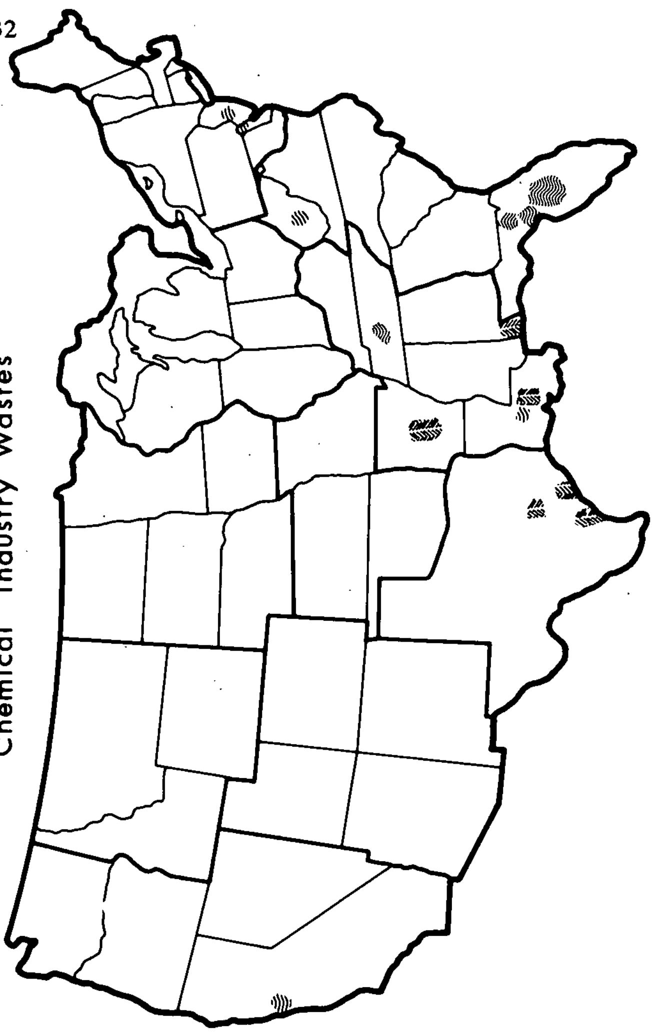


Figure B-1

TABLE B-3

TYPICAL CHEMICAL COMPOSITION
OF PHOSPHATE SLIMES

CONSTITUENT	TYPICAL ANALYSIS	RANGE
P_2O_5	9.06%	9-17%
SiO_2	45.86%	31-46%
Fe_2O_3	3.98%	7-7%
Al_2O_3	8.51%	6-18%
CaO	13.95%	14-23%
MgO	1.13%	1-2%
CO_2	0.8%	Trace - 1%
F	0.87	Trace - 1%
L.O.I.-1000 C	10.6%	9-16%

SOURCE: Reference No. 48, p. 59.

and polluting nearby streams. There is also the danger of seepage from slime ponds infiltrating existing groundwater supplies, causing possible pollution of water used for human consumption and recreational purposes.(254)

Phosphogypsum

Another waste material resulting from the chemical processing of phosphate is phosphogypsum, which results from the combination of phosphate rock with sulfuric acid in the production of chemical fertilizer. Unlike the gypsum used to make building products, which have flat-sided crystals, the phosphate gypsum is jagged and rough. It is highly acid and is disposed of in "gyp ponds" where it is de-watered. Neutralization of waters from these ponds is quite expensive.

These gypsum wastes have a grayish color due to the presence of small amounts of carbon.(48) Available information indicates that 5 million tons of gypsum waste are produced annually from the manufacture of phosphoric acid.*

Sulfate and Sulfite Sludges

Inorganic waste sludges from a variety of industrial processes are being produced by the chemical industry. One of the principal sources is the production of hydrofluoric acid from fluorospar and sulfuric acid. The resultant sludge waste is in the form of anhydrous calcium sulfate, which, after a period of exposure to water, will convert to calcium sulfate dihydrate.

* Mr. Charles L. Smith - I. U. Conversion System - Private Communication.

The total amount of sulfate sludge waste generated by the chemical industry is between 5 and 10 million tons per year, generally distributed across the country.*

c. ELECTRICAL POWER INDUSTRY

Ash wastes are derived from the combustion of coal in industrial and power boilers. These wastes are produced mainly by the electrical power generating industry.

The burning of pulverized coal is the principal source for generation of electrical power in the United States. More than 90 percent of the coal used annually by the electrical utility industry is burned in power plants east of the Mississippi River.(72)

There are two types of wastes which result from the burning of pulverized coal at electrical power plants. One is ash waste, consisting of fly ash, bottom ash, and boiler slag. The other is a sludge waste, resulting from the removal of SO_2 flue gas particles.

Fly Ash

Fly ash is the fine particulate matter precipitated from the stacks of pulverized coal-fired boilers at electrical power generating stations. It represents nearly 75 percent of all ash wastes generated in this country. Several factors directly affecting the quality of fly ash are the type of coal used, the ash content of the coal, the degree to which the coal

* Mr. Brian Cooper - I.U. Conversion Systems - Private Communication.

has been pulverized prior to combustion, and the type of ash collectors used. Because of the many variables inherent in its production and collection, fly ash exhibits a wide range of physical and chemical properties, even at the same source of production. The particle size, particle shape, density, color, and chemical composition of fly ash can and do vary widely.(24)

The particle size of fly ash ranges from 1 to 50 microns in diameter. Practically all particles are finer than a 325 mesh sieve. The particles themselves are mainly composed of finely divided pieces of siliceous glass. The color of fly ash varies from tan to brown, depending on the mineral and carbon content of the pulverized coal. Table B-4 indicates the range of chemical content of fly ash.(72)

Approximately 27 million tons of fly ash were produced in 1970. Fly ash production has been increasing at a rapid rate. It was nearly 32 million tons in 1972. It is now projected that by 1980 the production of fly ash will exceed 40 million tons. Since World War II, an estimated 300 million tons of fly ash have been produced in the United States, and only about 3 percent of this has been utilized. At the present rate, an additional 300 million tons will have been produced by 1980. Although the rate of utilization of fly ash has improved, only 12 percent of this material is now being used each year. The remainder is disposed of in landfills or in piles.

TABLE B-4

RANGE OF CHEMICAL COMPOSITION OF FLY ASH

CONSTITUENT	PERCENTAGE
Silica (SiO_2)	40-50
Alumina (Al_2O_3)	5-35
Iron (Fe_2O_3)	5-40
Calcium (CaO)	1-15
Magnesium (MgO)	0.3-4
Sodium (Na_2O)	0.3-4
Sulfur (SO_3)	0.1-4

SOURCE: Reference No. 24, p. 3.

Probable accumulations are between 200 to 300 million tons of fly ash, found in the areas designated in Figure B-2. The Appalachian and Great Lakes regions are the principal fly ash producing areas.(248)

Bottom Ash

Another form of ash waste is produced in the generation of electrical power, and is termed "bottom ash". The type of boiler used determines the type of bottom ash. There are two basic types of boilers used, therefore, two basic types of bottom ash. Most of the boilers found in recent power plant installations are of the dry bottom variety. These boilers have an open grate at the base, below which is an ash hopper. As the pulverized coal is blown into the boiler and ignited, the heavy ash falls through the open grate and into the ash hopper. A certain amount of molten slag also finds its way into the ash hopper. The ash material collected in the hoppers is referred to as dry bottom ash.

Dry bottom ash is composed of fine angular particles which are gray to black in color and resemble fine sand. Some of the smaller particles have a glassy appearance and the surface of the ash particles is very porous. The grain sizes of dry bottom ash particles are in the size range of a fine gravel to a fine sand with nearly half of the grain sizes ranging from Ø4 to Ø40 sieve.(165) Typical range of chemical composition of bottom ash is given in Table B-5.(24)

TABLE B-5

RANGE OF CHEMICAL COMPOSITION OF BOTTOM ASH

CONSTITUENT	PERCENTAGE RANGE
Silica (SiO_2)	20-60
Alumina (Al_2O_3)	10-35
Ferric Oxide (Fe_2O_3)	5-35
Calcium Oxide (CaO)	1-20
Magnesium Oxide (MgO)	0.3-4
Sodium Oxide (Na_2O)	1-4
Potassium Oxide (K_2O)	1-4
Sulfur Trioxide (SO_3)	0.1-12

SOURCE: Reference No. 164, p. 27.

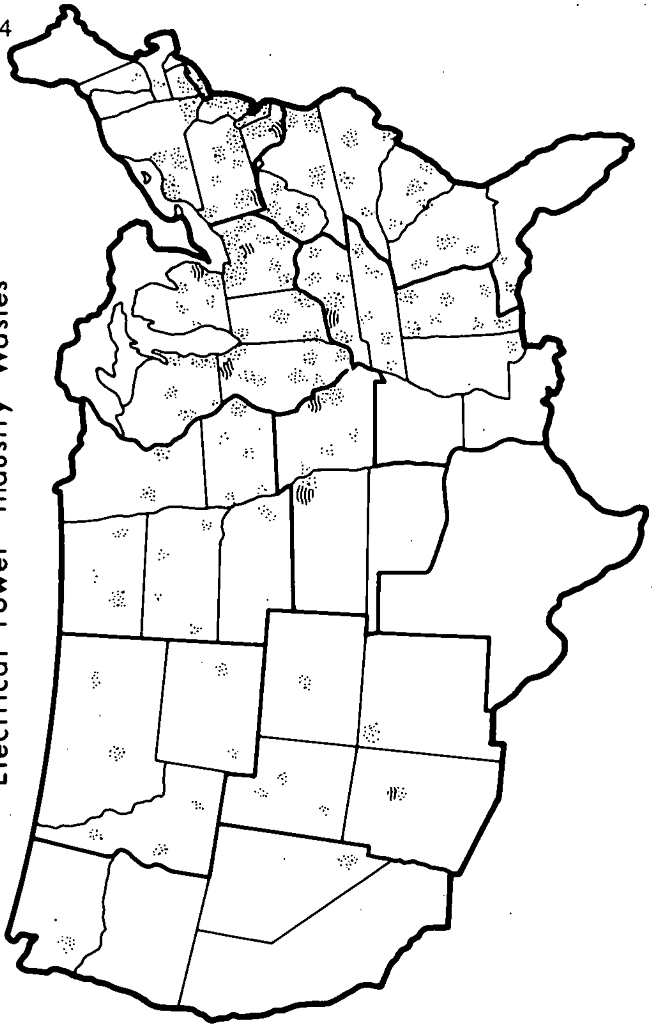


Figure B-2

The total production of bottom ash in 1972 exceeded 10 million tons. Probably about half of this total was dry bottom ash, produced in the same areas as fly ash and shown in Figure B-2. Normally, dry bottom boilers produce 80 percent fly ash and 20 percent bottom ash.

The other type of bottom ash is wet bottom ash or boiler slag and is discussed in the following section.

Boiler Slag

The second basic type of coal-fired boiler used in the utility industry is the wet bottom or slag tap boiler. There are two varieties of this type of boiler. One variety burns pulverized coals and the other burns crushed coals. Those burning crushed coals are called cyclone boilers. Both of these boiler varieties have an orifice in the base which can be opened to permit molten ash to flow into a water-filled ash hopper. The molten ash quenches in the water, crystallizes, solidifies, and forms angular, black, glassy particles, usually ranging from ¼ to ½ inch in size. This wet bottom ash is known as boiler slag, or "black beauty". Boiler slag is composed principally of fused silica, iron, and aluminum oxides. Typical chemical composition of boiler slag is shown in Table B-6.(163)

Production of boiler slag totalled almost 5 million tons in 1972. However, this figure represents only that portion of the boiler slag which was separated from dry bottom ash. In a wet bottom boiler, the boiler slag amounts to 40 percent

TABLE B-6

TYPICAL CHEMICAL COMPOSITION OF BOILER SLAG

CONSTITUENT	PERCENTAGE
Silica (SiO_2)	42.7
Ferric Oxide (Fe_2O_3)	27.5
Alumina (Al_2O_3)	21.0
Calcium Oxide (CaO)	6.4
Magnesium Oxide (MgO)	1.1
Sulfur Trioxide (SO_3)	0.2
Titanium Oxide (TiO_2)	0.9

SOURCE: Reference No. 163, pp. 1-2.

of the total ash produced, while in a cyclone boiler, the boiler slag amounts to 80 percent of the total ash produced. Over all, it is estimated that approximately 25 percent of all ash produced in electrical power plants is boiler slag.(163)

Production of boiler slag occurs throughout the entire fly ash producing region, but the most significant quantities are located in Ohio, West Virginia, and Pennsylvania.

Scrubber Sludge

Although fly ash particles are removed from power plant emissions, the discharge of sulfur into the air in the form of sulfur dioxide is unaffected by fly ash removal systems. Restrictions on the amount of sulfur dioxide have resulted in the development of several varieties of power station scrubbing systems now being used in pilot programs. The most practical and efficient of these SO_2 removal processes involve scrubbing with lime or limestone. Scrubbing systems are expected to be installed in existing and new generating stations within the next five years. This will mean a dramatic increase in the amount of sludge wastes to be disposed of by the utilities.

Sludge wastes from scrubbing processes will vary chemically, depending on the type of fuel burned, boiler operating conditions, and the amount of lime or limestone used. Typical power plant scrubber sludges are gray in color and composed of CaO, CO_2, SO_2, and sulfur.(214) Figure B-2 shows locations of power plants presently outfitted with scrubbing equipment which produces these sludge wastes.

d. IRON AND STEEL INDUSTRY

Iron Blast Furnace Slag

To produce pig iron in the blast furnace, iron ore, coke, and limestone are heated to 2700° F. Produced simultaneously with pig iron in the blast furnace is a material known as blast furnace slag. It has been defined as "the non-metallic by-product consisting essentially of silicates and aluminosilicates of lime and other bases", and it comes from the blast furnace resembling molten lava.(107)

There are three general types of blast furnace slag: air-cooled, granulated, and lightweight. They are characterized by differences in the method of cooling the molten slag. Air-cooled slag is allowed to cool in pits adjacent to the furnaces. Granulated slag is cooled by sudden immersion in water. Lightweight slag is the foamed product which is formed when molten slag is expanded by application of a limited quantity of water, less than that required for granulation. Air-cooled blast furnace slag currently comprises approximately 80 percent of all blast furnace slag and is of principal interest.(107)

Blast furnace slag contains oxides of silica, alumina, lime, and magnesia, along with other minor elements. Exact composition varies from furnace to furnace within well-defined limits, since the raw materials charged into the furnaces are carefully selected and blended for quality and uniformity. The normal

range of chemical composition for iron blast furnace slag is shown in Table B-7.(107)

Notable physical properties of air-cooled blast furnace slag are:

a. Angular shape with a minimum of flat or elongated particles.
b. Unit weight of 70 to 85 pounds per cubic foot.
c. Gradation meeting requirements of various state highway departments.
d. High durability and resistance to the effects of freezing and thawing or wetting and drying.
e. Hardness of particles.
f. Resistance to abrasion.
g. Non-corrosive effect on reinforcing steel.

The above properties are extremely important in order to obtain proper performance as an aggregate.(175)

Production of iron blast furnace slag has stabilized over recent years at 30 million tons per year, with output concentrated in the principal steel-producing regions of the country. Figure B-3 shows locations of blast furnace activity. The leading slag producing states are Pennsylvania, Ohio, Illinois, Indiana, and Michigan.(221)

Although no estimates were found of the total slag accumulations, extensive uses for blast furnace slag over the past thirty years have probably reduced the amount of this material contained in slag heaps.(66) Nevertheless, many iron

TABLE B-7

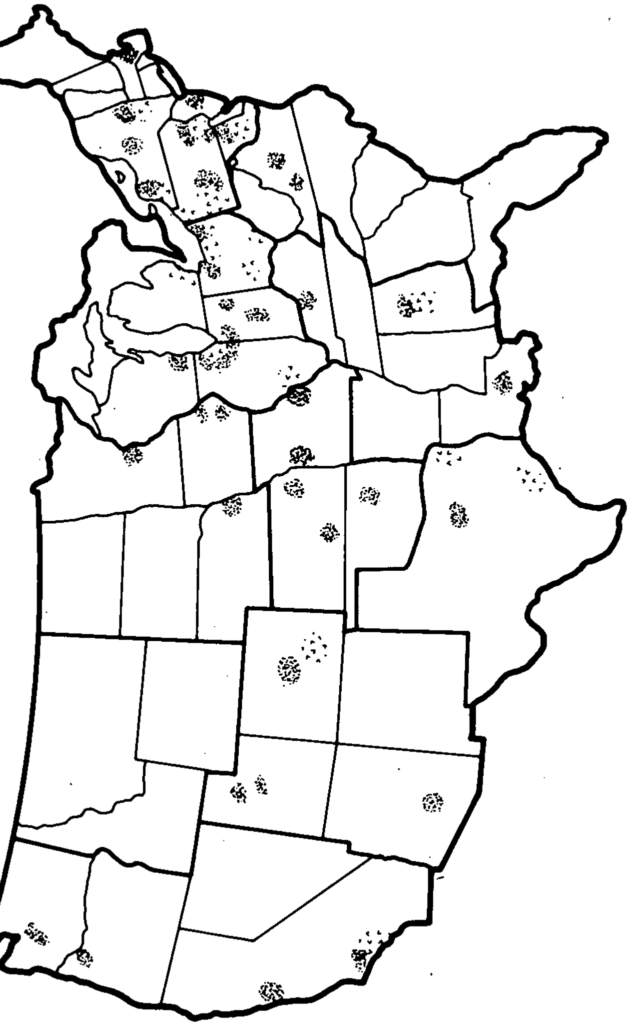
CHEMICAL ANALYSIS OF TYPICAL IRON BLAST FURNACE SLAG

CONSTITUENT	PERCENTAGE
Silica (SiO_2)	33-42
Alumina (Al_2O_3)	10-16
Lime (CaO)	36-45
Magnesia (MgO)	3-16
Sulfur (S)*	1-3
Iron Oxide (FeO)	0.3-2
Manganese Oxide (MnO)	0.2-15

*Principally in the form of Calcium Sulfide

SOURCE: Reference No. 107, p. 54.

36



Iron and Steel Wastes

Figure B-3

and steel mill locations will still have large stockpiles of iron blast furnace slag.

Steel Making Slags

Production of steel involves a process somewhat different from that of the iron blast furnace. In the blast furnace, the reduction of iron ore to pig iron is a continuous operation resulting in the production of a reasonably uniform slag by-product. In steel production, the reactions are not always completed, because the operation is a batch process, which produces a non-uniform slag material.(109)

Steel slag is formed as the lime flux reacts with molten iron ore, scrap metal, or other ingredients charged into the steel furnace at melting temperatures around 2800° F. During this process, part of the liquid metal becomes entrapped in the slag. The molten slag flows from the furnace into the pit area where it solidifies, after which it is transferred to cooling ponds. Metallics are removed by magnetic separation.(86)

The chemical compositions of steel slags are variable and unpredictable. Most steel making slags contain a substantial amount of unslaked lime (CaO), and magnesium oxide (MgO). The type of furnace and type of steel produced have an effect upon the composition of steel slag, although steel slags from all processes are basically similar.

The most often used furnace process at this time is the basic oxygen furnace. It is used in 60 percent of all steel

mills and has replaced many open hearth furnaces. The electric furnace is used in only 10 to 12 percent of all steel mills. The processes are different as far as the relative amounts of iron ore and scrap used. The basic oxygen furnace uses a 30 percent scrap charge with the other 70 percent being pig iron. The open hearth furnace, which produced over 90 percent of all steel until ten years ago, uses a 40 percent to 60 percent scrap to pig iron ratio. Electric furnaces rely almost totally on scrap for their charge.

The chemical analysis of typical open-hearth slag produced at Coatesville, Pennsylvania, is shown in Table B-8. It should be noted that these constituents are not normally pure compounds but solid solutions of two or more compounds, one of which predominates. Generally, there is a lack of chemical uniformity in an open hearth (steel) slag bank, due to the variations in grade of steel being produced.(109)

Steel slags have a high density and are very abrasive. Steel slags are denser and stronger than blast furnace slags, having a unit weight of from 115 to 125 pounds per cubic foot. One of the most objectionable properties of steel-making slags is its expansive character, caused by the amounts of free lime and magnesium oxide contained in the slag. The unslaked lime (CaO) hydrates rapidly and causes large volume expansion to occur within a period of a few weeks, but the magnesium oxide (MgO) hydrates much more slowly, causing volume changes that may continue for many years. Consequently, a long period of

TABLE B-8

CHEMICAL ANALYSIS OF A TYPICAL
OPEN HEARTH SLAG PRODUCED AT COATESVILLE, PA.

CONSTITUENT	PERCENTAGE
Silicon dioxide (SiO_2)	18.02
Insolvble Silicates	6.42
Iron Oxide (Fe_2O_3)	17.46
Aluminum Oxide (Al_2O_3)	8.54
Calcium Oxide (CaO)	36.17
Magnesium Oxide (MgO)	9.96
Undetermined	3.43

SOURCE: Reference No. 109, p. 5.

time is required for the complete hydration and expansion of steel slag.(109)

Estimated annual production of steel slag is somewhere between 10 and 15 million tons, concentrated in the same areas of activity as blast furnace slag. Locations are shown in Figure B-3. Since steel slag utilization has recently been averaging between 8 and 10 million tons per year, accumulations are still increasing. Although no reliable figures on accumulations are available at this time, many large slag dumps are known to exist in Western Pennsylvania and Ohio, as well as other steel-producing states. Increasing attempts by steel companies to recycle steel slag into blast furnaces may cause steel slag to become somewhat less available from future steel production.

Foundry Waste Products

There are several types of wastes resulting from iron foundry operations. Those potentially suitable for highway utilization are arc furnace dust, sand reclaimer residue, and furnace dust.

Arc furnace dust is a very fine black powder composed of iron and silica oxides. Wet or dry sand reclaimer residue occurs as a fine dark brown powder and is essentially siliceous with some alumina and carbon. Furnace dust is very similar to arc furnace dust chemically, but it has a rust brown color.

Other foundry waste by-products are cupola dust and shot blast waste, neither of which shows great potential for highway aggregate use.(91) However, these wastes could be considered as components of highway base course mixtures.

Table B-9 indicates approximate chemical composition of principal foundry wastes described above. Major constituents and trace elements have been indicated.(4)

Arc furnace dust, sand reclaimer residue, and furnace dust all consist of very small particles. More than 95 percent of all particle sizes from these waste products are less than 44 microns in size. However, all of these dusts are capable of being pelletized and fired into aggregates with acceptable crushing strength.

Most recently available statistics on annual production of foundry sand and melting dusts are from 1964. At that time, nearly 20 million tons of foundry wastes were produced.(251) Since 1964, several factors have combined to alter foundry productivity:

1. A decided increase in casting tonnage.
2. Increased use of sand reclamation systems which reduce disposal.
3. Intensified collection of all melting effluents, causing an increase in solid wastes.
4. Replacement of cupolas by electric melting furnaces, resulting in less effluent.
5. Closing of more than 500 of the smaller foundry locations over the past five years.*

* Mr. Mervin T. Rowley, American Foundrymen's Association - Private Communication.

TABLE B-9

CHEMICAL COMPOSITION OF VARIOUS FOUNDRY WASTE PRODUCTS

(Percent)

COMPOSITION	FURNACE DUST	SAND RECLAIMER DUST	ARC FURNACE DUST
Major Constituents			
SiO_2	30.60	66.46	35.00
Fe_2O_3	54.82	3.09	38.26
Al_2O_3		16.02	1.65
Cr_2O_3	0.54		
MoO_2	0.94		
ZnO	1.07		
Total Carbon		7.13	0.65
Sulfur		0.18	0.10
L.O.I.	0.32	16.18	
Trace Elements			
Chromium		0.1-1.0	
Copper	0.1-1.0	0.1-1.0	0.5-5.0
Lead			0.5-5.0
Magnesium		0.1-1.0	
Manganese	0.1-1.0	0.1-1.0	
Molybdenum			0.5-5.0
Nickel	0.1-1.0	0.1-1.0	0.5-5.0
Sodium	0.1-1.0		
Tin			0.1-1.0
Zinc			1.0-10.0

SOURCE: Reference No. 4, pp. 4, and 6.

In all probability, the net effect of these factors has been a small increase in the annual generation of foundry wastes. No accumulation figures are available. Locations of major centers of foundry activity are shown in Figure B-3. Principal production is concentrated in Michigan, Pennsylvania, Ohio, Alabama, and Illinois.(251)

B.3.2 MINERAL WASTES

The mineral industries of the United States produce more than 1.6 billion tons of ores and fuel each year. In the process, approximately 1.1 billion tons of solid waste are generated annually by these industries. The growth of the mineral industry is such that it is estimated that by 1980 the wastes from mineral processing will increase to 2 billion tons per year. Mining of lower grade ores will cause the amount of tailings to continue to increase.

The total accumulation of solid mineral wastes in this country is probably well in excess of 25 billion tons, and is constantly growing. Most of the mineral wastes deposited prior to World War II are considered to be no longer discernable, and are not included in the estimated accumulation figures.

These wastes are deposited in the form of mine wastes, mill tailings, washing plant rejects, processing plant wastes, and smelter slag and rejects. Excluded from consideration is the overburden from surface mining operations, which is not really a waste material.

Mine waste is the unsorted material which is removed along with the ore. Mill tailings are the wastes from the first processing of the ore. Washing plant rejects and processing plant wastes are self-descriptive. Smelter slags and rejects are the leftover result of smelting and refining processes.(256)

Mine waste falls into two general classifications: coarse (material which is 1 mm or larger in size) and fine. The manner of disposal of the two differs. For coarse material, the normal procedure is to stockpile the material in ridge-shaped banks. Fine material is usually sluiced into settling ponds in the form of a slurry. After the water has drained off, the dry material is stored for possible later use.(237)

Practically every branch of the mining industry generates some form of solid waste, although its quantity, physical state and chemical composition may vary widely. The following is a description of the principal industry sources of mineral waste having some potential for development as replacements for highway aggregates. Locations of principal mineral waste accumulations are shown in Figure B-4 and summarized in Table B-10.

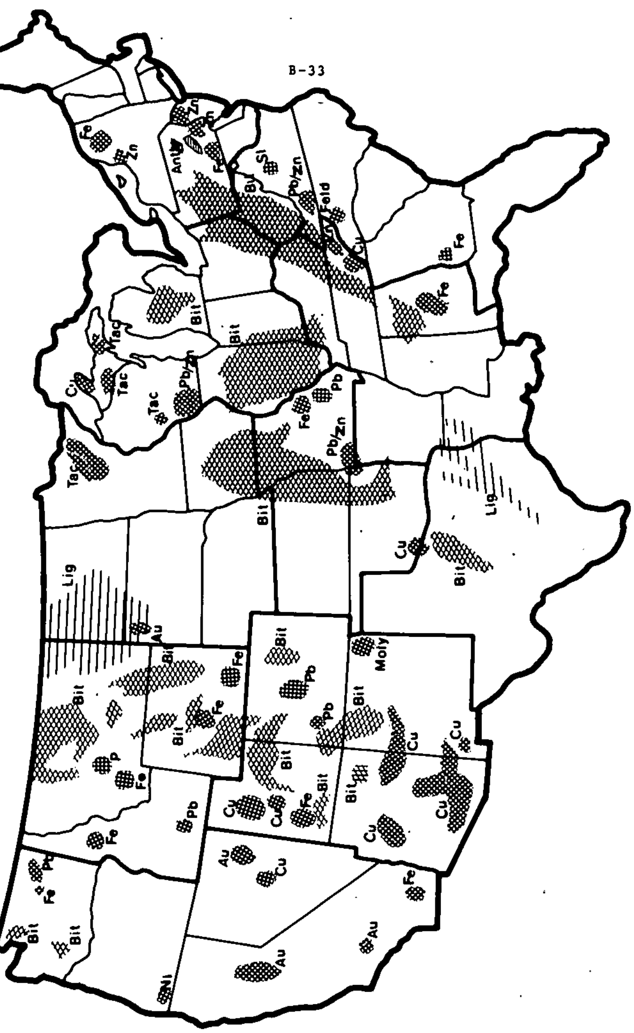
Anthracite Coal Refuse

The principal source of anthracite coal is in a region occupying 480 square miles in the northeastern portion of Pennsylvania. Total anthracite coal production has dramatically declined during the past fifty years from a peak production of 100 million tons per year to a current production of

LEGEND OF MAP SYMBOLS

MINERAL WASTES

- Anth — ANTHRACITE COAL WASTE
- Bit — BITUMINOUS COAL WASTE
- Lig — LIGNITE COAL WASTE
- Cu — COPPER TAILINGS
- Feld — FELDSPAR TAILINGS
- Au — GOLD MINING WASTE
- Fe — IRON ORE TAILINGS
- Pb — LEAD TAILINGS
- Moly — MOLYBDENUM TAILINGS
- Ni — NICKEL TAILINGS
- P — PHOSPHATE SLAG
- Sl — SLATE MINING WASTE
- Tac — TACONITE TAILINGS
- Zn — ZINC TAILINGS AND SMELTER WASTE



Mineral Wastes

Figure B-4

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TABLE B-10

SOURCES AND QUANTITIES OF MINERAL WASTES
(Millions of Tons)

MINERAL WASTE	SOURCE LOCATION	ANNUAL PRODUCTION	ACCUMULATED QUANTITY
Anthracite Coal Refuse	Northeastern, Pa.	10	1,000
Bituminous Coal Refuse *	Appalachian Reg. mainly in Pa.,W.Va., Ky.,Ohio, Ind., & Ill.	100	2,000
Chrysotile or Asbestos Tailings	California, Vermont and Arizona	1	10
Copper Tailings**	Ariz.,Utah.,N.Mex.& Michigan	200	8,000
Dredge Spoil	Seacoasts, harbors, & navigable inland wtrwys.	300-400	N.A.
Feldspar Tailings	North Carolina	0.25-0.50	5
Gold Mining Waste***	Calif., S.Dak., Nev., Utah & Arizona	5-10	100
Iron Ore Tailings	Alabama, New York, Pa.	20-25	800
Lead Tailings	Missouri, Idaho, Utah Colorado	10-20	200
Nickel Tailings	Oregon	N.A.	N.A.
Phosphate Slag	Idaho, Montana, Wyoming, & Utah	4	N.A.
Slate Mining Waste	New Eng., N.Y., Pa., Maryland & Virginia	N.A.	N.A.
Taconite Tailings	Minnesota & Michigan.	150-200	4,000
Zinc Tailings	Tennessee	10-20	200
Zinc Smelter Waste	Oklahoma	N.A.	N.A.

* Lignite coal is produced mainly in North Dakota and in Texas.
** Includes approximately 5 million tons of reverberatory slag.
*** Includes only those wastes from dredge mining operations.
N.A. = Information not available.

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10 million tons per year,(236) but the legacy of the years when the anthracite mines were at peak production remains in the form of unsightly culm banks. According to a survey conducted by the U. S. Bureau of Mines, there are 863 culm banks in the Pennsylvania anthracite region. These banks contain over 910 million cubic yards of material. At least 27 of these culm banks are burning, causing pollution of the air in the surrounding vicinity,(129) and over 70 percent of these waste piles are located within 2 miles of principal areas of population. Many are actually located within heavily populated areas. Decreased production of anthracite coal still generates over one million tons of refuse annually.(256)

Anthracite coal refuse is composed of unprocessed mine refuse and processed coal breaker refuse. In the coal breaker, deleterious material is separated from the coal by a sink-float process. The coal breaker refuse is further subdivided into coarse and fine refuse. The fine refuse is composed of rock, slate, and "bone" (a high ash, medium carbon material) with a small percentage of coal which has a wide range of sizes. Coarse breaker refuse has a similar composition with 5 percent or less coal content. At most, all of the sizes are smaller than "egg size", which is probably about 2 inches. Fine refuse or silt is composed of smaller sizes of the raw material. This refuse is carried in suspension in the waste water from the processing plant to a collecting pond where the solids will settle.(130)

Anthracite refuse is a gray slate-like material containing oxides of silicon, aluminum, iron, calcium, titanium, magnesium, sodium, and potassium. It also contains various amounts of carbon and pyrites. The carbon present in the refuse piles can lead to spontaneous combustion and result in the spewing of obnoxious, polluting gases into the air. Because of possible amounts of coal in some culm banks, many refuse piles, once ignited, may continue to burn for years at a time. The mineral pyrites, through oxidation and leaching, create an acid effluent responsible for pollution of adjacent streams and rivers. Incinerated anthracite refuse, termed "red dog", has a reddish, instead of a gray, appearance.

The "average" anthracite refuse would analyze as 6.5% ash. "Average" refuse is defined by averaging available analyses for anthracite refuse and ash. Table B-11 shows the analysis of the "average" anthracite refuse.(228)

More than 50 percent of "average" anthracite refuse is greater than one inch in size. Crushing and screening of this material is the minimum processing necessary for use of incinerated anthracite refuse in highways.

Bituminous Coal Refuse

Figure B-4 indicates various coal mining regions in the United States. Bituminous coal is produced primarily in Appalachia, with Kentucky, West Virginia, and Pennsylvania being the leading States. Annual production of bituminous and subbituminous coal exceeds 600 million tons, resulting in approx-

TABLE B-11

CHEMICAL ANALYSIS OF "AVERAGE" ANTHRACITE REFUSE

CONSTITUENT	PERCENTAGE RANGE
Silica (SiO_2)	50-57
Alumina (Al_2O_3)	30-37
Ferric Oxide (Fe_2O_3)	3-10
Titanium Dioxide (TiO_2)	1-2
Calcium Oxide (CaO)	1-2
Magnesium Oxide (MgO)	0-1
Potassium & Sodium (K_2O+Na_2O)	1-3
Sulfate (SO_3)	0-1

SOURCE: Reference No. 228, p. 197.

imately 100 million tons of refuse annually. Lignite coal production is an additional 6 million tons annually, mainly in North Dakota. Estimated accumulations of bituminous and lignite coal refuse since World War II are nearly 2 billion tons. This refuse is mainly evident in the form of "gob" piles, although there are numerous settling ponds containing fine waste material.

Although a list of coal waste banks has been published by the U. S. Bureau of Mines, there is no readily available information relative to precise amounts of refuse material to be found in each state. This would be directly related to coal production.

Bituminous coal refuse is a dark gray, shale-like material, somewhat similar in appearance to anthracite refuse. Refuse from different sources can vary widely in chemical composition.(167) Table B-12 indicates the range of chemical analysis for a typical sample of bituminous coal refuse.(253)

Environmental problems caused by "gob" piles of bituminous coal refuse are very similar to those attributed to the culm banks of anthracite coal refuse. The acid-producing potential of a "gob" pile increases with time as the bituminous shale deteriorates under the effect of weathering.*

Chrysotile or Asbestos Tailings

United States production of asbestos is about 125,000 tons annually. Only four States produce asbestos. California is the leader with over 63 percent of the total production, followed by Vermont, Arizona, and North Carolina. All asbestos

* Mr. William Buttermore, West Virginia University - Private Communication.

TABLE B-12

RANGE OF CHEMICAL ANALYSIS OF BITUMINOUS COAL REFUSE

CONSTITUENT	PERCENTAGE RANGE
Silica (SiO_2)	50-61
Alumina (Al_2O_3)	16-28
Ferric Oxide (Fe_2O_3)	6-21
Titanium Dioxide (TiO_2)	1-2
Calcium Oxide (CaO)	0-2
Magnesium Oxide (MgO)	0-2
Manganese Oxide (MnO)	0-1

SOURCE: Reference No. 253, pp. 95-99

mines, except those in North Carolina, produce chrysotile asbestos, which accounts for more than 46 percent of domestic consumption. The United States imports nearly 700,000 tons of asbestos annually from Canada, the world's largest producer.(245)

Asbestos is a name applied to a group of naturally fibrous minerals, of which the principal variety is chrysotile. Chrysotile asbestos is graded according to fiber length. Milling is a complex operation involving separation of the fiber from the rock and classification of the fiber into a series of grades. The fiber comprises from 5 to 10 percent of the rock mined, and the waste rock consists of broken and pulverized gray serpentine for which very little commercial use has been found.(244)

No estimates of accumulated or annually produced quantities of mill tailings could be found. Annual tailings production probably approaches one million tons per year, which is distributed among eight mining locations. Accumulations may be in excess of 10 million tons. Most mining locations are well removed from populated areas. Inhalation of asbestos dust is considered a hazardous air pollutant by the Department of Health, Education, and Welfare.(245)

Copper Tailings

Domestic copper mine production exceeds 1.7 million tons. Arizona is the leading state with 53 percent of the total production, followed by Utah, New Mexico, Nevada, and Michigan. These states account for 97 percent of total copper production.(245)

Since copper ore averages about 2 percent of the mineral deposits, huge volumes of waste result from copper extraction processing. Locations of these wastes can be seen in Figure B-4. A total of over 500 million tons of solid waste result from copper mining operations each year. Mine wastes account for 300 million tons per year, mill tailings nearly 200 million tons, and reverberatory slag from smelting operations represents approximately 5 million tons. Total accumulations of copper mine waste since World War II are estimated to exceed 8 billion tons. (256)

Mine wastes are comprised mostly of lean ores and to some extent, overburden and are deposited as unsightly piles. These are most often used to leach out last traces of metal. Mill tailings consist of grayish brown fine material left over after concentration of the copper ore. These tailings are discharged into ponds at 35 percent solids. Mill tailings from Michigan's Upper Peninsula are called stamp sands.

Depending upon the exact processing used, the particle size and pH will vary. Copper mill tailings are very fine, since 86 percent pass through a 325 mesh sieve, which is the equivalent of 44 microns. Table B-13 shows the chemical analysis of copper mill tailings.(170) A typical slag from a primary copper smelter is high in silica and iron and is dumped in a molten state or granulated in water prior to disposal or re-use.

Dredge Spoil

The United States Army Corps of Engineers is responsible

TABLE B-13

CHEMICAL ANALYSIS OF COPPER MILL TAILINGS

COMPOSITION	PERCENTAGE
Principal Constituents	
Silica (SiO_2)	71.1
Alumina (Al_2O_3)	13.2
Iron (Fe)	3.4
Magnesium (MgO)	2.1
Calcium (CaO)	1.1
Sodium (Na_2O)	0.3
Potassium (K_2O)	3.3
Loss on Ignition	2.6
Minor Constituents	
Nitrogen (Ni)	0.005
Titanium (Ti)	0.4
Copper (Cu)	0.005

SOURCE: Reference No. 170, p. 5.

for maintaining the navigable waterways which are important to the economic growth of this country. Maintenance dredging operations currently average 300 million cubic yards annually, and new dredging operations under contract average another 80 million cubic yards. Figure B-5 shows these waterways and spoil locations.

How is this dredging material disposed? Two-thirds of the material dredged during maintenance operations is disposed of in open water. It is virtually impossible to predict the amounts of dredging material from new work that will be disposed of in open water. The estimated quantity of total open water disposal is an average of 250 million cubic yards. Since much of the material dredged from rivers and channels is polluted, open water disposal will only intensify this pollution.

Grain size, moisture content, and plasticity are the important physical properties of dredge spoil. For engineering purposes, dredge spoil is divided into three types of materials: coarse-grained, fine-grained, and organic. Fine grained and organic dredge spoils normally cause dredging problems. Fine-grained materials are smaller than a 200 mesh seive.

Dredge spoil can be classified into five major soil groups:

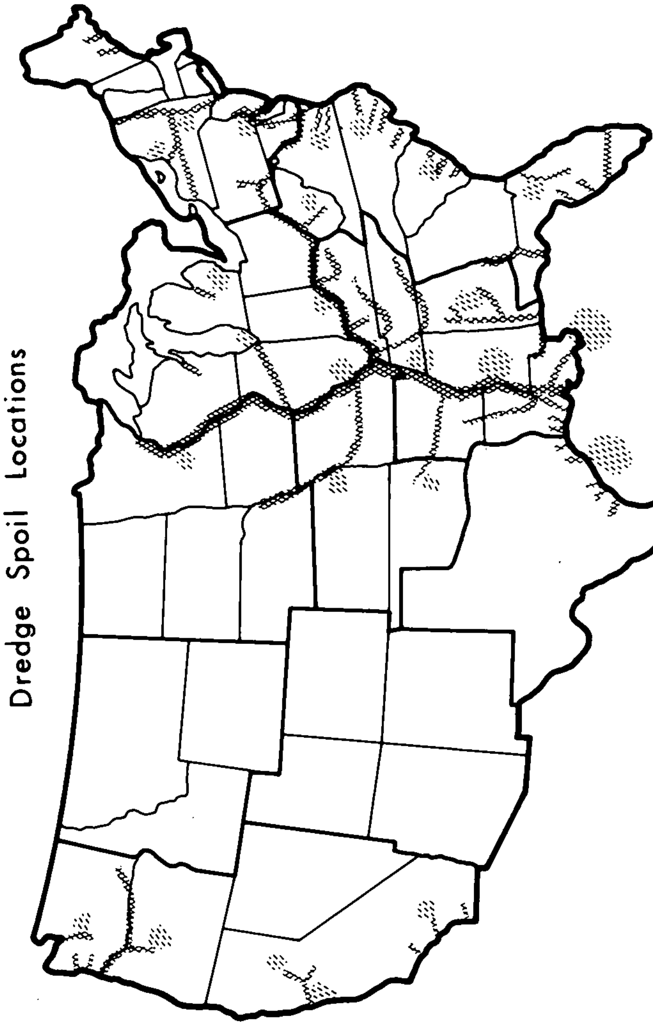
A. - Mud, clay, silt, topsoil, and shale.

B. - Silt and sand, mixed.

C. - Sand, gravel, and shell.

D. - Organic Mulch, sludge, peat, municipal and industrial wastes.

E. - Mixed.



Dredge Spoil Locations

Figure B-5

Groups A, D, and E are problem materials. Groups B and C make fairly good fill or foundation material. High organic content lowers the quality of the dredge spoil material.

Data regarding chemical properties of dredge spoils is very limited. Studies have indicated that dredge spoils are composed largely of silicates, but that the chemical composition of dredge spoil varies widely.(22)

<u>Feldspar Tailings</u>

Feldspar mining produces nearly 700,000 tons of ore annually. The leading producers are North Carolina, Connecticut, California, and South Carolina. The Spruce Pine district of North Carolina is the most prominent mining area for feldspar, producing about 250,000 tons of saleable feldspar each year. The amount of coarse tailings generated by these operations results in an almost equal amount of seemingly worthless waste material.(245 Accumulated quantities probably exceed several million tons at many different locations.

The coarse tailings resulting from the processing of feldspar are composed of nearly 65 percent feldspar and 20 percent quartz. Other minerals are clays and garnet. A fine filter cake material is also produced similar in gradation to fine sand.

Because of the high percentage of feldspar contained in the tailings, processing changes are being implemented at the plants in order to recover a higher percentage of feldspar and quartz in primary processing. By so doing, the amount of tailings produced in the future should be reduced by approximately 60 percent.(234)

<u>Gold Mining Waste</u>

The United States produces about 25 percent of its total gold demand domestically. In 1970, more than 1.7 million troy ounces of gold were produced in this country, resulting in the impoundment of several million tons of mill tailings. South Dakota, Nevada, Utah, and Arizona are the leading gold producing states. The nation's largest gold mine is Homestake at Lead, South Dakota. Second is the copper mine of Kennecott Copper Corporation in Utah, which recovers gold as a by-product of copper production. Other large gold mining operations are the Carling and Cortez mines in Nevada.

Methods of mining vary considerably, based on depth of ore deposit, size and shape of deposit, and the physical and mineralogical character of the ore and the surrounding rock. Placer mining, used for surface and sub-surface deposits, usually involves water and includes hydraulic mining, dredging, and drift mining of buried placers too deep to strip. Underground mining methods are used for deeper lode or vein deposits. Open-pit mining of low grade gold deposits has been a more recent development. Gold is also derived from porphyry copper deposits mined by open-pit methods.(244)

Although gold production has decreased greatly in recent years in California, it was, at one time, the leading gold producing State, and some of the largest deposits of gold mine

waste are located in the Mother Lode region west of the Sierra Nevada Mountains. Estimates are that as much as 100 million tons of gold mine waste have been deposited in this region.(149) Much of the gold in California was hydraulically mined. The resultant debris from these operations has been deposited in ravines, canyons and some of the main waterways of the gold mining district as boulders and quartzitic sand and gravel. Mill tailings from lode mines were impounded only at some of more recently operated mines, but almost 20 million tons of these tailings are available. A chemical analysis of a sample of gold mining waste is presented in Table B-14. This analysis indicates the siliceous nature of these wastes.(149)

No reliable estimates could be found regarding quantity or composition of waste from gold mining operations in other regions, but it is assumed that accumulations of siliceous material somewhat similar in character to that described in the California gold mining region can be found near the largest currently operating gold mines.

Iron Ore and Taconite Tailings

Iron ore is a mixture of iron oxide minerals with varying quantities of mineral impurities. In this report, iron ore is differentiated from taconite, a siliceous iron-bearing ore commonly associated with the Mesabi Range in Northeastern Minnesota. The United States produces over 90 million tons of iron ore annually. More than two-thirds of this production is

TABLE B-14

CHEMICAL ANALYSIS OF GOLD MINING WASTE

CONSTITUENT	PERCENTAGE
Silica (SiO_2)	93.0
Ferric Oxide (Fe_2O_3)	2.0
Alumina (Al_2O_3)	3.5
Calcium Oxide (CaO)	1.0
Magnesium Oxide (MgO)	0.41
Sodium (Na_2O_3)	0.07
Potassium (K_2O_3)	0.33
Loss on Ignition	0.23

SOURCE: Reference No. 98, p. 52.

derived from taconite ores in Minnesota, Michigan, and Wisconsin. Other producing areas are located in Alabama, New York, Pennsylvania, and several Western states. Locations of major iron ore or taconite tailings deposits are indicated in Figure B-4.

Most iron ore and taconite mining is done by open-pit methods. Processing of the ore produces both coarse and fine tailings, with fine tailings comprising about 60 to 70 percent of the total output. Coarse tailings are material mostly in the 4 to 100 mesh sieve size range, which is composed predominantly of silica and iron oxides. The fine tailings are discharged as a slurry of 45 percent solids content with 85 to 90 percent of the particles smaller than a 325 mesh sieve. The chemical analysis of a sample of taconite tailings is shown in Table B-15.(170)

More than 200 million tons of iron ore waste products are generated annually, with the processing of Mesabi taconite accounting for over 100 million tons of tailings. Overall accumulations are estimated at approximately 4 billion tons over the past thirty years.(256) No tailings' production figures are available for other iron producing regions, but Table B-10 indicates estimated accumulations for these areas.

Lead and Zinc Tailings and Zinc Smelter Wastes

Zinc and lead are often related as co-products in ore deposits. Lead and zinc ores are mined at more than 250 operations throughout the United States. Most lead and zinc ores are found in carbonate rocks, such as limestone or dolomitic limestone. Most ores range from 2 to 4 percent and average about

TABLE B-15

CHEMICAL ANALYSIS OF TACONITE TAILINGS

COMPOSITION	PERCENTAGE
Principal Constituents	
Silica (SiO_2)	59.0
Alumina (Al_2O_3)	2.7
Iron (Fe)	15.0
Magnesium (MgO)	3.7
Calcium (CaO)	2.7
Loss on Ignition	7.4
Minor Constituents	
Manganese (Mn)	0.73
Sulfur (S)	0.012
Phosphorus (P)	0.047
Carbon Dioxide (CO_2)	2.2

SOURCE: Reference No. 170, p. 5.

4 percent metal.(168)

Lead is derived from ores varying widely in lead content, from virtually zinc-free lead ores in Missouri, through the lead-zinc ores of the Western states, to nearly lead-free zinc ores of the Eastern United States. All ore is mined by sub-surface methods, beneficiated at mine sites, and shipped to smelters and refineries. Missouri is the leading producer of lead, accounting for 60 percent of over 500,000 tons of lead produced in 1970. Other leading producers are Idaho, Utah and Colorado.(245)

Approximately 50 percent of zinc ore production comes from ores designated as zinc ores. Possibly one-third comes from lead-zinc ores, and the remainder from lead ore and other ores containing some copper. Total amount of recoverable zinc mined annually compares closely with lead, in excess of 500,000 tons. Leading states are Tennessee, with over 20 percent of national production, followed by New York, Colorado, Idaho, and Missouri. Deposits located in Wisconsin, Utah, Eastern Pennsylvania, and Northern New Jersey also are large producers of zinc ore.(244)

Mining and milling of lead and zinc ores results in the production of two tailing waste products. One is a coarse fraction from jigs or ball mills, and the other is a fine fraction from the flotation cells. The composition of these wastes can be expected to vary from one location to another, depending upon the nature of the parent ore. The jig

tails contain minimal amounts of lead or zinc, and are dolomitic in character. Flotation tailings or slimes are also dolomitic with traces of iron, lead, and sulfur, as indicated in the chemical analysis of Table B-16.

Accumulations of lead-zinc tailings wastes since World War II probably exceed 500 million tons. Annual generation of wastes from processing of lead-zinc ores ranges between 20 to 25 million tons.(256) Concentrations of tailings and slimes can be expected to be generated in proportion to ore production. Most slime ponds cause problems because of the dusting of the dried material in windy weather.

Another waste resulting from processing of lead and zinc is the smelter waste from lead and zinc blast furnaces. These wastes resemble sand particles. They are usually black or red in color, cohesionless, glassy, and have sharp, angular particles which are cubical in shape.(104) There are no estimates at this time of the available quantities of lead or zinc smelter slags. Smelter locations are indicated in Figure B-4.

<u>Nickel Tailings</u>

The only domestic producer of primary nickel in the United States is the Hanna Mining Company, located at Riddle, Oregon. Their production of primary nickel averages 13,000 tons annually. The United States imports more than ten times this amount of nickel from foreign sources, principally Canada. Mining of nickel in the United States is done by the open-pit

<u>TABLE B-16</u>

CHEMICAL ANALYSIS OF
LEAD-ZINC TAILINGS

COMPOSITION	PERCENTAGE
<u>Principal Constituents</u>	
Silica (SiO_2)	9.8
Alumina (Al_2O_3)	0.3
Iron (Fe)	10.8
Magnesium (MgO)	17.8
Calcium (CaO)	29.4
Loss on Ignition	42.0
<u>Minor Constituents</u>	
Manganese (Mn)	0.037
Zinc (Zn)	0.18
Sulfur (S)	0.24

SOURCE: Reference No. 170, P. 5.

method. Although the concentration of nickel in the ore is about 1.5 percent, the amount of waste produced is not relatively significant in comparison to that of other ores. No figures are available regarding accumulations or annually produced quantities of wastes from nickel processing.(244)

<u>Phosphate Slag</u>

Mining of phosphate rock in several Western states produces a siliceous phosphate ore adaptable for smelting in electric furnaces. A by-product of the smelting process is calcium silicate slag, a gray, granular material composed of a variety of particle sizes, many of which are flat and elongated. Approximately 4 million tons of phosphate slag are generated annually, primarily in the Western states of Idaho, Montana, Wyoming, and Utah. There is no available information concerning estimated accumulations of phosphate slag.(245)

<u>Slate Mining Waste</u>

The major slate-producing quarries are located in Northeastern United States and include the New England States, New York, Pennsylvania, Maryland, and Virginia. The production of slate involves blasting to remove slate from the vein, which results in large chunks of quality slate together with low-grade fractured material. These low-grade tailings have been stockpiled and are composed of slate-like particles, which can be considered flat and elongated.(222)

B.3.3 DOMESTIC WASTES

Total estimated amounts of various domestic wastes are approximately 160 million tons annually and growing at a faster rate than the population. More than half of this is dry,organic material.(209) At the present time, nearly 90 percent of domestic waste is disposed of by land-filling.(9)

The overwhelming percentage of material generated under this category can be found in urban areas, where the production of solid waste is directly related to the concentration and amount of population. The majority of the following waste resources do not really require any great description. However, the relative quantities of these materials must be defined in order to gain awareness of various concentrations, accumulations, and possibilities for using some of these materials in combination. Table B-17 summarizes the estimated annual production figures for domestic wastes.

Building Rubble

The rubble resulting from demolition of structures due to urban renewal activity and the replacement of old buildings within urban areas amounts to sizeable quantities in many of the largest metropolitan centers. This material is a mixture consisting mainly of brick, concrete, plaster, steel, wood, and piping. Of these, only the portion containing brick and concrete can be considered usable as a potential aggregate replacement. The supply of demolition material is not steady or accurately

TABLE B-17

ESTIMATED ANNUAL QUANTITIES OF DOMESTIC WASTES (Millions of Tons)

DOMESTIC WASTE	ESTIMATED ANNUAL PER CAPITA PRODUCTION	ESTIMATED ANNUAL PRODUCTION
Building Rubble	250 lbs./person/yr.	20
Discarded Battery Casings	1 battery/ 2 vehicles/yr.	0.5-1.0
Incinerator Residue		10
Plastic Waste	30 lbs./person/yr.	2.5-3.0
Pyrolysis Residue*	N.A.	N.A.
Reclaimed Paving Material	N.A.	N.A.
Rubber Tires	2 Tires/vehicle/yr.	3-5
Sewage Sludge	75 lbs./person/yr.	8-10
Waste Glass	110 lbs./person/yr.	12

*Very few pyrolysis plants currently in operation
N.A. = Information Not Available

predictable on a population or location basis. However, the 1968 National Survey of Community Solid Waste Practices, conducted by the Solid Waste Program of the U. S. Public Health Service, estimated that demolition refuse in urban areas amounts to 0.72 pounds per capita per day, virtually all of which is disposed in landfills. At this rate, a total of 20 million tons per year of building rubble is generated, approximately half of which may be useable as aggregate.(166)

Discarded Battery Casings

It has been estimated that more than 50 million used batteries are discarded each year in the United States. Many firms located throughout the country salvage discarded batteries for the purpose of extracting the lead for re-use. The casings which remain after completion of the lead extraction processing are normally discarded. These battery cases are essentially made of rubber, plastics, and asphalt with various types of fillers and fibers. Crushed battery casing particles are black, mostly plate-like, and more angular than rounded, with a texture that varies from smooth to coarse. Gradation will depend on the amount of crushing, but generally, the gradation of this material is poor because the majority of particle sizes range between one-quarter to one-half inch. It must also be noted that particles of crushed battery casings are slightly elastic and are lightweight, having an approximate density of 55 pounds per cubic foot.(82)

Incinerator Residue

Many municipalities throughout the United States employ incineration as a means for solving solid waste disposal problems. At the present time, there are approximately 300 incinerator plants in this country. Locations of municipal incinerators are shown in Figure B-6.(7)

Estimates of solid waste treated by incineration range as high as 40 million tons annually. Even after incineration, an average of approximately 25 percent by weight of the original waste material still remains in the form of a non-combustible residue, depending upon waste composition and incinerator temperatures. Therefore, some 10 million tons of this residue must somehow be disposed of or recycled each year in those metropolitan areas with incinerator plants.(111)

There is not very much information available concerning the precise composition of incinerator residues. As might be expected, the heterogeneous character of these residues will cause a wide variation in composition from one incinerator plant to another. The residues themselves are a soaking wet mixture of metals, glass, ash, ceramics, unburned paper, charcoal organic material, wire, stones, dirt, and other components. Municipal incinerators are basically grate-type furnaces or rotary kiln furnaces.(7)

The United States Bureau of Mines conducted a study of municipal incinerator residues at its College Park Metallurgy

LEGEND OF MAP SYMBOLS

NAVIGABLE WATERWAYS

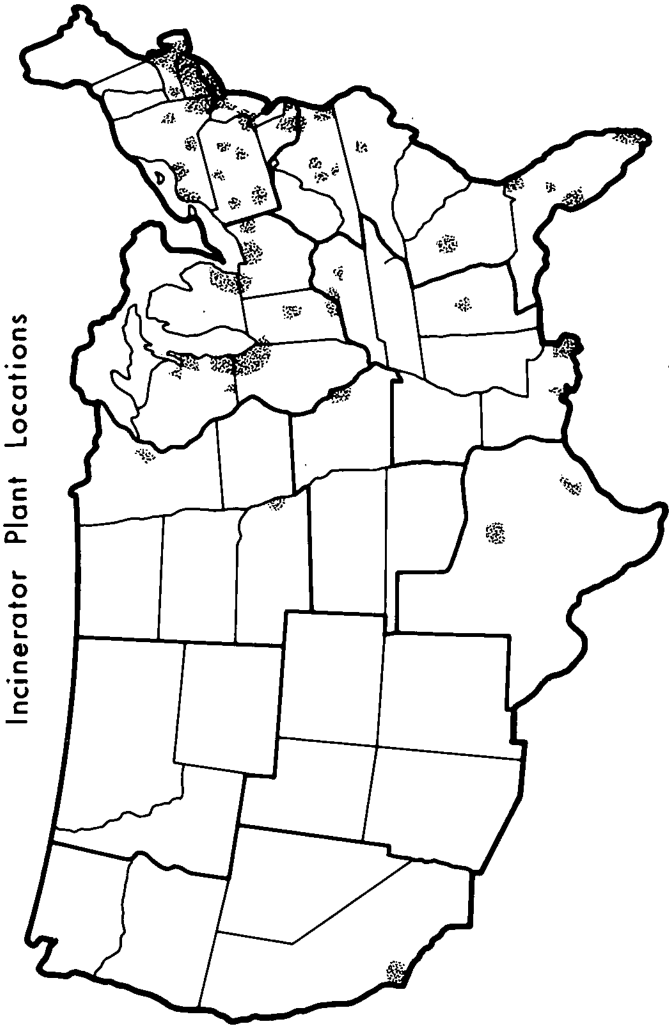
DOMESTIC WASTES

DREDGE SPOIL

INCINERATOR RESIDUE

RUBBER TIRES

WASTE GLASS



Incinerator Plant Locations

Figure B-6

Research Center. Samples from six different municipal incinerators were collected and analyzed. Although compositions of the different residues varied, the average material content of the constituents was fairly similar.(111) A detailed analysis of the chemical content of incinerator residue is shown in Table B-18.(125)

Plastic Waste

Plastics are used in the manufacture of a wide variety of finished products. About 25 percent of all plastics are utilized by the construction industry. Packaging accounts for another 20 to 25 percent of all plastics sold. Other major markets are aerospace, appliances, automobiles, housewares, electronics and toys.

Actually, the term "plastics" includes a large spectrum of chemical substances composed of complex hydrocarbons. There are two basic types of plastics: thermosetting and thermoplastics. Thermoplastics are the largest group of these, comprising approximately 80 percent of all plastics. Thermoplastics can be repeatedly melted and reshaped after initial forming. The thermosetting plastics cannot be melted and reshaped after their initial set. Theoretically, only the thermoplastics are recyclable, since no remelting of thermosets is possible.(52A)

Plastics are chemically synthesized from crude oil, natural gas, coal, and other organic materials. There are about 40 basic families of plastic materials, and each of these has unique characteristics. The major families of plastics are polyethylene (PE), polyvinyl chloride (PVC), polystyrene (PS), and polypropylene (PP), all of which are thermoplastics.(54)

TABLE B-18

AVERAGE COMPOSITION OF INCINERATOR RESIDUE

COMPONENT	PERCENTAGE
Magnetic	
Tin Cans	17.2
Mill Scale and Small Iron	6.8
Iron Wire	0.7
Massive Iron	3.5
Non-Magnetic	
Non-Ferrous Metals	1.4
Stones and bricks	1.3
Ceramics	0.9
Unburned Paper and Charcoal	8.3
Partially Burned Organics	0.7
Ash	15.4
Glass	44.0

SOURCE: Reference No. 125, P. 21.

Nearly 10 million tons of plastic materials are produced annually by the plastics industry. The amount of plastic waste resulting from this production is between 2.5 and 3.0 million tons per year. These wastes compose between 3 to 5 percent of municipal refuse, and are dispersed throughout metropolitan areas in direct proportion to the population. About two-thirds of plastic waste results from packaging in the form of bottles, jugs, tubes, and other containers. Most plastic packaging is produced from polyethylene, which is the most common plastic in use. The production of various types of plastics during 1970 is indicated in Table B-19.(106)

Much of the scrap resulting from the manufacturing of thermoplastic raw materials are recycled in the plants. The trim and rejects are chopped up and fed back into the forming machines possessing much the same properties as the original materials. However, the plastic wastes discarded in municipal refuse are, for the most part, unseparated and, even if separated, would contain some measure of impurities.(104)

Another factor to consider in the recycling of plastic waste is the fact that different types of plastics should be completely segregated in order to be re-used, since plastics having different molecular structures will not adhere to each other.

Although the total amounts of plastic wastes are relatively small, these materials are non-biodegradable, and some plastics, notably polyvinyl chloride, decompose when incinerated and release hydrogen chloride, which forms hydrochloric acid when

TABLE B-19

1970 PLASTICS PRODUCTION

TYPE OF PLASTIC	BILLIONS OF POUNDS	PERCENT OF TOTAL
Polyethylene (PE)	6.00	30.6
Polyvinyls (PV)	3.80	19.4
Polystyrene (PS)	3.35	17.1
Polypropylene (PP)	1.01	5.1
Phenalics	1.07	5.5
Other Polymers	4.37	22.3
TOTAL	19.60	

NOTE: Total Annual Production = 10 Million Tons.

SOURCE: Reference No. 106, p. 2.

combined with water. This is believed to be a cause of corrosion problems in many municipal incinerators.(195)

Pyrolysis Residue

Pyrolysis is the process of chemical decomposition of an organic substance by heating it in an atmosphere deficient of oxygen. It is also called destructive distillation, and is essentially the same as the commercial process used for years to produce coke for the steel industry.(209)

The pyrolysis of most organic materials results in the formation of several types of products:

1. A solid residue or char, composed mainly of ash and carbon.
2. An aqueous liquor, over 90 percent water plus some mixed organic compounds.
3. Tars, which represent only a small portion of the total products formed.
4. A mixture of gases, whose major constituents are hydrogen, carbon, neonoxide, methane, and ethylene.

Pyrolysis of a ton of wet municipal refuse will yield between 154 and 230 pounds of char residue. A ton of dry municipal refuse will yield up to as much as 626 pounds of char residue. A ton of pyrolyzed industrial refuse will yield 618 to 838 pounds of char residue, two to three times as much as a ton of municipal refuse.(208)

This solid residue, a lightweight, flaky char, is the material of interest for potential use as aggregate. Table B-20 shows the ultimate analysis of the pyrolysis residue from municipal and industrial refuse. The analysis can be expected to vary, depending upon the composition of the refuse, the moisture content of the refuse, and the pyrolysis temperature.

Although pyrolysis processing reduces the volume of solid waste by at least 90 percent, there are very few installations operating at this time. The amount of char residue which would potentially be available from the processing of municipal and industrial refuse would probably be on the order of 10 to 20 million tons per year once the installation of pyrolysis operations are fully completed and operating.

The U. S. Bureau of Mines has operated a pilot pyrolysis plant in Pittsburgh, Pennsylvania for a number of years. It has processed scrap tires and battery casings as well as municipal and industrial refuse. At the present time, several experimental pyrolysis plants are in operation.(208)

Reclaimed Paving Material

Demolition and removal of old roads, streets, curbs, gutters, and sidewalks, as well as highway structures such as bridges, provide an excellent source of potential aggregate materials for highway construction purposes. This rubble material consists of a mixture of stone, dirt, broken concrete, pieces of bituminous paving, and some reinforcing steel.

TABLE B-20

ULTIMATE ANALYSIS OF RESIDUE FROM PYROLYSIS OF MUNICIPAL AND INDUSTRIAL REFUSE
(Pyrolysis Temperature - 900°C)

CONSTITUENT	MUNICIPAL REFUSE	INDUSTRIAL REFUSE
Hydrogen	0.3	0.3
Carbon	36.1	14.8
Nitrogen	0.5	0.2
Oxygen	-	-
Sulfur	0.2	0.2
Ash	63.6	84.6
Heating Value, BTU per pound	5,260	2,180

SOURCE: Reference No. 209, p. 4.

The main step in processing this rubble is crushing. The crushed material may also be blended with natural aggregate.

Instead of disposing of such materials, it would be more practical to re-use them in highways. The biggest problem in processing paving rubble is the removal of reinforcing steel. This is accomplished by cutting torches and hand-picking of the steel. Another problem is the amount of asphalt contained in the paving material being reclaimed. This should be taken into account when designing the asphalt content of bituminous pavements which would incorporate reclaimed paving material.(138)

No estimates of the amounts of reclaimed paving material are available from a search of the literature. It is impossible to even predict the exact location or tonnage of such wastes. Their availability would be predominently in metropolitan areas, but the relocation or reconstruction of any portion of road or highway would cause such material to become available for re-use.

Rubber Tires

Increased ownership and use of the automobile has created many problems. Besides traffic congestion, growing highway demands, fuel shortages, and millions of abandoned vehicles, there is also the problem of how to handle the alarming number of rubber tires being discarded each year.

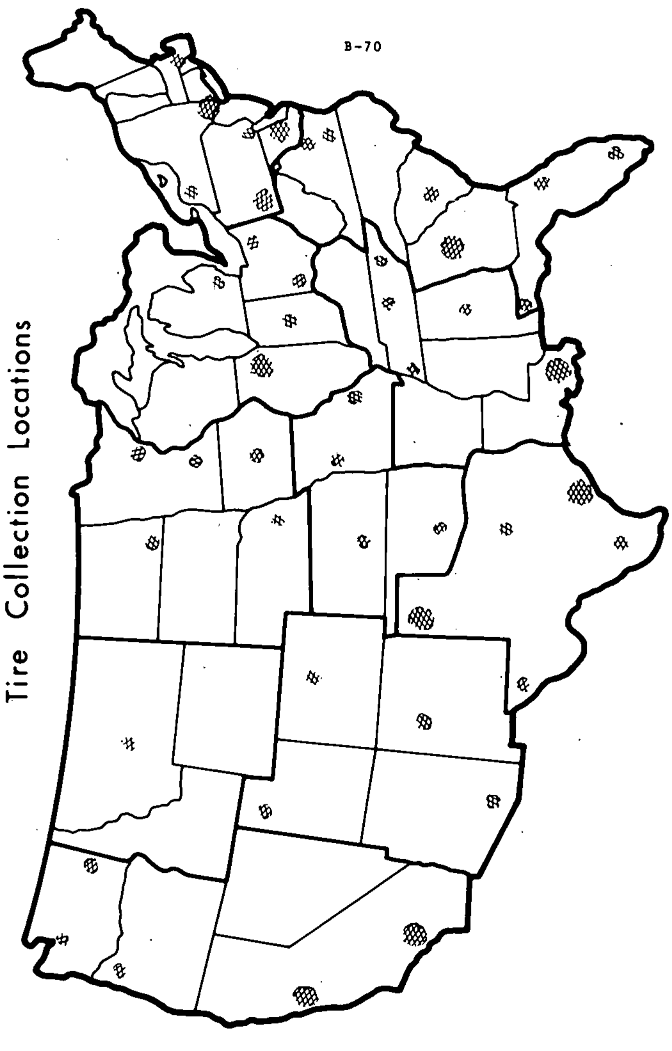
Between 180 and 200 million tires are scrapped every year, amounting to between 3 to 5 million tons. Only about 10 percent of these tires are presently being reclaimed. Latest

estimates are that more than 2 billion discarded tires have accumulated, with about 80 percent of these being passenger car tires. The production of new tires is increasing at 5 percent per year. At the same time, the reclaiming of rubber tires is declining, as are the number of rubber reclaiming companies.(213) The problem of discarded rubber tires is bound to intensify in the future. Open burning of tires and other wastes is forbidden. When buried in landfills, the tires have the disturbing tendency of "floating" to the surface. In addition, they do not degrade or compact. When incinerated, air pollution problems can result.

A study of the potential re-use of consumer rubber goods(67) indicates the source distribution of scrap tires to 48 major rail heads, as well as locating the existing and proposed tire re-use facilities. The distribution of scrap tires is shown on Figure B-7, and tonnage figures are given in Table B-17. Figure B-7 also shows the locations of existing and proposed tire re-use facilities.

Sewage Sludge

The sludge waste resulting from the treatment of municipal sewage waste poses a problem of disposal in most metropolitan areas. In most cases, the sludge is deposited in settling basins and allowed to thicken. Some municipalities dispose of this sludge by dumping it in waterways or at sea, while in other areas the sludge is incinerated, resulting in a product similar to fly ash.



Tire Collection Locations

Figure B-7

The amount of sewage solids generated annually is probably between 8 and 10 million tons, based on suspended solids estimated at the rate of 0.2 pounds per person per day. This amounts to 100 tons per day of sewage sludge solids in a city of 1 million persons.(166)

The sludge material has about a twenty percent solids content. It is dark brown to black in color, highly organic, and mainly composed of fine material sizes. The ash residue from the incineration of sewage sludge is nearly completely free from organic matter, is composed almost entirely of silt size material, and contains concentrations of up to 40 percent lime, which is usually added during dewatering.

Sewage sludge ash is disposed of either as a dry, black, powder called hearth ash or as a slurry mixed with plant effluent and called pond ash. The ash is not soluble in water, but is highly soluble in acid. The ash material is capable of being compacted to high strength and also exhibits strength gains over time. (93)

<u>Waste Glass</u>

Waste glass constitutes approximately 6 to 8 percent of all solid wastes generated in residential areas. Glass containers account for 80 percent of the total glass fraction in municipal refuse. It has been estimated that an average of 110 pounds of waste glass are discarded by each person in the United States every year. This amounts to an annual total of more than 40 billion containers, weighing 12 million tons and found primarily in urban areas.

Glass is composed mainly of silica or sand, but it also contains predetermined amounts of limestone and soda ash designed to produce uniform quality and color. There are three basic types of glass manufactured commercially in this country: borosilicate, soda-lime, and lead glass. Approximately 90 percent of all glass produced is soda-lime glass. The chemical composition of the three basic types of glass is shown in Table B-21.(225)

The most obvious way to recycle waste glass is to re-use it in the glass manufacturing process. The member companies of the Glass Container Manufacturers Institute operate 94 glass reclamation centers in 25 states for the purpose of reclaiming glass containers of all sizes, shapes, and colors and then re-using the crushed glass, termed "cullet", to help manufacture new glass. Locations of these glass reclamation centers are shown in Figure B-8. In addition, there are numerous other reclamation centers operating in various parts of the country under the auspices of civic organizations, community groups, food chains, beverage companies, and the like. It is estimated that nearly one billion glass containers are collected annually at various reclamation centers.(3)

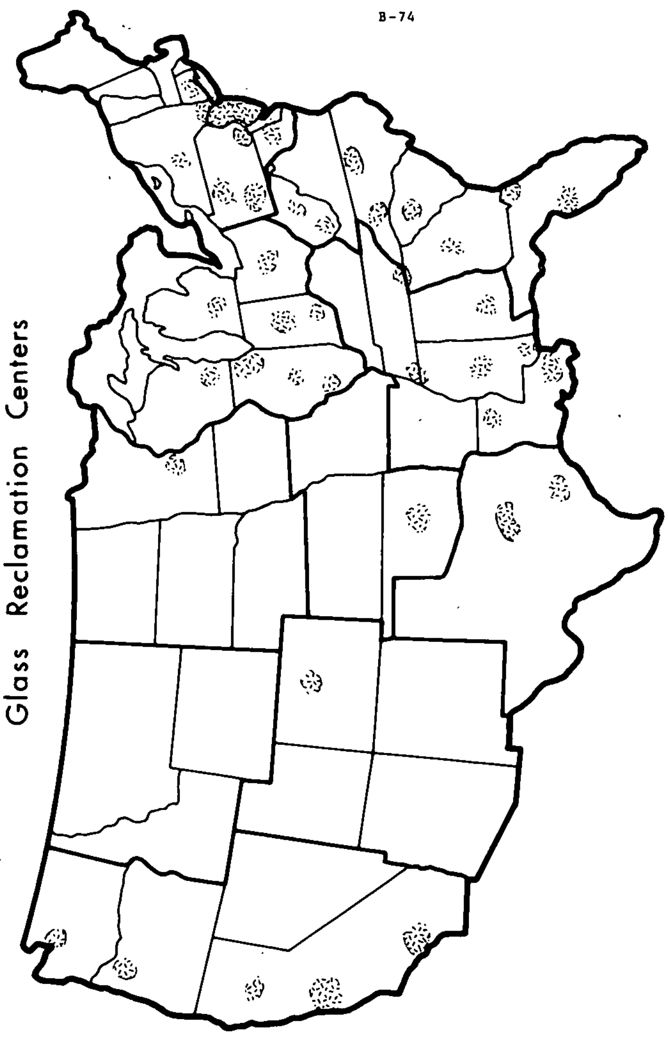
Glass is produced in a glass furnace by melting the ingredients at temperatures around 2700° F. After melting, the glass flows into a refining chamber, then drops to automatic feeders where it is formed into the desired shape. The capacity

<u>TABLE B-21</u>

CHEMICAL COMPOSITION OF VARIOUS TYPES OF GLASS

CONSTITUENT	BOROSILICATE	SODA-LIME	LEAD
SiO_2	81	73	63
R_2O_3	2	1	1
Na_2O	4	17	7
K_2O			7
B_2O_3	13	Trace	
CaO		5	
MgO		3	
PbO			22

SOURCE: Reference No. 225, p. 195.



Glass Reclamation Centers

Figure B-8

of the average furnace is 200 tons per day, and the entire operation is a delicate one. Reports by member companies which operate glass reclamation centers indicate that cullet, crushed waste glass, can provide 30 percent or more of the glass industry's raw material requirements.(2) This still leaves a sizeable amount of crushed glass to be disposed or recycled.

There are several problems associated with the re-use of waste glass by glass manufacturers. One is the amount of foreign material mixed with the waste glass, which could result in the possible alteration of a glass mixture in the furnace. Another problem is caused by colored glass. Half of all containers produced are clear or flint glass. The remainder are a variety of colors, produced by chemically varying amounts of sulfur, carbon, chromium or iron oxides. Once in glass, color cannot be removed without expensive masking. For this reason, colored glass and clear glass must be separated and various colors must also be kept separate, or else it will upset the delicate balance of ingredients necessary to produce a given batch of glass.(89)

Use of waste glass as an aggregate replacement requires crushing the glass to ¼ inch maximum size. The resulting material normally contains relatively large amounts of flat and elongated particles. These particles have a smooth surface with little or no porosity. However, the use of glass particles is said to improve the thermal characteristics of paving mixtures. (131)

APPENDIX C: CURRENT USES OF WASTE RESOURCES

C.1 INTRODUCTION

The current uses of a waste resource may be indicative of its potential for development as a highway aggregate replacement.

This potential will be viewed from the broad perspective of overall utilization of specific wastes. The status of current uses of waste resources will be presented in three parts:

1. Current uses, including use as highway aggregates, for all waste materials described in Appendix B.
2. Potential or actual highway use of other waste resources not included in Appendix B.
3. Summary of all known experimental and field work performed to date by local and state highway personnel in utilizing waste materials as replacements for aggregates in highway construction.

C.2 CURRENT USES FOR WASTE RESOURCES

This section of the report describes all uses noted in the literature for those waste resources listed in Appendix B, with emphasis upon the relative amount of the highway use of a particular waste material as compared to other uses. Where available, description of processing and costs are included. Information regarding current use of some waste resources has also been received from various agencies and individuals. Table C-1

TABLE C-1

CURRENT AND POTENTIAL USES FOR WASTE RESOURCES

WASTE RESOURCES	PHYSICAL STATE	CURRENT USES	POTENTIAL USES
Alumina Muds	Slurry and Dried Fines	Insulation, Pigment soil conditioner, concrete additive, binder	Lightweight building materials
Phosphate Slimes	Slurry	Brick, sewer pipe, lightweight aggregate for structural concrete	Lightweight aggregate for building and highway construction
Sulfate Sludges	Slurry	None	Lime-fly ash-sludge mixtures. For road base compositions and production of highway aggregate
Fly Ash	Dust	Fill material, cement replacement, lightweight aggregate, asphalt filler, road base compositions	Fill material, cement replacement, lightweight aggregate road base compositions and brick manufacture
Bottom Ash	Fine sand	Fill material, road base compositions, and asphalt paving mixtures	Same
Boiler Slag	Black gravel-size particles	Fill material, highway aggregate, base compositions, blasting grit and roofing granules.	Same
Scrubber Sludges	Slurry	None	Lime-fly-ash-sludge mixtures for base compositions and production of highway aggregate
Blast Furnace Slag	Coarse Particles	Construction aggregate, railroad ballast, and fill material	Same - Increased use in bituminous wearing surfaces

TABLE C-1 (Continued)

WASTE RESOURCES	PHYSICAL STATE	CURRENT USES	POTENTIAL USES
Steel Slag	Coarse Particles	Road base, Railroad ballast	Same
Foundry Dusts	Fine Dust	None	Pigments, Colorants highway aggregate
Coal Refuse	Coarse & Fine Particles	Anthracite coal refuse used as anti-skid material. No extensive use of bituminous coal refuse	Highway aggregate, carbonate bonded road base compositions
Copper Mining Waste Tailings	Slurry or Dust	Fill material Fill material	Fill material, highway aggregate
Reverberatory Slag	Fine sand	Railroad ballast	Fill material highway aggregate
Dredge Spoil	Slurry	Disposal or fill material	Fill material, building units
Feldspar Tailings	Coarse Particles	None	Highway aggregate
Gold Mining Waste	Wet sand or gravel	None	Sand-lime type brick manufacture, highway aggregate
Iron Ore & Taconite Tailings	Slurry	None	Foamed Lightweight block, carbonate bonded road base compositions
Lead and Zinc Tailings	Coarse particles and Slurry	Aglime railroad ballast, fillers, road stone.	Same
Phosphate Slag	Fine Stone Chips	Lightweight aggregate, concrete aggregate, railroad ballast	Same
Slate Mining Waste	Coarse particles	Limited use as highway aggregate	Highway aggregate
Zinc Smelter Waste	Fine sand	None	Highway aggregate

TABLE C-1 (Continued)

WASTE RESOURCES	PHYSICAL STATE	CURRENT USES	POTENTIAL USES
Building Rubble	Coarse Particles	Landfill	Landfill, highway aggregate
Discarded Battery Casings	Coarse Particles	Landfill	Highway aggregate
Incinerator Residue	Ash	Landfill	Highway aggregate
Pyrolysis Residue	Char	Highway aggregate	Highway aggregate
Reclaimed Paving Material	Coarse Particles	Landfill, Re-use in high-way as aggregate	Same
Rubber Tires		Landfill, rubber reclaiming and retreading	Granulated for seal treatment stress - relieving interface
Sewage Sludge	Slurry or Ash	None	Lime-flyash-sludge mixture for rd. base composition
Waste Glass		Glass production aggregate, glass-wool, slurry seal mixes	Same
Phosphogypsum*	Slurry	None	Plaster Substitute
Nickel Tailings*	Coarse Particles	None	Highway aggregate

* Practically no information is available concerning possible uses of these materials.

summarizes the uses for each waste resource.

C.2.1 INDUSTRIAL WASTES

The following section describes in some detail the possible uses which exist or have been developed for each of the industrial waste resources discussed in Appendix B of this report.

a. CERAMICS INDUSTRY

Most of the breakage and rejects from the manufacture of brick, ceramic tile, clay pipe, and pottery are disposed in landfills. Some smaller quantities are reclaimed and sold and some are also re-used in processing. Some breakage, or "bitten" as it is sometimes called, has been utilized locally on some unpaved municipal roads in combination with ash clinker. Crushed brick has been used as sub-base material. There is also a record of the investigation of crushed ceramic tile as a potential aggregate replacement in concrete mixes which showed some encouraging results.(139)

Because these materials make excellent landfill, it is most probable that this use will continue to be the primary means of disposing of the ceramic wastes, especially since the quantities of these materials are relatively small.

b. CHEMICAL PROCESSING INDUSTRY

Alumina Red and Brown Muds

There has been a great deal of effort put into finding uses for the red and brown muds resulting from processing of aluminum from bauxite. Some attempts have been made to recover

by-products from these wastes. Some direct uses for alumina muds have been as thermal insulation and as an agricultural soil conditioner. Red mud has also been used to some extent as a pigment for bricks, paints, and ceramic coatings, as an additive to concrete, as slag wool, and as a binder for taconite pellets.(191)

The most promising use of the alumina red and brown muds has been developed by the Illinois Institute of Technology Research Institute (IITRI). The feasibility of foaming and sintering compositions containing red mud in lightweight materials using mechanical foaming techniques was successfully demonstrated. The base compositions contained 65 percent solids and consisted of 82 percent red mud, 15 percent ball clay, and 3 percent perlite. A foaming agent was added as 1.8 percent of the mixture.(169)

The resultant lightweight materials can be formed into lightweight structural units having densities ranging from 30 to 70 pounds per cubic foot. These units would be useful for curtain wall, interior partitions, glazed wall tile, fireproof insulation, and for use in roof decking, floors, and ceilings. By varying porosity, superior thermal and acoustical properties can be developed for these products.

These lightweight materials are versatile, stable, and inorganic. They exhibit resistance to volume changes with time when exposed to heat, moisture, chemicals, or mechanical loading. Control over porosity during foaming and sintering

provides the ability to vary the strength to weight ratios for specific applications. Compressive strengths of these products can vary from 150 to 2200 pounds per square inch.

Scrap from the cutting of these foamed units would be useful as lightweight aggregate for both building and highway uses.(191) No cost figures have been developed for production of the lightweight foamed units.

Phosphate Slimes

The two most difficult obstacles to overcome in utilizing the slimes discharged from phosphate production are the retrieval of the slimes from holding ponds and dewatering. After years of settling, the solids content of these wastes is only about 25 percent. Because of the high moisture content of these materials, it is uneconomical to consider pumping them any great distance. Therefore, preliminary processing was done adjacent to the slime ponds.

The best method of drying the slimes is through the use of a fluid-bed reactor, where the slimes are continuously dried to a powder. Estimated cost of drying by this method are approximately $5.50 per ton of dry solids. Once dried, several products were made using this material, including brick, sewer pipe, lightweight aggregate, and lightweight concrete.(254) The slimes have also been used experimentally as a binder for agricultural fertilizer pellets , using phosphate slime as 3 percent of the agglomerated mix.

Extrusion of brick with a plastic mixture of 65 to 75 percent solids, drying and firing to 1100° C caused shrinkage,

warping and bloating of the finished product. Molding and firing at 1050° C with a mixture containing 36 percent quartz, produced a more satisfactory brick.(261)

Sewer pipe was successfully extruded and fired from phosphate slimes. However, high porosity and crushing strengths equivalent only to allowable minimum ASTM standards, indicate that this is not a high potential use for these slimes.

The most promising material developed from phosphate slimes was lightweight aggregate, which was produced by pelletizing dried slimes in a rotating disc agglomerator using a water binder. The pellets were then dried and fired in a rotary kiln at temperatures between 1050° and 1100° C. The aggregate product has a density of 20 to 30 pounds per cubic foot and conforms to ASTM Specification C330 requirements for lightweight aggregate for structural concrete. Estimated production cost for lightweight aggregate is approximately $9.00 per ton.(254)

The lightweight aggregates produced from phosphate slimes were used as coarse aggregate and tested in a number of concrete formulations. Unit weights ranged from 85 to 118 pounds per cubic foot, depending upon mix proportions. Compression strength values for various formulations indicate that concrete prepared using phosphate slime lightweight aggregate is satisfactory for use in structural lightweight concrete, provided the density exceeds 105 pounds per cubic foot and no foaming agents are used.(261)

Phosphogypsum

At the present time, there is no significant use of the gypsum waste from phosphoric acid production. Less than one percent of this by-product is sold as a soil conditioner.(244) Experiments conducted at the University of Utah(51) concentrated on dehydration and removal of impurities of various phosphate gypsum wastes, and the comparison of plaster specimens from these wastes with a commercial plaster of the same consistency. Carbon is the main impurity of Utah gypsum waste and fine sand is a problem for Florida gypsum waste. Removal of impurities and addition of retarders to lengthen setting time produced plaster samples exceeding compressive strength values of commercial plaster. Use of gypsum wastes as plaster substitutes does seem feasible.

No reference is made in the literature to possible use of this material in highways. However, there is the potential for using phosphogypsum to replace internal calcium sulfate in the process in which Portland cement is made from calcium sulfate and clay.(96)

Sulfate and Sulfite Sludges

Waste sludge from the manufacture of hydrofluoric acid was used as part of an experimental base course composition for the parking area and roadways at the site of the Transpo '72 demonstration at Dulles International Airport. The same sludge was also used in the manufacture of synthetic aggregate for the Transpo '72 project.

Both the base course composition and the synthetic aggregate were formulated using a mixture of lime, fly ash, and sulfate sludge. The optimum formulation used in the base course composition consisted of 2.5 percent lime, 4 percent sulfate sludge waste (50 percent solids content), 15 percent aggregate, and 80.5 percent fly ash. This formulation developed compressive strength values greater than 300 psi in seven days. Values of California Bearing Ratio exceed 30 percent after 7 days and develop to over 50 percent after 28 days. The permeability of the base course compositions are very low.

The optimum formulation used in the manufacture of synthetic aggregate consisted of 10 percent hydrated lime, 40 percent sulfate sludge waste of 50 percent solids content, and 70 percent fly ash. The aggregate strength was evaluated by two different testing methods. First, the aggregate was extruded, formed into standard 2 inch cubes, moist cured, and tested according to ASTM C109 procedures for unconfined compressive strength. The aggregate was also extruded, cured in pellet form, and tested for crushing strength. No heat was applied in forming the aggregates. Aggregate density was 62.7 pounds per cubic foot and absorption was 20.9 percent.

The aggregate pellets were tested for compressive and crushing strengths and optimum formulations were found to exceed strength limits after four weeks curing time. The unconfined compressive strength values of the 2 inch cube specimens

vary significantly, depending upon the formulation used. The compressive strength values for a 28 day curing period range from 900 psi to 4300 psi. The particle crushing strength values are dependent upon the formulation used and also the curing temperature. Particle crushing strength values for a 28 day curing period at 70° F range from 29 psi to 167 psi, with optimum formulations exceeding the minimum strength limit of 100 psi. Strength values continue to increase with time.

Synthetic aggregates from hydrofluoric acid sludge were used in the base course compositions as a substitute for the natural limestone and crushed stone aggregates. The mixes containing the synthetic aggregate showed more rapid growth of compressive strength. This is attributable to the fact that the synthetic aggregate acts, not only as an aggregate, but monolithically with the base course composition. The freeze-thaw resistance, bearing capacity, and permeability of these compositions all are well in excess of specification requirements. Weight losses averaged approximately one percent when subjected to 12 cycles of freezing and thawing. Optimum formulations show compressive strength around 1000 psi. Permeability values after 7 days curing at 100° F range from $.06 \times 10^{-5}$ to $.28 \times 10^{-5}$ cm/sec, which are quite low.

Synthetic aggregate from hydrofluoric acid sludge was also used in crushed stone base course, bituminous concrete mixtures, and Portland cement concrete, with no loss in strength.(155)

c. ELECTRICAL POWER INDUSTRY

Fly Ash

Although overall ash utilization has increased to nearly 20 percent of total production, the utilization of fly ash is only 11 percent. These figures are low when compared to the percentage utilization in some of the Western European countries, notably France, where up to 75 percent of the ash produced is used in highways.

The major use of fly ash in 1972 was as fill material for roads, construction sites, and land reclamation. Fly ash is also used as a partial replacement for cement in concrete, especially in mass concrete applications, such as dams, and as an aggregate and filler in concrete block. Nearly 134,000 tons of fly ash was used in the manufacture of lightweight aggregate during 1972. However, this is less than one percent of the total amount of fly ash produced and represents the total output for three operating plants. Other uses of comparable volume were as asphalt filler, road base stabilizer, and in the manufacture of cement.*

One problem encountered in the production of lightweight aggregate from fly ash is the variability of the raw fly ash from the power plant. This is caused primarily by the carbon

* Figures based on data from 1972 Ash Collection and Utilization Survey received from Mr. John Faber, National Ash Association.

and iron content of the ash. In order to produce satisfactory aggregate, the carbon content should be between 3 and 10 percent. Excessive iron in the ash can result in an aggregate which may cause staining. Beneficiation of the ash is sometimes necessary to make it more suitable for lightweight aggregate.

The main steps in the production of lightweight aggregate from fly ash are pelletizing and sintering. Pellets are formed by intimate mixing of water and ash. If the fly ash is collected in slurry form, it must be partially de-watered prior to pelletizing. Pelletizing is done by a revolving cone, disc, drum, or an extrusion device. One advantage of extruded type pellets is that a graded material can be produced without secondary processing after sintering. Sintering of fly ash is done in traveling grate furnaces at 2,200° F. Damp pellets must be dried to prevent spilling from rapid exposure to high temperatures.

Fly ash aggregate pellets normally range in size from one-quarter to three-quarters of an inch for structural concrete. During sintering, the particles should all be the same size. Crushing to desired sizes can be done after sintering. Unsuitable material is reprocessed. The cost of producing sintered fly ash aggregate has been estimated to be less than $4.00 per ton (FOB Plant) for a 1,000 ton per day plant (34), although these figures seem to be low.

Sintered fly ash aggregate has been used in structural concrete and compares favorably with lightweight aggregate made

from expanded clays and shales. Concrete can be designed with strength up to 4,000 psi. Properties of lightweight concrete made with sintered fly ash aggregate fall within the guidelines established by the American Concrete Institute for structural lightweight aggregate concrete.

Pelletized lignite fly ash from North Dakota has been found to be too heavy for use as lightweight aggregate. It has a bulk density range from 65 to 70 pounds per cubic foot. Lignite fly ash has recently been adopted for use in ASTM Specifications.*

In Yugoslavia, aggregate has also been produced from sintered lignite fly ash. These aggregates have bulk density values of from 23 to 40 pounds per cubic foot. Lightweight concretes with strengths exceeding 1800 psi can be made using these aggregates.

No indication has been found that fly ash aggregate has been used in concrete or bituminous paving mixes, except for the experimental work done at Transpo '72. Fly ash has been used as a cement replacement in concrete pavements and structures.(34)

Fly ash bricks have also been manufactured on a pilot plant scale from 75 percent fly ash, 23 percent bottom ash, with 3 percent sodium silicate binder. Bricks have also been produced from a mixture of fly ash and clay, fly ash and boiler slag, and fly ash and sand.(34) This application appears to have great potential for the future.

* Oscar Manz, University of North Dakota - Private Communication.

The use of fly ash as a pozzolan in base course compositions has been well proven over many years of laboratory testing and field experience. Fly ash is used with lime and aggregates in these mixtures, which are blended in a dry or semi-dry state and compacted at optimum moisture content. These mixtures develop strengths up to 1000 psi over an extended period of time and are virtually impervious.

Bottom Ash

Dry bottom ash utilization increased to 24 percent of production in 1972. The principal use of this material was as fill for roads and construction sites. Less than 25,000 tons of bottom ash were utilized in the production of lightweight aggregate. This material is used as anti-skid material for highways and as a component of stabilized base course compositions.*

An outstanding example of the use of bottom ash and boiler slag in highway work was the relocation of a 4 mile section of West Virginia Route 2, in which 250,000 tons of ash waste were utilized together with blast furnace slag.

The cement treated base course in this project consists of 45 percent boiler slag, 42 percent dry bottom ash, 5 percent Type I Portland cement, and 8 percent water. The aggregate base course is composed of 80 to 85 percent bottom ash and 15 to 20 percent blast furnace slag. The wearing surface is 2 inch bituminous concrete containing boiler slag and blast furnace slag as aggregate. Shoulders also contain boiler slag.(171)

* Figures based on data from 1972 Ash Collection and Utilization Survey.

Bottom ash has also been used in highway construction as a component of cold-mix emulsified asphalt mixtures. These mixtures have been used for the improvement of about 100 miles of secondary roadways in northern West Virginia and eastern Ohio, primarily as resurfacing material. The composition of the mixes varies, being a blend of sand, gravel, and/or blast furnace slag with the bottom ash, called "power plant aggregate". Normally, the asphalt content of these mixes varies between 5 and 7 percent.

Materials are mixed in a pug mill and the coated power plant aggregate must be stockpiled for at least 21 days before actual placement of the mixture. Being a cold mix, the material can be placed in cold weather conditions on untreated surfaces or over old roadbeds. Placement has been made with conventional pavers as well as spreader boxes. Successful compaction has been achieved using either rubber tired or steel wheeled rollers.(172)

Several observations can be made with respect to the use of bottom ash in highway construction. When used as a base course material, bottom ash can be spread and compacted very well when placed at or slightly above optimum moisture content. However, when the bottom ash dries out, it loses stability. It is, therefore, necessary to keep the material wet so that equipment could be used on its surface. Various mixtures of bottom ash with fly ash or blast furnace slag have been used to improve stability of base course mixtures.

Many bottom ash materials cannot always satisfy all specification requirements, especially with respect to gradation.

Blending of other materials such as fly ash can be done in order to meet existing specifications. A blend of 70 percent bottom ash and 30 percent fly ash adds the required amount of fine material and produces optimum stability. A greater percentage of fine particles of fly ash than acceptable under ordinary particle-size specifications would improve performance because of the cementitious properties of the fly ash. In such instances, specifications adapted to fit the particular materials are necessary (165).

Boiler Slag

In 1972, nearly 1.5 million tons of wet-bottom boiler slag were put to use. This represented 35 percent of the total produced.* As with fly ash and dry bottom ash, boiler slag is most often used as a fill material for roads, construction sites, and land reclamation. Other uses for boiler slag are for blasting grit, roofing granules, ice control, brick manufacture, stabilized base construction, and as highway aggregate.(24)

Boiler slag's permanent black color, hardness of particles, and resistance to abrasion have been responsible for its use as a base course and wearing surface aggregate material in several states. It has also been used in surface treatments and in shoulders where its black color creates an excellent contrast with concrete pavements. At this time, boiler slag has been approved as a surface aggregate in several states, including Illinois, Indiana and Ohio. This material is being used as a component of

* Figures based on data from 1972 Ash Collection and Utilization Survey

the base course and wearing surface of the West Virginia Route 2 relocation project, which has been previously described. Boiler slag has also been used in Minnesota as a seal coat aggregate and experimentally as an aggregate in bituminous mixtures.

Boiler slag, when used in bituminous surface course mixtures, can improve skid resistance. However, several states have blended other aggregates, such as sand or limestone screenings, with boiler slag in order to produce a stable paving mixture. Satisfactory performance of resurfaced pavements in West Virginia has been obtained using a mixture composed of 50 percent boiler slag, 30 percent sand, 3 percent fly ash, and an 8 percent asphalt content.(165)

Lignite boiler slag has been used to resurface residential streets in Texas. Mix proportions were 75 percent lignite slag, 25 percent limestone screenings, and 6 to 7 percent asphalt.(124)

Scrubber Sludge

The sludge waste from lime and limestone scrubbing for SO_2 removal from power stations stack gases has also been used in experimental base course compositions at the Transpo '72 demonstration project. The optimum formulation used was a mixture of 3 percent hydrated lime, 16 percent SO_2 scrubber sludge, at 50 percent solids content, 13 percent aggregate and 76 percent fly ash. The SO_2 scrubber sludge used in the Transpo '72 project was mixed with fly ash and contained 22 percent calcium sulfite and 20 percent calcium sulfate. This sludge had a much lower sulfate content than

the hydrofluoric acid and mine drainage sludges also used at Transpo '72.

Synthetic aggregate was also produced for laboratory study using the SO_2 scrubber sludge waste from Transpo '72. The optimum mixture for producing synthetic aggregate was 5 percent dolomitic lime, 40 percent sludge at 50 percent solids content, and 75 percent fly ash. Aggregate strengths of the SO_2 scrubber sludge aggregate material are comparable to the strengths attained for similar formulations using industrial sulfate and sulfite sludges.(155)

Aside from disposal, there are no other uses developed for SO_2 scrubber sludges at the present time.

The Federal Highway Administration is sponsoring a two year research project to develop technology for the use of sulfate wastes in highway construction. The main objective of this study will be to identify compound formations of these materials, lime-fly ash-sulfate reactions, and optimum formulations.

d. IRON AND STEEL INDUSTRY

Iron Blast Furnace Slag

Foreign and domestic literature contain countless examples of the use of air-cooled iron blast furnace slag in highway construction, which is the principal use of this material. In fact, over 50 percent of all blast furnace slag utilized each year is used as a base course material for bituminous and concrete pavements. In addition, it is used as an aggregate in Portland cement and bitum-

inous concrete pavements. Other significant uses for blast furnace slag are in concrete for building construction, concrete masonry units, railroad ballast, and as fill material. Expanded slag is used as lightweight aggregate building construction.

Blast furnace slag is almost universally accepted and specified as an acceptable material for Federal, State and municipal highway aggregate use. The fact that blast furnace slag has, for all practical purposes, achieved total utilization serves to point out that blast furnace slag is now considered more of a resource than a waste material.

Notable highway uses of air-cooled blast furnace slag are the bituminous surfacing of the Pennsylvania and Ohio Turnpikes, slag sand mixes used to resurface Baltimore City streets, and the concrete deck and pier sections of the I-75 Bridge over the River Rouge in Detroit. In addition, blast furnace slag is used extensively as a high quality base course material for such applications as the Penn Lincoln Parkway near Pittsburgh and I-77 in Cleveland.(175) Granulated slag is used as aggregate in base courses and concrete pavements in Allegheny County, Pa.(36)

Blast furnace slag can also be used as a component of lime-fly ash aggregate base course compositions or in various combinations with fly ash, bottom ash, or boiler slag in base course and wearing surface mixtures.

An outstanding property of bituminous pavements using blast furnace slag aggregate is their high skid resistance. This, in turn, increases highway safety on these pavements.

In base courses, the angular particle shape and rough surface texture of blast furnace slag aggregates produce high stability under all weather and climatic conditions.(174) Blast furnace slag can be used as coarse aggregate in reinforced concrete pavements and produce high strength concrete with negligible corrosion to reinforcing steel.(70)

Steel Making Slags

The principal use of steel slag is as a base course material for bituminous and concrete pavements. Other uses of steel slag are as railroad ballast and as aggregate in bituminous pavements.

Because of its expansive characteristics, not all of the steel slag produced annually is utilized. In fact, many state specifications require that steel slag be aged for a period of at least six or seven months prior to its use in order to assure that expansion of the aggregate will have already been completed.

Steel slag is approved for use as sub-base or shoulder material in Ohio and Pennsylvania. California has recently permitted steel-making slags for use in aggregate base and sub-base applications.

There are several examples of the use of open hearth slag in various highway applications in Pennsylvania. Over 400,000 tons of open hearth slag were used as base course material for the Eisenhower Interchange at the intersection of I-83, I-283, and Pennsylvania Route 322 East of Harrisburg. The material

required no crushing but was watered down and allowed to cure for six months.(135)

An open hearth slag was used in an aggregate in cement treated base course and sub-base on Pennsylvania Route 82 in Chester County. In this case, the slag material had not been adequately cured before use and considerable maintenance has resulted due to horizontal and vertical surface displacements of four to six inches (144). However, it is possible that even steel slag aged with an adequate curing period could cause problems when used in portland cement concrete with its highly alkaline environment.

Open hearth slag was also used as coarse and fine aggregate in the bituminous wearing surface of a widening an resurfacing project in Butler County, Pa. There were no problems with the workability of the mix and it was noted that open hearth slag was less porous than steel slag. Although no problem occurred on this project with aggregate expansion, the presence of waste steel particles and cuttings in the form of thin slivers caused some difficulty. The pavement has been in service since 1967, and is wearing satisfactorily with adequate skid resistance.(145)

Foundry Waste Dusts

Foundry waste products have not been utilized to any great extent so far. Studies were conducted by the Illinois Institute of Technology Research Institute (IITRI) to explore the feasibility of pelletizing and sintering various types of foundry effluents, as well as other means of utilization.

Arc furnace dust is recommended for application as a non-corrosive paint pigment, a coloring agent in rubber, vinyl, and asphaltic tiles, and as an aggregate material for use in

sub-bases. The fired aggregate pellets were in the normal weight aggregate range, but high absorption, between 15 and 20 percent, would limit their use to sub-base applications. These aggregates may also be useful as anti-skid material.

Furnace dust, like arc furnace dust, can be pelletized and sintered into aggregate particles suitable for use as normal weight aggregate in sub-bases only. There are also possible applications for furnace dust as a colorant and as fill material.

Dry sand reclaimer residue has several potential uses. This material can be pelletized and sintered into a vitrified type of aggregate material. Although sand reclaimer dust pellets are weaker and more porous than the furnace dust pellets, they show promise as an acceptable lightweight aggregate for use in lightweight concrete. Because of its content of bentonite, dry sand reclaimer residue could be combined with Portland cement as a grouting material for use as a soil stabilizer. Another possible use may be as a ceramic binder. Also, it has been found that sand reclaimer dust can be foamed.(251)

With respect to the production of aggregate, all three of the above foundry wastes have been pelletized rather easily with the addition of a binding agent. Firing was done in a rotary kiln. Furnace dust was fired at 1160° C, arc furnace dust at 1175° C, and sand reclaimer dust at 1215° C. Despite high iron contents, none of the aggregates rusted after immersion in water, indicating non-staining properties.(91)

C.2.2 MINERAL WASTES

Anthracite Coal Waste

In 1968, Pennsylvania State University undertook a study designed to develop ways to utilize the refuse from anthracite mining operations. The study was called Operation Anthracite Refuse. The final report for this project was submitted to the United States Bureau of Mines on January 15, 1973. It recommended the development of three specific uses for incinerated anthracite refuse: anti-skid material, bituminous resurfacing aggregate, and soilless plant growth media. Three potential future uses were also recommended. These are as an aggregate in lime-fly ash-aggregate, cement-aggregate, or bituminous aggregate base course compositions; as a substitute for slag in the production of mineral wool; and as an aggregate used for highway patching.

Raw anthracite refuse is currently being used to prevent underground subsidence in mine shafts, as a low grade fuel, and as a substitute for cinders in the manufacture of concrete block.

Incinerated anthracite refuse used as anti-skid material and as bituminous resurfacing aggregate was first crushed and then sized between one-quarter and three-quarter inch sizes. The Pennsylvania Department of Transportation has used over 4,000 tons of this material for anti-skid purposes on all classes of highways. Due to successful results, incinerated anthracite refuse has been specified for use as anti-skid

material.(37)

In order to test the potential of crushed incinerated anthracite refuse as an aggregate for bituminous resurfacing mixes, four experimental repaving projects were approved by the Pennsylvania Department of Transportation. All four projects were located in Luzerne County and involved primary and secondary highways, including one section of a two lane city street. Traffic conditions and volumes were variable.

In general, the repaving operations were conducted with no major problems. The aggregate particles did absorb more water than would normally be expected. Coverages were increased by as much as 30 percent due to the lighter specific gravity of the aggregates and greater stability values were also noted. Skid resistance tests have yielded excellent results so far, and the surface conditions are still satisfactory, despite several winters of wear.(143)

The Pennsylvania Department of Transportation conducted laboratory tests on samples of bituminous paving mixtures using unburnt (raw) anthracite refuse as aggregate. The anthracite refuse was processed before use in that the lighter coal and shale particles and the heavy sulfur bearing compounds were removed by a sink-float process. Stability and flow values were excellent. However, the aggregate particles were very absorptive, particularly in sizes larger than the #4 sieve, where complete coating of particles was not possible. Freeze-thaw failures

occurred in less than half the cycles of a control mix. Based on these problems, use of the raw anthracite refuse in shoulders and sub-bases is recommended more highly than use in bituminous paving mixtures.(264) In order to perform suitably in bituminous paving mixtures, anthracite refuse should be incinerated before use.

Laboratory tests were conducted on the use of incinerated anthracite refuse as a component of stabilized lime-fly ash-aggregate base course compositions. Various formulations were developed using refuse samples from five typical culm banks in the anthracite region. Compressive strengths for test cylinders have attained values of from 400 to 600 psi, indicating sufficient hardness for application in the field.

Field tests of the use of incinerated anthracite refuse as aggregate in patching material were discontinued. There is, therefore, no indication at this time of the potential usefulness of so-called "red dog" in highway patching.(37)

There are other references made in the literature to the use or attempted use of anthracite refuse in highways. As early as 1932, jig tailings were used as aggregate in a concrete pavement. However, the concrete weathered badly. The reason given was due to the laminated structure of the aggregate. Evidently no attempt had been made to incinerate the coal refuse prior to use. (229)

Anthracite refuse has been used as shoulder material

in the construction of a small portion of the Northeast extension of the Pennsylvania Turnpike. Some embankment construction has also been done using washery rejects.(229)

It has been generally stated that the main detrimental factor against the use of raw anthracite refuse in base and sub-base road construction is the inability of the refuse material to meet specification requirements for soundness, which indicates low resistance of aggregate to disintegration.(178) Incineration of anthracite refuse provides a suitable aggregate product for use in base and sub-base applications.

Bituminous Coal Refuse

Until recently, the utilization of coal refuse in the United States had been practically nonexistent. In Great Britain, where mounds of colliery shale have accumulated from the hundreds of years of coal use, much of the burnt spoil is now being used as embankment material for the construction of highways and railroads. Unburnt spoil is being utilized in embankments. The impetus of the National Coal Board has been largely responsible for efforts to utilize colliery spoil in the United Kingdom.(238)

A study was made in 1964 at the University of Kentucky to investigate the feasibility of using bituminous coal waste as an aggregate in bituminous paving mixtures. The study examined both coal refuse and red dog from Eastern Kentucky as aggregate with an asphalt cement, cutback asphalt, an emulsion, and a road

tar as the binder. It was found that mixtures containing 100 percent coal refuse or "red dog" as aggregate have sufficient unconfined compressive strength, but insufficient retained strength for use in bituminous paving. The retained strength is a measure of the effect of water on the strength of the mixture and indicates the durability of the mixture in resisting the stripping of the binder from the aggregates in the presence of water. No work was done in this study on blending the coal refuse with natural aggregate.(103)

Research was conducted at the Coal Research Bureau of West Virginia University on the potential use of bituminous coal shale in asphalt paving mixtures. Unburned "gob" shale was used as aggregate with no preliminary sizing. Maximum particle size was 3/8 inch. The "gob" shale was heated to 275° F and mixed with an AC-10 binder and compacted using the Marshall design method. Stability and flow values for asphalt contents ranging from 5 to 8 percent met Marshall design criteria for medium traffic. The carbon should be burned out of the "gob" particles before use. Temperatures of approximately 800° C are recommended for this purpose. In addition, the "gob" particles must be 100 percent coated with asphalt in order to obtain suitable mixtures.*

The Bureau of Mines, in cooperation with Truax-Traer Coal Company in West Virginia, investigated the feasibility of manufacturing lightweight aggregate from two sources of coal washery refuse. A plant was constructed and placed into operation in June of 1955 which processed 120 tons per day of coal refuse. Refuse larger than a No. 14 sieve was crushed, water was added, and the mixture was agglomerated in a rotating drum pelletizer and sintered in a traveling grate stoker. The combustible matter in the refuse helped supply the heat of reaction. On the basis of tests to determine compliance with lightweight aggregate specifications, it was concluded that a satisfactory aggregate can be produced from coal refuse and used in the manufacture of lightweight concrete block. Cost of the lightweight aggregate product was $4.50 per ton F.O.B. Plant in 1958.(167)

* Mr. William Buttermore, University of West Virginia, Coal Research Bureau - Private Communication.

Actually, Poland has introduced the concept of making use of the latent heat in the coal content of coal waste material as the fuel for sintering these waste materials and converting them into lightweight aggregate.(121)

Coal dust slurries from bituminous coal washing operations were studied for possible incorporation in concrete block to add greater resistance to water penetration. Results of the experiments confirm that the use of coal washing fines passing a 100 mesh sieve in concrete block did increase resistance to water penetration and transmission. Economic hauling distance from washery plant to block plant was found to be a 45 mile radius, based on truck hauling rates in the Philadelphia area. (102)

Bituminous coal waste, like anthracite waste, has potential for use in shoulders, sub-bases, and as a component of base course compositions. Another interesting potential use of this waste is in conjunction with carbonate bonding. Briefly, this technique involves placement of the coal refuse, tilling the material and blending lime hydrate and water and pumping gaseous carbon dioxide and flue products from a portable carbon dioxide generator into the blend through a perforated plastic pipe placed beneath the material. The permeating carbon dioxide gases through the lime hydrate material mixture cause a reaction which hardens the mixture. Compressive strengths of from 2200 to 4400 psi have been developed using this technique. At the time of this writing, no field experimentation has yet been conducted.(35)

<u>Chrysotile or Asbestos Tailings</u>

Almost 70 percent of all asbestos consumed goes into the manufacture of asbestos cement products. The tailings resulting from the processing of asbestos do not have any developed uses. Long fiber asbestos has been added to bituminous mixtures, but there is little possibility that asbestos tailings will ever be strongly considered for highway use due to dusting problems and potential health problems.(244)

<u>Copper Tailings</u>

The tremendous volumes of copper waste rock and mill tailings make it practically impossible to consider total utilization of these wastes for any purpose. Waste rock from open pit mines has been used for construction purposes such as fill material, rip rap, railroad ballast, and aggregate. Often this waste rock is processed by means of heap leaching to extract the remaining traces of metals. It is common practice in the copper

industry to construct dams for the impoundment of tailings ponds. These tailings have also been used as fill material for the construction of roads and railroads.

In underground mining operations, the tailings are usually returned to the mines themselves for roof support and overall mine stability.(19) Copper mill tailings have been used in Utah in the construction of embankments on a section of I-215.*

Reverberatory slag from primary smelters is an excellent fill material, and has been used as railroad ballast. Some work has been done also on its use as aggregate material in both concrete and asphalt mixes. The possible use of this slag material in the manufacture of glass wool is also being investigated. (19)

<u>Dredge Spoil</u>

A laboratory study was conducted at Franklin Institute Research Laboratories to investigate the potential for manufacturing quality material from dredge spoils. The most promising alternative was found to be the heating of the molded material to 1000° C to form a fused brick-like product. This dry pressed product exhibited compressive strengths ranging from 3,600 to 4,600 psi. By contrast, the pressed samples of moist material had compressive strength values ranging from 2,000 to 3,000 psi. The addition of polymers was also tested, but was not found to be a good approach for preparing building materials from dredge spoils.(101)

* Mr. William D. Hurley, State of Utah - Private Communication.

Feldspar Tailings

The amount of feldspar waste tailings available for utilization is likely to be reduced within the not too distant future as a result of changes being made in primary processing. These changes involve increasing the yield of feldspar and quartz from the basic ores, thereby decreasing the amount of waste.

A laboratory study conducted at North Carolina State University indicates that fine tailings or filter cake materials can possibly be stabilized with Portland cement, lime, and fly ash. These tailings can also possibly be used as road base or subgrade stabilization material. More comprehensive studies are necessary for these particular applications.

The coarse tailings can be used to make mortars of acceptable strength and stability. Water and cement requirements would make these mixtures marginal in competition with natural sand mortars.

Various combinations of these tailing wastes could be used in combination to make sand-lime bricks meeting ASTM strength specifications. Promising samples of lightweight, foamed calcium silicate building materials were also produced.(234)

Feldspar tailings appear to indicate some feasibility for potential highway aggregate use in the future. Laboratory and field experimentation are needed to determine the potential of this material for development as an aggregate for highways.

Gold Mining Waste

A study was made of the potential use of the siliceous waste products from the California gold mining industry. The production of calcium silicate bonded bricks and aerated lightweight concrete were under investigation.

The nature and quality of the sand or other aggregate used is the most critical factor affecting the quality of the sand-lime or calcium silicate bricks. There is a lack of sufficient high-quality sand to meet demands for this material in California. Therefore, gold mining waste is considered as a potential replacement for natural sand in the production of calcium silicate brick.

Aerated concrete is a fairly homogeneous fine-grained silicate mass of cellular composition. It is a mixture of cement or lime and a fine siliceous material, such as ground sand, fly ash, ground burnt shale, crushed slag, or a mixture of these. There are two ways of effecting aerated concrete. Gas can be generated within the mix chemically or air can be injected into the mix using a foaming or air-entraining agent. In the case of aerated concrete, gold mine waste could be used as the fine siliceous material in the mixture.(98)

Iron Ore and Taconite Tailings

Taconite tailings have been developed into fired lightweight blocks using foaming techniques. Densities ranged from 25 to 95 pounds per cubic foot, depending on the amount of foaming agent introduced into the mix.(170)

Use of carbonate bonding procedures have been applied to taconite tailings in the same way as the applications to coal refuse. High compressive strengths in excess of 4400 psi have been recorded on stabilized mixtures. No field experiments have been conducted to date using this method.* It is logical to assume that the iron ore tailings accumulations in Alabama would also be considered eligible for use of carbonate bonding procedures.

Lead and Zinc Tailings

There is very little information contained in the literature with respect to utilization of lead and zinc tailings. Mention is made of considerable amounts of lead and zinc tailings currently being used as aglime, ballast, fillers, and road stone.(5) No further details are given regarding any of these uses.

An investigation was made into possible utilization of the zinc mine tailings accumulations in the Southwestern part of Wisconsin. Several means of utilizing these tailings were investigated, including production of iron oxide feed for blast furnaces and recovery of sulfur from iron sulfide. After conducting an economic analysis of these alternatives, it was concluded that it is not economically profitable to utilize these zinc mine wastes.(100) There was no examination made in this study concerning possible highway use of this material.

Zinc smelter waste from Oklahoma was studied for possible use as a highway construction material. Results indicate

* Mr. Eugene Pelczarski-Black, Sivalls, & Bryson, Inc. - Private Communication.

that zinc smelter waste can be substituted for conventional aggregates in sand-asphalt mixtures. The material also appears feasible for use in surface courses because of its skid resistant characteristics, by blending with coarser grained limestone or dolomite. Zinc smelter waste is an excellent fine aggregate for stabilized base courses. However, use of zinc smelter waste in concrete mixtures is not recommended.(104)

Nickel Tailings

No information could be found concerning possible uses for nickel tailings or smelter waste. The wastes themselves are localized in one area and are not significant in quantity when compared to the tonnage of other mineral wastes.

Phosphate Slag

The slag from phosphorous furnace production is a waste product which has been crushed and used as a concrete aggregate, a foamed lightweight aggregate, as slag wool, and as ballast for use in railroad and highway construction. The amount used has been limited by freight costs to major markets.

Phosphate slag has been utilized in large quantities in the state of Montana. Several hundred thousand tons of this material have been used as aggregate for base courses in the area surrounding Butte.*

Slate Mining Waste

The Commonwealth of Virginia has made use of the mining waste from a local slate quarry for road cover stone, in concrete mix-

* Lehman B. Fox, State of Montana - Private Communication.

tures, in surface treatment applications, and in base courses. Although the flat, elongated particle shape was quite undesirable, crushing can improve particle shape, and other important properties such as particle strength, chemical stability, and freeze-thaw-resistance were satisfactory.

Acceptable concrete could also be made with proper mixture proportioning.(139) It would also seem feasible to urilize this material in bituminous mixtures. In 1972 a total of 30,000 tons of crushed slate waste was used by the Virginia Department of Highways.*

C.2.3. DOMESTIC WASTE

There are numerous examples of the utilization of domestic wastes. The following descriptions indicate the various known uses for domestic wastes.

Building Rubble

Demolished buildings have been used as fill material for many years. The rubble component of demolition material is most suitable for filling purposes. The most troublesome problems associated with demolition material is the disposal of the wood component. Very little salvage work is currently being done in conjunction with demolition activity.

The rubble portion of demolition material is well suited for use as aggregate in sub-base applications. In most cases, it must be separated from the demolition material. Rubble

* K. E. Ellison, Commonwealth of Virginia - Private Communication.

from concrete building construction is preferred. The processing necessary to prepare these materials for aggregate use is crushing and sizing, accomplished at either primary crushing plants or portable crushing operations. Demolition rubble was used as one of the components in a portable crushing plant for production of sub-base aggregate in the Washington, D. C., metropolitan area.(203)

Discarded Battery Casings

The Texas Transportation Institute has conducted research on the use of discarded battery casings as aggregate in bituminous pavements. The material itself is poorly graded, most of the particles being sized between one-quarter and three-quarter inch sieves. The crushed battery case particles are lightweight, predominantly smooth-sided and intermingled with a number of foreign materials, primarily glass. To provide acceptable gradation, secondary crushing or blending with other aggregate is necessary.

Various mixtures for Texas Highway Department fine graded surface course were formulated and tested by the Marshall design method. Different combinations of battery case crushings and fine aggregates were blended.

Results of the Marshall design tests indicate that crushed battery casings alone are not a suitable material for use as an aggregate in bituminous paving mixtures. It is difficult to obtain a suitable gradation and flow values are high. With mixtures composed of 50 percent crushed battery casings

blended with natural fine aggregates, all mixtures exceeded Marshall stability criteria, but some mixtures had excessive flow values. It was felt that gap grading of the aggregate combinations would reduce flow values while increasing stabilities.(134)

Crushed battery casings were also used as aggregate for some of the experimental lime-fly ash-sludge base compositions at the transpo '72 demonstration project.(155)

Incinerator Residue

Research has been conducted on the possible uses of processed incinerator residues as an aggregate material for paving and structural concrete applications. The Franklin Institute Research Laboratory has studied means of densifying samples of unfused incinerator residue and converting them into useful construction materials. The basic process consists of grinding the incinerator residue using a hammer mill, pre-heating at 1270°, then melting and fusing at 2000°F to form a column of semi-molten product. Final processing would involve crushing to aggregate sizes. Key steps are the grinding and melt-fusion operations. Full-scale processing would require small space and could be added to all new or existing incinerator plants with increased capital cost of about 5 percent. Market potential for the synthetic aggregate product appears excellent as road base, and as an aggregate replacement in bituminous, and Portland cement concrete mixtures in municipalities producing incinerator residues.(192)

The City of Philadelphia is currently using incinerator residues as an experimental aggregate material in bituminous mixes.(65)

The Pennsylvania Department of Transportation conducted a physical evaluation of the processed incinerator refuse as an aggregate in bituminous concrete mixtures. The material examined did not comply with existing gradation specifications due to uniformity of particle sizes. There was evidence of magnetic properties, probably due to iron particles produced by incineration of tinned cans. Particle shapes were classified as flat and elongated. Marshall test specimens did not meet design criteria for stability, air voids, or voids in mineral aggregate. There was also inadequate freeze-thaw resistance. It was recommended as a result of this study that incinerator residue not be used in bituminous concrete mixtures.(108) However, the Federal Highway Administration has reported that the fused incinerator residue appeared to be mechanically suitable for use as a concrete aggregate.(192)

A study of incinerator residue gangue, conducted at West Virginia University, indicates that the aggregate produced by processing the incinerator residue can be used in structural lightweight concrete applications. Pellets were made of the unfused incinerator residue by pelletizing and sintering in an electric kiln, between 2200 and 2400° F. The only additional processing needed to fully produce the aggregate material was a crushing operation. In almost all cases, water was used as

the binder. Compressive strengths on the order of 7000 to 8000 psi were obtained for the lightweight concrete samples using the incinerator residue aggregate. On the basis of tests conducted on the aggregate itself and the resultant concrete mixtures, it was concluded that high quality structural concrete could be produced using municipal incinerator residue as lightweight aggregate.(29)

The Franklin Institute is presently conducting research sponsored by the Federal Highway Administration on the feasibility of converting incinerator residue into road construction material. A laboratory scale plant will be constructed in Cleveland, Ohio, to utilize residue from a Cleveland incinerator plant to produce aggregate suitable for base course, concrete or asphalt construction.

The non-metallic fraction of unfused incinerator refuse was examined for potential use as a constituent of a hot-mix asphalt paving mixture. Preliminary Marshall test procedures indicate that this material could be used as an aggregate in asphalt mixtures. Although no tests were conducted for use as an untreated road base material, the incinerator residue was also considered suitable for this purpose. Tests on the use of unfused incinerator residue as an aggregate for concrete mixtures produced unsatisfactory results. The concrete swelled during the curing period and final strength values were much less than those achieved with concrete using normal gravel as aggregate.

Other potential uses for incinerator residue are heat recovery, metal leaching, and production of brick.(125)

Plastic Waste

At the manufacturing level, recycling of plastic waste is a standard practice. However, once plastics enter the solid waste stream, they must be segregated from other refuse before recycling.

With few exceptions, plastic waste fractions obtained from municipal solid waste do not exhibit great potential for re-use. Commercial recycling of collected waste plastic was first reported in 1970 by a San Diego, California, firm which manufactured drainage tile from scrap polyethylene milk bottles of high density. The project was halted when Federal and State authorities refused to allow use of any material other than clean material generated from the manufacturer's own production.

Several reclamation systems have been designed to recycle plastic scrap to plastic manufacturing firms for re-use. These usually require separation of plastic from other scrap, cleaning, and segregation of different plastic types. Hot pressed moldings have been made from chopped plastic waste and fused into dense, homogeneous solids. Injection molding is also feasible.(106)

The Portland Cement Association examined the use of granulated plastic scrap as a partial sand replacement in various concrete mixtures. It was found that the addition of plastic scrap

increased thermal expansion, reduced compressive and tensile strengths, and significantly increased creep, particularly in lightweight concrete.(69)

Granulated scrap plastic from milk jugs was used experimentally as a binder component of a bituminous mix. Tension and compression specimens were molded and tested. Results of this laboratory study indicate that use of granulated plastic in asphalt concrete would help improve the pavement.(30)

A pedestrian bridge utilizing scrap plastic was constructed in Elgin, Illinois. The concrete bridge deck was composed of a mixture containing 30 percent granulated plastic as a partial replacement for sand. The main advantage to using plastic scrap is the reduction in dead weight with small loss of compressive strength.

At the moment, the reclamation of plastic products from the municipal waste stream does not appear to be a practical means of waste disposal.(14)

Pyrolysis Residue

There are several experimental pyrolysis plants either planned or currently in operation. Monsanto has developed and field tested a 35 ton per day pilot plant in St. Louis, which is a totally enclosed and self-contained operation. The wet residue, which is only 6 percent of the original trash volume, is hauled away to a landfill.(148)

Torrax Systems, Inc. has constructed a demonstration plant in Orchard Park, New York, south of Buffalo. This plant processes 75 tons of refuse per day and achieves a 75 percent weight reduction. The unit weight of the residue is 150 to 160 pounds per cubic foot and is not presently being re-used.

Monsanto is developing a pyrolysis plant near Baltimore which will have a capacity of 1000 tons of refuse per day. This plant will produce 170 tons per day of refuse weighing approximately 150 pounds per cubic foot. The City of Baltimore is planning to use this refuse as an aggregate for road construction purposes.*

Reclaimed Paving Material

There are countless examples of the re-use of paving or base material from old pavements in the construction or reconstruction of highways. All of the instances cited in the literature involved the recycling of paving rubble into aggregate base courses, cement-bound macadam, bituminous base courses or bituminous wearing surfaces.

Processing included burning and hand removal of steel reinforcing bars, crushing, and sizing of the rubble. Depending on the type of application and specification requirements, gradation of the processed rubble can be altered to desired size ranges. Portable processing equipment has been used most succesfully.

* Mr. Edward Higgins, Environmental Protection Agency - Private Communication.

Research was done on the use of recycled concrete in the design of concrete mixtures. Although compressive strengths were somewhat lower than with conventional concrete mixtures, frost resistance was improved. The general conclusion is that recycled pavement concrete is promising for use as course aggregate, and even perhaps as fine aggregate in concrete pavements. However, recycled building concrete should not be considered since there is a possibility of sulfate attack due to contamination from plaster and gypsum wallboard.(27)

Rubber Tires

For the past 60 or 70 years, rubber reclaimers have been collecting discarded tires and producing pliable rubber for use in new tires and other rubber products. Unfortunately, rubber reclaimers never recycled all the tires discarded annually and in recent years the tonnage of reclaimed tires has been declining.

There are other uses for reclaimed rubber tires. A number of agencies have tested scrap tires as crash barriers for bridge piers and abutments. Tires have also been used to construct reefs off sea coasts. Due to their high Btu content, tires can be incinerated or pyrolyzed.

A number of highway-related uses have been developed from scrap rubber tires. Ground scrap rubber from discarded tires was blended with sand and asphalt emulsion and applied as a thin layered viscoelastic interface between a crack-prone base course and a bituminous concrete overlay. Installation of these interfaces in thicknesses of as little as one-quarter inch

were found to accommodate a considerable movement in the base course while eliminating reflection cracks in the wearing surfaces.(113)

Laboratory tests conducted at the Texas Transportation Institute using bituminous mixtures containing various percentages of ground rubber tire particles indicate that ultimate stress and strain are increased, but the asphalt content of the mixtures must increase.(32)

In Arizona, recycled rubber tires were granulated and used as aggregate on the resurfacing of two major roads. Another resurfacing project in Arizona utilized recycled tires with 5 percent of liquid latex emulsion. This mixture has an advantage in so far as the latex can be applied cold.

Perhaps the most promising use of reclaimed tire rubber is hot asphalt-rubber seal treatment, currently being widely used in the City of Phoenix. The unique feature of the hot asphalt-rubber mix is that the rubber constitutes 25 percent by weight of the total mix. The rubber is granulated by using a special grinding process. These hot asphalt-rubber mixtures are thoroughly mixed, spread at a specified rate, and stone chips are used as the surface course. Use of these mixtures has been found to be very effective in removing the continuing recurrence of alligator cracking in bituminous paving.(233)

The Portland Cement Association recommends that shredded rubber tires not be used in concrete because the rubber

particles would act largely as voids, decreasing the strength of the concrete. Thermal incompatability is quite possible because of large variations in the coefficient of thermal expansion between concrete and rubber.*

Sewage Sludge

Gray(93) performed a laboratory examination of the engineering properties of incinerated sewage sludge ash, particularly compaction, compressive strength, freeze-thaw resistance, and age hardening properties. On the basis of these tests, it was concluded that incinerated sewage sludge ash possesses many of the properties required for a suitable sub-base material.

Experiments are now being conducted in the field to determine the potential for combining sewage sludge with lime and fly ash for possible use as a stabilized embankment material in a section of I-95 in Philadelphia. Results are indefinite at this time.

Waste Glass

Waste container glass is being utilized in a number of ways. The most promising market is in the glass making process itself, where waste glass or cullet can supply up to 30 percent of the raw materials required for the production of new containers.

The second most attractive market for waste glass is in road construction, particularly in glasphalt paving mixtures.

* Private Communication from Mr. E. Hognestad, Portland Cement Association to Mr. John G. Pallo, National Tire Dealers and Retreaders Association.

The waste glass is used as a replacement for from 40 to 80 percent of the natural aggregate in bituminous paving mixtures. The glass must be crushed to specified gradation with a maximum size of one-half inch. Blending of one or two percent by weight of hydrated lime will improve adhesion between the asphalt and the glass. Research has indicated that unrefined waste glass can contain as much as 17 percent foreign matter and still be considered tolerable for use in glasphalt paving mixtures.(249)

There have been numerous field installations of glasphalt paving mixtures throughout the United States over the past five years. The largest tonnage application so far is in Toledo, Ohio, where 1450 tons of glass were used to pave 1000 feet of a four-lane arterial highway.(118) The project was divided into five 200 foot sections in which different combinations of surface, base, and sub-base layers were composed of glasphalt in varying mix proportions.(118) Glasphalt applications have also included access roads and parking lots.

Crushed waste glass has been approved and used as a subgrade material in the construction of a four lane Interstate highway in Ohio. Glasphalt is useful as a patching material for the maintenance of municipal roads. Glass has also been used as a component of slurry seal, which is an asphalt emulsion consisting of 50 percent waste glass. Slurry seal mixtures are used as an overlay or seal coat of one-quarter inch thickness over old pavements. (3)

Research conducted at Villanova University indicates that use of glass as coarse and fine aggregate in concrete results in a drastic loss of tensile and compressive strength, due mainly to a lack of bonding between the glass particles and the cement paste.(128) Use of glass as coarse aggregate in concrete still results in loss of tensile and compressive strength, although not as great as when used for coarse and fine aggregate.(179)

Other uses for waste glass also have some potential. Glass beads can be used in reflective paints for highways. Finely ground glass of 200 mesh sieve size can be used as mineral filler in bituminous paving. Mineral wool insulation can be manufactured from waste glass. Preliminary studies indicate that a durable foamed ceramic product can be made using glass. Waste glass has been converted into attractive wall panels, and has also been used in the manufacture of tile and concrete block.(2)

C.3 POTENTIAL HIGHWAY USE OF OTHER WASTE RESOURCES

Several other examples of waste or by-product use in highways have been cited in the literature. It is possible that some of these wastes could be utilized as aggregate replacements in highways on a purely local basis.

Scrap Iron and Steel

Previous studies(79,139) have listed scrap iron and steel as a waste material to be considered for application in highways or as an aggregate in base or sub-base courses or in bituminous and concrete pavements. The only reference to actual

use of this material outside of the steel industry was as aggregate in high-density concrete for nuclear reactor shields.(139) The scrap used was probably home scrap from steel mills or prompt industrial scrap from manufacturing industries, and not obsolete scrap resulting from discarded metal products.

A study on the use of highway litter in highway construction and maintenance discusses the use of discarded metal cans as aggregate. Since aluminum corrodes with Portland cement, aluminum cans should not be considered. The aluminum cans must be separated from steel cans before possible use of the steel cans. Magnetic separation of the steel cans should also be included in processing to remove any iron. It was concluded that steel cans could be crushed to form a dense aggregate for uses in bases and concrete pavements, but aluminum cans should not be permitted.(80)

Steel fibers have been added to concrete in order to minimize cracking. These fibers are from one-half to two inches long and .010 to .025 inches diameter, about the size of a common straight pin, and are added in amounts varying from 0.2 to 4.0 percent by volume of the concrete. In effect, the steel fibers act as supplemental reinforcing and do not in any way replace aggregate. Conceivably, scrap iron and steel or steel cans could be shredded into slivers suitable for use in fibrous concrete (63); however, shredding steel cans in this way may not be economical. The possible staining effects of rusted scrap particles is not known.

Highway Litter

A study of the potential highway uses of highway litter indicates that highway litter must be combined with other solid wastes in order to provide sufficient quantities to be considered economically feasible. When combined with other solid wastes and properly processed, highway litter can be used as an aggregate replacement for highway construction and maintenance purposes in or near large metropolitan areas. Possible uses are for sub-base and base courses, stabilized bases, concrete and bituminous paving surfaces. Material components of highway litter which are applicable individually or in combination for use as highway aggregate include glass, non-biodegradable plastic polymers, metals, ceramics and fly ash.

Papermill Waste Liquor

Some 2.5 million tons of inorganic sludge waste are generated annually by the paper industry. The nature of the sludge varies with the type of paper being produced, but most sludges possess high ash content. These sludges are clay-like in physical properties and appearance and have a solids content of between 5 and 15 percent. The fixed solids are composed mainly of silica and alumina.

These materials can be re-used within the paper industry as fillers for gypsum board and roofing felt. Other possible uses are in the production of synthetic lightweight aggregate using various additives, production of concrete block and firebrick, and as a product filler for the rubber and tile manufacturing industries.(88)

Steel Furnace Dust

The steel making industry, in addition to other wastes cited previously, also produces over 2 million tons of dusts annually from the operation of the steel furnaces. These dusts are not produced in great quantities at individual steel plants. The dust material is a grayish black powdery material less than 1 micron particle size and are similar in appearance to foundry waste dusts. Although these dusts exhibit variable chemical composition, depending upon furnace type and grade of steel produced, generally, they are composed of as much as 30 to 55 percent iron and 3 to 15 percent zinc.

Because of their high iron content, recycling to the steel furnaces is a logical approach. However, these dusts cannot be recycled in their existing physical state and, although several processes have been developed for removal of impurities such as lead and zinc, only minor amounts are being recycled.

These dusts can be pelletized and fired into pellets of high iron content, equivalent to iron ore pellets, which could be recharged into steel making furnaces.(12) The possibility of using manufactured pellets from steel furnace dusts as aggregate replacements in highways is remote because the most suitable use would be by the steel industry and volumes are not sufficient to satisfy local aggregate needs.

Polymer Concrete

Of particular interest to engineers is the development of polymer concrete. Concrete-polymer materials are the result

of years of research sponsored jointly by the Atomic Energy Commission and the United States Department of the Interior. These materials are composites of concrete and plastic polymers applied by different methods. The polymerization of monomers imparts greatly increased tensile and compressive strength resistance to chemical attack and freeze-thaw resistance to concrete mixtures. Monomers are polymerized by radiation or by a thermal-catalytic process.

There are four basic types of concrete polymer composites:

1. Polymer impregnated concrete (PIC), which is a hardened Portland cement concrete impregnated up to 6 percent by weight with a low viscosity monomer and polymerized.
2. Polymer cement concrete (PCC), which is a mixture of aggregate, Portland cement, water, and liquid monomer. This mixture is polymerized after placement.
3. Polymer concrete (PC), which is a mixture of aggregate and liquid monomer. This mixture is also polymerized after placement.
4. Polymer mortar (PM), which is a mixture of fine aggregate and liquid monomer, also polymerized after placement.(127)

Another development in this field is the impregnation of rocks (or aggregate) with various monomers and subsequent

polymerization. This technique was initiated in order to increase strength in mine support systems;(52) but, there are possible applications with respect to low-quality aggregate materials for use in highways.

Polymer impregnated concrete uses in highways are limited and do not exhibit great potential at this time for highway applications involving waste materials. However, it must be noted that concrete mixtures containing refuse and sewage sludge have been impregnated and polymerized on site and attained compressive strengths up to 3700 psi. A mixture of broken waste glass and monomer was polymerized and developed a compressive strength of 16,000 psi with only a 6 percent polymer content.(231)

In addition, the Federal Highway Administration, and the American Association of State Highway and Transportation Officials through the NCHRP Program (Project 18-2), are supporting work in impregnating in-place concrete to various depths to improve durability. Polymer-impregnated concrete may also have useful applications in the use of precast bridge deck sections. (127) However, these possibilities do not necessarily involve the use of waste materials in concrete.

Because it is a premixed material, polymer cement concrete probably has more potential for field application in highway work. The main problem is the incompatibility of most plastics with water, which is needed for the hydration of Portland cement.

Polymer concrete does not involve water; therefore, there is no problem with the compatibility of the organic monomer. Research is directed toward determining optimum gradation and

polymer loading. Tests of physical and chemical properties of concrete-polymer composites are still being conducted, but polymer concrete may develop as the most promising of these composites. Polymer concrete and polymer cement concrete both afford an opportunity for substituting waste materials as aggregates.

Polymer mortar has not been researched to any great extent in the United States. Its most obvious potential applications are for use as overlays for roadways and bridge decks, protective coatings for structures, hydraulic linings and grouting material.(127)

Spent Oil Shale

Untapped oil shale in the United States probably contains more than 2,000 billion barrels of petroleum. The richest known deposits are the reserves of the Green River formation, which extends through parts of Colorado, Utah, and Wyoming. Approximately 70 percent of all known oil shale reserves are on Federal land. For this reason, there is not yet a well developed commercial oil shale industry.

Since World War II there have been several major programs undertaken to develop the processing of oil from oil shale deposits. The most extensive of these programs was operated at Parachute Creek in Western Colorado, where the oil shale is mined, crushed to one-half inch sizes, preheated, mixed with heated one-half inch ceramic balls in rotating drums, and heated to 900° F. Oil vapors are drawn off, condensed, and treated in conventional

oil processing units. The processed shale and ceramic balls are separated. The balls are recirculated while the processed shale is cooled, moistened, and transported to a disposal site.

Depending on the retorting method used, the processed shale may vary in size from fine granular particles to lumps of up to 3 inches in diameter.(177) Large particle sizes result from the shaft retorts, while the more finely divided shale comes from rotating kiln retorts. The finely divided spent shale resembles a sandy or silty soil and possesses pozzolanic properties which account for increasing cohesion with increased water content. High burning temperatures do cause a reduction of pozzolanic activity.

The shale ash can be ground, moistened and compacted with possible strengths of 2000 psi or more. Leaching of calcium, sodium and potassium salts can be a potential problem.

Studies have been made of the engineering properties of various oil shale ashes for the purpose of defining optimum conditions for stabilized dumps of this material. Because of the uncertainty of development of this resource, combined with its inaccessibility, it does not promise to be a potential replacement for conventional aggregates.(62)

Sulfur

There is presently no excess in the supply of elemental sulfur in the United States. In Canada, the world's largest sulfur producer, the supply is twice the amount used and a surplus situa-

tion exists which, in effect, is nearly the same as a waste product.

Sulfur can be extracted from natural gas, mined by the Frasch process or recovered from the refining of crude oil. Recovery of sulfur dioxide from industrial emissions by scrubber systems produces a sulfur-based sludge waste which has been discussed earlier in this report. It is felt that use of limestone scrubber installations will be an interim solution to the problem caused by these emissions. By the mid-1980's, the technology will probably be developed to economically remove excess sulfur from coal itself, either at the mine or the power plant. Sulfur removal of this type will result in 10 to 30 million additional tons of elemental sulfur, depending on the extent to which low sulfur Western coals will be mined.*

The United States Bureau of Mines forecasts that recovery of sulfur could approach 40 million tons annually by the year 2000, resulting in a surplus of 15 to 20 million tons per year. Realizing this, the United States Bureau of Mines has been exploring potential new uses for sulfur. Previous mention has been made of an impending study of sulfate wastes sponsored by the Federal Highway Administration.(53)

Shell Canada, Ltd., has done extensive research on the possible use of sulfur in bituminous paving mixtures. A mixture of 13.5 percent sulfur combined with 80.5 percent low

* Mr. Harold Fike, Sulphur Institute - Private Communication.

grade sand and 6 percent asphalt has been developed. This mixture, called Thermopave, can be laid over weak subgrades, sets quickly, and requires no rolling. This material possesses low permeability and high skid resistance. However, special care must be exercised when handling sulfur. The mix should not be heated above 300° F because of the production of sulfur dioxide and hydrogen sulfide gases.(97)

Chevron Chemical Company has been researching the use of sulfur foam as a subsurface insulating material for highway sub-base applications. Consisting of 95 percent sulfur, the material can be poured in place as a three-inch bed.

Research into the addition of sulfur for asphalt paving mixtures has been conducted at Iowa State University. One conclusion of this research is that aggregates treated with small amounts of sulfur show improved adhesion and water resistance. It is possible that unsuitable aggregate materials can be made satisfactory for highway use by sulfur treatment.(116)

<u>Oil Refinery Coke</u>

Coke is the carbonaceous residue from the thermal cracking of heavy petroleum oils. There are two types of coke: delayed cokes and fluid cokes. Delayed coke can be crushed to desired size and converted to lightweight aggregate by heating at temperatures up to 1500° F in a fluidized bed reactor. Similar processing of fluid coke converts this material into a lightweight sand substitute.

In addition to petroleum cokes, there are coking coals of high sulfur and ash content which can be coked to make a lightweight aggregate product. The ash content of this product should not exceed 35 percent.

Most of the coke produced today is used to make carbon anodes for use in manufacturing aluminum. Other substantial uses of coke are for fuel purposes and in blast furnaces.(146)

<u>Composted Domestic Refuse</u>

Westinghouse has experimented with the use of composted domestic refuse as a filler material in asphalt wearing courses. The compost was produced by a five-day aerobic process consisting of magnetic and hand separation of non-compostable material, grinding, composting, drying, and final grinding. A mix containing 4.5 percent compost by weight exceeded Marshall stability criteria, but flow values were greater than maximum allowable. Although flow values exceed allowable ranges, this does not necessarily indicate that this material is unsuitable for use as a filler for asphalt wearing surfaces, especially when considering high stability values.

The compost mix was placed as an experimental strip at the Westinghouse Research and Development Center near Pittsburgh. After nearly two years of service, the wearing surface shows no cracks or disintergration and its wearing characteristics are no different from those of a control pavement.(263)

The Federal Highway Administration studied a test installation of compost pavement made at the Transpo '72 demonstration project. The mix was composed of 4.7 percent compost, 88.6 percent natural aggregate, and 7.7 percent asphalt. Marshall stability and flow values obtained from this mixture were

very comparable to those of the Westinghouse experimental pavement. The compost pavement at Transpo '72 was exposed to auto and bus traffic throughout the eight days of the exhibit, with no apparent damage or cracking of the pavement. (263)

There are several possible factors which could hinder incorporating composted domestic refuse in asphalt paving mixtures. The first is the relatively small amounts of the material which are available, since composting is not a major means of disposing of solid waste. Another potential problem could be in the biological stability of the composted refuse.

<u>Quarry Waste</u>

The by-products of quarrying and crushing operations from stone quarries have been considered for a long time as unsuitable materials for use in highway or building construction. These materials consist of low quality aggregate, dusts or screenings, and other materials such as clays. Some quarry waste byproducts can be beneficiated to improve quality and used to suplement more acceptable aggregate materials in lower type highway applications. Principal constituents of quarry waste are usually silica and alumina.

These materials often contain similar mineral content as the high quality aggregate from which they are derived.

The State of Florida has used screenings or stone chips as fine aggregate in bituminous mixtures and Portland cement concrete, as well as in the stabilization of soils. The screenings were blended with other fine aggregate materials in the proper proportions to obtain the required stability and gradation of the mixes. However, some carbonate screenings used in concrete pave-

ments resulted in low resistance to polishing and poor skid resistance.*

There are also examples of the use of mobile crushing plants to beneficiate waste rock from road construction projects and convert these wastes into aggregate.

Waste Lime

Waste lime is a by-product from the use of calcium carbide to generate acetylene gas. It occurs either in a dry powdered form resembling commercial hydrated lime or as a wet slurry or sludge. The chemical analysis of the dry by-product resembles the chemical analysis of commercial hydrated lime. However, due to the non-uniform quality of the sludges, these materials are both chemically and physically inferior to commercial hydrated lime.

The National Lime Association conducted an evaluation of carbide wastes and observed that waste limes possess physical properties which are considerably poorer than those of commercial limes. Waste limes are not as basic as commercial limes and, therefore, are not as effective in neutralizing acids. Furthermore, the waste limes can only develop about half of the compressive strength of commercial limes. Generally, there is a lack of uniformity among different sources of these waste by-products and even among samples from the same source.

Based on these findings, the study concluded that the

* Mr. J. D. Gammage, State of Florida - Private Communication.

use of waste limes in road stabilization or acid neutralization applications would be limited. Although some of these wastes may be successfully used, the physical characteristics of the materials are quite variable. This variability could cause uncertain strength development, making efficient use of this waste product impractical.(173)

Another form of waste lime is the powder collected as emmissions from the rotary valve of hydrated lime plants. About 30 percent of the lime dust is burnt. To date, the material has best potential as a liming material for agricultural uses.

C.4 GOVERNMENT USE OF WASTE MATERIALS IN HIGHWAYS

The most logical way of assessing the current use of waste materials in highways is to determine what efforts have been made by local and state governments in the research or field use of these materials. Valley Forge Laboratories contacted the materials engineering personnel of each State Highway or Transportation Department, requesting information concerning the use of waste materials as aggregate in their respective states.

Table C-2 provides an indication of the extent of work being done to date by various states to develop waste materials for highways. All states replied to the initial correspondence and follow-up letters were sent to those states where more information was believed to be necessary. Besides the information presented in Table C-2, further explanation of the work done by several states will help to better understand these applications, as well

TABLE C-2

HIGHWAY USE OF WASTE RESOURCES
BY FEDERAL, STATE AND LOCAL GOVERNMENT

NAME OF STATE	GOVERNMENTAL UNIT	WASTE RESOURCE	TYPE OF APPLICATION	STATE OF THE ART
Alabama	State Highway Department	Fly ash	Concrete	Highway Use
		Open hearth slag	Base course	Highway Use
Arizona	State Highway Department	Fly ash	Clay additive for lightweight aggregate	Laboratory Testing
		Rubber Tires	Bituminous paving	Highway Use
	City of Phoenix	Rubber tires	Hot asphalt-rubber seal treatment	Highway Use
California	Division of Highways	Blast furnace slag	Bituminous and concrete paving	Highway Use
		Steel slag	Bituminous paving	Field Experiment
		Waste glass	Bituminous paving	Field Experiment
		Waste glass	Cement treated base	Field Experiment
		Rubber tires	Bituminous paving	Field Experiment
Florida	Department of Transportation	Quarry screenings	Bituminous paving	Highway Use
		Quarry screenings	Concrete paving	Highway Use
	City of Miami	Boiler slag	Slurry seal treatment	Field Experiment
	City of Tampa	Incinerator residue	Embankments	Highway Use

TABLE C-2 (Continued)

NAME OF STATE	GOVERNMENTAL UNIT	WASTE RESOURCE	TYPE OF APPLICATION	STATE OF THE ART
Idaho	Department of Highways	Phosphate slag	Bituminous and conctete paving	Highway Use
		Mine tailings	Fill material	Highway Use
Illinois	Department of Transportation	Boiler slag	Bituminous wearing surface	Field Experiment
		Blast furnace slag	Bituminous and concrete paving	Highway Use
		Blast furnace slag	Pozzolanic base mixtures	Highway Use
		Fly ash	Pozzolanic base mixtures	Highway Use
		Fly ash	Mineral filler in bituminous paving	Highway Use
	City of Chicago	Incinerator residue	Composition base course	Field Experiment
Louisiana	City of New Orleans	Waste glass	Slurry seal	Field Experiment
Maryland	City of Baltimore	Blast furnace slag	Bituminous wearing surface	Highway Use
Michigan	Department of State Highways	Blast furnace slag	Stone base	Highway Use
		Blast furnace slag	Bituminous and concrete paving	Highway Use
		Fly ash	Mineral filler for bituminous paving	Highway Use

TABLE C-2 (Continued)

NAME OF STATE	GOVERNMENTAL UNIT	WASTE RESOURCE	TYPE OF APPLICATION	STATE OF THE ART
Minnesota	Department of Highways	Taconite tailings	Bituminous paving	Highway Use
		Boiler slag	Bituminous wearing surface	Field Experiment
		Boiler slag	Seal treatment	Highway Use
	City of St. Paul	Taconite tailings	Bituminous paving	Highway Use
Missouri	State Highway Commission	Boiler slag	Bituminous paving	Highway Use
		Mining tailings	Bituminous paving	Highway Use
		Steel slag	Bituminous paving	Field Experiment
Montana	State Highway Commission	Fly ash	Mineral filler in bituminous paving	Highway Use
		Phosphate slag	Stone base	Highway Use
Nebraska	City of Omaha	Waste glass	Bituminous paving	Field Experiment
New York	Department of Transportation	Blast furnace slag	Bituminous and concrete paving	Highway Use
North Dakota	State Highway Department	Lignite fly ash	Lime-fly ash-aggregate base	Highway Use
		Lignite fly ash	Mineral filler for bituminous paving	Highway Use
		Lignite bottom ash	Bituminous paving	Laboratory Testing

TABLE C-2 (Continued)

NAME OF STATE	GOVERNMENTAL UNIT	WASTE RESOURCE	TYPE OF APPLICATION	STATE OF THE ART
Ohio	Department of Transportation	Blast furnace slag	Bituminous and concrete paving	Highway Use
		Steel slag	Bituminous and concrete paving	Highway Use
		Boiler slag	Bituminous and concrete paving	Highway Use
Oregon	Marion County	Rubber tires	Bituminous paving	Field Experiment
	City of Portland	Waste glass	Bituminous paving	Field Experiment
Penn-sylvania	Department of Transportation	Open hearth slag	Cement-treated base	Field Experiment
		Open hearth slag	Bituminous wearing surface	Field Experiment
		Anthracite coal refuse	Bituminous paving	Field Experiment
	City of Philadelphia	Incinerator residue	Bituminous paving	Field Experiment
Texas	City of Houston	Incinerator residue	Bituminous paving	Field Experiment
Utah	State Road Commission	Copper tailings	Embankments	Highway Use
Vermont	Department of Highways	Waste glass	Bituminous paving	Field Experiment
Virginia	Department of Highways	Slate mining waste	Stone base	Highways Use
		Bituminous coal refuse	Stone base	Highway Use

TABLE C-2 (Continued)

NAME OF STATE	GOVERNMENTAL UNIT	WASTE RESOURCE	TYPE APPLICATION	STATE OF THE ART
West Virginia	Department of Highways	Fly ash	Filler in bituminous paving	Highway Use
		Boiler slag	Sub-base or base Material	Highway Use
		Boiler slag	Cement-stabilized base course	Highway Use
		Bituminous coal refuse	Sub-base	Highway Use
Wisconsin	Department of Transportation	Waste glass	Bituminous paving	Labortory Testing
		Rubber tires	Bituminous paving	Laboratory Testing

as potential or actual problems encountered in these projects.

In Arizona, several resurfacing projects were recently completed using granulated tire rubber as a fine aggregate. The City of Phoenix is utilizing ground rubber tires for hot asphalt-rubber seal treatment projects. This work was described earlier in this section. Previous work done by the State of Arizona has found that copper mine tailings are unsatisfactory for use as concrete aggregates or base course materials. Copper smelter waste has been used as aggregate material when supplies were available.

California has also used wastes from the asbestos, boron, and gold mining industries in specific instances, although no detailed information was readily available on these applications. Laboratory and field work has been done to evaluate the stabilizing effect of adding chopped rubber tires, broken glass, and flattened metal cans in highway embankments.

In Connecticut, efforts are being made to arrange for use of discarded rubber tires as an additive in bituminous mixtures. To date, there has been no research of field use of waste materials in Connecticut.

As noted previously, Florida has used screenings from limestone and gravel crushing operations as fine aggregate. A laboratory investigation was conducted for possible use of boiler slag in bituminous mixes and some research was also done on the use of gypsum sand as a stabilizing material.

Boiler slag and blast furnace slag are both specified as coarse and fine aggregate materials in Illinois. No boiler slag was used in highway construction during 1972 in Illinois; but, nearly 25,000 tons of blast furnace slag was used in bituminous, Portland cement, and pozzolanic base mixtures. Fly ash was also utilized, but not as an aggregate replacement. Over 17,000 tons were used as mineral filler in bituminous mixtures and 300,000 cubic yards were used in an experimental highway embankment construction.

Maine has experimented with expanded polystyrene beads as a sub-base insulating material. Although this is not a waste material, use of such insulators in high frost areas is one means of reducing aggregate requirements due to decreased pavement thickness for frost penetration.

The State Roads Commission in Maryland has done no work with utilizing waste materials; however, the City of Baltimore does use blast furnace slag as aggregate in bituminous resurfacing and is anticipating the use of pyrolysis residue. Both uses have been referred to earlier in this section.

Several waste materials are being considered for use in Michigan besides those listed in Table C-2. These include open hearth slag, crushed glass, copper slag, and reclaimed paving material. Tests are being conducted on the swelling characteristics of open hearth slag, but no conclusions have been reached regarding its potential for highway application. Very limited use of crushed glass in asphalt mixes in Michigan has indicated

that use of this material is not economical. Copper slag appears suitable as aggregate where locally available. Reclaimed paving material has been crushed and used as a base course in reconstruction projects.

In Michigan, the gradation of waste materials must meet specification requirements for a particular use. Blending of waste materials with natural aggregates is not permitted.

Taconite tailings are used in Minnesota as an alternate to sand and gravel at the option of the contractor, who must assume responsibility for any problems that might result from using the material. The main difficulty has been lack of cohesion when used as a base or sub-base, due to the non-plastic nature of the fines. The tailings mut be kept continuously wet and the upper portion capped with gravel or stabilized with an asphalt emulsion to carry traffic or provide a stable surface for a wearing surface. When used in bituminous mixes, additional asphalt is needed to provide durability of the pavement.

The use of a mixture of 50 percent boiler slag and 50 percent crushed trap rock appears to be feasible for seal treatments in Minnesota. Borderline stability values have been achieved for preliminary bituminous trial mixes, using boiler slag; but, the testing of durability and skid resistance must be analyzed by field performance before deciding on possible use of boiler slag in bituminous mixtures.

Several hundred thousand tons of phosphate slag have been used as a base course aggregate in the area surrounding Butte,

Montana. The State of Montana has also used fly ash as a mineral filler for bituminous resurfacing mixes.

Tailings from the Moly Corporation's molybdenum mine at Questa, New Mexico, were used in bituminous paving mixtures in New Mexico. About half of the material is crushed as coarse aggregate and half as fine aggregate. The final design mixtures required 20 percent sand filler and 2 percent commercial grade hydrated lime to meet gradation specifications. All installations paved using these tailings have performed satisfactorily to date.

No waste materials are currently being studied or used in Oklahoma. However, research has been conducted at Oklahoma State University on the potential uses of zinc smelter waste. This work has been mentioned earlier in the Appendix.

Use of waste glass and chopped rubber tires have yielded variable results in Oregon. Glasphalt was used to pave the parking area of a local glass company, using a mix containing 40 percent glass. After one winter of service the pavement raveled and the surface progressively broke apart, due to poor bonding of the asphalt to the glass particles.

A bituminous mixture using from 3 to 6 percent chopped rubber (1¼"x1¼" dimension) was blended with conventional aggregate and placed by the Marion County Road Department as a cold mix in 1971. The pavement has provided good service but further applications of chopped rubber tires were abandoned due to poor performance of various tire chopping equipment.

Details of work done in Pennsylvania utilizing open hearth slag and incinerated anthracite refuse on an experimental basis have been discussed in detail previously. Blast furnace slag has been extensively used for highway construction purposes in Pennsylvania and its uses have also been documented in the Appendix.

The Federal Highway Administration is sponsoring a project in the City of Houston, where 240 tons of unfused incinerator residue will be used as the coarse aggregate in an experimental section of bituminous base course. This "Litter-crete" mix will be composed of 75 to 95 percent incinerator residue, 10 to 20 percent natural aggregate, and an asphalt content of 5 to 8 percent. Maximum particle size of the incinerator residue aggregate will be one inch.

The State of Washington is not conducting any research on use of waste materials in highway construction. However, Washington State University has developed a process for firing fly ash into a synthetic aggregate. Work has also been done there on the use of epoxy toppings on a test track utilizing fly ash as a filler. Reclaimed rubber was also used in the epoxy topping.

The use of fly ash, bottom ash, and boiler slag for use in stabilized base courses and bituminous mixes in West Virginia has already been thoroughly discussed. Blast furnace slag has been used in similar applications and in sub-bases. Incinerated bituminous coal refuse has been used on secondary roads as a sub-base

aggregate mixed with Portland cement. Although no records of laboratory work were available, it has been stated that this combination will make an excellent material for use in highway construction. The Appalachian Regional Commission has discussed the possibility of producing synthetic aggregate from bituminous coal waste. So far, the coal waste has only been used in maintenance and shoulder work and to upgrade local roads.

APPENDIX D: EVALUATION OF WASTE RESOURCES

D. 1 DESCRIPTION OF EVALUATION PROCESS

The case for using waste materials in highway construction as part of the structural support system can be prejudiced in two ways. There is a natural reluctance on the part of experienced highway engineers to use materials that by their very name, "waste materials", imply that they are inferior to conventional, time-tested, construction materials. On the other hand, one must guard against the enthusiastic and sometimes exaggerated claims of researchers who have investigated the use of waste materials in laboratory studies.

The feasibility of using a specific waste resource depends on a large number of factors, many of which are interrelated. These factors must be evaluated objectively so that meaningful recommendations can be made.

The evaluation system used in this report considered three major aspects of waste resource utilization: technical, economic, and environmental. Each waste material having potential for use as a highway aggregate replacement was evaluated separately. Certain waste materials were noted in the literature as potential or actual components of stabilized base course compositions and these materials were also evaluated for that purpose.

The basic concept of the waste resource evaluation system is shown schematically in Figure D-1. The final recommendations indicate those waste materials considered most feasible for further research and development as replacements for aggregates in highway construction.

An initial screening process was used for the purpose of isolating waste materials of low potential. Only those waste materials meeting certain minimum requirements were completely evaluated. The next step was to conduct a technical evaluation of all waste materials passing the initial screening process. Following the technical evaluation, the same waste materials were evaluated for their economic feasibility. Based on the results of the technical and economic evaluation process, the waste materials were then placed into groups designating their respective potential for use in highway construction. An assessment of the environmental consequences of using the waste materials in highways was then made.

The overall feasibility for highway use of specific waste materials is based on combining the separate results of the technical, economic, and environmental evaluation process. Final recommendations are weighted more heavily in favor of the technical and economic feasibility, with environmental considerations being used to measure the positive and/or negative aspects of converting the waste material into a highway aggregate.

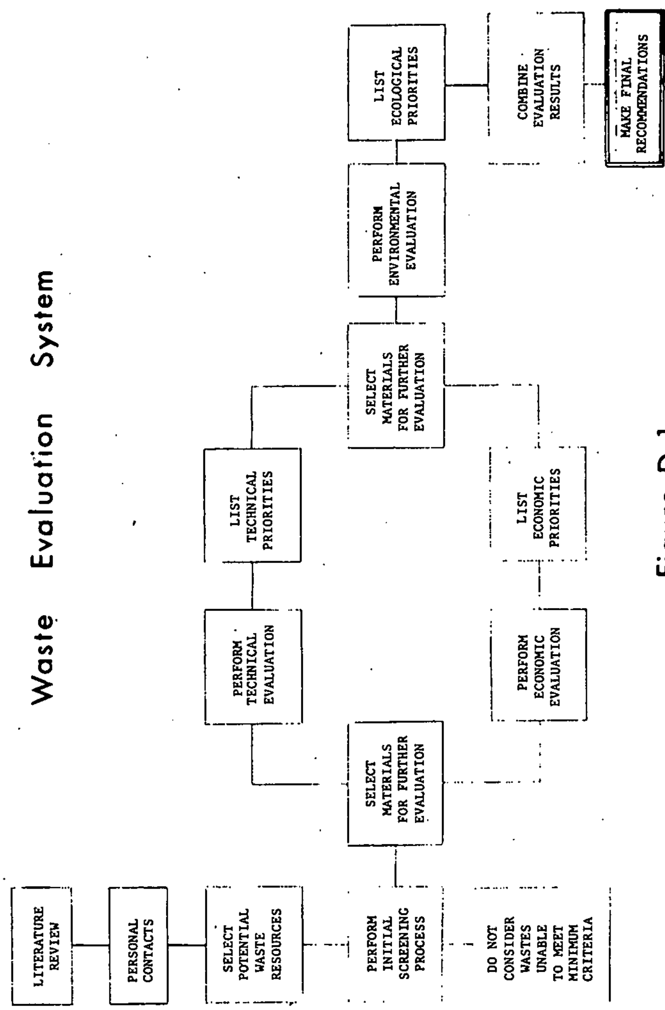


Figure D-1

D. 2. INITIAL SCREENING PROCESS

Some waste materials were classified very quickly as having low potential for use as replacements for conventional aggregates. The following factors served to determine the minimum acceptability of waste materials:

1. Accumulated or annually produced quantity of the waste material at a specific location. Fifty thousand tons per year was considered to be the minimum amount of material capable of fulfilling a reasonable portion of the aggregate requirements for an annual road improvement program at the municipal level. For wastes located in or near larger metropolitan areas, a range of from fifty to one hundred thousand tons is considered a minimum annual requirement. Accumulated quantities should be at least half a million tons.
2. Location of waste material with respect to potential market or usage areas and available modes of transport. The waste material must be located within a reasonable geographic distance from likely points of use or transportation costs will be prohibitive. Forty miles was considered a maximum economical hauling distance for truck transport. A distance of one hundred miles was selected as the maximum economical hauling distance for rail transport,

while three hundred miles was believed to be a maximum economical hauling distance for barge transport. These are approximate guidelines and judgment was exercised when considering the region of the country, since transport rates vary from one territory to another. Furthermore, more than one mode of transport may be employed to move the material from source to processing to market.
3. Is the waste material highly toxic? Will processing sufficiently reduce or eliminate toxicity?
4. Is the waste material composed of substances soluble in water? Will the processed waste material dissolve in the presence of water or leach out potentially harmful substances?

All of the waste materials listed in Appendix B were initally screened. On the basis of the initial screening, the following waste materials were not considered for further evaluation:

1. Ceramic Wastes
   Available quantities are relatively small because accumulations are usually in the form of landfills. Although the production of ceramic waste is not highly significant, the use of locally available quantities as aggregate replacement is possible.

2. Chrysotile or Asbestos Tailings
   In all but a few mining areas, the quantity of material available for use is insufficient for practical consideration.
3. Plastic Waste
   Several obstacles exist regarding possible utilization of plastic waste. It comprises a relatively small portion of total municipal solid waste, comprising only about 2 to 3 percent. It must be separated in order to be used. It may be unstable at temperatures exceeding 140° F.

The possibility does exist that several of the mine tailing wastes, such as lead and zinc tailings, have the potential to leach small amounts of heavy metals which could be harmful.

Although very few pyrolysis plants are currently in operation, this technique will become more widely used, resulting in continuous supplies of potential aggregate material in proximity to market areas. For evaluation purposes, the residue from incineration and pyrolysis operations will be considered jointly.

D. 3. TECHNICAL EVALUATION

D. 3. 1. Description of Technical Evaluation Process

There are two aspects to technical evaluation of waste materials as potential aggregate replacements for highway construction. The first involves a consideration of the properties necessary for an acceptable aggregate. The second is an evaluation, where applicable, of the past performance of the material as an aggregate in highway construction. Table D-1 indicates the properties of aggregates which were considered for the technical evaluation, in accordance with those defined in NCHRP Report No. 135. Table D-1 also

TABLE D-1

AGGREGATE PROPERTY RATING SYSTEM

	STONE BASE	SHOULDER MATERIAL	ASPHALT BASE	ASPHALT SURFACE	CONCRETE BASE OR SURFACE	STRUCTURAL CONCRETE
GENERAL PROPERTIES						
Uniformity	X	X	X	X	X	X
Workability			X	X	X	X
Performance of Pavement	X	X	X	X	X	X
PHYSICAL PROPERTIES						
Presence of Deleterious Substances	X	X	X	X	X	X
Gradation	X	X	X	X	X	X
Particle Shape	X	X	X	X	X	X
Maximum Particle Size	X	X	X	X	X	X
Porosity and Pore Structure	X	X	X	X	X	X
Specific Texture of Particles	X	X	X	X	X	X
Specific Gravity	X	X	X	X	X	X
Skid Resistance of Pavement				X	X	
MECHANICAL PROPERTIES						
Hardness & Soundness of Particles	X	X	X	X	X	X
Particle Strength	X	X	X	X	X	X
Wear Resistance (Polishing)				X	X	
Dusting Potential		X		X	X	
Permeability of Mix	X	X	X	X	X	X
Mass Stability	X	X	X	X	X	X

NOTE: Properties related to specific highway applications are denoted by X.

TABLE D-1 (Continued)

AGGREGATE PROPERTY RATING SYSTEM

	STONE BASE	SHOULDER MATERIAL	ASPHALT BASE	ASPHALT SURFACE	CONCRETE BASE OR SURFACE	STRUCTURAL CONCRETE
CHEMICAL PROPERTIES						
Solubility	X	X	X	X	X	X
Chemical Compatability			X	X	X	X
Resistance to Chemical Attack	X	X	X	X	X	X
Volume Change Due To Wetting & Drying	X	X	X	X	X	X
Resistance to Degradation from Freezing & Thawing	X	X	X	X	X	X
Resistance to Degradation from Wetting & Drying	X	X	X	X	X	X
Oxidation & Hydration Reactivity	X	X	X	X	X	X
Slaking	X	X	X	X	X	X
Surface Charge			X			
Electrical Conductivity				X	X	X
THERMAL PROPERTIES						
Thermal Conductivity					X	X
Coefficient of Thermal Expansion			X	X	X	X
Integrity During Heating			X	X		
OPTICAL PROPERTIES						
Reflectivity		X		X	X	
Glare		X		X	X	
Aesthetic Quality (Color)		X				

indicates the types of highway aggregate applications which were considered and which properties were related to each application.

The number of potential highway applications were determined for each waste material. The relevant properties for each application were then examined. A quantitative rating system was used for examination of each of the properties. A weighted average approach was used in order to properly measure the relative importance of each of the properties with respect to its effect on performance of the material as an aggregate. For instance, the gradation of an aggregate material is normally more critical than the maximum size of the particles. However, the maximum particle size will vary in importance with different types of applications.

It was generally assumed during the process of the technical rating that, when a specific material was obviously unsuitable for aggregate use in its existing state, it could be pelletized and fired into an aggregate product. That is, it was assumed there were no technical limitations on beneficiation to produce some type of aggregate product, regardless of quality.

This detailed approach to evaluation of individual properties had several advantages.

1. It forced the researcher to examine all known properties of the waste material as it exists and in its processed state and to consider all aspects of its potential as an aggregate for different applications. Where information was lacking, comparison with properties of similar materials could be made.
2. It weighed the relative importance of the various properties with respect to each other and as these properties interact in different applications.

3. It avoided making an evaluation of a specific waste material on the basis of one or two outstanding properties, since no single characteristic was used as the basis for forming a judgement of the feasibility of a material.

Disadvantages of this approach were:

1. Some of the properties listed in Table D-1 are related to each other. These inter-relationships were difficult to assess quantitatively.
2. There was no opportunity, within the scope of the project, to test the reliability of the system.

The main difficulty encountered was the wide variation in the amount and detail of information concerning different waste resources and their properties. For those wastes where existing data is meager, a comparison with similar materials was made. Materials such as blast furnace slag, existing lightweight aggregates, pelletized fly ash, bottom ash, waste glass, and incinerated anthracite refuse ("red dog") were used for comparison purposes in most cases. Often, engineering judgement acted as a substitute for specific information. The judgement of the research team was aided considerably by the physical inspection of samples of most of the waste materials under consideration.

A rating system was also established to identify the degree of reliability of the available data used in the evaluation. The rating of data reliability is shown in Table D-2.

As a result of the technical evaluation the waste materials were grouped in order of their relative feasibility. A comparison was then made between the known performance of those waste materials being used as aggregate in highway or building construction and the

TABLE D-2

DATA AVAILABILITY RATING SYSTEM

RATING	EXPLANATION
A	Data which are reliable and directly related to a specific aggregate property.
B	Data which are either not reliable or not directly related to a specific aggregate property.
C	No data available, but a possible comparison can be made with similar materials or prior experience.
D	No data available, and no possible comparison that can be made with similar materials or prior experience.

results of the evaluation of individual waste aggregate properties of the same waste materials. This comparison involved materials such as blast furnace slag, steel slag, fly ash, bottom ash, boiler slag, waste glass, and rubber tires. Where obvious differences resulted from the comparison, adjustments were made in order to effect closer agreement with established performance data.

D. 3. 2. Results of Technical Evaluation

The results of the technical evaluation are presented in Tables D-3 through D-6. Table D-3 lists the waste materials in terms of their potential for general use as aggregates for all highway construction applications. Table D-4 lists the waste materials in terms of potential as a stone base aggregate. Table D-5 lists the waste materials in terms of potential as an aggregate in bituminous mixtures. Table D-6 lists the waste materials in terms of potential as an aggregate in portland cement concrete.

Waste Materials for General Aggregate Use

Each waste material has been placed in one of four classifications (I through IV) according to its potential as determined by the technical evaluation. Almost all the wastes require some processing requirements are shown in Table D-7.

Class I contains those wastes that appear to have the highest potential for use. In general, these wastes require a minimum of processing such as crushing, grading, and blending prior to use. The non-conventional aggregates obtained from these wastes are characterized by having reasonably adequate properties of soundness, hardness, gradation and particle shape, and resistance to chemical or physical deterioration.

TABLE D-3

TECHNICAL FEASIBILITY FOR GENERAL USE AS HIGHWAY AGGREGATE

CLASS I	CLASS II	CLASS III	CLASS IV
Fly Ash	Feldspar Tailings	Alumina Muds	Sewage Sludge
Bottom Ash	Steel Slag	Bituminous Coal Refuse	Nickel Tailings*
Boiler Slag	Anthracite Coal Refuse	Battery Casings	Phosphogypsum *
Gold Mining Waste	Taconite Tailings	Iron Ore Tailings	
Reclaimed Paving Materials	Lead-Zinc Tailings	Slate Mining Waste	
Blast Furnace Slag	Zinc Smelter Waste	Rubber Tires	
	Phosphate Slag	Dredge Spoil	
	Copper Tailings	Sulfate Sludge	
	Waste Glass	Scrubber Sludge	
	Incinerator Residue		
	Building Rubble		
	Phosphate Slimes		
	Foundry Waste		

* Indicated as Class IV due to lack of information

TABLE D-4

TECHNICAL FEASIBILITY FOR AGGREGATE USE IN STONE BASE APPLICATION

CLASS I	CLASS II	CLASS III	CLASS IV
Fly Ash	Slate Mining Waste	Phosphate Slimes	Iron Ore Tailings
Bottom Ash	Steel Slag	Rubber Tires	Sewage Sludge
Boiler Slag	Anthracite Coal Refuse	Foundry Waste	Nickel Tailings*
Zinc Smelter Waste	Taconite Tailings	Dredge Spoils	Phosphogypsum*
Gold Mining Waste	Lead-Zinc Tailings	Bituminous Coal Refuse	
Reclaimed Paving Material	Phosphate Slag	Battery Casings	
Waste Glass	Incinerator Residue	Sulfate Sludge	
Blast Furnace Slag	Feldspar Tailings	Scrubber Sludge	
	Building Rubble		
	Copper Tailings		
	Alumina Muds		

* Indicated as Class IV due to lack of information

TABLE D-5

TECHNICAL FEASIBILITY FOR AGGREGATE USE IN BITUMINOUS MIXTURES

CLASS I	CLASS II	CLASS III	CLASS IV
Fly Ash	Anthracite Coal Refuse	Rubber Tires	Sewage Sludge
Bottom Ash	Lead-Zinc Tailings	Bituminous Coal Refuse	Nickel Tailings *
Boiler Slag	Building Rubble	Foundry Waste	Phosphogypsum *
Zinc Smelter Waste	Steel Slag	Battery Casings	
Gold Mining Waste	Feldspar Tailings	Iron Ore Tailings	
Reclaimed Paving Material	Copper Tailings	Slate Mining Waste	
Taconite Tailings	Phosphate Slag	Dredge Spoil	
Blast Furnace Slag	Alumina Muds	Sulfate Sludge	
Waste Glass	Phosphate Slimes	Scrubber Sludge	
	Incinerator Residue		

* Indicated as Class IV due to lack of information

TABLE D-6

TECHNICAL FEASIBILITY FOR AGGREGATE USE IN PORTLAND CEMENT CONCRETE

CLASS I	CLASS II	CLASS III	CLASS IV
Fly Ash	Feldspar Tailings	Bituminous Coal Refuse	Sewage Sludge
Bottom Ash	Taconite Tailings	Building Rubble	Waste Glass
Boiler Slag	Anthracite Coal Refuse	Iron Ore Tailings	Nickel Tailings*
Gold Mining Waste	Steel Slag	Zinc Smelter Waste	Phosphogypsum*
Reclaimed Paving Material	Foundry Waste	Rubber Tires	
Blast Furnace Slag	Incinerator Residue	Slate Mining Waste	
Phosphate Slag	Alumina Muds	Dredge Spoil	
	Phosphate Slimes	Battery Casings	
	Copper Tailings	Building Rubble	
	Lead-Zinc Tailings	Sulfate Sludge	
		Scrubber Sludge	

* Indicated as Class IV due to lack of information

TABLE D-7

PROCESSING REQUIREMENTS FOR WASTE MATERIALS

REQUIRED PROCESSING STEPS

WASTE MATERIAL	RETRIEVAL OR SEPARATION	DE-WATERING	NEUTRALIZATION	PRELIMINARY CRUSHING	PELLETIZING	SINTERING	FINAL CRUSHING AND SIZING
INDUSTRIAL WASTES							
Alumina Red & Brown Muds	X	X			X	X	X
Phosphate Slimes	X	X			X	X	X
Sulfate Sludges	X	X	X		X	X	X
Fly Ash	X				X	X	X
Bottom Ash	X	X					
Boiler Slag	X						
Scrubber Sludge	X	X	X		X	X	X
Blast Furnace Slag							X
Steel Slag							X
Foundry Waste	X				X	X	X
Phosphogypsum		X			X	X	X

Note: Processing steps required for a specific waste material are denoted by X. For example, alumina red and brown muds require retrieval, de-watering, pelletizing, sintering and final crushing and sizing.

TABLE D-7 (Continued)

REQUIRED PROCESSING STEPS

WASTE MATERIAL	RETRIEVAL OR SEPARATION	DE-WATERING	NEUTRALIZATION	PRELIMINARY CRUSHING	PELLETIZING	SINTERING	FINAL CRUSHING AND SIZING
MINERAL WASTES							
Anthracite Coal Refuse				X		X	X
Bituminous Coal Refuse				X		X	X
Copper Tailings	X	X			X	X	X
Dredge Spoil	X	X			X	X	X
Feldspar Tailings							X
Gold Mining Waste							X
Nickel Tailings					X	X	X
Lead-Zinc Tailings		X			X	X	X
Phosphate Slag							X
Slate Mining Waste				X			
Taconite Tailings		X		X	X	X	X
Zinc Smelter Waste				X			X

TABLE D-7 (Continued)

REQUIRED PROCESSING STEPS

WASTE MATERIAL	RETRIEVAL OR SEPARATION	DE-WATERING	NEUTRALIZATION	PRELIMINARY CRUSHING	PELLETIZING	SINTERING	FINAL CRUSHING AND SIZING
DOMESTIC WASTES							
Building Rubble	X			X			X
Discarded Battery Casings	X						X
Incinerator Residue*	X			X	X	X	X
Reclaimed Paving Material	X			X		X	X
Rubber Tires	X						X
Sewage Sludge	X	X	X	X	X	X	X
Waste Glass	X						X

* Includes Residue From Pyrolysis Operations.

Blast furnace slag is a good example of Class I material because it has hard, angular, cubical particles which can be crushed and graded to meet various specification requirements. It also possesses outstanding resistance to abrasion, soundness of particles, and resistance to the effects of freezing and thawing or wetting and drying. These properties have resulted in the acceptance of blash furnace slag as an aggregate which is suitable for a wide variety of highway construction applications.

Class II contains those wastes that, in general, require more extensive processing and/or whose physical properties are not deemed as adequate as those in Class I. Eight of the fourteen wastes shown in this category in Table D-7, for instance, require pelletizing and sintering.

Incinerator residue was chosen as a Class II material for several reasons. The composition of the residue varies to some extent depending upon the composition of the local refuse being incinerated and the degree of incineration. Although fused incincerator residue does have dense, hard particles, many of the particles are flat and elongated in shape and quite porous. The metallic content of this material causes it to be somewhat magnetic. In order to produce a good aggregate product, incinerator residue should be fused and some separation should take place before the fusion process.

Class III contains wastes that show less promise than those in classes I or II for a variety of reasons. They may require a formidable amount of processing, they may have some outstanding undesirable physical property, or they may have rather non-uniform characteristics. In general, it is felt that these materials could

be used only in local, isolated cases.

An example of a Class III material is dredge spoil. The composition of dredge spoil is highly variable from one location to another, and may contain amounts of organic muck, sludge, mud, wood, pieces of metal, and other undesireable matter. Fine-grained dredge spoils exhibit poor engineering properties because of their compressibility. Differences in particle sizes present some problems when firing dredge spoil. In some cases, the presence of a large amount of clay particles could necessitate additional processing in the form of de-watering.

Class IV contains those wastes that show little or no potential for synthetic aggregate use. At best they might be used in small amounts as a filler or in very specialized applications. In some cases, waste materials for which there was very little available data were placed in this class. These instances have been noted on the appropriate table.

Aggregate Base Applications

Materials considered for aggregate use in base or sub-base applications were evaluated with the following properties considered most important:

1. Gradation.
2. Particle shape.
3. Particle strength.
4. Hardness and soundness of particles.
5. Resistance to degradation from applied loading.
6. Freeze-thaw-resistance.

Portland Cement Concrete Applications

The most important properties required for evaluation of an aggregate material for potential use in a concrete pavement or structure are:

1. Mass stability.
2. Presence of Deleterious substances.
3. Particle shape.
4. Particle size.
5. Hardness and soundness of particles.
6. Particle strength.
7. Chemical reactivity.
8. Thermal compatibility with binder.
9. Freeze-thaw resistance

Bituminous Paving Applications

The following properties are considered most critical in assessing the potential of a waste material for use as an aggregate in bituminous paving mixtures:

1. Mass stability.
2. Gradation.
3. Particle shape.
4. Particle size.
5. Particle strength.
6. Wear resistance (surface applications only).
7. Integrity during heating.

Composition Base Courses

Generally speaking, all processed aggregates which are rated as Class I, II, or III for general use will probably be acceptable

as an aggregate for use in a stabilized base course composition. This refers particularly to the application of lime-fly ash-aggregate and cement-treated base courses. In addition, the combination of lime and fly ash mixed with a material such as scrubber sludge can be processed into an aggregate having some technical feasibility.

D. 4. ECONOMIC EVALUATION

D. 4. 1. INTRODUCTION

The main objective of the economic evaluation was to identify those waste resources that are the most feasible for economical utilization as aggregates in highway construction. The economic evaluation process also served to point out areas where additional information of the type derived from pilot operations and demonstration projects is sorely needed.

Benefit-cost analysis is a well-developed tool for highway planning, but widespread use of the benefit-cost technique has still not overcome the problem of assessing costs and benefits for intangible factors. The intangible aspects of the economic and social factors related to the disposed and/or use of waste materials presents even more difficulty. This, together with the unspecific nature of the economic evaluation in this study, makes it necessary to caution the interested reader concerning the following:

1. The use of approximate costs for processing, transportation, and construction enables one to make a gross economic analysis which, only within broad limits, can establish the feasibility of use of a synthetic aggregate made from waste materials.

2. In a local, competitive, real-life situation, an extensive marketing study, supported by exact current costs, would be required in order to determine more precise costs per ton and enable a truer comparison to be made with conventional aggregates.

D. 4. 2. DESCRIPTION OF ECONOMIC EVALUATION PROCESS

The initial step in the economic evaluation process was to develop reasonably reliable cost figures for disposal and transportation of specific waste materials and for the processing operations that might be necessary to convert the waste into a synthetic aggregate.

These costs were developed for selected waste resources believed to be fairly representative of the different types of wastes being considered. Development of such costs provided an initial impression of economic feasibility for certain materials.

Following an examination of the cost factors, each waste material was further evaluated with respect to a number of related economic factors.

D. 4. 3. DEVELOPMENT OF COST FIGURES

DISPOSAL COSTS

The cost of disposing of a waste material is an important input in the determination of the economic feasibility of utilizing a specific waste material. If the waste material can be processed at its source and eliminate or reduce current disposal costs, such a savings may be reflected in the overall price of the finished product.

Generally, it can be expected that disposal costs for any waste

material considered for use as an aggregate in highways will be reduced somewhat by processing at the source. However, the demand for highway aggregate is seasonal in many regions. This requires stockpiling in order to meet peak requirements. Disposal costs will not usually be eliminated or even significantly reduced and any savings due to reduced disposal costs may be marginal. Some wastes are disposed of in such a condition that they must be stockpiled or ponded for a definite period of time in order to be considered physically suitable for development as an aggregate product. Examples are phosphate slimes, alumina red and brown muds, and steel slag. For these wastes, it is virtually impossible to achieve any reduction of current disposal costs.

As might be expected, disposal costs for different waste materials vary quite widely. Factors affecting disposal costs are the physical state of the waste, type of disposal required, and availability of adequate disposal sites within a reasonable distance of the waste source.

Estimated costs for disposing of Florida phosphate slimes approximate \$.25 per ton of phosphate produced. (23) The amount of slime produced is approximately equal to the phosphate production. At 20 percent solids, the actual disposal cost per ton of useable solid material is more on the order of \$1.25 per ton.

The disposal costs for bituminous coal waste in Kentucky ranges between \$.25 and \$.30 per ton of waste material. These costs are low because of the availability of disposal sites at or near the

source(s) of the waste production. Such costs are probably typical of all large mining operations.

Wastes which cannot always be disposed of at the production site can be expected to incur rapidly increasing disposal costs due to transport of the waste material to an available off-site disposal area. The disposal costs for such materials as fly ash, building rubble, and incinerator residue will vary widely in some areas.

Disposal costs for fly ash normally range from \$.50 per ton to \$2.00 per ton, but in some cases have even been as high as \$15.00 per ton.* The cost of disposing of incinerator residue is presently averaging \$2.50 per ton. (193)

PROCESSING COSTS

Probably the most influential factor in determining the overall economic feasibility of developing a waste material for use as an aggregate product is the cost of processing the material and converting it into a suitable aggregate product. In most cases, the processing of the waste material will represent the most costly input into the economic evaluation process.

Processing costs were determined from the literature or were developed during the study for several typical waste materials, including:

1. Air-cooled steel slag
2. Fly ash
3. Coal refuse
4. Incinerator residue
5. Sulfate sludges
6. Phosphate slimes

* Mr. John Faber, National Ash Association - private communication.

Table D-8 indicates a cost breakdown for the necessary equipment and estimated annual operating costs for processing 120,000 tons per year of air-cooled steel slag. This is essentially a crushing, sizing, and stockpiling operation, similar to the type of processing which might be expected for building and paving rubble and possibly some coarse mine tailing materials.

The estimated cost of \$.75 per ton is well within the limits of economic feasibility and can be considered a realistic figure since expanded air-cooled steel slag normally sells for \$1.00 to \$1.20 per ton F.O.B. plant.

Although waste glass also needs to be crushed and sized, the reluctance of many quarry operators to use their equipment for this purpose has resulted in costs being as high as \$10.00 per ton for the crushing of waste glass. (130)

Table D-9 presents estimated annual operating costs for a sintered fly ash lightweight aggregate processing plant. The estimated capital investment on a 200,000 ton per year plant was taken as \$2.5 million. The annual operating cost for this plant is \$8.09 per ton. By contrast, the annual operating cost for a sintered fly ash processing plant with a 100,000 ton per year capacity is \$11.17 per ton. In Appendix C, the production cost of a 1,000 ton per day plant was given as approximately \$4.00 per ton. These cost figures are comparable to the price range of expanded clay and shale lightweight aggregates. The processing requirements for fly ash are quite similar to those of fine mill tailings and foundry dusts.

Table D-10 compares estimated annual operating costs for processing coal mine refuse by sintering and "cold processing" for a 150,000 ton per year plant capacity. The operating cost for sintering is estimated at \$1.90 per ton, compared to \$.77 per ton for cold processing.

TABLE D-8

ESTIMATED PROCESSING COSTS FOR
AIR-COLLED STEEL SLAG
(PLANT CAPACITY - 120,000 TON PER YEAR)

EQUIPMENT	COST
1. Molten slag cooling and solidifying pits (2)	$250,000.00*
2. Loading equipment	40,000.00
3. Crusher load hopper	5,000.00
4. Jaw crusher or gyratory crusher	15,000.00
5. Intermediate conveyor	3,000.00
6. Screening apparatus	18,000.00
7. Scrap removal conveyor	4,000.00
8. Electro-magnet assembly	20,000.00
9. Stockpile conveyor	20,000.00
10. Buildings	15,000.00
11. Miscellaneous equipment (20%)	28,000.00
TOTAL	$168,200.00

*Equipment already available as part of mill operation

ANNUAL OPERATING COST	
Amortization (10yrs.)	$ 16,820.00
Interest (Average 5%)	8,410.00
Labor (3 @ 8,000.00)	24,000.00
Overhead (@ 50% of Labor)	12,000.00
Supervision (1 @ 12,000.00)	12,000.00
Maintenance (4%)	6,700.00
Fuel and Electric	10,000.00
TOTAL	$ 89,930.00

$89,930.00 / 120,000 Tons = $.75 Per Ton

SOURCE: I. U. Conversion Systems, Inc.

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TABLE D-9 (Continued)

Assume $1,750,000 Capital Investment - 100,000 TPY (20hrs./day at 20 TPH) 3 shifts/day - 5 days/wk. - 50 wks./yr.

ANNUAL OPERATING COST	
Amortization (10Yr.)	$ 175,000.00
Interest (4% Avg.)	70,000.00
Labor (14 at $8,000)	112,000.00
Supervision (15,000 + For. 12,000)	27,000.00
Overhead (50% Labor and Supervision)	69,500.00
Maintenance at 4%	70,000.00
Fuel (400,000 BTU/Tons at 60¢/M.BTU)	24,000.00
Electric Power (200 HP at 1½¢/KWH)	7,000.00
Taxes and Insurance at 2½%	44,000.00
G. & A. (15% Labor and Supervision and Overhead)	31,000.00
Fly Ash at $.50/Ton	50,000.00
PROCESSING COSTS	$ 679,500.00
RETURN ON INVESTMENT AT 25%	438,000.00
TOTAL ANNUAL COST	$1,117,500.00

$1,117,500.00 / 100,000Tons = $11.17/Ton

SOURCE: I.U. Conversion Systems, Inc.

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TABLE D-9

ESTIMATED PROCESSING COSTS
FOR SINTERED FLY ASH AGGREGATE PLANT
(PLANT CAPACITY - 100,000 TONS PER YEAR)

Assume $2,500,000.00 Capital Investment - 200,000 tons per year (20 hrs./day at 40 tons per hour for lightweight aggregate plant.

ANNUAL OPERATING COST	
Amoritization (10yr.)	$ 250,000.00
Interest (4% Average)	100,000.00
Labor (20 at $8,000.00)	160,000.00
Supervision (15,000 + For. 12,000)	27,000.00
Overhead (50% Labor and Supervision)	93,500.00
Maintenance at 4%	100,000.00
Fuel (400,000 BTU/T. at 60¢/M.BTU)	48,000.00
Electric Power (300 HP at 1½¢ KWH)	10,500.00
Taxes and Insurance at 2½%	62,500.00
G. & A. (15% Labor, Supervision and Overhead)	42,000.00
Fly Ash at $.50/Ton	100,000.00
PROCESSING COSTS	$ 993,500.00
RETURN ON INVESTMENT AT 25%	625,000.00
TOTAL ANNUAL COST =	$1,618,500.00

$1,618,500 / 200,000 Tons = $8.09/Ton

(Continued)

SOURCE: I.U. Conversion Systems, Inc.

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TABLE D-10

ESTIMATED PROCESSING COSTS FOR
COLD PROCESSING OF COAL MINE REFUSE
(PLANT CAPACITY = 150,000 TONS PER YEAR)

EQUIPMENT	COST
1. Reclaimation and loading	$ 40,000.00
2. Crusher load hopper	5,000.00
3. Jaw Crusher	20,000.00
4. Intermediate conveyor	3,400.00
5. Secondary crusher hopper	3,000.00
6. Secondary crusher	17,000.00
7. Conveyor	8,500.00
8. Screening apparatus	18,000.00
9. Stockpile conveyor	20,000.00
10. Buildings	15,000.00
11. Miscellaneous Equipment (20%)	30,000.00
TOTAL	$179,900.00

ANNUAL OPERATING COST	
Amortization (10yrs.)	$ 17,990.00
Interest (Average 5%)	8,995.00
Labor (3 @ 8,000.00)	24,000.00
Overhead (@ 50% of Labor)	12,000.00
Supervision (1@ 12,000.00)	12,000.00
Maintenance (4%)	7,000.00
Fuel and Electric	10,000.00
PROCESSING COSTS	$ 91,985.00
RETURN ON INVESTMENT AT 25%	22,905.00
TOTAL ANNUAL COST	$114,890.00

$114,890.00 / 150,000 Tons = $.77 Per Ton

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TABLE D-10

ESTIMATED PROCESSING COSTS FOR
SINTERED COAL MINE REFUSE
(PLANT CAPACITY = 150,000 TONS PER YEAR)

EQUIPMENT	COST
1. Reclamation and loading	$ 40,000.00
2. Crusher load hopper	5,000.00
3. Jaw Crusher	20,000.00
4. Intermediate conveyor	3,400.00
5. Fuel storage and feeders	12,500.00
6. Sinter strand feed hopper	6,400.00
7. Sinter strand	300,000.00
8. Cooling area conveyor	4,500.00
9. Cooling area stockpile	1,500.00
10. Front end loader	40,000.00
11. Crusher feed lopper	5,000.00
12. Secondary crusher	20,000.00
13. Conveyor	3,400.00
14. Screening apparatus	18,000.00
15. Stockpile conveyor	20,000.00
16. Buildings	15,000.00
17. Miscellaneous equipment (20%)	102,940.00
	$617,640.00
Scrubbing equipment	100,000.00
TOTAL	$717,640.00

(Continued)

TABLE D-10 (Continued)

ANNUAL OPERATING COST	
Amortization (10yrs.)	$ 71,764.00
Interest (Average 5%)	35,882.00
Labor (5 @ 8,000.00)	40,000.00
Overhead (@ 50% of Labor)	20,000.00
Supervision (1 @ 12,000)	12,000.00
Maintenance (4%)	28,705.00
Fuel and electric	20,000.00
PROCESSING COSTS	$228,351.00
RETURN ON INVESTMENT AT 25%	57,090.00
TOTAL ANNUAL COST	$285,441.00

$\frac{\$285,441.00}{150,000 \text{ Tons}} = \$1.90$ per ton

SOURCE: I.U. Conversion Systems, Inc.

Table D-11 shows an estimated annual operating cost of $4.16 per ton for fused municipal incinerator residue, based on a continuous operation where 37,500 tons of incinerator residue are densified into 31,750 tons of aggregate per year. This corresponds to an incinerator plant with a capacity of 150,000 tons of munic-pal refuse per year. For an intermittent operation, the annual operating costs can be expected to be as high as $8.00 per ton. (193)

Table D-12 projects a cost of $3.83 per ton for pelletizing ponded sulfate sludge without sintering. This cost is comparable to the cost of pelletizing a lime-fly ash-sulfate sludge mixture without sintering, indicated at $5.35 per ton in table D-13.

The cost of a de-watering or sludge thickening operation may often be the single most expensive step in the processing of a waste material. The cost of drying phosphate slimes in a fluid bed reactor has been estimated at $5.50 per ton. This figure does not include pelletizing and sintering costs. Total processing costs for phosphate slimes are estimated at $9.00 per ton. (254)

A unique method of processing coal refuse and taconite tailings has recently been proposed, based on bench-scale experimentation. Tests have indicated that carbonate bonding techniques can impart high strength to piles or layers of these waste materials at comparatively low costs. For example, a 2 inch thick layer of asphalt on a 12 inch thicklayer of carbonate bonded coal refuse sub-base will cost $5.17 per square yard, compared with $7.87 per square

TABLE D-11

ESTIMATED PROCESSING COSTS FOR
MUNICIPAL INCINERATOR RESIDUE DENSIFICATION UNIT
(PLANT CAPACITY = 31,750 TONS AGGREGATE PER YEAR)

EQUIPMENT	COST
1. Residue conveyor	$ 4,000.00
2. Hammermill (Williams GP 1512)	5,000.00
3. Screw Feeder (into Rotary Furnace)	6,000.00
4. Rotary furnace (With scrubber and afterburners)	135,000.00
5. Fusion furnace (With burners)	25,000.00
6. Product Removal Jacks	6,000.00
7. Product Gripper and Cutter	5,000.00
8. Air Blowers	4,000.00
9. Product conveyer (From cooling pits to jaw crusher)	15,000.00
10. Blake-jaw-crusher	6,000.00
11. Building (40'X50' area @ $20/ft^2)	40,000.00
12. Instrumentation and Controls (@ 6% of Equipment Cost)	12,000.00
Sub-Total	$263,000.00
13. Contingencey (@15%)	39,000.00
TOTAL	$302,000.00

(Continued)

TABLE D-11 (Continued)

ANNUAL OPERATING COSTS

1. Fuel (Natural Gas @ $1.10/1,000 cu. ft., 1,070 cu. ft./Ton)	$ 37,400.00
2. Electrical Power (Conveyors, rotary, jacks, grinder, and crusher: 102 HP, 6000 hrs. @ $.007/KWH)	3,230.00
3. Labor (1 Operator/shift, 3 shifts/day, plus 1/3 foreman/shift)	49,000.00
4. Maintenance (@ 3% capital cost)	9,060.00
5. Capital charges (Principal and interest paid over 15 yrs. @ 7.5% interest/yr.)	33,650.00
TOTAL	$132,340.00

$\frac{\$132,340}{31,750 \text{ Tons}}$ = $4.16 Per Ton

SOURCE: Franklin Institute Research Laboratories

TABLE D-12

ESTIMATED PROCESSING COSTS FOR
PONDED SULFATE SLUDGE PELLETIZING PLANT
(PLANT CAPACITY = 87,500 TONS PER YEAR)

EQUIPMENT	COST
1. Clam shell loader	$ 60,000.00
2. Primary hopper or tank	7,000.00
3. Pumping	4,500.00
4. Vacuum filters (2)	120,000.00
5. Filter cake conveyor	3,400.00
6. Hopper	2,000.00
7. Screw Feeder	3,000.00
8. Mixers (Pug mill) (2)	22,000.00
9. Additive Storage Bins (2)	54,000.00
10. Additive Feeders (2)	7,600.00
11. Additive conveyors (2)	8,000.00
12. Mixer Feed Hoppers (2)	4,000.00
13. Mixer Discharge conveyor	3,000.00
14. Pelletizer feed hoppers (2)	4,000.00
15. Pelletizers (2)	140,000.00
16. Discharge conveyor	3,500.00
17. Stockpile conveyor	22,500.00
18. Buildings	20,000.00
19. Miscellaneous equipment (20%)	97,700.00
	$586,200.00

(Continued)

TABLE D-12 (Continued)

ANNUAL OPERATING COST

Amortization (10yrs.)		$ 58,620.00
Interest (Average 5%)		29,310.00
Labor (3 @ 8,000)		24,000.00
Overhead (@ 50% of Labor)		12,000.00
Supervision (1 @ 12,000)		12,000.00
Maintenance (4%)		23,448.00
Fuel and Electric		12,000.00
	Sub-Total	$171,378.00
Additives		96,250.00
TOTAL PROCESSING COSTS		$267,628.00
RETURN ON INVESTMENT AT 25%		66,907.00
TOTAL		$334,535.00

$\frac{\$334,535.00}{97,500 \text{ Tons}}$ = $3.83 Per Ton

SOURCE: I. U. Conversion Systems, Inc.

TABLE D-13

ESTIMATED PROCESSING COSTS FOR
LIME-FLY-ASH NEUTRALIZED SULFATE SLUDGE PELLETIZED PLANT
(PLANT CAPACITY = 87,500 TONS PER YEAR)

EQUIPMENT	COST
1. Clam shell loader	$ 60,000.00
2. Primary hopper or tank	7,000.00
3. Pumping	6,400.00
4. Vacuum Filters (2)	120,000.00
5. Filter Cake Conveyor	3,400.00
6. Hoppers	4,000.00
7. Screw feeders (2)	6,000.00
8. Dryers (2)	620,500.00
9. Dryer Discharge conveyor	4,200.00
10. Additive Bin (1)	27,000.00
11. Additive feeder	3,100.00
12. Pug mill mixer (1)	11,000.00
13. Pelletizer feed conveyor	3,400.00
14. Pelletizer feed hoppers (2)	4,100.00
15. Pelletizers (2)	140,000.00
16. Discharge conveyor	3,500.00
17. Stockpile conveyor	22,500.00
18. Buildings	20,000.00
19. Miscellaneous equipment (20%)	213,220.00
TOTAL	$1,279,320.00

(Continued)

TABLE D-13 (Continued)

ANNUAL OPERATING COST	
Amortization (10yr.)	$127,932.00
Interest (Average 5%)	63,966.00
Labor (4@ 8,000.00)	32,000.00
Overhead (@ 50% of Labor)	16,000.00
Supervision (1 @ 12,000.00)	12,000.00
Maintenance (4%)	51,173.00
Fuel and Electric	20,000.00
Cost of additives	50,000.00
PROCESSING COST	$373,071.00
RETURN ON INVESTMENT AT 25%	93,267.00
TOTAL	$466,338.00

$\frac{\$466,338.00}{87,500 \text{ Tons}} = \$5.35$ Per Ton

SOURCE: I. U. Conversion Systems, Inc.

yard for 4 inch concrete on a 6 inch sub-base, or $7.62 for 3 inch asphalt on a 12 inch sub-base. (35)

Although the foregoing figures provide the reader with an idea of the range of processing costs for various waste materials, many factors operate to make such estimates difficult to predict. The capacity of the plant is a principal factor. Type of operation, intermittent or continuous, also has a big influence on cost. The cost of labor, fuel, taxes, and interest must also be carefully studied when considering such processing on a competitive basis.

CONVENTIONAL AGGREGATE COSTS

Processing costs for synthetic aggregates are meaningful when compared with the cost of conventional aggregate materials. Obviously, the cost of conventional aggregates will vary from one location to another, depending on the availability of these materials. Table D-14 summarizes the cost of sand, gravel, crushed stone, and lightweight aggregate products for twenty major metropolitan areas, according to recent construction cost index figures from Engineering News-Record. These figures are the material cost F.O.B. plant, not including transport costs, and provide some basis of comparison with the cost of processed waste materials.

TRANSPORTATION COSTS

Several alternatives are available for the transport of waste materials. The most feasible of these are truck, rail, and barge. Air transport is not practical because the expense involved in prohibitive. Pipelines, although advantageous from a cost standpoint, present problems regarding ownership and the type of material which can be pumped through the facility.

TABLE D-14

AGGREGATE COSTS IN MAJOR METROPOLITAN AREAS

(DOLLARS PER TON F.O.B. PLANT)

LOCATION	1½" GRAVEL	3/4" GRAVEL	SAND	1½" CRUSHED STONE	3/4" (STONE
Atlanta	$2.92	$3.13	$2.82	----	----
Baltimore	2.95	2.95	2.60	$2.35	$2.95
Birmingham	----	1.65	6.45	1.60	1.65
Boston	3.25	3.25	3.00	3.36	3.65
Chicago	4.25	4.25	4.70	2.95	2.95
Cincinnatti	1.90	1.90	1.69	2.20	2.20
Cleveland	5.35	4.85	4.40	4.60	4.60
Dallas	2.75	2.75	2.00	2.00	2.25
Denver	2.95	2.95	1.77	----	----
Detroit	2.20	2.93	0.95	2.40	2.50
Kansas City	4.50	4.50	1.25	3.00	3.00
Los Angeles	5.00	5.70	4.80	6.60	6.10
Minneapolis	4.45	4.45	3.45	6.60	6.60
New Orleans	5.20	5.20	----	----	----
New York	----	3.75	4.10	3.73	3.73
Philadelphia	----	3.85	2.95	4.13	4.13
Pittsburgh	5.55	5.55	5.65	5.50	5.70
St. Louis	----	5.00	5.00	1.55	1.55
San Francisco	3.36	3.36	3.52	3.88	3.88
Seattle	4.00	4.00	4.00	4.75	4.75

SOURCE: Engineering News-Record, Vol. 190, No. 19, May 10, 1973.

BARGE TRANSPORT

The most reasonable form of transportation, where available, is barge transport. Determination of precise rates for barge transport of a specific commodity can often be difficult, particularly if the commodity is a waste material not subject to tariff restrictions. In this case, barge companies can charge exempt rates which can vary according to the commodity, the points of origin and destination, local regulations, lock and channel limitations, and whether the haul is upstream or downstream. Upstream rates are usually higher than downstream rates.

Barge rates are not usually available for waste materials and such materials which lack a commodity designation fall under an all-commodity rate of $2.87 per ton, also subject to ex parte increases. By comparison, sand can be shipped from Peoria to Chicago, a distance of 150 miles, for $1.00 per ton. (251)

Although rates vary from origin to destination, barge rates for the same commodity are normally about one-quarter of rail rates and the potential is available for moving large tonnages. The standard open-top coal barge is rated at 1000 tons and the jumbo barge at 1500 tons. In the larger navigable waterways, barges are towed in combinations of as many as 30 jumbo barges. (112) Locations of navigable waterways are shown in Figure B-5.

RAIL TRANSPORT

The subject of rail rates is both fascinating and confounding. Interstate rates for movement of goods are regulated by the Interstate Commerce Commission (I.C.C.). Rates for intra-state movements are established by the different rail companies subject to I.C.C.

approval. The I.C.C. regulates rail rates, as well as rates for other forms of transport, in such a way that the rates between various modes are not directly competitive.

Rail rates vary from one territory to another. The United States is divided into five territories. Generally, the official territory, which is composed of the Northeast part of the country, has the highest rail rates for a particular commodity. Rates also vary from one commodity to another and can be widely different for the same commodity when hauling between different locations, regardless of the mileage involved. In fact, the rate for hauling between the same two points in opposite directions can be significantly different.

The type of rail equipment needed for transporting most waste materials would be hopper cars, although tank cars could be used for transporting slurry-type wastes.

The hauling rate for a particular commodity can only be determined by negotiation with an individual rail carrier. Their rates are based on tariff schedules which have been established for many different commodities. These rates are quoted for point to point hauls, usually in terms of cents per hundred-weight, and do not necessarily reflect charges per unit of distance.

For example, coal refuse can be hauled from Scranton to Philadelphia either in box cars or hopper cars for an average of $.35 per hundred-weight. Fly ash can be hauled from Harrisburg to Philadelphia, approximately the same distance, for an average of $.23 per hundred-weight. Fly ash is considered a recyclable material, causing a lower tariff rate. To haul glass from Harrisburg to

Philadelphia in hopper cars would cost $.36 per hundred-weight. It would cost $.48 per hundred weight if hauled between the same two points by box car. Therefore, the complexity of determining rail transportation costs applicable to all situations can be easily demonstrated.

One concept, used by the coal industry, which could prove beneficial when considering a large scale processing and marketing operation involving waste materials is the "unit train". A "unit train" is a train in which all cars are used to transport the same commodity from one point to another with a definite minimum tonnage in order to qualify for special rates. A "unit train" normally consists of 140 hopper cars of 125 ton nominal capacity, having the capability of transporting 17,400 tons of coal at approximately $.12 per hundred-weight using railroad-owned cars, over a 450 mile hauling distance. Another unit train completes a 300 mile haul at a rate of $.065 per hundred-weight. (112)

Most rail carriers are reluctant to quote rates for unit train movements. Theoretically, a unit train can move any commodity where a rate has been established. In reality, it is not known whether other commodities besides coal have been transported by unit train, but there have probably been very few others. The Penn Central, Reading, and Delaware and Hudson Railroads all indicated that unit trains cannot be used to haul coal waste. However, a request for unit train rates for a certain commodity can be made to the Territory Freight Bureau, stating the commodity, amount to be transported, rate desired, and supporting information for that rate. A decision will then be made by the Freight Bureau on whether

or not to grant a unit train rate for the particular commodity.

TRUCK TRANSPORT

Truck hauling rates for Interstate or government deliveries are subject to regulation by the Interstate Commerce Commission(I.C.C.). Intra-state movements are regulated by State Public Utility Commissions (P.U.C.). Truck haulers use the P.U.C. or I.C.C. tariffs where applicable, but, unlike rail rates which can vary widely from point to point for different commodities in different areas, truck haul rates are somewhat more standardized. As a general rule of thumb, truck haul rates can be figured on the basis of $.25 per ton for the first mile and $.05 per ton for each additional mile. Thus a forty mile haul will probably cost $2.30 per ton, which in many cases will equal the cost of conventional aggregates at the plant.

D. 4. 4. DEVELOPMENT OF ECONOMIC FACTORS

Cost figures for processing and transporting waste materials are subject to wide variations. Furthermore, economic and social factors related to the disposal of wastes and generation of markets for their use are not always clearly defined.

Therefore, as a further guide in determining economic feasibility, each waste resource was studied to assess its relationship with economic factors developed to measure overall potential for economical development. These factors are defined in Table D-15.

Each waste resource was evaluated with respect to the following factors:

1. Location and Quantity.

   This factor was examined closely with respect to location of potential market areas, aggregate deficiencies, and transportation modes relative to the

TABLE D-15

FACTORS INFLUENCING ECONOMIC FEASIBILITY
FOR DEVELOPING WASTE MATERIALS AS AGGREGATES

LOCATION AND QUANTITY OF WASTE MATERIALS

1. Accumulated and/or annually produced waste quantities.
2. Proximity to potential aggregate markets, particularly near metropolitan areas.
3. Location with respect to existing or projected aggregate shortages.
4. Access to cheap modes of transportation - barge and rail.
5. Location with respect to other wastes for potential mixing.
6. Location in area with growing demand for aggregates.

APPLICATION OF WASTE MATERIALS IN HIGHWAYS

1. Current acceptability of material for highway aggregate use.
2. Principal use of material is, or would be, for highway aggregate.
3. Possesses outstanding properties to recommend highway use.
4. Technical feasibility is good for overall use as highway aggregate.
5. Technical feasibility is good for aggregate use in stone base.
6. Technical feasibility is good for use in bituminous mixtures.
7. Technical feasibility is good for use in Portland cement concrete.
8. Technical feasibility is good for use in composition mixtures.

TABLE D-15 (Continued)

FACTORS INFLUENCING ECONOMIC FEASIBILITY
FOR DEVELOPING WASTE MATERIALS AS AGGREGATES

RESOURCE VALUE OF WASTE MATERIALS

1. Developed a variety of current or potential uses.
2. Exists in large supply as inert, combinable material.
3. Separation or retrieval of material required.
4. Material possesses some heat value.
5. De-Watering or thickening required before processing.
6. Pelletizing and/or sintering required in processing.
7. Crushing and sizing only required processing steps.
8. High percentage of available waste material is useable after processing.
9. Processed material posses low unit weight.

ECOLOGICAL AND SOCIAL CONSIDERATIONS
RELATED TO WASTE MATERIALS

1. Material is a nuisance because of accumulation or disposal.
2. Contributes to blight near population or recreational areas.
3. Represented by special interest groups.
4. Material is the object of conservation groups efforts.
5. Government interest exists to alleviate specific waste problem.
6. Disposal costs are comparatively high.
7. Disposal sites are a problem.
8. Material presents possible health and safety hazards.

sources and available amounts of the waste material.

2. Application.

This factor relates to the actual use or potential applications for use of the waste material in highways as an aggregate.

3. Resource value.

This factor takes into account the possible value of a material due to other potential or developed uses, heat value, and extent of required processing in order to produce a useable product.

4. Ecological and Social Considerations.

These considerations include such factors as the presence of a nuisance or ecological blight, governmental interest in development of uses for a specific waste material, backing from special interest groups for certain wastes, and conservation efforts possibly directed at specific waste materials.

Table D-16 presents an evaluation of each waste resource with respect to its location and quantity. Table D-17 presents an evaluation of each waste material with respect to its actual or potential application in highways, as determined from the literature or the technical evaluation. Table D-18 indicates the economic potential of each waste material with respect to its value as a resource, as well as the required amount of processing for conversion into an aggregate material. Table D-19 is an evaluation of the ecological and social factors which could influence the economics of developing a specific waste material into an aggregate replacement.

TABLE D-16

ECONOMIC EVALUATION OF THE LOCATION AND
SOURCES OF WASTE MATERIALS

WASTE MATERIAL	LARGE QUANTITIES	NEAR MARKETS	NEAR AGGREGATE SHORTAGES	NEAR CHEAP TRANSPORT	POTENTIAL FOR MIXING	AREA GROWTH
INDUSTRIAL WASTES						
Alumina Red & Brown Muds			X			X
Phosphate Slimes	X		X			X
Sulfate Sludges				X		
Fly Ash	X	X	X	X	X	X
Bottom Ash	X	X	X	X	X	X
Boiler Slag	X	X	X	X	X	X
Scrubber Sludge		X		X		X
Blast Furnace Slag	X	X	X	X	X	X
Steel Slag	X	X	X	X	X	X
Foundry Waste	X	X	X	X	X	X
Phosphogypsum	X		X			X

Note: Location and source factors related to a specific waste material are denoted by X. For example, phosphate slimes are produced in large quantities, are located near aggregate shortages, and are located where area growth is occurring.

TABLE D-16 (Continued)

WASTE MATERIAL	LARGE QUANTITIES	NEAR MARKETS	NEAR AGGREGATE SHORTAGES	NEAR CHEAP TRANSPORT	POTENTIAL FOR MIXING	AREA GROWTH
MINERAL WASTES						
Anthracite Coal Refuse	X	X		X	X	X
Bituminous Coal Refuse	X	X	X	X	X	X
Copper Tailings	X		X			
Dredge Spoil	X	X	X	X		
Feldspar Tailings				X		
Gold Mining Waste	X		X			X
Nickel Tailings			X	X		
Lead-Zinc Tailings	X		X	X		
Phosphate Slag			X			
Slate Mining Waste		X	X			X
Taconite Tailings	X		X	X		
Zinc Smelter Waste			X			

TABLE D-16 (Continued)

WASTE MATERIAL	LARGE QUANTITIES	NEAR MARKETS	NEAR AGGREGATE SHORTAGES	NEAR CHEAP TRANSPORT	POTENTIAL FOR MIXING	AREA GROWTH
DOMESTIC WASTES						
Building Rubble	x	x	x		x	x
Battery Casings		x	x		x	x
Incinerator Residue*		x	x		x	x
Reclaimed Paving Material		x	x		x	x
Rubber Tires		x	x	x	x	x
Sewage Sludge		x	x		x	x
Waste Glass		x	x		x	x

*Includes Residue From Pyrolysis Operations.

TABLE D-17

ECONOMIC EVALUATION OF POTENTIAL
HIGHWAY APPLICATIONS OF WASTE MATERIALS

WASTE MATERIAL	CURRENT HIGHWAY ACCEPTABILITY	PRINCIPAL USE IN HIGHWAYS	OUTSTANDING AGGREGATE PROPERTIES	GENERAL HIGHWAY USE	AGGREGATE BASE	BITUMINOUS MIXTURES	CONCRETE	MIXTURE COMPOSITIONS
INDUSTRIAL WASTES								
Alumina Red & Brown Muds				X	X	X	X	
Phosphate Slimes				X		X	X	
Sulfate Sludges								X
Fly Ash	X	X	X	X	X	X	X	X
Bottom Ash	X	X	X	X	X	X	X	X
Boiler Slag	X	X	X	X	X	X	X	X
Scrubber Sludge		X						X
Blast Furnace Slag	X	X	X	X	X	X	X	X
Steel Slag	X	X	X	X	X	X	X	X
Foundry Waste		X		X			X	
Phosphogypsum		X						X

Note: Highway applications which appear to be potentially feasible for a specific waste material are denoted by X. For example, alumina red and brown muds exhibit feasibility for general highway use and uses in stone base, Bituminous Mixtures and Concrete.

TABLE D-17 (Continued)

WASTE MATERIAL	CURRENT HIGHWAY ACCEPTABILITY	PRINCIPAL USE IN HIGHWAYS	OUTSTANDING AGGREGATE PROPERTIES	OVERALL HIGHWAY USE	STONE BASE	BITUMINOUS MIXTURES	CONCRETE	MIXTURE COMPOSITIONS
MINERAL WASTES								
Anthracite Coal Refuse	X	X	X	X	X	X	X	
Bituminous Coal Refuse		X	X					
Copper Tailings				X	X	X	X	
Dredge Spoil								
Feldspar Tailings		X	X	X	X	X	X	
Gold Mine Waste			X	X	X	X	X	
Nickel Tailings		X						
Lead-Zinc Tailings				X	X	X	X	
Phosphate Slag	X	X	X	X	X	X	X	
Slate Mining Waste	X	X	X		X		X	
Taconite Tailings				X	X	X	X	
Zinc Smelter Waste		X	X	X	X	X		

TABLE D-17 (Continued)

WASTE MATERIAL	CURRENT HIGHWAY ACCEPTABILITY	PRINCIPAL USE IN HIGHWAYS	OUTSTANDING AGGREGATE PROPERTIES	OVERALL HIGHWAY USE	STONE BASE	BITUMINOUS MIXTURES	CONCRETE	MIXTURE COMPOSITIONS
DOMESTIC WASTES								
Building Rubble			X	X	X	X		
Battery Casings		X	X					
Incinerator Residue*		X	X	X	X	X	X	
Reclaimed Paving Material	X	X	X	X	X	X	X	
Rubber Tires	X	X						
Sewage Sludge								X
Waste Glass	X	X	X	X	X	X		

* Includes Residue From Pyrolysis Operations.

TABLE D-18

ECONOMIC EVALUATION OF THE RESOURCE VALUE OF WASTE MATERIALS

WASTE MATERIAL	VARIETY OF USES	INERT AND COMBINABLE	SEPARATION OR RETRIEVAL	HEAT VALUE	DE-WATERING REQUIRED	PELLETIZING AND SINTERING	CRUSHING AND SIZING ONLY	HIGH PERCENT USEABLE	LOW UNIT WEIGHT
INDUSTRIAL WASTES									
Alumina Red & Brown Muds	X		X	X	X	X			X
Phosphate Slimes	X		X	X	X	X			X
Sulfate Sludges		X	X	X	X	X			X
Fly Ash	X	X	X	X	X	X		X	X
Bottom Ash	X	X	X	X	X	X		X	X
Boiler Slag	X	X	X	X			X	X	X
Scrubber Sludge			X	X	X	X			X
Blast Furnace Slag	X	X		X			X	X	
Steel Slag		X		X			X	X	
Foundry Waste		X	X	X		X		X	X
Phosphogypsum			X		X	X			

Note: Resource value factors related to a specific waste material are denoted by X. For example, steel slag is inert and combinable, possesses some heat value, requires only crusing and sizing for use, and a high percentage of the material is useful.

TABLE D-18 (Continued)

WASTE MATERIAL	VARIETY OF USES	INERT AND COMBINABLE	SEPARATION OR RETRIEVAL	HEAT VALUE	DE-WATERING REQUIRED	PELLETIZING AND SINTERING	CRUSHING AND SIZING ONLY	HIGH PERCENT USEABLE	LOW UNIT WEIGHT
MINERAL WASTES									
Anthracite Coal Refuse	X	X		X		X			
Bituminous Coal Refuse	X	X		X		X			
Copper Tailings	X	X		X	X	X			X
Dredge Spoil		X	X		X	X			X
Feldspar Tailings		X					X	X	
Gold Mining Waste		X	X	X			X		
Nickel Tailings		X	X	X		X		X	X
Lead-Zinc Tailings	X	X	X	X	X	X			X
Phosphate Slag	X	X					X	X	
Slate Mining Waste		X					X	X	
Taconite Tailings	X	X	X	X	X	X			X
Zinc Smelter Waste		X		X			X	X	

TABLE D-18 (Continued)

WASTE MATERIAL	VARIETY OF USES	INERT AND COMBINABLE	SEPARATION OR RETRIEVAL	HEAT VALUE	DE-WATERING REQUIRED	PELLETIZING AND SINTERING	CRUSHING AND SIZING ONLY	HIGH PERCENT USEABLE	LOW UNIT WEIGHT
DOMESTIC WASTES									
Building Rubble			X				X		
Battery Casings		X	X	X			X	X	X
Incinerator Residue*		X	X	X		X		X	X
Reclaimed Paving Material	X	X	X	X			X	X	
Rubber Tires	X		X	X			X	X	X
Sewage Sludge			X	X	X	X			X
Waste Glass	X	X	X	X			X	X	X

* Includes Residue From Pyrolysis Operations.

TABLE D-19

ECONOMIC EVALUATION OF ECOLOGICAL AND SOCIAL CONSIDERATIONS RELATED TO WASTE MATERIALS

WASTE MATERIAL	NUISANCE	BLIGHT	SPECIAL INTEREST	CONSERVATION EFFORT	GOVERNMENT INTEREST	HIGH DISPOSAL COST	DISPOSAL SITE PROBLEMS	POSSIBLE HEALTH HAZARD
INDUSTRIAL WASTES								
Alumina Red & Brown Muds	X							
Phosphate Slimes	X	X					X	X
Sulfate Sludges	X				X		X	
Fly Ash	X		X			X	X	
Bottom Ash			X			X	X	
Boiler Slag			X			X	X	
Scrubber Sludge	X		X		X	X		
Blast Furnace Slag			X					
Steel Slag			X					
Foundry Waste	X		X					
Phosphogypsum	X	X					X	X

Note: Political and social considerations related to a specific waste material are denoted by X. For example, fly ash is a nuisance which has representation by a special interest. Fly ash also has high disposal costs and problems associated with availability or regulation of disposal sites.

TABLE D-19 (Continued)

WASTE MATERIAL	NUISANCE	BLIGHT	SPECIAL INTEREST	CONSERVATION EFFORT	GOVERNMENT INTEREST	HIGH DISPOSAL COST	DISPOSAL SITE PROBLEMS	POSSIBLE HEALTH HAZARD
MINERAL WASTES								
Anthracite Coal Refuse	X	X		X	X			X
Bituminous Coal Refuse	X	X		X	X			X
Copper Tailings	X	X					X	
Dredge Spoil	X				X		X	
Feldspar Tailings								
Gold Mining Waste								
Nickel Tailings								
Lead-Zinc Tailings	X							
Phosphate Slag								
Slate Mining Waste								
Taconite Tailings	X	X					X	
Zinc Smelter Waste								

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TABLE D-19 (Continued)

WASTE MATERIAL	NUISANCE	BLIGHT	SPECIAL INTEREST	CONSERVATION EFFORT	GOVERNMENT INTEREST	HIGH DISPOSAL COST	DISPOSAL SITE PROBLEMS	POSSIBLE HEALTH HAZARD
DOMESTIC WASTES								
Building Rubble	X					X	X	
Battery Casings								
Incinerator Residue*	X	X			X	X	X	X
Reclaimed Paving Material								
Rubber Tires	X	X	X				X	
Sewage Sludge	X				X	X	X	
Waste Glass			X				X	

*Includes Residue From Pyrolysis Operations.

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LOCATION OF WASTE SOURCES

The consideration of waste resource locations assumes that the critical use of waste materials as aggregates will be within or surrounding the major metropolitan areas. For this reason, the proximity to potential market areas and transportation facilities are emphasized, together with annual production quantities for each waste material.

The density of the processed waste material would also be a factor in determining how far a material could be economically hauled. Lighter weight materials would be more economical to transport than heavier ones. Processed lightweight aggregate products have some advantage in this respect.

Based on proximity and transport considerations, the most promising resources are fly ash, bottom ash, boiler slag, waste glass, blast furnace slag, steel slag, rubber tires, incinerator residue, building rubble, reclaimed paving material, foundry waste, dredge spoil, and sewage sludge. These wastes are located in areas where they are close to markets and capable of being used in various combinations.

The majority of the mining wastes are distantly located with respect to urban areas and would require substantial hauling. Transportation costs will be a major obstacle to the use of these wastes in any significant quantity.

APPLICATION OF WASTE RESOURCES

There is a definite relationship between the technical capability of a material to perform satisfactorily in certain applications and its potential to be economically developed. Waste materials that have good prospects for technical use should be seriously considered economically. Others that are seemingly not as well suited to specific highway uses can also be considered for possible use at the municipal level or for applications in lower-class roads. Some materials poorly rated from a technical standpoint, could be used as partial aggregate replacements in certain types of highway applications without significantly affecting the properties or performance of the pavement system.

The technical evaluation recommends fly ash, boiler slag, bottom ash, paving rubble, blast furnace slag, and gold mine waste as having the best overall potential for highway use, based on a consideration of aggregate properties. Gold mine waste is the only one of these materials not to have proven its value, as yet. Blast furnace slag has been widely accepted and used for such a long period of time in highway construction that it can almost be considered as an aggregate source instead of a waste material.

Other waste materials which have gained some measure of acceptability for aggregate use by the highway industry are steel slag, waste glass, rubber tires, some mine tailings, coal refuse, incinerator residue, and building rubble. Waste materials which have been used to some extent in base course compositions are the ash wastes, slags, sulfate sludges, and power station scrubber sludges.

It is important to know whether a specific waste material can best be used as highway aggregate or for some other purpose. There are waste materials which could be used in highway or building construction, but for which a more practical or profitable use exists. Economically, wastes in this category should not be as vigorously developed for aggregate purposes, since a good part of the available supply would be consumed in other markets. Examples of such wastes are alumina muds and foundry wastes.

RESOURCE VALUE AND PROCESSING

There are instances in which waste materials have established uses which cause those materials to acquire a value. Ashes, slags, waste glass, and scrap tires are all examples of waste materials which are sold to potential users at a price related in some way to their value for a particular use.

Some wastes have inherent value by virtue of their reclaimable constituents. For example, culm banks or gob piles could be processed by coal companies for extraction of lower grade coal. Tailings banks which have accumulated over many years may contain sufficient low-grade ores to make them attractive for reworking and extraction. Separation techniques can be used to reclaim valuable metallics from fly ash, incinerator and pyrolysis residue, and various mineral wastes.

Another consideration of resource value is the amount of processing required to produce a suitable aggregate from a raw waste material. Processing needs will vary considerably for different wastes, depending upon the physical state of the waste

material.

Waste materials such as anthracite and bituminous coal refuse, incinerator and pyrolysis residue, sewage sludge and rubber tires possess some heating value and could be used to partially fulfill the energy requirements of a sintering or rotary kiln operation. Use of these waste materials as aggregates may be advantageous economically, insofar as fuel costs could be reduced or perhaps even eliminated.

Waste materials recommended because of resource value or ease of processing should be developed according to a priority system which would:

1. Attempt to solve urgent pollution problems.
2. Reduce large accumulations of waste.
3. Utilize waste materials having some heating values.
4. Favor waste materials with minimal processing steps.

On the basis of resource value and probable processing cost, the materials most promising for economical development for highway aggregates are boiler slag, coal refuse, blast furnace slag, steel slag, rubber tires, glass, paving rubble, and incinerator or pyrolysis residues.

ECOLOGICAL AND SOCIAL IMPLICATIONS

Ecological and social pressures most often cannot be measured directly in dollar terms. However, the interest or desire expressed by society in general and by government and the private sector in particular, most often provides the impetus for the solution of problems.

Some waste materials, because of their volume, location, or disposal problems, pose an environmental threat and arouse groups concerned with ecology, wildlife, and preservation. Others, although not attracting such attention, nevertheless are objectionable due to their proximity to major arterials, developed areas, park and recreation areas or public lands. There is some implied social pressure to find means to stabilize, remove, or reuse these wastes because they are a nuisance.

Certain waste materials are represented by special interest groups which are organized for the purpose of developing further utilization of such resources. These groups are responsible for spear-heading research efforts aimed at creating or expanding markets for their respective utilization of these products. Wastes, (such as slag, ash, glass, and rubber), are being vigorously promoted by such organizations. These deserve additional consideration because of extra efforts being made in their behalf.

On the basis of social and ecological pressures, anthracite and bituminous coal refuse, rubber tires, incinerator residue, phosphate slimes, sulfate sludge, sewage sludge, alumina muds, dredge spoil, and to a lesser degree, mining and milling wastes should be developed and utilized.

D. 4. 5. RESULTS OF ECONOMIC EVALUATION

Based on a consideration of relative costs and economic factors the relative economic feasibility of the different waste materials studied is summarized in Table D-20. Those waste materials placed in Class I are most highly recommended for development as aggregates. These include fly ash, bottom ash, boiler slag, anthracite and bituminous coal refuse, blast furnace slag,

TABLE D-20

OVERALL ECONOMIC FEASIBILITY OF
WASTE MATERIALS FOR USE AS AGGREGATES IN HIGHWAYS

CLASS I	CLASS II	CLASS III	CLASS IV
Fly Ash	Incinerator Residue	Rubber Tires	Phosphate Slimes
Bottom Ash	Slate Mining Waste	Battery Casings	Phosphogypsum
Boiler Slag	Steel Slag	Iron Ore Tailings	Sulfate Sludge
Anthracite Coal Refuse	Zinc Smelter Waste	Feldspar Tailings	Scrubber Sludge
Bituminous Coal Refuse	Taconite Tailings	Waste Glass	Sewage Sludge
Reclaimed Paving Material	Foundry Waste	Building Rubble	Alumina Red & Brown Muds
Blast Furnace Slag	Phosphate Slag	Dredge Spoil	
	Gold Mining Waste	Lead-Zinc Tailings	
		Copper Tailings	
		Nickel Tailings	

and reclaimed paving material. Class II materials demonstrating some favorable economic aspects for utilization as highway aggregates are steel slag, incinerator residue, taconite tailings, slate mining waste, foundry waste, zinc smelter waste, and phosphate slag.

Extensive processing, small quantities, and remote locations caused materials such as battery casings, glass, dredge spoil and copper tailings to be place as Class III materials. Class IV waste materials are sulfate sludge, sewage sludge, alumina red and brown muds, dredge spoil and phospate slimes. Although oil refinery coke and plastic waste had been eliminated from further evaluation by a preliminary screening process, these materials were evaluated economically for the sake of comparison and were also found to be marginal.

D. 5. ENVIRONMENTAL EVALUATION

D.5 1. INTRODUCTION

There is a need to evaluate the environmental impacts of using processed waste materials as aggregates in highways. Evaluation of the environmental impacts of waste aggregate use was performed for all waste resources indicating some measure of technical and/or economic feasibility for use as aggregate replacements in highways.

Waste resources not evaluated were sulfate sludge, sewage sludge, and battery casings. It was felt that none of these materials demonstrated sufficient technical or economic feasibility to consider their extensive use as aggregates because of poor aggregate properties, extensive processing or small

available quantities. Sulfate sludge has potential use in a composition mixture with lime and fly ash was evaluated for the environmental aspects of this use.

Some factors included in the environmental evaluation are directly or indirectly related to technical and economic considerations. Throughout the evaluation process an inter-relationship has been observed between technical and economic factors.

The environmental effects associated with the processing and use of waste materials in highways were considered in three ways:

1. Effect on the environment of recycling a specific waste resource, i.e. what benefit might be derived from altering the present method of waste disposal or of removing existing stockpiles by recycling.
2. Probable effects of processing a specific waste resource as part of the recycling system.
3. Probable effect on the surrounding environment of using a specific waste resource in various types of highway applications.

The evaluation was then performed in three separate steps. The pertinent factors considered for each of these environmental aspects are listed in Table D-21. These factors were evaluated quantitatively, using a weighted approach based on the relative magnitude and importance of each of the various factors. Positive

TABLE D-21

ENVIRONMENTAL EVALUATION FACTORS

EFFECTS OF RECYCLING WASTE MATERIAL

1. Severity of existing ecological problem caused by disposal of specific waste material.
2. Amount of waste material currently being disposed of or accumulated.
3. Reduction of a possible health and safety hazard by recycling.
4. Degree by which use as highway aggregate would alleviate ecological problems associated with a specific waste material.
5. Type of ecological area where disposal or accumulations exist.
6. Proximity of waste material to centers of population.
7. Extent of conservation of natural aggregate resources by recycling of a specific waste resource as an aggregate.

EFFECTS OF PROCESSING WASTE MATERIAL

1. Possible effects to the environment due to type of processing required.
2. Possible effects to the environment due to disposal of any by-products from the processing of a specific waste material.
3. Amounts of possible by-products from processing operations.
4. Location of processing operations with respect to populated areas.

TABLE D-21 (Continued)

ENVIRONMENTAL EVALUATION FACTORS

EFFECTS OF HIGHWAY USE OF WASTE MATERIAL

1. Possible effect on ground water quality due to leaching of objectionable substances from the highway to ground water supplies.
2. Possible effect on surface water quality due to runoff from highway containing potentially objectionable material.
3. Possible effect on surrounding air and atmosphere due to dusting.
4. Possible effect on surrounding soil conditions due to leaching of objectionable substances from the highway.
5. Possible effect of waste material use on highway aesthetics.
6. Possible effect of waste material use on plant life.
7. Possible effect of waste material use on surrounding animal life.
8. Possible effect of waste material use on adjacent land use.

and/or negative effects were considered for all three aspects of the environmental evaluation.

Evaluation of the various environmental factors was based in part upon information derived from the literature, but primarily from value judgments founded upon knowledge of the properties of various waste materials. Examination of waste material samples proved to be valuable in forming judgments concerning potential environmental impacts resulting from their use in a highway system.

Table D-22 lists the results of the environmental evaluation. Waste materials are ranked in terms of the most benefit (or least damage) to the environment from recycling, processing, and highway use of these materials as aggregate replacements. A discussion of each of these aspects pertaining to specific waste materials follows.

D.5.2. EFFECTS OF RECYCLING

The possible effects of recycling certain waste materials are positive in nature and reasonable judgments can be made concerning these effects. The most significant factors to be considered are the severity of the ecological problem caused by the waste material, the amount disposed or accumulated, and the degree by which the problem can be alleviated by use as highway aggregate.

From the standpoint of environmental benefits, recycling of unsightly coal refuse banks should be a top priority. The culm banks in the anthracite regions of Pennsylvania are quite

TABLE D-22

RANKING OF WASTE MATERIALS ACCORDING TO ENVIRONMENTAL ASPECTS

RECYCLING	PROCESSING	HIGHWAY USE
Anthracite Coal Refuse	Waste Glass	Blast Furnace Slag
Bituminous Coal Refuse	Copper Tailings	Reclaimed Paving Material
Phosphate Slimes	Cold Mining Waste	Rubber Tires
Phosphogypsum	Feldspar Tailings	Waste Glass
Dredge Spoil	Nickel Tailings	Steel Slag
Fly Ash	Blast Furnace Slag	Building Rubble
Bottom Ash	Steel Slag	Gold Mining Waste
Boiler Slag	Lead Tailings	Nickel Tailings
Foundry Waste	Zinc Tailings	Feldspar Tailings
Incinerator Residue	Bituminous Coal Refuse	Alumina Muds
Building Rubble	Rubber Tires	Boiler Slag
Rubber Tires	Taconite Tailings	Fly Ash
Blast Furnace Slag	Iron Ore Tailings	Bottom Ash
Steel Slag	Boiler Slag	Incinerator Residue
Taconite Tailings	Fly Ash	Foundry Waste
Iron Ore Tailings	Bottom Ash	Dredge Spoil
Alumina Muds	Anthracite Coal	Copper Tailings
Lead Tailings	Reclaimed Paving Material	Phosphate Slimes
Zinc Tailings	Foundry Waste	Phosphogypsum
Reclaimed Paving Material	Incinerator Residue	Bituminous Coal Refuse
Copper Tailings	Alumina Muds	Anthracite Coal Refuse
Gold Mining Waste	Dredge Spoil	Taconite Tailings
Waste Glass	Building Rubble	Iron Ore Tailings
Feldspar Tailings	Phosphogypsum	Zinc Tailings
Nickel Tailings	Phosphate Slimes	Lead Tailings

often located within built-up areas, are easily ignited by spontaneous combustion, and often burn for months or years before being extinguished. The burning condition of these culm banks contributes to high levels of air pollution in the immediate areas.

Many of the larger coal waste banks are between 50 and 100 feet high and are a serious blight to the surrounding landscape. In addition, because these banks do not easily support vegetation, the potential for embankment failures does exist.

The gob piles which exist in the bituminous coal producing areas of the Appalachian region and, to a lesser extent, in other bituminous and lignite coal areas, exhibit environmental problems similar to those of the anthracite region. The total amount of accumulated refuse is greater, but accumulations generally do not infringe upon populated areas to as great an extent as with anthracite coal refuse. Because of an inherently lower carbon and ash content, the percentage of burning bituminous coal banks is not as large as that of the anthracite region.

Recycling or carbonate bonding of coal refuse would help to make practical use of some of the tremendous stockpiles of accumulated coal refuse. However, highway use alone would not even be sufficient to consume the annually produced quantities of anthracite or bituminous coal refuse, let alone result in any appreciable reduction in accumulations.

Another top priority waste material in terms of recycling is phosphate slime. The impounding basins which hold these slime wastes occupy large tracts of land and present a

very real threat to the ecology of the surrounding areas. Existing ground and surface water supplies are endangered by seepage of the slime waters or breakage of holding dams. Even after setting periods of many years, the slimes only thicken to between 25 to 30 percent solids content. Thus, the ecological threat from these wastes remains undiminished over time.

Recycling of phosphate slimes for use as lightweight aggregate in highway or building construction applications will partially solve the ecological problems caused by these voluminous, unwanted wastes. Unfortunately, as with coal refuse, accumulations are so large that it would be impossible for the material to be consumed to any significant extent simply by using it for aggregate purposes.

The dumping of dredge spoils in open water is one of the factors causing an increase in the pollution of major waterways. Because most of the dredge spoil is polluted to a certain degree, uses must be found for this material to prevent its continuing disposal in open waterways. Recycling of this waste material would be of great benefit from an environmental standpoint because it would have a positive effect upon water quality, marine life, and aquatic plants associated with these waterways.

Efforts have made for more than twenty years to promote the further utilization of ash wastes from coal burning utility plants. Because of limited quantities used over this time period, millions of tons of fly ash, bottom ash, and boiler

slag have been disposed of by landfilling or simply creating unsightly waste piles. Although fly ash piles will support certain types of vegetation, the fineness of the particles makes them prone to dusting.

Some power plants dispose of fly ash in slurry form, mixed with bottom ash or boiler slag. The holding ponds are not the principal means used to dispose of ash wastes, but deserve mention from an ecological standpoint.

The variety of uses and outstanding performance characteristics displayed by fly ash, bottom ash, and boiler slag in many types of highway and construction applications make these wastes a logical choice for recycling purposes. Their potential usefulness as aggregate materials could result in utilization of a majority of ash wastes within the foreseeable future.

Relatively large quantities of heretofore unuseable foundry wastes in industrialized areas create a need for some means of reducing these accumulations. These materials are not by their nature obnoxious, but the fineness of the particles presents problems of dusting. Use of these materials as highway aggregate would help to reduce the volume of such wastes.

Many mine tailings deposits, although of large volume, are so far removed from populated areas that there is not as great a priority for removal and re-use of these accumulations as with other materials which are significantly less in quantity, but located within metropolitan areas. For instance, the recycling of incinerator residue, building rubble, and rubber tires as highway aggregate would be of greater relative impact in solving the problems posed by disposal of these wastes than the recycling of comparatively small amounts of various mining and milling wastes.

Recycling of slag wastes has been practiced over a number of years, and has been highly significant in utilizing the produced quantities of these wastes, as well as reducing some of the slag heaps that had accumulated over many years. Blast furnace slag is almost totally recycled at the present time. Steel slag is widely used, but total production is not being recycled. Therefore, some additional use can be made of steel slag. The benefits realized from utilizing these materials are many, from conservation of natural aggregate sources to the minimal growth of slag dumps.

Waste materials which would have the least comparative benefit from the point of view of recycling are glass, feldspar tailings, and gold mining wastes. Glass constitutes only about 6 percent of total municipal solid waste and must often be separated in order to be utilized. Gold mining waste is basically a sand and gravel type material which is not a blight and does not present a threat to the environment, although significant quantities are available. Feldspar tailings are basically inert, are produced in comparatively small volumes, in localized areas and thus are not highly objectionable from an ecological standpoint.

Although this report is primarily concerned with waste utilization in highways, it must be remembered that there are often more suitable ways to recycle wastes and the best solution to each particular waste problem should be implemented.

D.5. 3. EFFECTS OF PROCESSING

The factors most influential in determining the possible environmental effects of processing waste materials for use as aggregates are the location of the processing operations and the number of processing steps. Waste materials which are generated in fairly isolated areas may be processed at their source due to difficulties encountered in handling the waste. Waste materials located in metropolitan areas will normally be processed at their location or elsewhere within the immediate metropolitan area.

In most cases, the treatment of waste materials will involve some measure of air pollution from thermal processing, as well as dust from crushing and sizing. De-watering operations can be a potential contributor to water pollution. Therefore, on the basis of processing steps, the most practical waste materials for processing from an ecological standpoint are those requiring only a crushing and sizing operation. Next most acceptable would be those requiring only a pelletizing process. Those waste materials requiring pelletizing and some form of heat treatment would be somewhat more objectionable environmentally, while waste materials requiring all of the above treatment, in addition to some type of a de-watering process, are the least attractive for use as an aggregate simply on the basis of ecological considerations. In order to determine the probable effect of processing on the environment, the number and type of processing steps

must be analyzed together with the probable location of processing with respect to the source of the waste material and populated areas. The nature of processing operations is such that location of this type of facility in or near a residential area could contribute to blighting conditions. because of the generation of unwanted dust and noise. Therefore, relative location of a processing plant is quite important to consider when evaluating the environmental impacts of processing certain waste materials. Domestic wastes would most likely be processed within the areas in which they are generated. Many industrial wastes are generated in or near metropolitan areas and would also be processed in proximity to their accumulations. Mineral wastes generally are located in rural or unused land, at great distances from populated areas. Often it may be practical to process these waste materials at their source, although the economics involved in new plant construction in outlying or isolated areas may dictate that these materials be processed close to potential markets.

On the basis of these factors, the probable ranking of waste materials in terms of environmental effects associated with processing is indicated in Table D-22. It was felt that the crushing of waste glass, although located in or near centers of population, would have the least damaging effect on the environment. The pelletizing and sintering of copper tailings would probably be located in isolated areas or near existing smelters.

Because of the remote location, processing would not be likely to contribute to any objectionable air or noise pollution effects. Very little processing is required of gold mining waste, feldspar tailings, blast furnace slag, or steel slag, hence, little in the way of objectionable effects can be expected.

Pelletizing and sintering of waste materials such as mine tailings, ash wastes, and coal refuse can expected to contribute to air and noise pollution and a degradation of the immediate areas in which they are processed. For this reason, waste materials requiring a sintering operation are not as highly ranked as those needing simply to be crushed.

The crushing of building or paving rubble has all the objectionable aspects of a quarrying operation to the general public because these operations must be located in the urban areas. This is ecologically undesirable because of the size of the operation and the dusting problems associated with processing this type of material.

The heating and fusion of incinerator residue, located within densely populated areas, will add to the amount and concentration of air pollution normally associated with incineration. The inherent heat value of this waste material will help to offset fuel requirements and result in somewhat cleaner emissions.

The most objectionable environmental effects of processing waste materials can be expected to result from processing wastes which are disposed of in sludge or slurry form. These

wastes, including phosphate slimes, alumina muds, and dredge spoil, require de-watering, drying, pelletizing, sintering, and crushing and offer the potential for more types of pollutants and/or by-products due to the variety of processing steps involved. The necessary processing will normally be conducted at waste sources, which in some cases are not far removed from populated centers. Therefore, these wastes received the lowest ranking regarding the possible effects to the environment from processing.

D. 5. 4. EFFECTS OF HIGHWAY USE

An examination was made of adverse environmental effects associated with the construction process and/or the presence of waste materials in a highway. Harmful effects could result from leaching of aggregate constitutents, dusting, staining, dissolved substances, or even objectionable odors. Practically all study in this area was based upon value judgments since very little work has been done regarding such environmental effects of waste material use in highways.

Several factors interact to influence the potential of a waste material in a pavement system to degrade the surrounding environment. Presence of objectionable chemical constituents, potential reaction of these substances with water or a binder material, leaching potential of the aggregate or the mixture, type of highway application, and climatic conditions are the principal contributing factors.

Leaching potential appears to be one of the more significant environmental hazards associated with the use of waste materials. The type of application will influence the potential for leaching. More leachate would be expected to result from a permeable open graded aggregate base course than from a bituminous or Portland cement concrete pavement. Maximum leaching potential was assigned where aggregates are to be used in stone base or sub-base applications.

It was assumed that waste aggregates used in Portland cement concrete or bituminous mixtures are encapsulated by a practically impermeable binder and the leaching potential would be minimal. Qualitative, rather than quantitative, assessments were made of leaching potential because of the lack of leachability standards and because of a scarcity of data on leaching rates.

The most significant environmental hazard during construction would be the dusting potential of waste aggregate particles. Dusting potential can be expected to be closely related to the hardness and soundness of the particles. Because of the fact that dusting during construction can be virtually eliminated by the use of proper procedures (wetting, covering trucks), this undesireable property was given only cursory examination. In addition, at the present time no known problem exists with respect to odors associated with waste materials under consideration.

The worst offenders, with respect to adverse environmental effect, are considered to be the mineral wastes because of the possibility of small concentrations of heavy metals being contained in the aggregate particles and possibly leaching into surrounding water supplies. A remotely possible side-effect would be the incorporation of such objectionable substances in runoff where the waste material is used as aggregate in surface applications. Some of these processed mineral wastes could also have a dusting potential. Incinerator residue, if not subjected to magnetic separation prior to processing, could also pose leaching problems with respect to the ferrous content of the residue itself. Use of such a material with high iron content would also present the possibility of staining a concrete pavement.

Use of anthracite and bituminous coal refuse in bases or sub-bases could lead to possible leaching of small amounts of sulfur which could form sulfuric acid. For this reason, and for a better aggregate product, the incineration of coal refuse is recommended prior to use as an aggregate.

Table D-22 indicates those waste aggregate materials most favorable when considering the environmental effects of highway use of the aggregates. Blast furnace slag and reclaimed paving material have for many years demonstrated their feasibility for highway use without any damaging effects to the surrounding environment. Both materials are fairly inert, require minimal processing, and have favorable service records.

Rubber tires, waste glass, steel slag, and building rubble can also be expected to function as inert materials within a pavement system. Deleterious matter must be separated from building rubble prior to use in a highway, but the possibility still exists for building rubble to cause some measure of sulfate attack within a concrete mixture due to the presence of plaster or gypsum within the rubble.

Preliminary testing of composition mixtures (using a lime-fly ash-sulfate sludge aggregate) indicate that no problems can be expected to result from leaching of this material due to the low rate of permeability of the mixture composition. Because the aggregate material is not sintered, the particle soundness could be such that some dusting may occur if used in a wearing surface, but this would be expected to be minimal.

Gold mining waste and feldspar tailings would probably not degrade the environment to any greater extent than a sand or gravel aggregate with respect to any possible leaching. However, a minor possibility may exist for dusting to occur when feldspar tailings are used in a bituminous wearing surface.

Alumina muds will probably exhibit similar aggregate properties to expanded clay lightweight aggregate materials. No leaching effects seem likely from these materials, but dusting potential could be a possibility.

No ecological problems have been noted from using ash materials in highways over a period of many years. The only reservation, from an environmental viewpoint, exists because of the variable chemical nature of the ash wastes and the range of metal content in the ash which could possibly contain up to 40 percent iron oxide. Traces of other metals are also present although no apparent problems have ever resulted from these constituents.

D. 5. 5. SUMMARY

Table D-23 summarizes the composite results of the environmental evaluation by combining the three aspects of waste material use as aggregate. The only materials not recommended for development as aggregate on the basis of ecological considerations are lead-zinc tailings, because of the potential, though admittedly not a strong one, that some leaching of traces of heavy metals could occur if these materials are used in a base, sub-base, or composition mixture.

No other waste materials present problems of sufficient magnitude to cause them not to be recommended. For some, the positive and negative environmental aspects appear equally balanced and these are considered to be marginal. Other wastes appear to present more positive overall environmental effects and these waste materials have been recommended for aggregate use from an ecological standpoint.

Most outstanding of those recommended are blast and steel furnace slags, ash wastes, rubber tires, and waste glass.

TABLE D-23

OVERALL RANKING OF WASTE AGGREGATE USE IN TERMS OF POTENTIAL ENVIRONMENTAL EFFECTS

RECOMMENDED	MARGINAL	NOT RECOMMENDED
Blast Furnace Slag	Building Rubble	Lead and Zinc Tailings
Steel Slag	Alumina Muds	
Fly Ash	Dredge Spoil	
Bottom Ash	Feldspar Tailings	
Boiler Slag	Gold Mining Waste	
Rubber Tires	Copper Tailings	
Waste Glass	Phosphate Slimes	
Reclaimed Paving Material	Phosphogypsum	
Anthracite Coal Refuse	Iron Ore Tailings	
Bituminous Coal Refuse	Taconite Tailings	
Incinerator Residue	Nickel Tailings	
Foundry Waste	Sulfate Sludge	
Battery Casings	Scrubber Sludge	
Slate Mining Waste	Sewage Sludge	
Phosphate Slag	Zinc Smelter Waste	

Use of these materials in highways would and does consume a significant percentage of the available quantities of these materials, presents little if any processing problems, would alleviate to a great extent waste disposal problems, and exhibits little if any potentially harmful side effects when used in a highway.

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