INTRODUCTION
The recycling of waste materials has in recent years extended to many types of materials. Industry and government support and public enthusiasm have combined efforts to recover and recycle many materials ordinarily destined for disposal. In this era of limited natural resources, public sentiment favors continued and expanded materials recovery programs. It is in this spirit of innovation that the California State Solid Waste Management Board commissioned a study of the potential for recycling the ash, or residue, from resource recovery facilities.

With a serious loss of landfill capacity anticipated in the next few years, cities and counties all over the State of California are examining the development of resource recovery facilities to help solve their solid waste disposal problems. Drawing on extensive European experience, and somewhat limited domestic experience, proponents of resource recovery are planning a variety of projects for California that will incorporate a range of standard to innovative technologies. But after the materials and energy are recovered from the MSW (municipal solid waste), there will remain a residue requiring disposal.

The purpose of this paper is to answer two key questions — can residue be put to good use and can it be done in California? Although several types of possible uses are identified, the only clearly demonstrated use of residue is in bituminous pavement construction. Other types of uses generally require further research and development work or more extensive testing. The research also shows that relatively simple, proven technologies exist for preparing residue for use while also recovering potentially valuable incinerated metals. But the question remains — can this be done in California?

The research project has encompassed examination of all aspects of residue utilization — technical, environmental, economic, institutional and regulatory — in an effort to accurately determine the promise and problems of developing residue utilization. The study serves as both a documentation of research and a source document for those desiring further information.

The research for this project was conducted on three levels: a literature search, using two computerized data base searches and a manual search of periodicals; interviews conducted by telephone and correspondence; site visits — observations made by the consultant’s staff at facilities in the U.S. and abroad. One of the key factors observed during the course of research was the lack of a clear compendium of information. The necessary information was widely dispersed, of variable quality and a great deal of work was not well documented.

The State of California is especially concerned about the environmental impacts associated with residue generation and disposal. Also considering a persistent decline in landfill capacity of all classifications, the state is motivated to find a use for residue. This study presents an analysis of residue utilization in California by identifying impediments, assessing the feasibility of implementation, and providing general recommendations regarding residue utilization and research. Also presented is a plan for developing residue utilization in California, a series of clearly defined and practical steps to encourage recycling of residue.
APPLICATIONS IN EUROPE & JAPAN

As in the development of resource recovery, the European industrial community is established as a leader in residue recycling. Incineration of refuse has been practiced in Europe since the 1870's and much of the early work in residue recycling occurred in the European community. The principal uses of residue in Europe are as fill material and in road construction. From available sources, it would appear that a significant quantity of residue is customarily used for these purposes. The greatest concentration of residue recycling activity occurs in Germany, where several facilities make use of their residue. A number of facilities have privately designed and operated residue processing systems. They are designed primarily for the recovery of incinerated ferrous metals and some grading of the residue for aggregate-type uses. Widespread use of residue is also reported in Switzerland, Denmark, and to a lesser extent, in France. In all of these countries residue is processed to remove incinerated ferrous metals, and to grade the residue for use an aggregate material usually in road construction or as fill material. Recycling of residue also occurs in Sweden, although translated documents on the current practices are not available.

Much of the European technology in resource recovery has moved across the world to Japan. Incineration is the primary means of MSW disposal in Japan today. Many different technologies are employed there including those developed within the country and systems from Europe and the United States. Strict environmental regulations have provided impetus to the Japanese to develop methods for recycling residue. The processes developed by the Japanese industry tend to be of a more complex nature than the relatively simple mechanical systems originating in Europe and the United States. Most of the Japanese technologies are designed to use residue as an ingredient in the production of an aggregate material. The aggregate materials range from a briquet of residue and hot asphalt, to a pelletized calcinated lightweight aggregate substitute, to a fused aggregate product produced in a submerged arc electric furnace. The critical shortage of landfill capacity and of natural aggregate have contributed to the development of these types of technologies. The technologies are generally energy intensive and complex.

APPLICATION IN THE U.S.

The history of residue utilization in the United States is sporadic, with concentrated efforts not occurring until the passage of the Federal Solid Waste Disposal Act in 1965. Until that time, relatively few instances occurred when residue was put to useful purpose. Documentation of the early uses of residue is sparse; however, certain information has been recorded. Various reports document the use of residue as construction material for pavement subbases, base course pavements, embankments, and as fill material. Since these early efforts, which occurred approximately from the time of World War II through the middle 1950's, residue related activity in this country has been mostly research and development work. This intensified after 1965, and the U.S. Department of the Interior spearheaded the research through the Bureau of Mines. The Bureau’s work included research on the composition and characteristics of municipal incinerator residues and development of a processing system designed to extract the valuable components of the residue. Much of the USBM early research and development work later formed the basis for further development in German and French residue recycling techniques. The vast majority of research in the United States has focused on the use of residue in various types of pavement. As documented in many reports, residue was found to perform acceptably when used in a residue/aggregate asphalt pavement, or when mixed with lime as a binding agent.

In addition to the main focus on pavement applications, research work has addressed a broad spectrum of possible uses for residue. Some of these research efforts have focused on using residues in Portland cement concrete, in the manufacture of cement and masonry bricks, as landfill cover material, and as a growth medium for different types of plants. One interesting experiment involved the use of the glass-rich fraction of residues for the manufacture of mineral wool.

With the recent upswing of resource recovery activity in the United States and the accompanying lack of landfill capacity, residue recycling has become a subject of greater interest than ever before. Research and development programs are currently in process all over the country. Actual residue utilization in the United States, however, does not occur outside of the research and experimental programs recorded in the literature. A number of facilities in the eastern U.S. are anticipating routine residue recycling within the near future.

Research has shown that several applications are currently feasible or have promise for residue. Several uses have been identified and/or demonstrated for the residue or fractions of it. These are: structural fill — for construction, land reclamation, trench backfill, embankments, etc.; landfill cover — to replace, or in combination with, natural soil for use as daily cover material; mineral wool manufacture — from the glass fraction of the residue; or as aggregate material — a graded, ferrous-free residue used as a substitute or extender for natural rock materials in road pavement, Portland cement concrete, ceramic and masonry brick manufacture. The aggregate type materials are either an unfused material, that is, having only under-
gone mechanical processing, or a fused material, which has been subject to some sort of heat or chemical process to form a hard, cohesive mass.

While several promising applications have been identified for residue, the best demonstrated use is as an aggregate material in bituminous base course pavements. Residue has also been shown to perform excellently as subbase and fill material; however, use of residue in this manner raises serious environmental questions in California. The use of a residue aggregate material in Portland cement concrete has not been demonstrated to be feasible at this time, primarily due to expansion problems resulting from residual aluminum and glass reactions with alkalai materials. Portland cement concrete made with residue suffers from inadequate strength due to these expansion problems. However, residue may be utilized as a partial aggregate replacement or if methods are developed to remove aluminum or reduce alkalai reactivity. For this same reason, use of residue in cement stabilized pavements is not feasible.

Residue has been shown to perform well in lime-stabilized pavements. Several paving projects have been completed and are performing well. Use of residue in surface course pavements, i.e., the wearing surface of the pavement, has not shown great success due to some problems of asphalt stripping from the residual glass in the residue.

Residue has performed very well as landfill cover, particularly in regard to the material's workability and other necessary characteristics. Processing is minimal for this use, and what processing is required may be performed by mobile equipment at the landfill site. The use of residue as a landfill cover, however, raises questions in regard to possible leachate from the material.

Using a glass-rich fraction of residue, mineral wool was successfully manufactured in a laboratory experiment. Due to market conditions, and the complexity of extracting the glass-rich fraction, it is highly unlikely that this is a feasible use for residue on a commercial scale.

Two important by-products can be produced from residue processing, depending on the particular type of processing technology. These by-products are incinerated ferrous metals and incinerated aluminum. While many facilities across the country have installed and, at some time, run equipment to remove ferrous from residue, almost all of these facilities have ceased operation due to variable market conditions and lack of consistent product quality. Incinerated ferrous metals generally exceed contamination standards, require further processing to meet unit size specifications, and are in less demand than any other type of ferrous scrap material. An excess of ferrous scrap material across the country indicates that recovery of incinerated ferrous is not particularly attractive at this time.

At least one residue processing technology recovers incinerated aluminum from the residue. A good market exists for incinerated aluminum, although further cleaning of the material will probably be required in order to meet buyers' specifications.

TECHNOLOGIES THAT RECOVER RESIDUE

Of the eleven technologies identified in the study, two are particularly promising — UOP/Martin and WMI/Volund. Each of these companies has European experience in residue processing system design and operation. Each is engaged in developing residue processing at an American facility. While either process may be modified in design from that presented in the report, the key technologies are essentially proven and readily available in California. This, in itself, makes the technologies attractive. Both systems are described below.

UOP/JOSEF MARTIN

Based on work at Martin's European facilities and with additional research and development activities at the Paris: Ivry facility, Josef Martin and UOP, its former American licensee, have developed a residue processing system which incorporates much of the early U.S. Bureau of Mines research. The system, which is implemented at the Pinellas County, Florida facility recovers ferrous, aluminum, heavy nonferrous and sized residue for use as an aggregate substitute in road construction.

The residue processing system handles fly ash from the boilers and electrostatic precipitators as well as incinerator ash. It is a wet quench system and all the ash streams are fed into the ash discharger(s). The residue processing system is designed to handle immediately burned-out residues from a mass-burning incinerator. The Martin facility at Parish: Ivry, France plant does not include a fly ash discharge system but discharges instead to fly ash silos for storage. This design was used to avoid contamination of recovered ferrous scrap. It is not known why the different ashes are combined in the design of the Pinellas County facility.

Process Flow Description

As illustrated in Fig. 1, the Martin Process Flow Diagram shows the residue is removed from the ash dischargers via a vibrating conveyor, which feeds the residue into a heavy-duty vibrating grizzly bar screen to remove oversize items. The residue is then conveyed to a rotary trommel screen to separate the plus 2-in. (5.08 cm) from the minus 2-in. (5.08 cm) material. The oversize material is discharged
FIG. 1 UOP/MARTIN PROCESS FLOW DIAGRAM
from the system. The plus 2-in (5.08 cm) residue moves through an electro-magnetic drum separator to remove ferrous. The minus 2-in (5.08 cm) residue moves through an inclined vibrating wet screen separator to remove ash and fines. The washed residue then moves through an impact mill, crushing the friable portion of the residue to facilitate nonferrous recovery. The crushed residue then is conveyed to an inclined vibrating single deck screen which removes the fines generated in the milling process.

The residue enters a heavy media separation system designed to separate the heavy nonferrous from the total nonferrous feed stream. Residue passes through a single gravity heavy media drum separator. Equipment in the system includes a vibrating pan and wash screen, drum magnetic separator, media densifier, a media demagnetizing coil and media pumps.

The heavy media float product moves to a heavy-duty, single deck inclined vibrating screen to separate large aluminum nuggets. A double roll crusher is then used to crush the friable portion of the feed stream, flattening malleable aluminum into flakes. A single deck inclined vibrating screen is then used to separate the flakes from the fines produced by the roll crusher. The system is designed to re-utilize process water.

Products

Oversize material for landfill, plus 2-in. (5.08 cm) ferrous, minus 2-in. (5.08 cm) ferrous, large aluminum nuggets, aluminum flakes and sized residue.

**WMI/VOLUND**

The Volund Company has been active in MSW incineration resource recovery for years in many parts of the world, particularly in Europe. Translated data is available on the Copenhagen, Amager and Copenhagen: West resource recovery facilities. Residue processing at Amager is limited to ferrous removal; the residue is then used as fill in a land reclamation project. The residue processing system at Copenhagen: West is much more advanced and it is this type of system that is to be implemented in the United States by Volund and WMI. The Volund resource recovery facility and residue processing facility will be implemented in Tampa, Florida. The system will recover ferrous and produce sized residue for use as an aggregate substitute.

The Volund residue processing system is designed to handle only the well burned-out ash from its rotary kiln furnace, a two-stage incineration system. While it is not intended for processing residue from mass burning systems, residue from rotary combustors should be appropriate feedstock. The Volund system is mechanically less complex than the Martin residue processing system, the difference occurring primarily in the technology required for recovery of incinerated aluminum. No aluminum recovery occurs in the Volund system.

**Process Flow Description**

The residue removal system is a wet quench method with discharged residue deposited in a quench tank. The residue is removed from the tank by either a series of conveyors or a skip hoist. Fly ash is included in the residue processing system; the system to be implemented in Tampa will separate fly and bottom ash. The residue is conveyed either to a coarse vibrating screen or a rotary trommel screen to separate the feed stream into plus 2-in. (5.08 cm) and minus 2-in. (5.08 cm) fractions. The minus 2-in. (5.08 cm) residue passes under a magnetic belt separator to extract ferrous, which is removed from the processing system. The remaining residue is then conveyed to a series of vibrating screens to separate it into coarse (1/4 to 2 in.) (0.64 to 5.08 cm) nonferrous residue and fine (less than 1/4 in. (0.64 cm) nonferrous residue. The plus 2-in. (5.08 cm) residue fraction is conveyed under a magnetic belt separator and coarse ferrous removed; remaining oversize residue is discharged for disposal.

**Products**

The Volund residue processing system produces plus 2-in. (5.08 cm) and minus 2-in. (5.08 cm) ferrous scrap, fine residue and coarse residue and oversize, which is landfilled. WMI/Volund estimates that such a residue processing plant would produce the following proportions of recovered products: ferrous, 15 percent; coarse residue, 65 percent; fine residue, 15 percent; and oversize, 5 percent. The System Flow Diagram is presented in Fig. 2.

Other technologies of interest in the study and worth highlighting include:

- Smith & Mahoney (U.S.)
- FIRL (U.S.)
- AIST (Japanese)
- Kawasaki (Japanese)
- NKK (Japanese)

The Smith & Mahoney processing technology may prove to be an extremely effective design. As of this writing, however, the process can only be considered developmental. Due to this stage of development, it is not clear that the process design will be widely available in the near future. The level of complexity of the Smith & Mahoney design does not appear to indicate any difficulties in operation, but only a proven record of performance will establish the technology’s viability.
FIG. 2 WMI/VOLUND PROCESS FLOW DIAGRAM
The FIRL fusion process presents interesting possibilities of encapsulating potentially harmful materials from residue in an impermeable aggregate material. There are obvious problems, however, in scaling up the design and in construction of the fusion furnace. It might be expected that procedures of operation at a large scale would require modification and a well-trained crew. Fused residue aggregate produces somewhat better results in wearing surface course applications than unused residue aggregate. Skid resistance is good, asphalt is not observed to strip away from the particles and pavements generally perform as well as traditional paving mixtures. More project specific studies would be required to determine if the prospect of additional revenue, at slightly higher levels, would justify the necessary development work.

The Japanese technologies appear to be most promising. The AIST residue processing systems for pyrolysis and mass burned residues appear to be, on the basis of available information, well developed technologies. It is unlikely that much demand will exist for AIST's pyrolysis residue processing design due to the low level of pyrolysis activity in this country. In addition, AIST bases their design on a relatively high organics level in the pyrolysis residues while American data indicates good levels of burnout. The same basic design appears to have been successfully modified to accommodate residues from mass burning facilities. It is quite possible that either of these two designs would be appropriate for implementation in this country; however, differences in residue composition might require some design modification. Perhaps the most important aspect of these designs is their energy intensive nature; both processes include supplementary materials, heat and numerous processing steps.

The Kawasaki process of manufacturing residue/asphalt briquets is relatively simple in design, although not a great deal of information is available on long-term performance. It is not anticipated that the costs of producing a material used for subbase and fill material would be justified; Japan faces a critical lack of natural aggregates on a national basis while domestic shortages are mostly localized.

The NKK submerged arc furnace fusion process design is an interesting one, providing an alternative to the FIRL process. Additional information is needed to evaluate the characteristics of the residue product; it is anticipated that the process would be very energy intensive and not economically viable in this country, given the relative abundance of aggregate materials.

Technologies to remove incinerated ferrous from residue are numerous; standard metallurgical processing equipment is commonly used. The current market for ferrous scrap, however, would not justify a residue processing system with the sole purpose of ferrous recovery. Removal of ferrous metals, however, is necessary if residue is to be used as an aggregate product in paving mixtures.

The state-of-the-art of residue processing, as identified in this research effort, is both simplistic and sophisticated. There is a wide range of available, or nearly so, technologies producing several types of residue products. Due to the relatively moderate prices of aggregates in California today, it would appear that the more simple processes are most attractive. Two of them, the UOP/Martin and WMI/Volund systems analyzed in this paper, appear to offer all necessary processing steps in a well demonstrated technology. It is these systems, or ones that would be similar in design and execution, that most closely fit the needs of California projects and are available for implementation.

**ECONOMIC ASSESSMENT**

The key factors identified as variables are geographic location, sale of ferrous metals, price levels for various residue aggregate products and disposal costs for various classes of landfill.

Geographic location was not found to be a significant factor in either capital or O&M costs. Regional differences were noted, of course, but these variations do not appear to indicate residue processing is viable in one part of the state and not in another. Projects may then consider residue processing in any geographic location, in regard to this particular factor.

The sale of incinerated ferrous metals, however, is of somewhat more concern. The market for ferrous scrap is depressed, as of this writing, and industry representatives are not optimistic in predicting its recovery. In addition to a depressed market, there are also very few steel mills in California, presenting a much smaller market than would be available in the midwestern and eastern parts of the country. A third consideration is that incinerated ferrous is usually quite dirty, exceeding the contamination standards for No. 2 scrap bundles. Washing or air cleaning would be required. The scrap would also need to meet density and unit size specifications, necessitating use of equipment not specified in any of the current designs.

All of these considerations led to an analysis of residue processing where ferrous scrap was not sold. Again, residue processing remained a more attractive alternative than disposal of residue in landfills whether or not the ferrous scrap was sold. It is possible, of course, that ferrous scrap can be successfully marketed at the time many of California's facilities are expected to come on-line, about 1988. Even so, it would appear that precombustion removal of ferrous would be advantageous. Some post-combustion ferrous removal will still be necessary, however, if residue
is to be used in pavement applications. In either case, regardless of quantity, sale of incinerated ferrous does not appear to be a decisive factor in the overall economic viability of residue processing.

The revenues for each scenario were calculated on the basis of residue aggregate sales for the sizes of material exiting the systems as currently designed, in addition to consideration of ferrous revenues. Two considerations should be noted. Some of the systems, notably the WMI/Volund processes, produce a preponderance of small sized aggregate material most suitable for wearing surface course pavements. Because of the somewhat higher prices for this type of aggregate, the revenues for these projects, or for the wearing surface course portion of others, are correspondingly higher. It should be noted, however, that the use of unfused residue as aggregate in wearing surface courses is not well demonstrated at this time. In light of this, it may be reasonable to assume that the screen sizes of some systems may need to be adjusted so that more residue is produced for use in base course pavements. Revenue projections performed in further studies should take this into account.

In the analysis, revenues were calculated at levels comparable to current prices for base course and wearing surface course pavement aggregates. Prices were regionally averaged; a project specific analysis would need to consider more specific and clearly identifiable prices within the project's market area. A radius of 30 miles is mentioned several places in the literature as a reasonable transport distance for aggregates. Local conditions, of course, may set much shorter or greater distances and is one of the variables to be noted.

In order to successfully enter the market, it may be necessary to price residue aggregate below market prices. This may also be necessary if the residue aggregate is marketed on a wide scale by rock product dealers rather than by the processing facility itself. To accommodate this, revenues were calculated again at a rate of twenty percent below current market value. Even with this change, economically viable projects remained so. It can be expected then that residue aggregate products could be competitive while still producing sufficient revenue to warrant their production, even with below market prices.

With the classification of residues currently under consideration by state agencies, it is possible that residues may eventually be disposed of in landfills of Class II-1 or Class II-2 designation. The classes of disposal sites are summarized below. The wide range in drop charges at the different types of disposal facilities necessitated an evaluation at two levels: the most expensive disposal, Class I; and the least expensive disposal, Class II-2. Analysis demonstrated that residue processing and sale resulted in savings at either level of disposal.

CLASS I

There must be no possibility of discharge of pollutant substances to usable waters. Artificial barriers may be used for the control of lateral waste movement only. Usable groundwater may underlie the site, but only under extreme cases and where natural geological conditions prevent movement of the wastes to the water and provide protection for the active life of the site. Inundation and washout must not occur. All waste groups may be received.

CLASS II-1

These sites may overlie or may be adjacent to usable groundwater. Artificial barriers may be used for both vertical and lateral waste confinement in the absence of natural conditions. Protection from a 100-year frequency flood must be provided. Group 2 and 3 wastes can be accepted and under special conditions, certain Group 1 materials may be accepted.

CLASS II-2

These sites may have vertical and lateral continuity with usable groundwater but have features that provide for the protection of water quality. Group 2 and 3 wastes may be accepted.

Considering the interest in reclassifying residue, it is ironic that residue processing is more attractive if disposal at Class I sites is required. Even with a classification of nonhazardous, the opposite end of the spectrum, residue processing still presents savings over Class II-2 disposal. Over the twenty year project life of a resource recovery project, it can be expected that savings would continue to increase as landfill capacity decreases due to closures and difficulty in developing new sites. In terms of savings, residue processing appears attractive regardless of the type of disposal required. This is of particular importance to areas where Class I landfill capacity is scarce and disposal of residues in Class II-1 has not been approved.

The capital cost of residue processing facilities, when developed simultaneously with a resource recovery facility, generally constitutes a reasonable percentage of overall capital expenditures.

On the basis of analysis performed, residue processing appears to be an economically attractive alternative to landfill disposal. It remains attractive despite variations in geographic location, class of landfill disposal, and with or without sale of incinerated ferrous materials. The revenue from sales of aggregate products may differ somewhat based on modifications to process designs and production of more large size aggregates; however, they are expected
to be within relatively close range of the figures presented.

With all these factors considered, the clearest indication is that residue processing warrants further detailed economic analysis on a project specific basis.

MARKET ASSESSMENT

Determination of the strength and extent of demand for residue products is difficult to do in a study of this scope. Any project considering sale of residue products should consider a marketing study, detailed and specific to local conditions, as an integral part of early project feasibility analyses. Several factors are worth noting in assessing California's market for residue products: type of project, location of production, demand and current material sources, type of market and receptivity to the residue product.

Given the types of available residue processing technologies and their products, the market for natural aggregates is the primary target area. Aggregate-type uses of residue are the only ones that can be considered well demonstrated at this time and even within that category, applications are limited.

A variety of uses appear possible for residue aggregate products, primarily in base course pavements, as daily landfill cover and as structural fill material. Of these, only the pavement aggregate market can be considered for consistent, long term sales. Residue, when properly prepared, has been shown to be a suitable extender or replacement for natural aggregates. While California has adequate natural resources, various institutional factors may restrict aggregate extraction. In addition, aggregates tend to be in relatively short supply in urban areas compared to rural locations. Costs of transporting aggregates to urban areas is another factor favoring introduction of residue aggregate on a wide scale.

Almost without exception, California resource recovery projects will be located in urban areas where the shortage of disposal capacity is most critical. Given the location of the aggregate industry, this is an ideal generation point for residue aggregates. It is perhaps an unusual geographic factor in favor of a new raw materials.

The preparation of residue for marketing is relatively simple, consisting of ferrous metals removal and sizing to the appropriate gradation. The particle size gradation required is determined by the end use.

There are two types of markets for residue aggregate: the public and the private. The public market consists of the cities and counties generating the feedstock MSW. While most municipal governments have curtailed public works activities as a result of Proposition 13 (State limitation on property taxes), pavement maintenance and construction activities continue. The survey of municipal governments in the three study areas revealed that the majority of municipal pavement work involves patching or resurfacing of existing roadways. Most construction or reconstruction work is contracted to private industry.

These governments could be a ready market for residue aggregate for a variety of activities, supplying municipal raw material requirements from municipal waste. While fused residue aggregate performs well in wearing surface course, unfused residue aggregate is not well demonstrated in this use nor as a suitable material for patching. To meet the needs of the municipal market, testing of unfused residue in these applications would need to occur or the fusion process for residues would require further development work.

The private market for residue aggregates is the paving and construction industry. Most construction of new roads and reconstruction of older pavements is done on a contract basis, with specifications supplied by the contracting agency. Two incentives to market penetration are apparent: (1) by offering an attractive residue aggregate product at below market prices; and (2) by specifying its use whenever the material is available, as a condition of the contract.

A key question in marketing any new product is that of receptivity. Each of the industry representatives contacted, rock products producers and dealers, contractors, and asphalt batch plants, were asked about using a residue aggregate product. The general response was positive, qualified by the material meeting specifications, primarily Caltrans specifications, and being competitively priced. Negative responses were not received. It should be noted that residue aggregate production would constitute a small share of the market, perhaps one to two percent in the year 2000 with a doubling of planned resource recovery project capacity. This in itself favors market development, as the material would not significantly affect the existing aggregate industry.

The market for residue aggregate products in California appears to be good, based on initial studies of current conditions. As noted in the following section, there are a number of impediments to marketing residue products; recommendations to resolve some of these impediments are discussed later in this paper. Two other points should be noted: the market for residue processing by-products varies, with aluminum in strong demand (it should be noted, however, that the market for incinerated aluminum may not be as strong as that which exists for the present product, i.e., unincinerated source separated metal) and a weak market for ferrous metals; resolution of problems in some applications, such as wearing surface courses, Portland cement concrete and cement block or masonry brick manufacture, would greatly
broaden the market for residue aggregate materials.

ENVIRONMENTAL ASSESSMENT

In addition to the potential impacts from residue leachate, gaseous emissions and dust generation are the principal areas of environmental concern associated with residue processing and use. The State of California's concern about deleterious effects from residue leachate impact on the future utilization of residue. Questions focusing on testing methods and analysis are not resolved as of publication. Perhaps it is sufficient to note that states around the country are watching California's decision-making process, for concern continues over the possible impacts of leachate.

Residue processing does not appear to pose significant environmental impacts, either in the material itself or the processing facility. The residue processing system designs chosen for further study in this report are not energy intensive. The main areas of concern are dust control in the processing transport/storage phases and gaseous emissions that occur in certain applications. Dust impacts can be mitigated relatively easily by separating fly and bottom ashes, using spray mist systems or particulate control devices, and by control of storage areas. Dust or fine particulate matter is a common industrial problem and control should not require any extraordinary measures.

Control gaseous emissions is also a common industrial problem and should be fully mitigated through existing means. Hydrogen gas emissions were noted when residue was used in Portland cement mixes, resulting from the alkali-aluminum reactions. It is not known whether such emissions would be present, or the degree of magnitude, should residue aggregate products be used in widespread commercial Portland cement applications in the future. Hydrogen gas emissions have also been noted in the lime-stabilized "Chempac" pavement, although adequate mitigation measures have been identified by the developer.

The only widespread environmental concern that might be anticipated would be the potential for leachate occurring at multiple sites of residue processing, storage and application. Obviously, if residue leachate continues to be classified as hazardous by the state, it cannot be regularly used as structural fill material, nor could it be used as cover material in any site other than a Class II-I or Class I. Not only would possible applications be restricted, but any site storing the material over sixty days would require a Hazardous Waste Facility Permit, a deterrent significant enough to prevent any residue utilization development in the state. Leachate collection systems, and appropriate treatment and discharge of the leachate, would be required of producers and users storing residue subject to precipitation or contact with any surface or groundwater.

If residue and its leachate does continue to warrant a hazardous classification, the associated regulatory measures — facility permit and transport by a hazardous material carrier — would make the logistics of utilization extremely difficult. It would also substantiate broad environmental concern over the disposal of the material over a wide area, although it is anticipated that using residue in asphalt-stabilized pavements would prevent leaching.

Aside from the relatively minor environmental concerns of dust and gaseous emissions, the overall potential for environment impacts from residue and its uses are difficult to determine, given that a conclusion on its status has not been reached in the state's current residue testing program.

IMPEDIMENTS

As part of a feasibility analysis of residue utilization in California, it is necessary to examine a number of factors that could impede development. It does not appear, at this time, that any of the factors identified are without suitable mitigation measures. It is difficult, however, to determine the extent or severity of the impediments or what time may be required to resolve them.

Perhaps the most significant factor is that residue is not well demonstrated for any use other than bituminous pavement construction. This obviously limits the potential markets for the residue, processed or unprocessed. It appears that a limited market exists for residue as structural fill material or landfill cover, but these uses are particularly sensitive to geographic conditions, they should not be generally considered as a stable market. All other uses of residue identified in the research are not sufficiently demonstrated to be considered commercially viable means of utilization at this time.

Residue is not well demonstrated as a wearing surface course pavement material. The overwhelming majority of research work has focused on the use of residue in base course pavements. In this case, the material has performed in a manner comparable to traditional paving materials. In the few instances, however, where residue was used in a wearing surface course, the asphalt was observed to strip or pull away from the glass particles in the residue. Research documents note that the addition of hydrated lime appeared to mitigate the condition, but it is not recorded how effectively this improved performance over a long period of time. The use of residue is thus limited for resurfacing work, which constitutes a large portion of pavement maintenance.

The use of residue in pavements is additionally limited by the lack of demonstration in pavement patching. No
instances were identified where residue was used to repair pavements. Patch work of pavement, although usually an interim measure, is routinely performed on all types of bituminous pavements. It is the cheapest and fastest means of ensuring road availability. It is not known how the residue/asphalt mixture would perform in hot- or cold-patch operations or if such patchwork would perform suitably.

When examining the use of residue for pavement construction or maintenance, it should be noted that California municipal government public works budgets have been reduced in the post-proposition 13 era. Less money is available for road repair or the construction of new roads; in many areas, maintenance schedules have been significantly curtailed. While this indicates a decreased demand for pavement materials, until such time as budgets may be restored, cities and counties may also be more receptive to utilizing residue from resource recovery facilities serving their jurisdictions, especially if it is less expensive than natural aggregates. These financial problems may act as both an impediment and an incentive.

A factor that could be of considerable importance is the potential for industry resistance to a residue aggregate product. This could depend on the quantity of residue aggregate to be marketed, and what share of the market that represents. Calculations based on anticipated quantities of residue and historical aggregate production indicate that residue aggregate tonnage would represent approximately 1 percent of total aggregate production; this is based on optimum figures of residue production in future years. It would appear that, depending on the geographic origin of the residue and availability of local aggregates, residue would not present a threat to existing industry. Aggregates are historically in short supply in urban areas, the generation point for most residue from resource recovery. Industry structure, i.e., long-term supply contracts and vertical integration, could in some cases discourage residue aggregate use. The relatively small quantity of residue aggregate, however, would seem to preclude such problems.

Closely related to industry resistance is the potential for consumer reluctance to use residue aggregate. The consumer could be the asphalt batch plant, who buys the material for its mixes; the contractor buying rock products for a job; and the city or county needing stockpiles, small or large, for patch work. It can be anticipated that the primary concern here would be the performance of the residue aggregate material. Research has demonstrated that residue performs well in bituminous pavements under experimental conditions. There has not been, however, long-term and widespread use of the residue as an aggregate material and much concern could be expected as to the consistency and quality of the product. A certain measure of predictability is necessary to establish consumer confidence.

Perhaps the key to consumer acceptance is the State of California's approval of residue for use in specific applications. The absence of official approval of the material and absence of specifications for the type and quality of residue for each use discourages utilization. Several potential consumers contacted during the course of research specifically indicated that certification by the state was ample assurance of the material's performance. By assuming an official position on residue use, the state could set specifications to ensure mandatory levels of material quality, much in the same way as specifications are prescribed for various grades of aggregate. Without state approval, residue aggregate products could not be used for construction purposes unless approved by local regulations.

Raw materials of any nature, however, must meet certain standards of quality, composition and reliability. Effective marketing requires a predictable product and the lack of production standards and material classification is a serious impediment to widespread utilization of residue. Production standards are especially critical to changing a waste material into a useful product. A common terminology must be created to facilitate marketing and utilization.

One of the most serious impediments to residue utilization is state regulation prohibiting the importation of hazardous waste materials into California. A number of research programs could not be conducted due to difficulties associated with residue importation. As identified earlier, there are several areas of research that could benefit resource recovery projects in California, particularly in regard to residue use in cement and manufacture of ceramic, masonry and concrete brick materials using residue. Resolution of problems in these applications would considerably broaden the market for residue. But although the greatest motivation exists in California, due to the hazardous classification of residue, researchers must now go outside the state to conduct their work.

The classification of residue as a hazardous waste material could, in itself, pose several impediments to the utilization of residue. The first impediment would be the necessity of a Hazardous Waste Facility Permit for any facility storing the residue on its premises for more than ninety (90) days. This could include not only the generator but also, in some instances, the consumers, e.g., the rock products dealer who stockpiles and markets the material, the city or county using residue for repair work, or the asphalt batch plant storing residue aggregate for mixing.

The second impediment resulting from this classification would be the necessity of hazardous waste transport
of residue. This could apply to every instance of residue transport, from generating facility to asphalt batch plant to construction site. Cost and inconvenience would be considerable.

Probably the most dramatic impediment resulting from the hazardous waste classification would be the perception of the material as toxic and dangerous to handle. Considering the large number of people who might come into contact with the residue, it is not unlikely that a fearful perception of the material could effectively preclude its use on a customary basis.

An additional impediment would be the necessity of installing leachate collection systems at every site where residue storage could be subject to precipitation of any kind. Leachate treatment and disposal would incur additional expense and inconvenience, serving as a significant deterrent.

An additional consideration is whether vendors would make residue processing systems available separately from their own resource recovery systems. Almost all of the residue processing systems identified in this paper were developed in conjunction with an existing resource recovery technology; the exceptions are the FRL fusion process and the Tuscaloosa Metallurgy Laboratory experiment, which were developed as government research projects. If residue processing systems are not available separately, two things may occur: technology selection may be skewed to favor systems with residue processing capability, assuming residue utilization is encouraged by the state, or duplication of effort may occur in developing residue processing systems on an individual project basis when proven systems already exist. If such systems can be procured without the parent resource recovery technology, it can be expected that production standards for the raw residue would be definitive, required by the residue processing system designer in order to ensure performance.

RECOMMENDATIONS

This section addresses recommendations which could result in greater knowledge about residues, their processing and use. General and specific recommendations are made; however, it is the intent of this section only to provide suggestions for further work.

- The most apparent need is for more information on residue characteristics. Carefully designed and documented research programs should be conducted, especially with attention to codisposal residues, RDF/PRF residues, and rotary kiln or rotary combustor residues. To establish a consistent standard of information, additional documentation of mass combusted residues would be helpful. Ideally, these programs would use similar procedures in both the collection and testing of samples.
- More research should be conducted on Japanese residue processing systems. The lack of translated documents raises questions about the certainty of the level of information obtained; it is possible that additional processing systems are available and that residue processing is more widely practiced than perceived in the course of research.
- Further study of Scandinavian uses of residue is merited. Conversations with WMI/Volund representatives and company literature indicate that residue utilization is common, especially in cement and concrete applications. No translated documents, however, were available and it is probable that some useful information has not been recorded in this work.
- An areas of research deserving particular attention is the potential utilization of fly ash as a separate residue stream. Because of its very fine particle size and somewhat different characteristics, fly ash may be a more appropriate material than residue (bottom ash) for use in certain applications, notably in masonry brick and some cement mixtures. Another area of interest is current research into the useful properties of sludge from flue gas desulfurization units (FDG). While work conducted to date has focused on coal fly ash, it is possible that MSW residue from FGD units will also exhibit pozzolanic qualities.
- If problems in using residue in Portland cement concrete could be resolved, a much wider market would exist for the material. Since promising results have been achieved in some laboratory situations, further research in this area is worthwhile. As mentioned in this paper, several possible solutions to problems of alkalai-aluminum and alkalai-silica reactivity have been suggested but none have been tested to date. As cement uses represent a large potential market for residue without particular geographic restrictions, additional research and development is strongly recommended.

A more general recommendation is for more industry organization and support for MSW residue utilization. Powerful industry support has accelerated the use of coal fly ash in a wide variety of applications. Similar resource recovery industry support would likely produce similar accomplishments. The coal-focused National Ash Association has been an effective promotional and educational organization; it is not difficult to envision a similar group effort to develop residue use. This could perhaps easily be accomplished by formation of a special group within an existing industry organization.

A more specific system for classification of residues needs development. If residues are to be widely marketed, there must be a system for identifying residue types and
qualities. The same system could serve as a standard for production. The system suggested in this study is based on the basis of LOI/OI (loss on ignition/organic impurities) factors; an additional useful measure would be particle size gradation, similar to the classification of natural aggregates.

• More research should be conducted on the performance of unfused residue aggregate in wearing surface course pavements. Documentation on the relatively little research done on this type of application reports some stripping of asphalt from glass particles in the residue; addition of small percentages of hydrated lime was suggested as a solution. More test pavements and performance documentation is needed, however, before this use can be considered well demonstrated and appropriate for widespread implementation.

• Similarly, more research is necessary to determine the suitability of either unfused or fused residue aggregate in pavement patching. Research did not indicate that any studies of this kind have been performed. The different types of patch methods could represent a large market for residue aggregate products and it should be determined if the products perform adequately in these applications.

• An improved flow of research and development data is necessary. Not only do problems exist in adequate documentation of past research, but on-going efforts would also greatly benefit from some sort of residue utilization information clearinghouse. One of the keys to expediting research is sharing information gathered in past projects; a relatively small effort of information organization and maintenance would create a valuable resource for all those interested in residue utilization, avoiding duplication of research activities. More educational activity is necessary.

SUMMARY

If uses are restricted to those that are well demonstrated, adequate technology exists to prepare the residue. Initial economic analysis indicates that processing and sale of residue products and by-products is, in almost all cases, more attractive than landfill disposal in either Class I or Class II-2 sites. No significant environmental impacts are anticipated from residue processing that cannot adequately be mitigated through existing means. The market for residue products, with the exception of incinerated ferrous, appears to be good.

There are a number of impediments to the development of residue utilization. Some of these can best be resolved by private industry. The most significant impediments, such as classification of the residue and approval of specifications for its use, require action on the part of state agencies. While it is appropriate that private industry resolve many of the technical questions regarding residue processing and use, some institutional impediments can only be resolved by state involvement.

There are many types of action available to the state and private industry to develop and promote residue utilization. These range from literature translation and further documentation of foreign practices to practical testing and demonstration programs. One of the most important factors in promoting residue utilization, however, will be the interest and support of the resource recovery industry. If this area is to advance in a reasonably expedient manner, better organization and exchange of information is necessary.

In regard to development of residue utilization in California, probably the most important single action is for the state to adopt a clear policy on residue development. Because many California resource recovery projects will be operating within a relatively short time, it is important that action be taken soon to ensure that residue utilization will be possible by the time projects come on-line. Because of these time considerations, it would be advantageous if a state policy decision was available shortly after conclusion of the toxicity testing program.

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