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INDUSTRIAL WASTE EXCHANGE:
A MECHANISM FOR SAVING ENERGY AND MONEY

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INTRODUCTION

What is a Waste Exchange? A waste exchange is a facility that enables industrial process wastes, by-products, surpluses, or materials that do not meet specifications to be transferred from one company to another company where they are used as process inputs. Because many of these materials are of low or negative value, it does not pay to transport them great distances. (Higher-value materials may find more-distant markets and even markets overseas.) A waste exchange is therefore a regional venture by nature; on the other hand, the area it serves must be large enough to include a variety of industries. Several too-small exchanges have merged with others or ceased operation. A list of operating waste exchanges in the U.S. and their locations is shown in Table 1.

The waste generator involved in waste exchange benefits from the revenues from the sale of waste and the avoided disposal costs, and the user benefits from reduced raw-materials costs. Benefits to the nation include decreases in its dependence on imported resources, in energy required for production of new materials, in public-health hazards, and in amounts of land and money required for waste disposal. The benefits are achieved through any successful waste exchange. However, the characteristics and methods of industrial waste exchanges may differ in several important aspects.

Types of Waste Exchanges. Waste exchanges differ according to whether or not they actually handle materials. The most common type of waste exchange does not handle materials, but is only an information clearinghouse. Waste-generating companies inform the exchange about the quantity, composition, and location of the wastes they generate and the frequency with which the wastes are available for exchange. Companies wishing to use wastes as process inputs supply similar information about their needs. The required information is usually sent to the exchange on a standard form, and a nominal listing fee is often required. The information on wastes available and wanted is published in the exchange's catalog, which typically appears quarterly and may be available free or for a small charge. Waste-exchange catalogs sometimes include a newsletter and advertisements for consultants and firms offering waste-handling services. Figure 1, reproduced from Ref. 1, shows typical listings from a catalog. To protect company proprietary information and to discourage possible government involvement, catalog listings are often confidential. A party interested in using available wastes or supplying needed materials must write an inquiry to the exchange, which forwards the letter to the listing company. The function of the information clearinghouse generally ends there; it is up to the listing company to contact the inquiring party and negotiate an exchange, which may involve a one-time transfer, several transfers, or even the continuous transfer of wastes. The companies are generally under no obligation to inform the clearinghouse of the results of negotiation. They may even prefer to "keep a good deal quiet" from their competitors. A schematic showing how an information clearinghouse assists the transfer of wastes is shown in Figure 2. Sometimes an information clearinghouse makes an active effort to find possible users for available wastes, most of which are not successfully exchanged simply by catalog listings. (The California Waste Exchange, for example, determines possible users and informs them of appropriate materials available.) This function requires more than the usual small part-time staff. One waste-exchange operator suggested a central information service funded by the Departments of Commerce and Energy and the Environmental Protection Agency (EPA).

The other type of waste exchange is a materials exchange that, for a brokerage fee, actually takes possession of the wastes and participates in the negotiations. This type of exchange often actively seeks buyers for wastes. A schematic of waste transfer through a materials exchange is shown in Figure 3. In some cases, the materials exchange performs minimal processing on the waste to make it a suitable raw material for the buyer's use. Still other companies, as their main line of business, reprocess wastes into valuable products for resale. More detail concerning the operation of specific waste exchanges can be found in Ref. 2.

The second important characteristic of waste exchanges is their status as public, nonprofit operations or profit-making businesses. This characteristic is not uncorrelated with the first; most information clearinghouses are operated and subsidized by government, chambers of commerce, or trade associations, and most materials exchanges are private enterprises. (ome privately run exchanges regard subsidized changes as direct competitors with an unfair ivantage.) It is clear that little money is t be made by publishing a quarterly catalog, but materials brokerage fees do offer potential profits.

The third important characteristic of a waste exchange is the types of material it handles. This topic will be treated in the next section.

Types of Materials Handled by Waste Exchanges. The word "waste" is interpreted in various ways by the different waste exchanges. Some include surplus materials -- oversupplies of virgin materials -- in their listings, while others specifically exclude them. One for-profit materials exchange deals almost exclusively in surplus textiles. Other exchanges restrict their operations to materials for which no markets or extremely limited markets now exist. Wastes with limited markets are generally disposed of in landfills or otherwise, at a cost to the generator. These are the materials for which waste exchange offers the greatest potential for dollar and energy savings, and therefore these are the ones discussed in this report. A list of the categories of wastes chosen for study is shown in Table 2.

Another necessary distinction is that between hazardous and non-hazardous wastes. Some exchanges handle only one or the other. The distinction is not strictly correlated with the categories in Table 2, but most hazardous materials are found in categories 1 (acids and alkalis), 2 (organics and solvents), 3 (metals and metal-containing sludges), and 11 (inorganics). The operative definition of "hazardous," for our purposes, is to be found in the Resource Conservation and Recovery Act of 1976 (PL94-580, RCRA)[3] and its associated regulations (for example, 40 CFR Parts 260-265[4]). Because of the importance and complexity of these regulations, we will summarize the relevant points in the the following section.

RCRA, Hazardous Waste, and Waste Exchanges. Although RCRA deals with a number of topics related to resource recovery, the area of hazardous waste has generated the bulk of regulations and the most interest. There is a chain of regulation that extends from those who generate hazardous waste to those who transport, store, treat, and dispose of it. However, facilities that recycle or reuse hazardous wastes are excluded from these regulations for all wastes except those containing the most hazardous materials. This exemption should provide considerable incentive for material recovery, but because of the length (hundreds of pages) of the hazardous-waste regulations and their complexity, many people (including some waste-exchange operators) are not aware of it. However, transport and storage of the particularly hazardous materials is still regulated. (See p. 33120 §261.6 in Ref. 4 for the exact regulations that apply.)

Hazardous waste is defined in RCRA to be "a solid waste, or combination of solid wastes, which because of its quantity, concentration, or physical, chemical, or infectious characteristics may:

(A) cause, or significantly contribute to, an increase in mortality or an increase in serious irreversible, or incapacitating reversible, illness; or

(B) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of, or otherwise managed."[3]

Subsequent regulations define criteria for determining if a waste is hazardous and, in addition, list particularly hazardous materials for special consideration. These materials, for which transport and storage regulations apply even if the materials are to be reused or recycled, are listed in 40 CFR Part 261 Subpart D. Sludges are also regulated. In 40 CFR Part 261 Subpart C, four criteria for identifying hazardous wastes not specifically listed in Subpart D are defined precisely. These are ignitability, corrosivity, reactivity, and EP toxicity (toxicity determined by an extraction procedure). It has been estimated that on the order of 20% of industrial wastes are hazardous according to these definitions, and many of them are listed as available in waste-exchange catalogs. The hazardous nature of these wastes is extremely important in determining the benefits of exchanging them, because the costs of regulated disposal, storage, and treatment may be avoided by recycling. Several of the materials discussed in the next section are hazardous wastes that can be economically recycled.

OPPORTUNITIES FOR MATERIALS RECOVERY USING A WASTE EXCHANGE

This section presents examples of materials that, though now disposed of, could be transferred using a waste exchange and recycled for monetary and energy savings. For each category listed in Table 2, relevant characteristics of the materials are discussed and a single example of a listed material is chosen for more detailed examination. Possible methods for recycling or reusing the waste material are suggested and compared with current disposal alternatives with respect to cost and energy savings. Impediments and incentives to exchange of the specific materials are noted.

Several impediments common to the exchange of waste materials can be identified. Once a buyer for a listed material is located, there are some fixed costs that must be borne by the companies involved in an exchange. These include costs related to price negotiations, arrangements for transport, material testing, and any equipment adjustments or modifications needed to handle the material. These costs may be small on a per-pound basis when large quantities of material are exchanged regularly, but they are considerable for materials available one time only, irregularly, or in extremely small quantities.

Category 1: Acids and Alkalis. A page of typical waste-exchange listings of acids and alkalis available is shown in Figure 4. The most obvious characteristic of these listings is their diversity. Each includes a different reagent with different impurities, and reagent concentrations range from 6% to 80%. The next important characteristic is that most of the wastes are available in large quantities, generally tens of thousands of gallons per month, increasing the chances for economical treatment. The final characteristic is that many of the wastes are hazardous under RCRA regulations because they are corrosive ($pH < 2$ or $pH > 12.5$). This means that they cannot be disposed of without prior treatment, such as neutralization and precipitation. The cost of this treatment is $30-150/ton, including screening and sedimentation;[5] thus there is considerable incentive to avoid disposal. Although several firms, for instance the Stauffer Chemical Company in Martinez, California, recycle acids commercially, large volumes of acids and alkalis are still available for exchange. One impediment to the recycling of these materials is their high water content, which makes transport over long distances expensive. It is therefore plausible that a central regional recycling facility, perhaps specializing in one type of waste, such as spent hydrofluoric acid (HF) from printed circuit etching, would be most successful.

The specific material from the acid and alkali category chosen for more detailed examination is sulfuric acid (H_2SO_4). Large volumes of sulfuric acid are produced annually in the U.S. (42.2×10^6 tons in 1978)[6] and, although over 60% is consumed in phosphoric acid production, on the order of 10% is used and spent in cleaning, plating, and copper leaching and as a catalyst. The 15-40% H_2SO_4 listed as Code A-118 in Fig. 4 is typical of many waste-exchange listings of available acid. The material is hazardous because it has a pH below 2. Several possibilities are available for recycling it. The first of these is purification and reconcentration to recycle the spent acid to its original use. It is estimated that reconcentration of H_2SO_4 from 88% to 99% cost about $60/ton in 1979, about 10% more than the cost of virgin acid.[7] In addition, the process was reported to be energy intensive; the energy requirement is calculated to be 0.6×10^6 Btu/ton with no heat recovery, and virgin acid requires only 0.8×10^6 Btu/ton.[8] Therefore, reconcentration appears to be justified primarily to avoid disposal costs. The Stauffer plant in California is reported to be regenerating H_2SO_4 by using a thermal reaction to break it down and reformulate it.[5] The company apparently finds the process economically attractive.

Another possible use for spent acid is as a replacement for virgin acid in processes that require less-concentrated or less-pure acid.

Lead-acid storage batteries require a weight concentration of only 36%. Thus, the most concentrated part of the example stream (40% H_2SO_4) could possibly be used in batteries after filtration of the suspended sand. Cost of this treatment would be less than the avoided disposal cost. The value of 40% H_2SO_4 is now about 15¢/gal (about \$35/ton) on the East coast,[9] so the stream should be worth up to \$15,000 a month. Note, however, that this discussion assumes there are no troublesome contaminants in the acid that would be difficult to remove and would lower the resale value. Waste-exchange listings may not contain sufficient information on material composition for all end-users to be certain of the material's usefulness and should in many cases be supplemented with more precise data from the generator.

Waste streams with higher concentrations of acid (more than 65%) can be used to produce superphosphate fertilizers. In cases where the H_2SO_4 is too dilute or is otherwise unsuitable for reuse, neutralization may be necessary. However, this need not necessarily be followed by disposal, because neutralization with lime ($Ca(OH)_2$) yields gypsum ($CaSO_4$), which is of low value (about \$5/ton) but salable. Neutralization with sodium hydroxide (NaOH) yields sodium sulfate (Na_2SO_4), which can be dehydrated and used as a dessicant. It is interesting to note that the caustics used to neutralize waste acid are themselves energy intensive (5×10^6 Btu/ton for $Ca(OH)_2$, 25×10^6 Btu/ton for NaOH)[8] and expensive (\$31/ton of CaO, \$1220/ton of NaOH).[9] Therefore, only unrecyclable waste caustic should be used for this purpose.

Category 2: Organics and Solvents. There are many listings in the organics and solvents category from all of the waste exchanges. A large variety of materials is offered, but they all have one thing in common: they are combustible and can be burned to recover 10,000-20,000 Btu/lb. Some of the materials, in particular aromatic compounds and halogenated organics, are listed as hazardous. These therefore cannot be disposed of in landfills, and their storage, transport, and incineration must be accompanied by various permits, manifests, and licenses. Combustion of these materials is an acceptable method of disposal, but the temperature must be high enough to insure complete destruction, and acid gases (in particular HCl from decomposition of chlorinated organics) must be removed. Acid gas may be removed by installing a scrubber or avoided by incinerating the wastes in a cement kiln. Cement-kiln combustion is acceptable even for such highly toxic materials as PCBs (polychlorinated biphenyls), because the combustion temperature is high and the alkaline cement neutralizes the HCl. (This approach has been endorsed by the California Air Resources Board even for PCBs, and the State of Ohio endorsed as environmentally acceptable a plant burning nonhalogenated wastes.[5]) A decision concerning whether or not cement-kiln combustion is acceptable will be made by each state. Combustion in a cement kiln is reported to cost \$50-70/ton;[5] but $20\text{-}40 \times 10^6$ Btu are displaced, saving \$30-60/ton if the displaced energy is from coal, the major fuel used in cement plants, and \$60-120/ton if it is from gas. The process is economical because substantial disposal costs are avoided. High-temperature waste incineration is not economical, costing \$250-500/ton.

The bulk of the waste-exchange listings in this category are for solvents of various types, most available in large quantities. Most are not hazardous or are hazardous (flammable) but not listed in 40 CFR Part 261 Subpart D, so they are not regulated if they are to be reused or recycled. Solvent recycling (distillation, steam stripping, extraction) is reported to cost \$50-100/ton,[5] and the value of the solvent recovered is at least \$300/ton, so the process is economical. Many companies (for example, Systech) are in the business of solvent recycling, and there are several listings in waste-exchange catalogs for waste solvents wanted. However, large quantities of solvents are still available for recycling. Possible reasons for this are (a) contaminants that are difficult to remove, (b) high water content that increases treatment and transport costs, (c) the presence of close-boiling compounds that are difficult to separate, and (d) the lack of a local recycling facility.

The example chosen for more detailed analysis is a mixture of phenol and oil, about 4000 lb of which are available daily in Piedmont, N.C.[10] This material was probably disposed of in drums prior to enactment of RCRA regulations, but this is no longer an acceptable alternative because phenol is on the hazardous-waste list in Subpart D. No data are available on the proportions of the two components, so the analysis is done conservatively, for a 90% oil, 10% phenol mixture. This mixture can be burned to recover about 17,500 Btu/lb, replacing about \$0.11 worth of oil. On the other hand, the two components can be separated by first extracting the phenol into an aqueous alkaline solution and then stripping or distilling it from that solution. The approximate cost for this treatment is \$50-100/ton.[5] The current price of phenol is \$0.36/lb,[9] so a 10% phenol stream would yield materials worth \$0.14/lb, or \$280/ton. This is \$60/ton more than the revenues from combustion. The energy required to make one pound of phenol is about 27,000 Btu,[11,12] so recovering a 10% solution saves about 3,000 Btu in process energy (6×10^6 Btu/ton), much of it in the form of oil. Both the revenues and the energy recovered increase for higher proportions of phenol, so the separation should be economical. This phenol/oil mixture may be unrecovered because only 4000 lb/day (about 500 gal/day) are available, and this may be too small a quantity to justify the capital expenditure for separation equipment. In this case, a specialized recycling facility would be required locally.

Category 3: Metals and Metal-Containing Sludges. Metals and metal-containing sludges materials are not flammable, and, except for concentrated acid solutions and certain wastes containing heavy metals like lead and cadmium, are not hazardous. In a typical catalog, there are numerous acid solutions listed (from electroplating and cleaning processes) that contain small quantities of metal, and there are often many sludges listed. There may also be some listings of surplus metals and scrap that have established markets. The acid solutions can often be cleaned and reconcentrated with known technology. Many of the listed wastes contain metals in higher concentrations than the concentrations in ores currently being mined, and could be treated as ores. However, the quantities of waste are often too small to justify a facility; therefore either a central plant or transport to a primary metal-producing plant is needed.

The example chosen in this category is a copper oxide (CuO) sludge containing 6-8% Cu and 80% moisture. It is not classified as hazardous. The other constituents are unspecified and are presumably neither valuable nor problematic. The sludge can be dewatered, leaving a solid containing 30-40% copper (a typical ore concentration is 0.6%). The solid could probably be charged to the converter of a conventional copper smelter, where it would be reduced to copper metal. The energy saved would be approximately 60×10^6 Btu/ton of displaced copper from ore, or about 5×10^6 Btu/ton of sludge processed. The value of the copper is \$0.78/lb,[13] or about \$110/ton of sludge, and the marginal cost of increased charge to the converter would be low. The major impediment to recycling this waste stream is that only a small quantity (50-75 tons) is available annually. Total annual revenue from copper recovery would be only about \$6000.

Category 4: Minerals, Including Glass and Sand. Examples of minerals available are shown in Figure 5, reproduced from Ref. 14. There are not many listings; most of the materials offered are of extremely low value and are available in large quantities. Their production is generally not energy intensive. The materials are neither combustible nor hazardous, so disposal in landfills is possible. Because of the materials' low value, transport does not pay; however, if a local user can be found, disposal costs can be avoided and energy that would have been used to mine the material displaced can be saved. Waste exchanges are an appropriate medium by which to find local customers for these materials.

Several of the materials listed are not obviously useful or recyclable — for example, glass cullet with ceramic inks, china pieces, and a mixture of sand, mica, and feldspar. Perhaps these could be used as soil conditioners or filtration media; testing would be needed to determine the usefulness of each waste material.

The chosen example in this category is 137,000 lb of sand, available monthly. Mining and transport of sand requires about 1×10^6 Btu/ton, some of which could be saved by using this waste material. If the energy saved were from oil, it would be worth about \$400/month. Possible customers include cement- or glass-manufacturing companies. The waste sand's actual usefulness will of course depend on its grain size and purity.

Category 5: Oils, Fats, and Waxes. Most of the available wastes in the category of oils, fats, and waxes are lubricating or hydraulic oils; all are combustible, with heats of combustion about 19,000 Btu/lb. Some are hazardous because of high aromatics content or, as is often the case with used automotive lubricating oil, high lead content. This means that the current practice of spreading this material on roads cannot be continued. Most typical listings are for relatively small quantities of material, so a central facility for treating wastes from many sources is appropriate. An economical means for collecting such dispersed commodities needs to be developed.

Used lubricating oils will be examined in more detail. In some cases, extensive processing may not be necessary to reclaim this material; oil and water separation and sedimentation and filtration may be all that is required to remove contaminants. The used oil can then be burned as a fuel, replacing virgin oil valued at \$0.11/lb. Alternatively, more extensive treatment of "lube" oils can be used to refine them again (or "re-refine" them) into a replacement for virgin lube-oil base stock valued at \$1.12/gal, or about \$0.17/lb. Table 3 adapted from Ref. 15, compares the economics of processing used oils for fuel and of re-refining by the solvent/distillation process developed at the Department of Energy's Bartlesville Energy Technology Center (BETC). The re-refining process has higher costs and higher revenues, but sale as fuel has a higher return on investment. Future regulatory decisions will influence businesses' choice of market for used oil.

Combustion recovers only the oil's heat of combustion. Re-refining by the BETC solvent/distillation process requires 2500 Btu/lb,[15] and the refined product replaces virgin lubricating oils that have a process energy requirement of 8000 Btu/lb,[16] thus displacing processing energy of 5500 Btu/lb each time it is recycled. When it can no longer be refined, it is still available for combustion. It is estimated that re-refining of used crankcase oils alone could save 43-76 x 10^{12} Btu/yr, or 7-12 x 10^6 bbl/yr of oil more than combustion could save.[15]

<u>Category 6: Food Processing Wastes</u>. Few food processing wastes are available. None of the materials is hazardous. Their value is low, and so transport over large distances (more than 25 miles) does not pay. Typically, there are listings of wastes of both animal and vegetable origin, but the latter predominate. These materials are all combustible, but they are generally wet, so the heat of combustion is only about 5000 Btu/lb. Direct combustion is feasible in some old boilers, and bioconversion is possible using fermentation and anaerobic digestion. Thermal processes for gasification and liquefaction are also known.

The example chosen was listed in the June 1981 bulletin of the Oregon Industrial Waste Information Exchange. The waste material is steer and cow manure from the paunches of slaughtered animals, available in bulk year-round on a regular basis. The quantity is unspecified. Anaerobic digestion is suggested for this material, even if the quantity is low, because the technology is simple and capital costs are low. Total cost of the process is about \$8-9/10^6 Btu, or \$16-18/ton of manure (assuming 20% overall gas yield). The value of the gas displaced is about \$3/10^6 Btu, or \$6/ton of manure, and the sludge can be sold as low-value fertilizer. The process is therefore economical if disposal costs of greater than \$10/ton are avoided or if gas prices rise to \$8/10^6 Btu.

<u>Category 7: Paper and Wood</u>. Typically, the paper and wood wastes available are uniform in chemical composition and could be burned as fuel if no possibility existed for recycling. The heat of combustion is 8000 Btu/lb (dry), so each ton burned displaces \$24 worth of coal. However, these materials can only be burned in certain boilers equipped to handle untreated solid fuels. In addition, with wood selling at \$30/ton, it does not pay to transport it over large distances. Paper recycling is a well-established industry, but collection and transport of small quantities of waste to a large central facility may not be economical. This is a frequent impediment to recycling of waste materials.

The example chosen for this category is 250 tons/month of sawdust and shavings, available in Tennessee. This example is typical in that the quantity of material available is extremely small. This material would be an excellent feed for paper manufacture, and each ton would save on the order of 2 x 10^6 Btu in processing energy used to reduce wood to a small particle size, plus the energy required to grow the trees displaced. The material could also be used in particle-board manufacture, with similar energy savings.

<u>Category 8: Plastics and Rubber</u>. Figure 12 shows examples of plastics and rubber available from one waste exchange. They share two important characteristics: they are nonhazardous and they are combustible, with heating values up to 20,000 Btu/lb. Therefore, if no higher-value use is found, these materials can be burned; each ton replaces \$40-60 worth of coal. An exception is polyvinyl chloride (PVC), a ton of which replaces only \$25 worth of coal. On combustion, PVC

releases HCl gas; if the material burned contains more than a few percent PVC, the HCl must be scrubbed from the stack gas. PVC can be burned in cement kilns or fluidized-bed combustors with alkaline media, as can all chlorinated organics, to eliminate HCl emissions.

Thermoplastic scrap of a single material can often be recycled back to the same material if it is clean or can be cleaned. Recycling can be done in-house or by commercial scrap dealers and processors. The costs of this type of recycling are low, and the recycled material can usually be sold for about half the price of virgin material. Almost all of the approximately 35,000 Btu/lb (mostly oil and gas) required to make these plastics is recovered in the recycling process. In spite of the advantages of recycling, numerous listings of single-component plastic materials appear in waste-exchange catalogs. Of course, some plastics are colored or otherwise contaminated, decreasing their value as recyclable thermoplastics.

Although technology exists for plastics separation, mixed thermoplastic streams cannot generally be separated economically. With new material often costing only about $0.40/lb, separation does not pay, even though energy savings from reuse are substantial. More research needs to be done to find an economical means of separating mixed or contaminated plastics.

The example chosen in this category is 100 tons a month of clean rubber chips from automotive batteries, available in the Midwest. Most automotive battery cases are now made of polypropylene, but hard rubber is still used for heavy-duty vehicle and industrial battery cases. This material can be treated in the same way as discarded tires; technologies are described in more detail in Ref. 17, and impediments are discussed in Ref. 18. The quantity available is too small to justify a dedicated treatment facility. This waste stream has a heat of combustion of 15,000 Btu/lb, and one ton could be cofired with coal in a stoker-fired boiler to displace $45 worth of coal. The marginal cost is extremely low, because the battery cases are chipped already and they must be transported even for disposal. The energy displaced is valued at about $0.023/lb, or $4,600/month. Alternatively, the material could be pyrolyzed, as could any of the materials in this category. However, the process is only economical on a large scale, and therefore many suppliers would be needed to make it pay. This is an impediment to construction of a pyrolysis plant. Net products from the pyrolysis of rubber are oil (up to 0.6 lb/lb input) and char. Together these are valued at about $0.12/lb of input if the char can be used to replace carbon black, and they cost $0.08 to produce. Materials requiring up to 23,000 Btu can be displaced by each pound of rubber pyrolyzed. Note, however, that the favorable economics and energy balance depend on the suitability of the char product to displace carbon black, and this is still under dispute.

Still another possibility for this material is to further reduce its size cryogenically or by the Gould mechanical process and use it as an extender for the original compound. The cost to freeze this material with liquid nitrogen (LN_2) and grind it in a hammermill is less than $0.05/lb, and material costing $0.50/lb is displaced. The energy to freeze and grind the material, including the energy to produce the LN_2, is about 1,500 Btu/lb, and this displaces 38,300 Btu/lb that would have been required to make new rubber. Thus the process looks good on both energy and financial grounds.

Another attractive possible use for waste battery chips is as a replacement for some of the asphalt in pavement. The mixture known as asphalt-rubber lasts considerably longer than conventional asphalt. If a 25% rubber mix lasts twice as long as ordinary asphalt, each pound of rubber displaces 5 lb of asphalt at $0.056/lb, for a total value of $0.28. Savings in labor from not having to resurface as frequently more than offset the small additional first cost of using asphalt-rubber. The asphalt displaced has a heating value of 90,000 Btu per lb of rubber used. However, a major impediment to the use of asphalt-rubber is that highway officials do not always consider life-cycle costs when deciding on road surface materials, especially if they are short of capital because of shrinking gasoline-tax revenues. In addition, further study is needed to document the performance of asphalt-rubber.

Category 9: Spent Catalysts. There are very few listings of spent catalysts in any of the bulletins, probably because of the high value of the precious metals contained in many catalysts. These are generally recovered either in-house, by the catalyst manufacturer, or by a specialized firm. Appropriate buyers for spent catalysts can probably be found by consulting the Thomas register;[19] however, if no buyer can be located, or the materials do not meet specifications, they may be offered through a waste exchange.

One catalyst that did find its way onto a waste-exchange listing is 110 gal/year of 25% palladium (Pd), 25% hydrochloric acid catalyst. Insufficient information was given on the chemical composition to be certain of appropriate treatment. Presumably, the other 50% is water and the material is not 25% Pd, but 25% of Pd on alumina or zeolite support. This is a typical hydrocracking catalyst, and cost $10-15/lb in 1979.[7] Therefore, material worth $3,000 or more could be recovered from the small quantity of spent catalyst listed for exchange if it found its way to a firm handling this type of waste.

Category 10: Textiles, Fur, and Leather. Textile, fur, and leather materials are nonhazardous, and they are combustible. Typical heating values are on the order of 10,000 Btu/lb, so each pound burned would displace $0.015 worth of coal. Pyrolysis would yield products worth $0.06 or less, and bioconversion would yield even less-valuable products. It is therefore worth looking for higher-value uses for these materials that typically cost over $1.00/lb new. No furs were listed in any of the waste-exchange bulletins, and no way was identified for the small scraps of leather available to be used as material, so we will discuss textiles only. Mixed textile wastes are of extremely low value; the only use identified was in vulcanised fiber, a composite material made by pressing fibers with a resin binder to produce a reinforced plastic. Cotton wastes, such as mattress- ticking trim, could be bleached and used in the production of rag paper.The waste examined in greter detail is 50-75 lb/ week of leg blanks and nylon panty-hose rags. This is clearly another example of material recovery impeded by small quantity. Nylon is a thermoplastic material and can simply and cheaply be remelted and used to replace virgin nylon for an energy saving of about 90,000 Btu/lb, much of it in the form of oil. The material would be some nonstandard beige color and therefore unsuitable for wearing apparel unless dyed a darker shade, but the mechanical properties should be adequate for production of gears or other mechanical parts. The price in November 1981 of virgin nylon 66 was $1.81/lb,[20] so considerable savings are possible from using recycled material.

Category 11: Inorganic Chemicals. There are many listings of inorganic chemicals, with a tremendous variety of materials offered in various quantities. Some of the wastes are valuable, others are worthless. Some are harmless, and others, such as cyanide sludge, are extremely hazardous. Many of the offerings are for sludges, and valuable materials could be reclaimed if an economical technology were developed for recovery of materials from sludge.

The waste chosen for discussion is a solution of copper sulfate ($CuSO_4$), from a printed-circuit plating line, containing 14-21 oz Cu/gal (average, 18-19 oz/gal). The solution did not meet specifications and is available once only, in a relatively small quantity (1,600 gal), and this is a major impediment to recycling. The listing did not give sufficient information to ascertain why the solution did not meet specifications. Reuse would save the most energy and money. Water or additional salt could be added to adjust the concentration. Solid impurities could be filtered out. If treatment and reuse as $CuSO_4$ solution is not practical, the copper could be recovered by electrolysis (electrowinning) at an energy cost of 12,000 Btu/lb, much less than the 50,000 Btu/lb needed to produce copper from ore.[21] The value of the copper in this waste is $1,440.

CONCLUSION: IMPEDIMENTS TO SUCCESSFUL WASTE EXCHANGE AND RECOMMENDATIONS FOR OVERCOMING THEM

We have demonstrated in the preceding section that in almost every category of waste there are materials that could be exchanged with substantial benefits. Calculation of energy savings potentially achievable if all wastes listed as available were exchanged would, because of the diversity, require analysis of each material.

Little information is available on the success rates achieved by waste exchanges; clearinghouses do not usually collect statistics, and materials exchanges keep them proprietary. However, one clearinghouse estimated that 20-25% of their listings resulted in exchanges;[22] another source estimates an average of 10%.[23] A recent study analyzed the effectiveness of one exchange during its first six months of operation.[24] The results are summarized in Table 4, where it can be seen that, in terms of percent of material available, inorganic chemicals were the most actively exchanged materials.

Considerable benefits are possible through waste exchange; more material transfers would increase the benefits actually realized. We have identified several major barriers that impede waste exchange, and we will now recommend actions that can be taken to overcome them.

One major barrier to the successful exchange of many listed wastes is the lack of economical technology for their treatment. This lack is greatest in the area of separation of mixed or contaminated wastes. Technology is generally available but often is not economical. Some examples in which economical separation technology is needed are materials recovery from sludges, separation of close-boiling liquids, and separation of mixed plastic or fiber wastes. Research on improved separation processes is strongly recommended. In addition, industrial waste generators should be encouraged to think about recycling before they unnecessarily mix or contaminate process waste streams. As one commercial recycler puts it, "Recycling works only when materials are known to be and planned to be recycled."[25] Alternatively, process or feedstock modifications that result in less waste can be considered. The government could provide incentives, through tax credits or rapid-depreciation allowances, for capital expenditures that reduce the volume or hazard of wastes or make the wastes more amenable to recovery (for example, by source separation).

A second impediment to waste exchange is that many listings are for small quantities of materials or for materials available only once and dispersed over a broad geographical area. It is generally not economical to treat a small quantity of material, and a continuing supply of input is needed to justify purchasing equipment to treat materials that can't be reused as is. Thus, in the absence of economical small-scale technology, dispersed wastes must be collected and transported to a central recycling facility that receives material from many sources. Not enough of these facilities are in operation to treat available wastes. Their establishment should be encouraged in any way possible. Loan guarantees, regulatory exemptions, and tax relief (the Senate is considering several measures in this area) might be appropriate. The problem of dispersed wastes is compounded by the fact that the low value per pound of many of the materials, particularly those with high water content, makes transport over large distances uneconomical. Therefore, research on appropriate methods for collection of dispersed low-value materials is badly needed. The methods would apply to recycleable materials in municipal waste, and to biomass and biomass wastes as well. It would also be worthwhile to develop portable recycling equipment.

Many waste-exchange operators identify restrictive regulation of hazardous waste -- and uncertainty about and misunderstanding and fear of regulations -- as a third impediment to waste exchange. First, many people do not realize that recyclers of all but listed hazardous wastes are exempt from RCRA regulations. Second, RCRA mandates cradle-to-grave responsibility for generators of hazardous waste, who therefore fear that they are liable for improper handling of their wastes by treatment facilities. However, it appears that responsibility can be transferred to a licensed facility through contractual agreement; this matter will be decided by the courts. Third, under RCRA regulations, generators need a permit if they are to store listed hazardous wastes for more than 90 days, even if the wastes are to be recycled. However, waste-exchange catalogs are often published quarterly, and negotiations for transfer take time, so this restriction severely limits hazardous-waste exchange. Finally, regulations concerning hazardous waste have changed several times and could change still further.* The resulting uncertainty deters companies from getting involved. Therefore, regulations must be finalized and people educated as to their proper interpretation. Numerous companies have sprung up to help waste generators cope with hazardous-waste regulations. In addition, the EPA maintains the "RCRA Hotline" to answer questions about hazardous-waste regulations (800-424-9346; in Washington, D.C., 382-3000). However, still more public education about regulations is needed. To complicate the situation even further, states have their own hazardous-waste regulations, and these are not uniform. A waste may be listed as hazardous in one state and not in another.

Another impediment to waste exchange is that many companies do not know what materials are available or what they could be used for. Companies are also reluctant to deviate from established practice in waste handling; the current system works, and a new system is an unknown. Small companies often do not have the technical expertise either to recognize or to

*But it must be noted that once avenues are found for reusing waste materials, they are used routinely without further involvement of the waste exchange.

*The EPA expects to propose a new definition of solid waste that will affect recycling of hazardous wastes. Even if the new definition is clearer and exempts certain recyclable materials, the change may cause additional confusion.

treat potentially usable materials offered for exchange. This problem can be solved in large part by an "intelligent" waste exchange that does not simply pass information about material availability through to its clients. Instead, the listings are examined and the exchange contacts potential users with information explaining how they could use specific materials. "In most cases, market research and development is necessary in order to establish an outlet for waste materials."[26] Most subsidized waste exchanges do not have the technical staff needed to do this, but most for-profit exchanges offer this service, among others, and appear to be operating successfully.* Therefore, waste exchanges should be encouraged to find uses for available materials. Recycling companies that treat wastes to make them suitable for reuse and then seek markets for them, as well as consultants who help generators recover their own wastes, should also be encouraged through such means as tax or regulatory relief and loan guarantees.

In summary, we find that, although considerable savings of both energy and money are possible through waste exchange, several major impediments limit the number of actual exchanges that take place. These impediments include the lack of economical separation technology, the small quantities of material available at each site, restrictive or uncertain regulation, and lack of knowledge on the part of potential waste users. None of these barriers is insurmountable if appropriate action is taken.

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Table 2 Categories of Wastes

Category	Materials Included
1	acids and alkalis
2	organic chemicals and solvents
3	metals and metal-containing sludges
4	minerals, including glass and sand
5	oils, fats, and waxes
6	food processing wastes
7	paper and wood
8	plastics and rubber
9	spent catalysts
10	textiles, fur, and leather
11	inorganic chemicals
12	other

State	Exchange or Company	Address	Phone, Contact	Type	Profit Status	Area Served
Calif.	Zero Waste Systems, Inc.	2928 Poplar St. Oakland 94608	(415) 893-8257 T. Pitts	M	P	unspecified
Calif.	California Waste Exchange	2151 Berkeley Way Berkeley 94708	(415) 540-2043 Dr. P.H. Williams	IA	N	California
Colo.	Colorado Waste Exchange	1390 Logan Denver 80203	(303) 831-7411 O.L. Webb	I	N	Colorado
Fla.	ICM Chemical Corp., Inc.	8282 Western Way Circle Jacksonville 32216	(904) 731-8614 A.L. Tripi	M	P	Southeast
Ga.	Georgia Waste Exchange[c]	181 Washington St. S.W. Atlanta 30303	(404) 659-4444 R.D. Sumner	I	N	Georgia
Ill.	Industrial Material Exchange Service[g]	2200 Churchill Rd. Springfield 62706	(217) 782-6760 L. Moore	I	N	Illinois
Ill.	American Chemical Exchange	4849 Golf Rd. Skokie 60076	(312) 677-2800 J.T. Harris/I. Eler	M	P	unspecified
Ill.	Environmental Clearing-house Organization	3426 Maple Lane Hazel Crest 60429	(312) 335-0754 W. Petrick	M	P	unspecified
Ind.	Environmental Quality Control, Inc.	1220 Waterway Blvd. Indianapolis 46202	(317) 634-2142 N.L. Beck	I	N	Indiana
Ky.	Louisville Area Waste Exchange[c]	300 W. Liberty St. Louisville 40202	(502) 582-2421 S. Lampe	--	--	--
Maine	New England Materials Exchange	P.O. Box 947 Kennebunk 04043	(207) 985-6116 D.L. Trask	IA	N	New England
Mo.	Midwest Industrial Waste Exchange	10 Broadway St. Louis 63109	(314) 231-5555 C.H. Wiseman, Jr.	I	N	Midwest
N.H.	Resource Conservation and Recovery Agency	P.O. Box 268 Stratham 03885	(603) 772-6261 D. Green	--	--	--
N.J.	Industrial Waste Information Exchange	5 Commerce St. Newark 07102	(201) 623-7070 W. Payne	I	N	New Jersey
N.Y.	Enkarn Research Corp.	P.O. Box 590 Albany 12201	(518) 436-9684 J.T. Engster	I[d]	P	World
N.Y.	Northeast Industrial Waste Exchange	700 E. Water St. Syracuse 13210	(315) 422-6572 W. Banning	I	N	Northeast
N.C.	Piedmont Waste Exchange	Inst. for Urban Studies Charlotte 28223	(704) 597-2307 E. Dorn	I	N	Carolinas
N.C.	Pacific Environmental Services, Inc.	1905 Chapel Hill Rd. Durham 27707	(919) 493-3536 D. Kent	I[e]	P	Carolinas, Virginia
Ohio	Ohio Resource Exchange	2415 Woodmere Dr. Cleveland 44106	(216) 371-4869 R. Immerman	IA	P	Midwest
Ohio	Industrial Waste Information Exchange[f]	1646 W. Lane Ave. Columbus 43221	(614) 486-6741 N.A. Brokaw	I	N	Columbus area
Ore.	Oregon Industrial Waste Information Exchange	3335 W. 5th Ave. Portland 97204	(503) 221-0357 D. Clark	I	N	unspecified
Penn.	National Wastes Exchange	P.O. Box 190 Silver Spring 17575	-- R.D. Schaible	I[g]	--	U.S.
Tenn.	Tennessee Waste Exchange	708 Fidelity Fed. Bldg. Nashville 37219	(615) 256-5141 N. Niemeier	I	N	Tennessee
Texas	Chemical Recycle Information Program	1100 Milam Bldg. Houston 77002	(713) 651-1313 J. Westrey	I	N	Gulf Coast
Utah	W.S. Hatch Co.[g]	P.O. Box 1825 Salt Lake City 84110	(801) 295-5511 --	--	--	--
W. Va.	Union Carbide Corp.	Box 8361, Bldg. 3005 S. Charleston 25303	(304) 747-5362 R.L. Floyd	M[h]	P	U.S.

[a]M = Materials exchange, I = Information clearinghouse, IA = Active information clearinghouse.

[b]P = for profit, N = nonprofit.

[c]Information from R. Hill, U.S. Environmental Protection Agency (1981); unverified because no response received to letter.

[d]Handles surplus materials; charges a commission for successful transfer.

[e]Want to become brokerage.

[f]Dormant.

[g]Manages other exchanges.

[h]In-house only.

Table 3 Recycling Used Automotive Lubricating Oil:
Annual Economics of Re-refining and of Processing for Fuel

Economic Factor	Rate	Recycling Method: Processing for Fuel	Recycling Method: Re-refining
Process costs ($\$10^3$)			
Raw used oil, 10^7 gal	\$ 0.37/gal	3700	3700
Power	\$ 0.06/kWh	19	246
Steam, 150 psi sat	\$ 5.04/100 lb	--	98
Solvent	\$ 2.00/gal	--	108
Fuel	\$ 0.40/gal	--	308
Catalyst	\$125.00/ft^3	--	17
Hydrogen	\$ 6.00/10^3 SCF	--	162
Operating labor	\$ 20.00 x 10^3/ operator	50	240
Overhead	100% of operating labor	50	240
Maintenance	5% of investment	13	260
Insurance, taxes	3% of investment	8	156
Depreciation	10% of investment	27	520
Total		3867	6055
Revenues ($\$10^3$)			
Lube oil	\$ 1.12/gal	--	7840
Fuel	\$ 0.45/gal	4455	945
Total		4455	8785
Profits ($\$10^3$)			
Before taxes		588	2730
Income taxes	50% of profit	294	1365
After taxes		294	1365
After-tax return on investment (%)		111	26.3

Table 4 Status of Wastes Listed with One Exchange[a]

Waste Type	Transferred (%)	Negotiations in Progress (%)	Not Transferred (%)
Acids	4	9	87
Alkalis	13	25	62
Other inorganics	27	27	46
Metal/metal sludges	5	19	76
Organics/solvents	13	23	64
Oils/fats/waxes	—	27	73
Plastics	—	67	33
Textiles/leather/rubber	—	58	42
Wood/paper	—	40	60
Miscellaneous wastes	14	19	67

[a]Status at end of first six months of operation of the waste exchange.

PWIX PENNSYLVANIA WASTE INFORMATION EXCHANGE

SAMPLE

ITEMS AVAILABLE

CLASSIFICATION: 3 — **Code #A-4**

Item: Hydrated Lime Slurry or paste-chemical analysis, approximately the same as dry hydrated

Quantity: Tonnage amounts in bulk

ITEMS SOUGHT

CLASSIFICATION: 4 — **Code #S-3**

Item: Mixture of Paints and Solvents

Quantity: 50 to 75 55-gal. drums/month

SERVICES NEEDED

Code #N-2

Services/Process: Solvent Regeneration

DIRECTORY OF GENERAL SERVICES

ENGINEER/CONSULTANTS

Green Valley Engineering Associates
10 Cedar Drive
Dillsburg, PA 17019

Contact: Jane Doe, Director - Technical Services
Telephone: 717/555-1212
Service: Solid and hazardous waste management, including testing, and assistance with regulatory compliance.

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222 NORTH THIRD STREET
HARRISBURG, PENNSYLVANIA 17101
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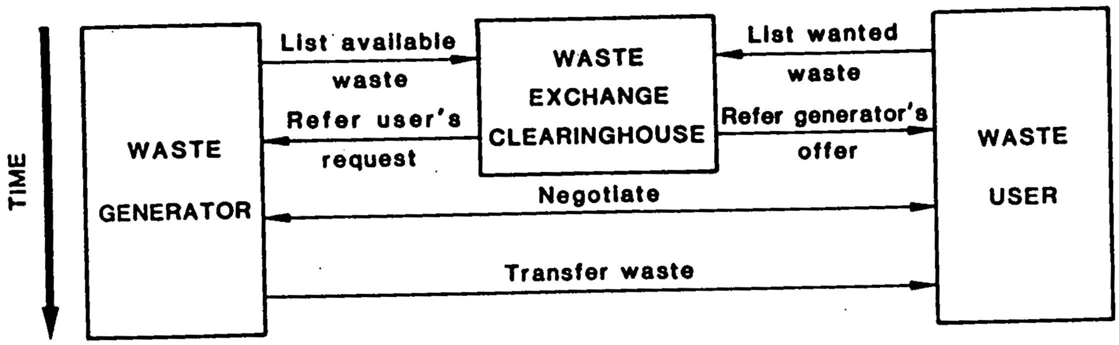
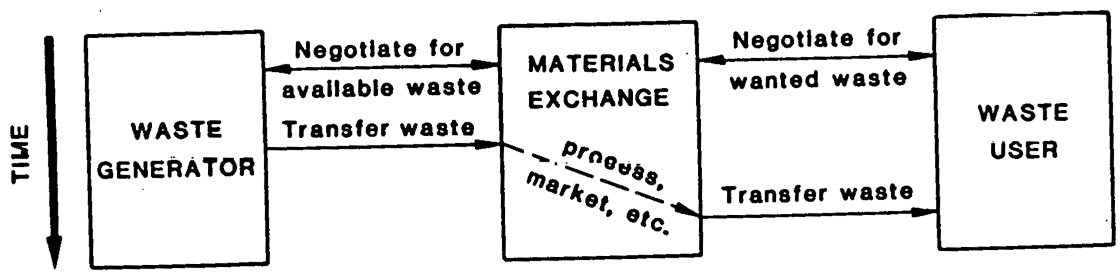
1 Example of Listings of Acids and Caustics



2 Schematic of Waste Transfer Assisted by an Information Clearinghouse



3 Schematic of Waste Transfer through a Materials Exchange

Acids

- Code #: A-76
  Material: Industrial Chemical Products of Detroit, Inc., Sol-Klean 1177M. Approx. 80% phosphoric acid, 10 butyl ether, no contaminants, clear colorless liquid Bp 210°F, Sp. gr. 1.40 solubility in H_2O complete. Possible use derusting steel parts, cleaning/finishing.
  Quantity: One time offer - 220 gals.
  Packaging: 55 gal. drums
  Location: Joplin, MO

- Code #: A-116
  Material: A 32% solution of hydrochloric acid. Has a slight green coloration and contains 1% phosphorous acid and 5-10% acetic acid.
  Quantity: Approx. 2,000 gals./week. Available on a continuous basis.
  Packaging: Bulk
  Location: Northeastern PA

- Code #: A-118
  Material: Spent sulfuric acid, 15% to 40% H_2SO_4, suspended solids approx. 100 ppm sand, balance water.
  Packaging: 100,000 gal./mo. available on daily basis
  Location: Western PA

Caustics

- Code #: A-14
  Material: Alkalin solution, primary components: sodium hydroxide (60-70 gms./liter), sodium carbonate (80-120 gms./liter), sodium aluminate (50-75 gms./liter).
  Quantity: 100-120,000 gals./mo.
  Packaging: Bulk transport
  Location: Pittsburgh, PA

- Code #: A-31
  Material: Caustic treated aluminum chloride material comprised of aluminum hydroxide (6%), sodium chloride (13%), organics (1%), and water (80%).
  Quantity: 1500 gals./day
  Packaging: Tank cars

- Code #: A-34
  Material: Caustic solution of organic and inorganic salts. Prevalent salts are sodium methacrylate, sodium acrylate, and sodium chloride. Normal pH is 9-13.
  Quantity: 25,000 gals./week continuous
  Packaging: Bulk

4 Example of Listings of Minerals

Category 4: Minerals

Available

A6 - 4	Gypsum Plaster: $CaSO_4 \cdot \frac{1}{2}H_2O$); (80%) Chips: 2 - 3" sq. X 1/8" thick; (15%). Formed Molds discarded, average 12X12X6 inches; (5%) Powder. Color: White. 3000 lb/wk. In unsealed 100 lb. sacks. Portland.
A64 - 4	Silicon Sludge in powder form when suspended in 70% water. Hardens like concrete when water is removed. Approx. 10.000 lbs/mo. beginning in late 1979. Stored in plastic-lined tanks. Portland area.
A101 - 4	Scrap/Broken Glass: 1 ton/wk. on a regular basis. Loose. Portland metro area.

5 Example of Listings of Minerals