LANDFILLS: WHERE DOES OUR TRASH GO?

The United States is facing a huge solid-waste disposal problem, especially in urban areas (Fig. 1). US citizens produce more than 4 lbs (~2 kg) of waste per person per day, more waste than can be disposed of in an environmentally sound but economic and local manner. Currently totals represent an increase of more than 60% over 1960 per capital waste generation. Most landfills are within 5 to 10 years of closing unless current facilities are expanded or new landfills opened. Urban areas lack space for new landfills due to the associated urban sprawl of affluent suburbs that uphold a NIMBY, "Not-In-My-Back-Yard", mentality. New England and the rest of the northeast is the most pressed region in the US. Costs to dispose of municipal solid waste have skyrocketed in recent years as well. The evidence indicates that we currently face a national waste crisis, and perhaps our basis premise for solid waste management must change if we are to survive the next decade or two.

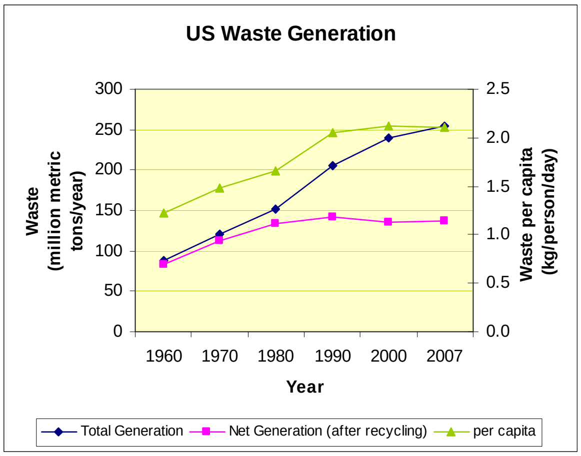

Fig. 1. The amount of municipal solid waste in the US. US EPA data

During the first 100 years of the Industrial Revolution, the volume of waste was relative small. A "dilute and disperse" waste disposal axiom prevailed. For example, industry and cities were purposely situated near rivers for a source of drinking water, supply water for industrial processes and cooling, provide an easy means for transportation of people and goods, and an easy avenue to remove the wastes dumped into them. Further expansion of urban and industrial centers, discovered that the "dilute and disperse" mentality quickly turned inadequate as rivers began to suffer noticeable "sight and smell" degradation and increasing health concerns. The waste disposal mentality subsequently changed to a "concentrate and contain" axiom, i.e., everything we throw away should be disposed of locally in a safe and inexpensive manner. Open dumps were used first but they quickly gave way to landfills in the US, as the open dumps smelled, were unsightly, contaminated the surrounding air, soil, surface water and groundwater, and attracted varmints, that posed a significant health hazard. Since the 1980s, this country initiated the next stage of waste management, an integrated waste management (IWM) approach. A set of management alternatives were developed that focus on the three Rs of IWM, recycling, reusing, resource reduction. Additional options also include expanding composting and incineration. This third view on waste disposal has been slow to mature as landfills still dominate the waste disposal scene, but their use has declined from accepting 90% of the solid waste generated by municipalities in 1980 to 45% today.

Municipalities generate approximately 154 million metric tons of waste each year but they are not the only sources of solid waste in the US. The primary sources of solid waste are split between livestock (39%), extraction and processing ore minerals (38%), crops (14%), municipalities (5%), and industry (3%), totaling over 4 **BILLION** tons of solid waste each year. The vast (> 90%) majority is linked to mining and agricultural activities. The mining and agricultural wastes however are not pressing problems. Mining wastes are typically dealt with on site and buried in the underground mine, or the open-pit. These pulverized wastes are covered with a layer of soil to prevent the leaching of sulfur and other heavy metals that would have otherwise induced acidification and delivery of toxic compounds to the environment. Agricultural wastes are typically added to local soils where microbes decompose the organic materials and return the organic bound nutrients to the soil.

Even though the quantity of industrial wastes is small in comparison to other major sources, their environmental consequences are high. The ~50 million metric tons of solid industrial wastes each year are categorized by their impact on the environment, by law, into toxic, corrosive, ignitable or otherwise hazardous material categories. The materials are also strongly regulated with “cradle to grave”, i.e., manufacture to disposal, federal legislation (Resource and Recovery Act, 1976). It stems from the media coverage and public outcry over the Love Canal problems of the early 1970s. The US is still swamped with the cleanup of approximately 40,000 known contaminated sites due to unsound pre-1970s indiscriminant dumping of industrial wastes. The cleanup will keep lawyers, environmental engineers, government officials, and many others busy for decades.

Municipal waste disposal is an environmental problem that costs users billions of dollars each year. The EPA reported that the typical composition, before recycling, includes paper, yard wastes, food wastes, plastics, metals, rubber, leather & textiles, wood, glass, and other materials including disposable diapers (Fig. 2). These numbers exclude construction and demolition debris, biosolids like sewage sludge, industrial wastes and other waste materials that might also be disposed in a landfill. The refuse is not harmless. A wide variety of toxic and other hazardous materials are included in the “other” materials category and sent to landfills every day from the home and the other sources. They include poisons, corrosive cleaning agents, disinfectants, unused prescription drugs, solvents such as paint thinner and dry-cleaning fluids, insecticides and pesticides, heavy metals, and so on. Unfortunately, even these small amounts are at sufficiently high concentrations to pollute and degrade nearby air, water and soils.

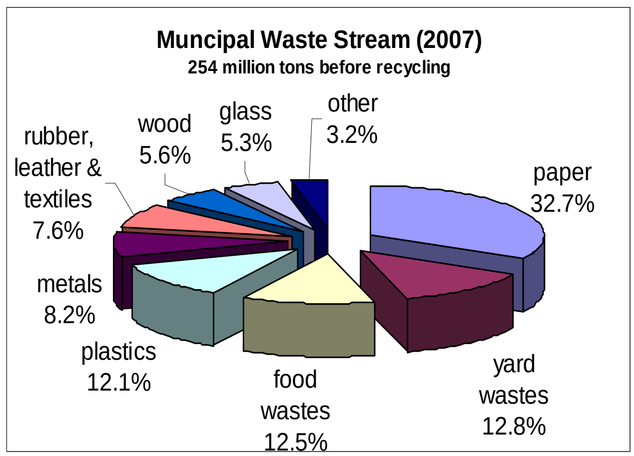

Fig. 2. The composition of municipal solid waste in the US. US EPA data

SANITARY LANDFILLS:

Sanitary landfills are designed to “concentrate and contain” our solid waste at a specific site and minimal environmental cost (Fig. 3). Each day, a layer of waste is compacted by heavy machinery and buried under a layer of earth or clean construction debris to keep out the vermin, confine the refuse, reduce the odors, and divert leachate forming rain water from entering the landfill. Once the site is full, the entire landfill is covered by a thick layer of earth, and the land is typically used for other purposes, including parks, pastureland, parking lots, golf courses, and other uses not requiring excavation. Evanston is famous for its Mt. Trashmore, a ski resort built on an abandoned landfill. These uses are only possible if the leakage of noxious gases and/or toxins are minimal. Once a landfill is closed however, city/county managers face significant hurdles to find more space to dispose the constant stream of solid waste, or ship their trash elsewhere.

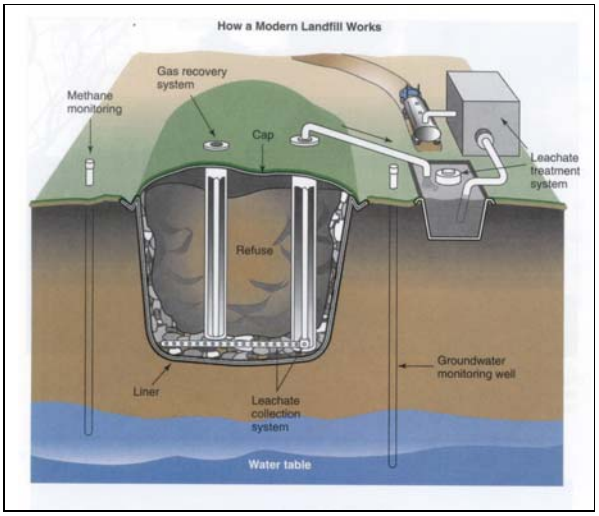

Fig. 3. A sanitary landfill schematic.

Unfortunately, landfills leak gaseous, liquid and solid materials. Bacterial decomposition of organic refuse generates gases, and gas composition changes if the process is aerobic or anaerobic. Initially the organic refuse is decomposed aerobically, producing carbon dioxide (CO_2) and water (H_2O), and perhaps some sulfur dioxide (SO_2) and other gases. Due to the landfill's isolation from the atmosphere, the bacteria quickly consume the available oxygen. Then anaerobic bacteria decompose the remaining organic material and generate gases like methane (CH_4) and the rotten egg smelling, hydrogen sulfide (H_2S) if sulfate is available. Typically, the ground cover traps the gases in the landfill, and they must be vented to prevent explosions from the accumulating pressure. In larger facilities, the methane can be collected, stripped of other gases, and used as natural gas. At smaller sites where methane recovery is less economic, the vented gas can be burned onsite. Bacterial decomposition is very slow. Archaeologists in the southwest have unearthed capped landfills to find readable newsprint and uneaten hot dogs in 40 year old garbage.

Liquid pollutants, commonly called leachate, can escape from landfills to contaminate surface or ground water. It forms when water percolating through the refuse, collects and dissolves chemicals from the refuse. The water originates as rainfall or groundwater, especially if the protective layer above or below the landfill is permeable. The exact composition of the leachate depends on the water soluble / transportable materials homeowners throw out with the garbage, and may include poisons, corrosive cleaning agents, disinfectants, unused prescription drugs, solvents such as paint thinner and dry-cleaning fluids, insecticides and pesticides, heavy metals, and so on. This list excludes other compounds that may originate from industries or wastewater facilities. Leachate contamination problems were particularly problematic in older sites when landfills typically lacked impermeable barriers beneath the landfill and were typically sited in valleys and other areas near or below the water table. Leakages were also un-noticed early on because the leakage was underground and out of sight.

Modern landfills are now built on several meters of impermeable clay-rich material, and situated well above the water table. In addition, plastic or rubberized, thus waterproof, liners may also be used to line in new or expanding landfills. Finally, leachate collection tiles can be utilized to collect the leachate and send it for treatment and/or disposal, typically to a municipal wastewater treatment facility or liquid hazardous waste disposal site. Unfortunately, it converts a solid-waste disposal problem into a liquid-waste disposal problem, as the leachate can present detoxification and disintegration problems and adds toxic heavy metals and other compounds not typically removed by typical wastewater treatment facilities. In the case of Ontario County, leachate from the county landfill is shipped to the Geneva wastewater treatment facility, where it gets diluted and sent on to Seneca Lake, a drinking water supply for ~100,000 local residents. Leachate is less problematic in arid areas but most US urban centers are located in humid climates, like those through out New York State and the rest of the northeast. Thus, landfills are carefully monitored to detect and remediate leachate leakages.

Protecting the environment from leachate problems is one reason why landfills are now more expensive to operate and maintain. In the author's opinion, the best strategy to reduce or eliminate the leachate problem is to prevent leachate forming materials from entering the landfill in the first place. This could be accomplished by passing legislation to prevent hazardous, i.e., leachate forming, materials from landfills. For example, municipal service could mandate separate collection of hazardous and non hazardous wastes. The non hazardous trash could be trucked to the landfill. The hazardous materials could be sent to a secure landfill or hazardous waste collection/treatment/disposal center. Those failing or unwilling to separate their trash could be charged for the separation before placing the waste in a landfill.

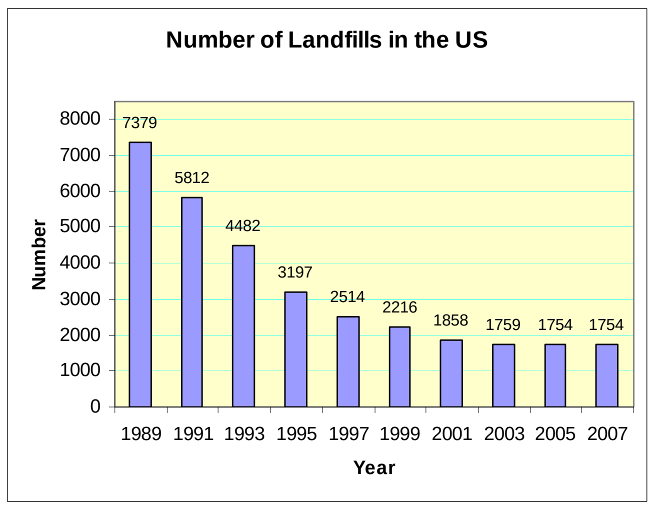

Fig. 4. The number of landfills in the US. US EPA data

Landfills require space and current facilities are filling fast (Fig. 4). A simple rule of thumb indicates that every 10,000 people require approximately 3 acre-ft of space each year, i.e., three feet (1 meter) of compacted trash spread over one acre each year. For a large city of a million people, the space is a considerable chunk of real estate. The number of landfills in the US has declined in the past few decades from over 7,300 in 1989 to fewer than 1,800 in 2007. New Jersey has to ship 50% of its solid wastes, or 11 million tons per year to nearby states. In March 2001, New York City closed its Fresh Kills Landfill on Staten Island. This one facility was the largest landfill in the world, accepting over 12,000 tons of trash each day from 50% of the 8.36 million people in New York City. Today, NYC exports 20% of its trash to other parts of New York, Pennsylvania, Virginia, and other states. Toronto outsources up to 40% of its refuse, some of it to the United States.

Landfills also generate litter. Each day the top most layer attempts to contain the wastes on site. Neighboring residents are painfully aware of how easily plastic bags, plastic bottles, pieces of paper and other light litter are blown from the landfill on windy days. Despite wind fences and landfill crews devoted to litter pickup, this problem will always plague landfills.

Alternatives exist to landfills that can alleviate the total tonnage sent to landfills each year (Fig. 5). Composting, incineration, and the three R's, recycle, reuse and source reduction, are the primary alternatives to landfills. Each alternative has numerous benefits, and each has numerous environmental problems and socioeconomic pitfalls.

COMPOSTING:

Composting is a practice long familiar to gardeners and farmers. Many types of organic matter, food, plant and animal wastes, and even soiled paper can be handled in this way. The natural partial decomposition of this organic matter by microorganisms (aerobic respiration) produces a crumbly, brown material rich in plant nutrients. Finished compost is a very useful soil additive as it augments the soil structure, increases the soil's water holding capacity, and releases nutrients to the soil. Air and moisture must be properly managed to transform these organic materials into compost. Composting reduces the volume of materials send to a landfill, up to 25 or 30%. By 2005, nearly half of the states had banned yard wastes from landfills and many others have developed yard waste composting facilities. However, back-yard compost piles can attract rodents and other pests, and create foul odors if done incorrectly, and it only redirects a portion of the solid waste stream.

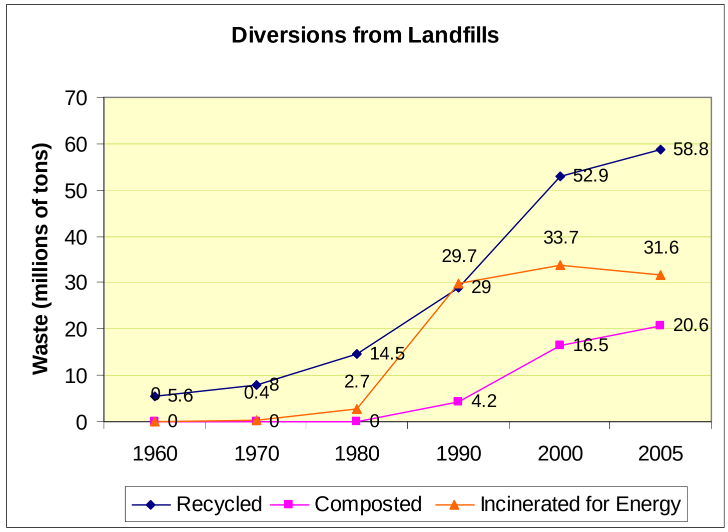

Fig. 5. Tonnage of waste diverted from landfills by recycling, composting and incineration for energy. US EPA data

The steps for successful back-yard composting are simple. Select a dry, shady spot near a water source for your compost pile or bin. Shred or chop all large pieces of material into 1x1 inch size. Green materials (e.g., grass, kitchen wastes, flower clippings) should be mixed with brown materials (e.g., twigs, dry leaves, and soiled paper) in a 1:3 ratio provide a balance of nitrogen and carbon for efficient decomposition. Turn the pile once every two weeks to aerate (oxygenate) the pile to maintain the aerobic decomposition of the organic matter and add moisture to maintain a suitable environment for the microorganisms. The compost will be ready once the pile does not reheat after turning. It typically takes one to four months from start to finish. Municipal systems use the same principals, but on a much larger scale.

The list of materials that can be composted include animal manure, cardboard rolls, clean paper, coffee grounds and filters, cotton rags, dryer and vacuum cleaner lint, eggshells, fireplace ashes, fruits and vegetables, grass clippings, hair and fur, hay and straw, houseplants, leaves, nut shells, sawdust, shredded newspaper, tea bags, wood chips, wool rags, and yard trimmings. Some materials should NOT be composted and include: black walnut tree leaves or twigs (releases substances that might be harmful to plants), coal or charcoal ash, (might contain substances harmful to plants); dairy products (e.g., butter, egg yolks, milk, sour cream, yogurt - create odor problems and attract pests such as rodents and flies), diseased or insect-ridden plants (diseases or insects might survive and be transferred back to other plants), fats, grease, lard, oils, meat or fish bones and scraps (create odor problems and attract pests such as rodents and flies), pet wastes (e.g., dog or cat feces, soiled cat litter - might contain parasites, bacteria, germs, pathogens, and viruses harmful to humans), and yard trimmings treated with chemical pesticides (might kill beneficial composting organisms). Local communities could easily rewrite legislation to initiate a community, town, city or county-wide mandatory composting program, where local residents put out yard wastes and other compostable materials for picked up and processing in a county facility. The finished compost can be sold.

INCINERATION:

Incineration is the process of burning refuse in a controlled manner. The US incinerates approximately 10% or approximately 30 million metric tons per year of the municipal solid waste (MSW) stream. Land starved Switzerland, Japan, Denmark, France, and Sweden incinerate up to 80% of their MSW. Numerous advantages and disadvantages exist. Incinerators drastically reduce the volume of MSW by 90% and weight of MSW by 70%. Thus incineration saves space required for, but unfortunately, does not eliminate landfills. Most incinerators are designed to utilize the generated heat to create electricity. An operation in North Little Rock, Arkansas, is a good example where the burnt waste generates steam used to drive steam generators to create electricity. It saves the city an estimated $50,000 per year and reduces the volume of refuse to be eventually sent to a landfill by 95%.

The environmental problems for incineration primarily involve air-quality issues and the disposal of the potentially toxicity ash. Burning refuse always releases carbon dioxide and thus enhances the planet's greenhouse effect. The combustion of sulfur bearing refuse generates sulfur dioxide (SO_2), and any combustion process that uses atmospheric oxygen will also "burn" the nitrogen (N_2) in the atmosphere and release nitrogen oxides (NO_x), both are acid rain making gases. At moderate temperatures, incineration produces a variety of toxic gases as well, depending on the material burned and the temperature of the burn. Plastics can generate chlorine gas (Cl_2) and hydrochloric acid (HCl), toxic and corrosive gases, or deadly hydrogen cyanide (HCN). Dioxins and furans can be released as well and both have been implicated in birth defects and several kinds of cancer. Recent improvements to incineration processes have reduced these threats. High temperature incineration (up to 1,700ºC or 3,000ºF) breaks down these hazardous chemicals into carbon dioxide and water. The volatile elements that are still released with the waste gases, including lead and mercury, can be removed from the flue gases using scrubbers and precipitators at an additional cost to the consumer. The majority of the heavy metals remain in the ash. In fact, they are concentrated in the ash as the carbon-rich material is burned away increasing the toxicity and disposal difficulty of the ash residues. When toxins are present, the ash must be disposed of in a *secure* landfill, a landfill specifically designed to "contain" toxic materials.

Critics also point out that the heat recovered from burning refuse (typically 5,000 BTUs/lb) is at least half of the heat generated by burning coal (13,500 BTUs/lb), natural gas (23,000 BTUs/lb) or oil (18,000 BTUs/lb). Thus, incinerators create two to four times as much greenhouse or acid rain emissions per unit of electrical output. Many plastics and rubber have much greater heat outputs, and incinerators may want to utilize processed pellets from specific materials instead of mass burn technologies.

Finally, yard wastes could be burned to reduce the volume of materials set to a landfill. However, the incineration pollutes the air (see above) and can lead to uncontrolled fires. The smoke can make breathing difficult for people who suffer from asthma, emphysema, chronic bronchitis or allergies. For these reasons, a number of states currently ban leaf burning. Alternatively, mulched yard wastes and lawn clippings can be easily left on the lawn and allowed to decompose naturally releasing nutrients back to the soil.

GASIFICATION:

Gasification is a process that converts carbonaceous materials, such as coal, petroleum, biofuels, biomass, or even plastic and other carbon-rich trash into carbon monoxide and hydrogen gas. The process was originally developed by the Germans in World War II to convert their abundant coal supply into diesel fuel for the war. The process happens at high temperatures (> 700ºC) and combines steam with a limited amount of atmospheric oxygen. The scarcity of oxygen prevents the complete combustion of the carbonaceous materials into carbon dioxide. The generated carbon monoxide combines with steam at high temperatures to generate carbon dioxide and more hydrogen gas. The hydrogen can be used directly in a fuel cell or gas turbines to generate electricity. Both methods are more efficient at creating electricity than the typical coal-fired, electric generation plants.

Alternatively, the hydrogen can be further converted into methane, methanol or a synthetic fuel which can be transformed into a clean diesel, aviation fuel or gasoline using the Fischer-Tropsch or Bergius processes. Many of the non-carbonaceous materials not burnt in the process collect as ash, and must be disposed of in a landfill. The high temperatures typically convert the ash and any harmful chemicals into a chemically inert glass providing a less hazardous material for disposal. Alternatively, they could be separated from the refuse beforehand. Various groups are trying to refine the process to reduce the amount carbon-rich, non-recyclable solid waste like plastics currently sent to a landfill, meet current emission and waste disposal standards, and more importantly create energy to fuel society’s future. This technology is currently unproven, and communities need to be careful before allowing one at their landfill.

OCEAN/LAKE DUMPING:

Ocean dumping provided a means to either incinerate or dump solid waste in the oceans or lakes. Shipboard incineration removes the site from populated areas and allows the oceans to absorb the emissions and ash. Proponents indicate that offshore incineration is not handicapped by emission control requirements that apply to land-based units in the United States. The ash is dumped into the ocean as well. Thus, it would be very cost effective. However, the ability of the ocean to deal with the emissions and ash is not well understood, and the released carbon dioxide would still enhance the greenhouse effect. Oceans are better left undisturbed and refuge for future food stocks. Ocean dumping of un-incinerated chemical wastes, municipal garbage and other refuse has also occurred. The potential for water pollution is apparent. In some cases, raw waste washed back onto beaches and the shoreline. The Ocean Dumping Ban Act of 1988 has curtailed ocean dumping of most materials. Lakes are too small to accept municipal quantities of garbage, and other solid refuse.

Currently, dredge spoils, sediments dredged from a channel, canal or harbor floor to maintain or deepen depths, are still dumped into the ocean (or lakes). At first glance it may seem harmless enough, as they are nothing but dirt (sediment). However, fine sediments may create sufficiently turbid waters to harm the existing marine organisms. The clay-sized fraction potentially could have attached heavy metals and other toxic organic-based compounds. Thus, ocean dumping may pollute the seafloor of the ocean.

RECYCLING:

Proponents of recycling eagerly point out, that it saves energy, reduces air and other pollutants, reduces roadside litter, reduces mining of additional raw materials, and reduces the waste stream sent to landfills (Fig. 6). For example, glass bottles are made from quartz and other raw materials including soda (Sodium), lime (Calcium) and borax (Boron). Even though these specific commodities are not scarce today, reuse of a glass bottle only requires one third of the energy to make new bottles, and eliminates the associated air pollution and energy resources required to make new bottles. Overall, recycling glass diverts over 5 million tons of material currently sent to landfills. Recycling aluminum saves approximately 95% of the energy required to make a can as the disassociation of aluminum from its ore mineral is extremely energy intensive. Thus recycling 1 ton of aluminum cans conserves more than the energy equivalent of 1,665 gallons of gasoline. Glass and aluminum beverage containers account for 40%, by volume, of the litter by our roads and highways. Thus container recycling efforts significantly reduce litter. Each ton of newspaper recycled saves approximately 18 trees, 3 m^3 of landfill space, and the energy equivalent of 185 gallons of gasoline. Despite these savings, recycling efforts face major hurdles.

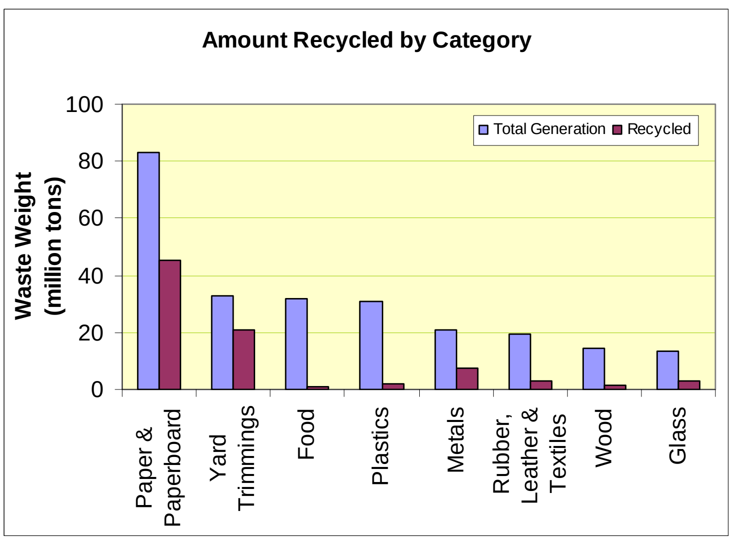

Fig. 6. Amount generated and recycled by selected categories. US EPA data

Clear, brown, green and other types of glass vary in composition. Like metal alloys, scarp glass can not be mixed indiscriminately and reprocessed. Instead, each type must be separated and reprocesses individually. Plastic also comes in many different types, polyethylene terephthalate (PETE – soda bottles), high density polyethylene (HDPE – milk jugs), polyvinyl chloride (V – shampoo bottles), low-density polyethylene (LDPE – shopping bags), polypropylene (PP – cereal box liners), and polystyrene (PS – foam cups, egg containers). Each type must be separated and reprocessed individually. Even after separation, plastics pose additional hurdles for effective recycling. The recycled plastics do not have exactly the same properties as the original material, thus the recycled materials are typically used for something else such as plastic piping, plastic lumber, fiber for carpets, plastic trash bags, or shredded plastic for upholstery stuffing. Steel and paper recycling faces similar, degraded quality, reprocessing hurdles. The re-pulping and deinking of recycled paper creates considerable amount of industrial wastes as well (5 to 35% of the feedstock), that is saved from in the municipal waste stream but instead sent to a “secure” landfill or hazardous waste disposal facility.

Supply and demand economics of recycling is also a major hurdle. The price for various recycled materials fluctuate from year to year, with recycled steel seeing the largest increase; aluminum, plastic and laser paper seeing modest increases; and car batteries, other types of paper and glass seeing small decreases in price from 1999 to 2004. The increase in recycling efforts in many industrial nations has generated a glut of some materials on the open market. Supply and demand economics dictates that excess supply reduces the price for the recycled material, occasionally making the material uneconomic to sell. It then promotes stockpiling of the commodity at the recycling center for future sale when the price is right. Hopefully the demand for recycled products will keep pace with the growing supply into the future. Finally, some manufactured goods are too complex and components too intertwined thus too energy and/or labor intensive to recycle in the US. For example, TVs, computers, monitors, IPods, and other electronics with detailed circuitry are composed of too many different types of materials in too a small package, thus each component is hard to separate for recycling. The trend is to send these complicated and/or difficult items overseas where labor is cheap and environmental concerns and threats to human health of minimal concern, to isolate each component for recycling.

The biggest problem is changing people’s attitudes from a throw away society to a more environmentally friendly society. Those states with the most effective recycling efforts typically provide economic or legal incentives to recycle. A beverage container deposit is a common means to promote recycling of glass, plastics and aluminum. It also provides a financial incentive not to litter. Oregon paved the way, and passed pertinent initial legislation in the early 1970s. Additional states have followed suite with mandatory recycling or bottle deposit laws (California, Connecticut, Delaware, Hawaii, Iowa, Maine, Michigan, Minnesota, New York, Oregon, and Vermont). These states account for over 90% of the container and other specific commodity recycling effort in the US (Fig. 7a). Michigan with the highest deposit (10 cents compared to 5 cents), has the largest recovery rate of containers. Many argue that a national container deposit bill is long overdue. Others say that the container recycling effort should expand to include all plastic, glass and aluminum containers. It would reduce litter, save energy and money, and create jobs. However, bottled water, soft drink and brewing industries lobby against it, proving it difficult for passage through congress.

Still, the US only manages to recycle 20% of its solid waste, significantly smaller than the recycling efforts in Switzerland and the Netherlands, where the proportion recycled reaches 75%. Some US communities are getting close. In 2008, Seattle, WA, Portland, OR, Los Angeles, CA, Minneapolis, MN, achieved recycling rates of over 50% of their solid waste stream. These success stories have mandatory curbside recycling, and accept a wide variety of materials. As of 2005, over 10,000 cities have curbside recycling programs (Fig. 7b). The specific laws vary in scope and forcefulness. Some are mandatory, some are not; some only request separation from the remaining trash, others are aimed at only businesses and not residences, finally some states passed laws to forbid certain types of materials from landfills like yard wastes. In contrast, cities without curbside recycling such as El Paso, TX, and Detroit, MI, have recycling rates of less than 10%. Remember, current recycling and composting practices save the equivalent of 10 billion gallons of gasoline each year, and reduced the equivalent emissions of 193 million metric tons of carbon dioxide each year (comparable to the annual output of 35 million automobiles). However, this country can do much more. Local communities should pass legislation for mandatory single-bin recycling efforts to reduce the waste stream to landfills, save natural resources and our dependence on foreign oil.

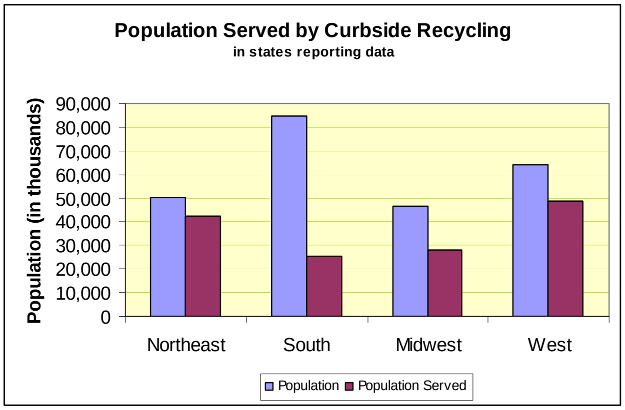

Fig. 7a. The number of people served by curbside recycling programs in the US. US EPA data

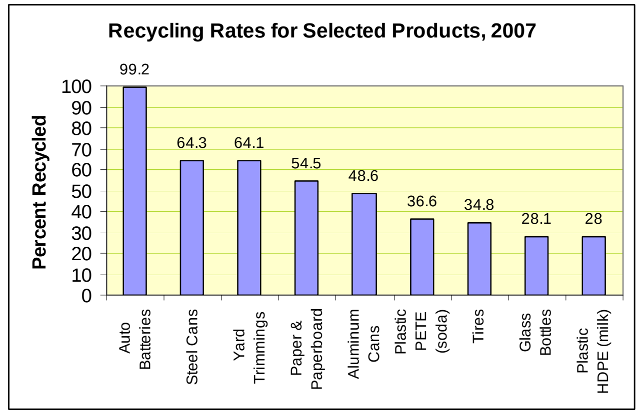

Fig. 7b. Recycling rates for selected products. US EPA data

SOURCE REDUCTION:

The simplest way to reduce waste is to prevent it from becoming waste in the first place. Source reduction is the practice of careful design, manufacture, purchase, use, and reuse of material goods so that the amount of waste and the degree of toxicity of the waste stream is significantly reduced. This is a major change in current “output” waste disposal ideology, i.e., dispose of everything dumped into the waste stream in a sound and efficient manner, to instead, an “input” ideology that focuses on and significantly reduces the input or creation of waste in the first place.

Examples are numerous. Design changes in milk bottles and soft drink bottles have reduced the weight of a plastic 2-liter bottle from 68 grams to 51 grams, approximately 30% reduction. This translates to preventing over 100 million kilograms of plastic from entering landfills each year and an equivalent reduction in the use of petroleum feedstock to make new bottles from scratch.

Manufacturing processes that play careful attention to leaks, spills and accidents during the manufacturing reduce the amount of raw materials required and waste produced to manufacture the product. Alternatively, design products with reuse in mind like refillable bottles, reusable pallets, and reconditioned barrels and drums.

Purchasing decisions that focus on items with minimal packaging. For example, buy things in bulk instead of individually. Grocery stores could start charging the consumer for the use of plastic or paper bags. The economic incentive curbs the use of grocery bags and increases the use of reusable cloth bags.

Other incentives could include taxing industries for the waste they generate. The tax scale could be adjustable with a smaller tax levy for industries following sound waste reduction strategies. For example, waste from plywood and chipboard manufacturing plants provides excellent fuel for coal powered electric generating stations and diverts sawdust/resin wastes from landfills.

The use of wood instead of coal would also decrease the net contribution to greenhouse gasses, as wood products are carbon-neutral, and also reduce acid rain making gases and other air pollutants as well.

Using materials that are less harmful to the environment due to a lower concentration of toxic compounds or materials that can be easily recycled will decrease the toxicity and total amount of the waste stream. Using only the required amount of toxic materials, like herbicides, pesticides, paints, will reduce the leftover waste when the project is complete.

Finally, manufacturing products so they last longer will decrease the waste stream. A widget or car built to last 2 times longer than previous widgets will cut the widget waste stream by 50%. However, this final thought will dictate additional rethinking of our current capitalistic society.

These new directions must be well thought out and potential solutions may not work as anticipated. For example, on-site disposal of food wastes, i.e., in a home in-sink garbage disposal instead of a landfill, is not really a disposal solution. It only diverts a solid waste problem to a liquid waste problem for on-site and municipal waste water treatment facilities.

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