Managing Solid By-products of Industrial Food Processing

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The food processing industry generates large amounts of solid by-products in the production of food items. Instead of treating these by-products as waste and landfilling them, many food firms are turning them into useful products. For example, in 1987 over 9 million tons of food and fiber by-products were further processed into animal feeds. Another 3 million tons were recycled for fuel. Currently, less than 3 percent of food processing by-products are landfilled.

Transportation costs to landfills and disposal fees are increasing and government regulations are becoming more stringent. As a result, food firms are finding that they can reduce costs and increase profits by transforming their by-products into useful items such as animal feeds, other human foods and additives, soil amendments, or fuel for energy production. Many are high-value products.

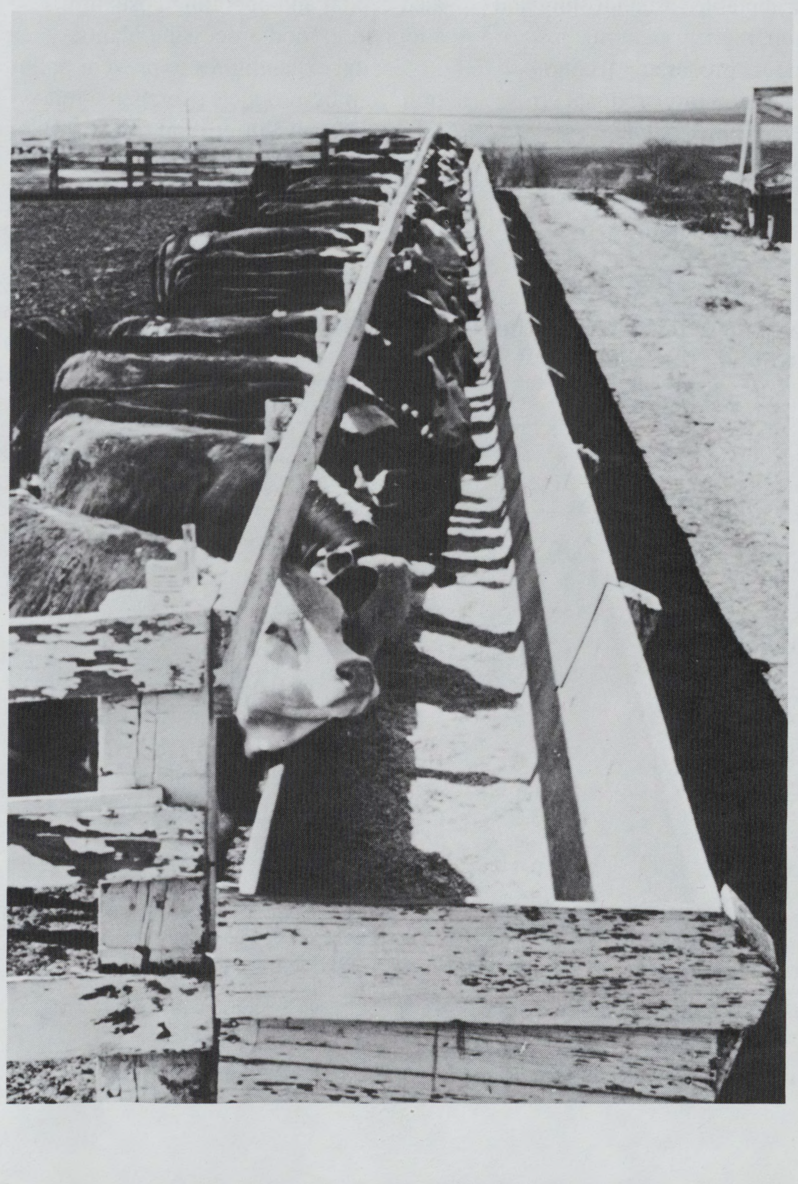
Hazardous By-products

A certain percentage of solid by-products from food processing is considered hazardous. For example, residues from pesticides or fertilizers may be in peelings or other by-products from fresh produce. Chemicals used in food processing plants for treatment or cleaning of produce and meats may also create by-products with toxic wastes. In 1988, 10 percent of solid by-product processing capital costs and 5 percent of corresponding operating costs went toward by-product hazardous waste management in the food processing industry.

The U.S. Environmental Protection Agency (EPA) is particularly alert to the potential for toxicity from concentrated chemical residues in by-products used for human foods and animal feeds. Toxicity is a concern for land disposal methods as well. Solid hazardous materials must be handled differently from other types of solid by-products, and are not included in the following discussion of by-product disposal.

By-product Disposal Costs

Currently, the costs to reduce or eliminate pollution from solid by-products in the food processing industry are low. They were estimated to total $348.2 million in 1988—just 0.1 percent of the value of final product shipments. In part, these low costs are due to the industry's



The largest category of identified uses for food processing by-products is animal feeds.

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capacity to process and divert waste by-products to other uses.

Expenditures include processing, packaging, and other materials costs to transform by-products into usable inputs. The expenditures are divided into operating costs, capital costs, and payments to government agencies for collection and disposal. The largest share is operating costs *(table 1)*. The amount depends on the quantity and form of by-products to be managed and the available methods for handling them. In 1988, operating costs were 80 percent of total disposal expenses.

Operating costs for disposal or redirection of solid wastes are rising (inflation-adjusted dollars). In 1983, these were $140 million and, by 1988, $278 million *(figure 1)*. The increases were due mostly to environmental regulations that require more processing of by-products before disposal, limitations on types of materials acceptable for landfilling and land application, higher operating costs of new by-product processing technologies, and increases in raw products processed.

Conversely, recovered costs—revenues from by-product sales or process cost savings—declined in the early 1980's as saturated markets reduced by-product prices. Between 1985 and 1988, real recovered costs averaged $14 million compared with an average of $12 million for 1981 through 1984.

Payments to government agencies for collection and disposal of by-products in landfills increased throughout the 1980's. From a low of $18 million in 1982, collection costs nearly tripled to $51 million in 1988. Dramatic increases in disposal (tipping) fees accounted for most of the change.

Operating costs and government payments grew more rapidly than recovered costs. Average net by-product processing costs increased from $150 million during 1981-84 to $250 million in 1985-88.

Capital costs include the technology necessary to make alternative products from food processing firms' by-products. New technology increases marketability of processed by-products, but the associated capital and operating costs limit adoption in food processing plants.

Capital expenditures to prevent pollution from by-products averaged a relatively constant $11 million from 1981 through 1985. In 1986, they rose to $15 million and by 1988 they were $19 million. New technologies for waste reduction and recycling of food by-products are being adopted by a wide variety of firms. Most capital expenditures are for pollution abatement, not operating cost reductions. Such reductions are less costly to achieve by changes in processing management than with expensive capital additions.

Table 1. Operating Expenses Were the Biggest Share of Solid Waste Abatement Costs for the Food Processing Industry in 1988

Subsector	Solid waste abatement costs: Capital	Operating	Payments to Government	Total	Value of shipments
	Million dollars				
Meat products	3.8	27.9	8.0	39.7	74,168.4
Dairy products	3.1	22.4	8.2	33.7	41,289.1
Preserved fruits and vegetables	4.0	46.3	10.3	60.6	36,826.1
Grain mill products	0.7	17.9	2.9	21.5	37,493.4
Bakery products	1.2	17.2	3.5	21.9	20,956.3
Sugar and confectionary products	1.4	21.5	1.2	24.1	19,461.7
Fats and oils	1.1	13.6	3.0	17.7	19,955.1
Beverages	3.5	72.3	9.5	85.3	47,271.4
Miscellaneous foods and kindred products[1]	0.4	39.1	4.2	43.7	29,306.1
Total	19.2	278.2	50.8	348.2	326,727.6

[1]This category includes fresh, frozen, canned, and cured fish and seafood, and roasted coffee.

Sources: Bureau of the Census, Manufacturers' Pollution Abatement Capital Expenditures and Operating Costs. *1988 Current Industrial Reports.*

Bureau of the Census, Value of Product Shipments, *1988 Annual Survey of Manufactures.*

By-product Uses and Disposal

A 1987 survey by the National Food Processors Association (NFPA) showed how raw agricultural commodities (RAC) are used in the food processing industry. The survey included several industry subsectors: preserved fruits and vegetables, grain mill products, sugar and confectionery products, fats and oils, dry beans, beverages, miscellaneous foods and kindred products (such as processed fish and seafood, and roasted coffee). The RAC tonnage reported in the survey represented 25 percent of the total for these subsectors in 1986.

Based on this survey, only 30 percent of RAC was used as food products; the rest were by-products. The by-products were processed into animal feed, human food, energy, and soil amendments, or were landfilled or dumped into the sewer.

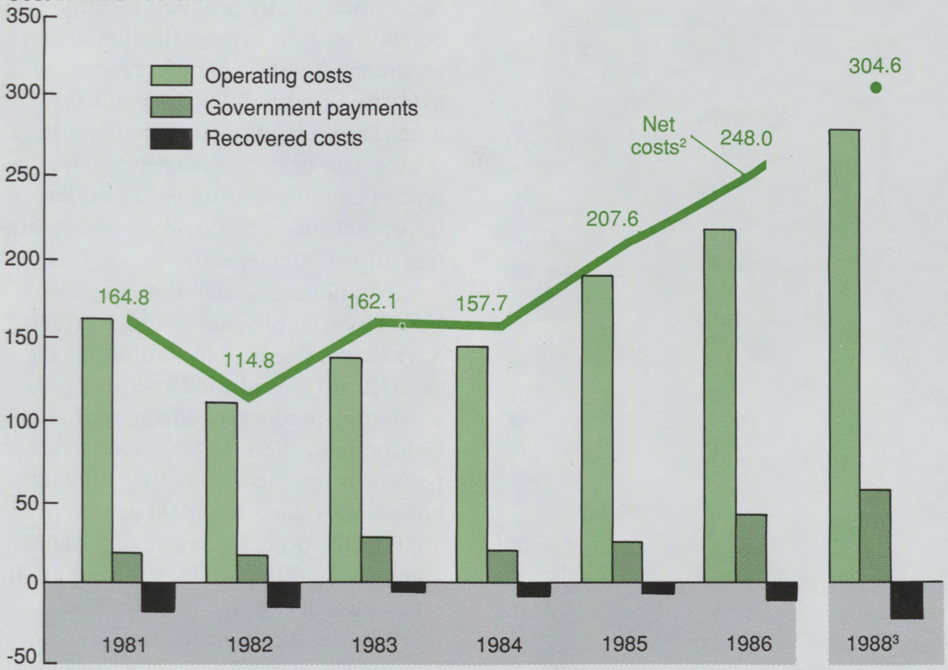
As Animal Feeds

The largest category of identified uses for food processing by-products was animal feeds *(table 2)*. Dry feeds accounted for 17 percent of by-products (6 million tons) and wet feeds for 9 percent (3 million tons). Wet- and dry-milling by-products are almost exclusively used as cattle feed, worth about 10 percent of the total value of the RAC. Culled fruits and vegetables, sugar beet pulp, molasses, and spent brewer's grains are also commonly used as animal feeds for beef, dairy cattle, and hogs.

The value and quality of by-products as feed are well known and, subject to market availability, they are easily sold. Characteristics of feeds vary with nutrient composition and moisture content. Sometimes it is necessary to remove moisture from the feeds by dehydration or to store the wet feeds in silos. Substitution of by-products for other feeds in animal diets must be done carefully to

Figure 1. Net Operating By-product Disposal and Processing Costs Have Increased

Cost in million dollars[1]



[1]1988 dollars. [2]Net equals operating costs, plus payments to government, minus recovered costs.
[3]Data for 1987 is not available.

Table 2. Animal Feeds Were the Top By-product Disposal Method for the Food Processing Industry in 1987

Food processing subsector	By-product volume	Wet feed	Dry feed	Land applied	Fuel	Land-filled	Other	Losses
		Utilization method						
	Tons	*Percentage of by-product volume*[1]						
Preserved fruits and vegetables	3,598,892	44.9	4.7	12.4	0.7	4.2	20.3	12.7
Grain mill products	2,573,236	23.3	44.2	0.1	1.7	0.3	25.7	4.8
Sugar and confectionary products	24,069,408	2.2	2.6	0.1	12.7	2.8	29.7	49.8
Fats and oils	4,334,838	2.6	92.5	0.0	0.1	0.3	4.1	0.4
Beverages	386,986	32.7	12.9	1.9	0.0	2.8	48.8	0.9
Miscellaneous foods and kindred products [2]	329,065	34.4	2.8	1.1	0.0	1.0	62.2	NA
Dry beans	13,175	23.3	47.4	0.0	0.0	5.7	24.7	NA
Share (percentage)		8.8	17.0	1.4	8.9	2.5	25.8	35.6
Volume (millions of tons)		3.1	6.0	0.5	3.1	0.9	9.1	12.6

[1]Percentages do not add to 100 due to rounding and recorded errors in materials balance for each subsector.
[2]This category includes fresh, frozen, canned, and cured fish and seafood, and roasted coffee.

Source: Rose, W. W., L. D. Pederson, H. Redsun, and R. Scott Butner, "Significance of Food Processing By-Products As Contributors to Animal Feeds," EPA/HED 8, October 1989.

prevent adverse effects on animal performance.

By-products for feed are used in concentrates, including energy feeds and protein products, and roughage. Energy concentrates have somewhat more protein (1 to 88 percent) than fiber (1 to 39 percent). Protein concentrates have 20 to 65 percent crude protein and at most 30 percent crude fiber, though a typical range is 3 to 15 percent. Roughage contains mostly fiber, ranging from 20 to 50 percent, but typically around 40 percent, with less than 10 percent protein *(table 3)*.

Most feeds made from food processing by-products cannot completely replace other animal feeds, nor can all species equally utilize the same by-product feeds. For cattle, a typical rate of substitution for energy concentrates is 10 to 25 percent in the dairy ration, and 10 to 30 percent for beef in feedlots. By-product protein concentrate substitutes for 10 to 25 percent of the usual ration for dairy cows. Roughage is measured in weight fed, with acceptable substitution from 20 to 35 pounds per cow per day for most by-product roughage feeds listed.

Research on feeds in the food processing industry focuses on finding new uses for by-products and in refining existing uses to better meet animal nutritional needs. A promising area is the recovery of solids from effluents. Chemical precipitation, using a flocculating agent to separate suspended materials, can be applied to slaughterhouse effluents or fish processing wastewater.

Ultrafiltration, a pressure-driven membrane separation process, has been used to isolate proteins from whey, a by-product of cheesemaking, to concentrate and clarify fruit juices, and to recover edible oils and fats from wastewater. This process also separates proteins and enzymes from potato washwater, yeast from brewery waste, proteins and oils from fish brine, and red dye from beets. These by-products may be reused in the food processing system or used as feed or food additives.

Processes such as chemical precipitation and ultrafiltration not only recover more of the by-product solids for higher

Table 3. Animal Feeds Are Derived from Many Food Processing By-products

Sample by-products	Crude protein	Crude fiber[1]
	Percent	
Energy concentrate feeds		
Egg shells and liquids, hair and feathers, leather tannery meal, paunch contents, dried meat processing effluents	12 -75	2 - 33 (4 - 39)
Dried and liquid whey	1 -13	1 - 9
Citrus pulp and sludge, fruit and vegetable culls, fruit cannery sludges, dried tomato and fruit pomaces	7 -40	3 - 35
Grain screenings, hominy feed, wheat and rice brans	14 -18	9 - 32
Bakery wastes	10 -12	1
Wet and dry beet pulp, sugarcane and beet molasses, almond hulls, cacao shells	4 -16	5 - 20
Whole cottonseed	25	18
Dried winery pomaces, brewers' wet and dried grains	5 -26	16
Fish meal, oil, solubles	65 -70	NA
Protein concentrate feeds		
Corn gluten, meal and feed	25 -65	3 - 9
Meals from coconut, cottonseed, linseed, soybean, safflower and sunflower	20 -50	3 - 30
Distillers' dried grains	26 -30	13 - 16
Roughage feeds		
Corn and snap bean cannery waste, pineapple wastes	3 - 8	22 - 27
Barley, oat and wheat straws, rice hulls	3 - 5	40 - 44
Sugarcane bagasse and strippings	2 - 4	45 - 48
Cottonseed hulls, cotton gin trash	3	44

[1]For animal products, ash rather than crude fiber is measured. The numbers in parenthesis represent the range of crude fiber percentages in paunch contents.

Sources: Bath, D. L. "Feed By-Products and Their Utilization by Ruminants." *Upgrading Residues and By-Products for Animals.* Boca Raton, FL: CRC Press, Inc. 1981. pp. 1-16.

National Research Council. *Underutilized Resources as Animal Feedstuffs.* Washington, DC: National Academy Press. 1983. pp. 5-45.

valued uses, but also produce cleaner effluent. These processes reduce pretreatment costs for wastewater disposal and water reuse in the plant. Liquids such as recovered brines and syrups may also be reused.

The possibility of toxicity from pesticides on crops or heavy metals in meat products and fruit cannery sludges is of particular concern to food processors when they redirect their waste by-products into feed or food. Testing for chemical residues in by-products may be necessary because of the potential for concentration of toxins. Some by-products have naturally occurring chemicals that cause toxic results. For example, apple pomace with nonprotein nitrogen may lead to weight loss, birth defects, and reproductive problems when fed to cattle. Cacao shells (from the production of chocolate) contain theobromine and caffeine which adversely affect horses, pigs, poultry, and calves. Familiarity with feed and by-product characteristics makes substitution safe and effective.

The grain mill product subsector includes pet foods, and prepared livestock and specialty feeds as final products. By-products from other food processing activities are added in making these final feed products. In 1988, pet foods and livestock feeds were valued at $17 billion or 89 percent of the total value of shipments from the grain mill product subsector, which includes breakfast cereals and flours.

As Fuel

Another 9 percent, or 3 million tons, of food processing by-products were used as combustion fuel. Fruit and olive pits, nut shells, rice hulls, straw, and sugar cane bagasse (the dry pulp remaining from sugar cane after the juice has been extracted) make suitable fuels for burning in boilers to produce steam and electricity.

Although the NFPA surveyed processors only about by-products directly combusted, gasification, distillation, and anaerobic digestion are other means of extracting energy from by-products. Materials with up to 50 percent moisture content can be burned, depending on the type of combustion unit used. Boilers heat water for electricity or steam generation, or both (cogeneration).

Operational cogeneration projects fueled by fruit pits, nut shells, and hulls have been successful in California. Of the 312,500 tons of food and fiber processing by-products available for fuel in California in 1986, 187,500 tons (60 percent) were used. As a fuel, almond hulls were valued at $50.00 per ton in 1986, while peach and olive pits were valued at $0.50 to $10.00 per wet ton. In other areas of the country, the share is much lower due to inadequate amounts of by-products in single locations, transportation costs, and limited availability due to seasonal production.

Energy production from direct combustion of wet fuels (skins, peels, and culls with greater than 30 percent moisture content) is curtailed by the short processing season for fruits and vegetables. This causes the payback period for equipment investment to be unacceptably long. Reduction of moisture content is sometimes necessary to use these types of by-products in direct combustion. Moisture reduction, in turn, reduces fuel degradation, enabling energy generation beyond the processing season. With rising disposal fees, combustion of wet fuels such as apple pomace makes more economic sense.

In recent years, other energy conversion technologies for high-moisture by-products have been developed. One of these is the water-slurry gasification system, which uses high pressure to produce methane, carbon dioxide, and hydrogen from slurries containing up to 95 percent moisture. Eliminating the drying step usually needed before gasification can result in substantial cost savings. Using this process, 46,000 tons of potato by-products at 16 percent solids can be converted to 100 billion BTU's of methane (the main ingredient of natural gas). The methane replaces 25 to 40 percent of the natural gas required by the potato processing plants.

Anaerobic digestion has been successfully applied to wet by-products such as beet pulp to produce methane. The biomethanation process, consisting of a two-stage anaerobic section followed by polishing steps, is used to convert 90 percent of organics in the pulp to methane. Not only does the fuel provide energy cost savings to the facility, but costs of drying and transporting pulps for animal feeds are eliminated. However, the effluent from biomethanation carries a heavy pollution load, which requires treatment of the effluent before discharge. About 10 percent of the initial dry material ends up as sludge and must be stored or spread. In one test, 286 tons of beet pulp generated 3.7 billion BTU's on a daily basis.

Ore-Ida Foods uses an anaerobic process known as Biothane to treat wastewater at its potato processing plant in Wisconsin. The process features a digester vessel of forced fluidization without mechanical agitation or a filter. Soluble solids removal is 90 percent, and methane purity is 75 percent. While the wastewater is clean enough to discharge, the anaerobic sludge must still be disposed of.

Another system, known as the anaerobic filter system, is used by Bacardi Corp. in Puerto Rico for wastewater treatment. The digester is a tank containing a plastic matrix resembling a filter. The anaerobic organisms, which are fixed in layers to the plastic matrix, ferment wastewater as it flows down through the system. Biogas is discharged through the top and burned as a boiler fuel, resulting in cost savings of $600,000 to $900,000 per year.

Ethanol fuel has received more attention as air pollution from automobiles is targeted by Federal regulations. *(See "Ethanol in Agriculture and the Environment" elsewhere in this issue.)* There are commercial processes for converting by-products such as cheese whey to ethanol. Cheese whey, which is about 90 percent of the original milk volume in cheese manufacturing, is a major pollutant when discharged into waterways. Although drying for animal feeds is one alternative, ethanol is a higher valued use for some processors.

The Carbery whey-ethanol process uses ultrafiltration to generate whey protein concentrate, which is then fermented and centrifuged to create ethanol. However, the effluent still requires treatment before discharge into surface waters. The output from the Carbery process is suitable for the production of vodka and may be used to fortify wine. These uses are of higher value than use as a fuel.

Much of the fuel and fuel-derived research was initiated as a response to wastewater problems. Combustion, anaerobic digestion, and gasification all generate solids to be disposed of. While the quantity of solids may be reduced, any toxic elements that are present before the treatment may become even more concentrated. Inert materials may be used as soil amendments or simply spread on the land surface. Disposal options may be limited by local environmental regulations.

The economics of using by-products for fuel depends on transportation distance to haul the material, costs of treatment and disposal of raw by-products, costs of alternative fuel inputs, and the availability of capital for installation. Payback curves for seasonal operations are longer than for those that process foods all year.

Other Uses

A category of specialized by-products, called "other" in the survey, was 26 percent or 9 million tons. This category includes essential oils, dyes, pits for fragrance and cosmetics manufacture, starch derivatives, pectin, fermentation by-products, biogas, and quantifiable solid losses from roasting, blanching, and cleaning. As the "catch-all" class of by-product uses, this category includes a number of high-valued niche markets, which may have potential for expansion.

There is substantial interest in recovering more human food products from materials that are currently disposed of. One method, counter-current extraction, uses a large screw which rotates continuously through the solids in a trough, intermittently changing directions of rotation. The liquid portion is squeezed out of the solid portion by this action. The process has been successfully used to extract apple juice, grape extract (containing aromatic compounds, tartarates and color), citrus peel liquids (for liqueur production), poultry stock and fat for soups and flavorings, seafood components such as prawn and crayfish juices and chitinous residues, and fruit pectins high in fiber.

There is also interest in the commercialization of processes to produce single-cell proteins, which can be converted to animal feeds or human food. Microbiological agents, such as pure and mixed cultures of yeasts and fungi, produce protein during fermentation of by-products. Most single-cell proteins are derived from cane and beet molasses, but other materials such as meatpacking wastes, straw, and seed husks have been tested. Fermentation of cheese whey produces single-cell protein as a secondary output from ethanol production. Biotechnological processes may be necessary for widespread adoption.

Sewage Discharge

The survey showed that over a third of food processing by-products were lost as soluble solids in wastewater (especially with potatoes and wet milled corn), and as moisture through evaporation processes (particularly with citrus, sugar cane, sugar beets, tomatoes, malted products, potatoes, cottonseed, and apples). Such losses accounted for 13 million tons of by-product. New technologies may provide opportunities for increased recovery of materials, but economic viability depends on demand for materials and disposal costs.

Land Disposal

Land disposal methods (land application as soil amendments and landfilling) accounted for less than 5 percent of the by-products generated *(table 2)*. Land applied and landfilled materials totaled less than 2 million tons of by-products in 1987. Wastes in the form of stems, leaves, dirt, small stones and other debris, most peelings and corings, some hard pits, and some solids screened from wastewater are either landfilled or land applied. Although food processors could be paid for by-product application to farming land, many firms view this as a disposal option rather than a revenue-generating alternative.

Land applied by-products often have economic value, but firms may have difficulty realizing returns. The Cooperative for Environmental Improvement, Inc. (CEI), started in 1969 by a group of California canners in Santa Clara County, uses spread-and-disc methods to return fruit and vegetable processing residues to agricultural lands at a cost of $2.25 per ton. A full-time manager inspects loads and rejects nonprocessing and nonbiodegradable materials. Soil improvement on leased disposal land has been so dramatic that land has been returned to productive use and new disposal sites have been leased.

Land application involves obtaining permits from State and local environmental protection agencies. In turn, specialists may be needed to determine acceptable loading levels. Michigan State University researchers have assisted companies in finding application rates which minimize risk of nutrient overload and leaching on agricultural lands. One spice extracting company saves $100,000 per year in landfilling costs by diverting by-products to land application and animal feeding. At a return of about $5 per ton for feed, the company covers the associated handling and transportation costs.

One problem with wet food processing waste is its instability—decomposition is rapid. By-products sometimes need to be transformed to create greater stability. Composting, the controlled aerobic decomposition of organic materials, is one such process.

Compost is a humus-like material of crumbly texture and earthy odor, high in organic matter, and resembles rich topsoil. It makes a valuable soil amendment and, depending on the source material and added nutrients, may make a good fertilizer. Correctly composted material has no pathogens and is stable to further decomposition.

Composting reduces the volume of source material by more than 50 percent. It has been used successfully to reduce fish residues, potato trimmings, apple pomace, grape skins, fruit cannery wastes, and other by-products. An Ocean Spray plant in New Jersey composted cranberry and prune wastes, a process which required 25 to 30 weeks to complete. In Maine, composting has been successful with potato waste and fish residues as base materials. The active composting period for potatoes was 4 weeks and for fish waste, 9 to 10 weeks.

Vermicomposting is a variant of the decomposition process. This system utilizes red manure worms or tiger worms in an aerobic environment with a shallow waste layer in a box with a moist bottom to break down materials. Depending on worm numbers, breakdown of materials may be from 2 to 4 weeks. The worms may be harvested and dried for animal protein feed and the composted material sold. Expenses include purchasing stock worms, and constructing or purchasing containers. A study on potato wastes determined that this process is feasible on a commercial scale.

Composted products may need to be tested for toxic elements and heavy metals before they can be sold. Careful attention to the by-product inputs should prevent toxicity. Odors and flies are not problems with correctly composted systems. Odors result from improper carbon to nitrogen ratios or inadequate aeration. Groundwater, surface water, and odor monitoring are required at some land application sites. In some cases, regulations designed for human waste sludges are enforced for food by-product applications.

Another alternative for management of solid by-products is landfilling. State and local regulations regarding acceptable materials for landfills have become much stricter in recent years. Moisture content restrictions are major barriers for many food processing materials that require significant moisture reduction before landfilling. Disposal fees range from $10 to $50 per ton. Along with high transportation costs, the fees are making some higher cost, alternative by-product processing feasible. ■

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