Chapter 27

Solids Management

Solids management refers to the use or disposal of solids that have been removed from wastewater, processed, and are ready to leave the treatment plant. The solids in this context are typically biosolids but could also be scum, grease, screenings, grit, or ash. [The Water Environment Federation defines *biosolids* as "primarily organic solids produced by wastewater treatment processes that can be beneficially recycled." Before treatment, this material is called *wastewater solids* or *sludge*. To be classified as biosolids, the material must meet state and U.S. Environmental Protection Agency (U.S. EPA) criteria for beneficial use.]

TYPES OF SOLIDS

Wastewater treatment plants receive and generate many types of solids, including ash, scum, grease, screenings, grit, and sludge (e.g., raw, treated, primary, secondary, tertiary, combined, and chemical). Some also receive septage from onsite treatment systems and liquid sludge from other treatment plants. (For more information on solids, see Chapter 28.)

Treatment plants also generate solid wastes, including paper, garbage, automotive residuals, equipment oils and greases, chemical-impregnated rags, lab wastes, office wastes (e.g., printer cartridges and copy- and fax-machine chemicals), light bulbs, batteries, and barrels. These wastes must be disposed or recycled according to local regulations. [Given that wastewater treatment plants are supposed to protect the health of both the public and the environment, it behooves them to recycle as much of their wastes as possible (Fisichelli, 1992).]

CHARACTERIZATION

The physical, chemical, and biological characteristics of biosolids affect both its use and the public's perception of it. For example, federal and state regulators base land-application requirements on biosolids' pollutant and pathogen concentrations. A land-application site's neighbors, on the other hand, base their acceptance on the material's consistency and odor.

Biosolids should be sampled for metals and organics after they have been processed so the analytical results will describe the actual material to be used or disposed. Once the chemical and biological standards have been met, the biosolids characteristics that will affect its management options are

- nutrient concentrations, which can affect surface water quality;
- micronutrient concentrations, which can affect soils and plant growth (a certified agronomist may be needed to pinpoint the source of abnormal plant growth); and

- concentrations of various constituents (e.g., mercury and sulfur), which can affect an incinerator's air-pollution controls.

A wastewater treatment plant should keep a large database containing multiple years' worth of chemical analysis results, so staff can prove that the plant's biosolids have not contained harmful levels of constituents such as metals, organics, pathogens, dioxin, radioactive components, polychlorinated biphenyls (PCBs), and so is unlikely to contain them in the future. To be convincing, the data should show that metals and organics concentrations are stable or decreasing—no wild variations—and every result should have been promptly checked by experts and quality-control personnel.

Also, the treatment plant should have an active pretreatment program to minimize unwanted constituents in its influent. Such constituents tend to end up in the solids, and the presumption may be that the resulting biosolids should not be land-applied if these constituents might cause the soil to need remediation for certain uses. However, biosolids typically are land-applied before many test results are available, so plant staff and regulators need to be confident that the material will not harm humans or the environment. They should be able to base this confidence on historical data and a successful pretreatment program.

To demonstrate that a wastewater treatment plant's biosolids management program is based on best management practices (BMP), staff should:

- Do the sampling and analysis required to demonstrate that regulatory standards are being met;
- Do additional sampling and analysis (e.g., priority pollutant analysis, radioactivity, dioxin, and possibly others) on a regular basis (because telling the public that the plant's biosolids meet all federal and state standards does not inspire confidence; specifying how the biosolids surpass those standards does);
- Maintain an effective pretreatment program (even if only to show that there are no industries in the plant's service area) and an active pollution prevention program to help industries and the public reduce their use of pollutants;
- Develop and use a written sampling plan and chain-of-custody form;
- Review every analysis, including those done by a contract lab, to verify that the appropriate test was done, the results are accurate, the appropriate quality-control measures were taken (if the tests were done onsite, the quality-control procedures should be written based on appropriate industry protocols); and
- Ensure that the biosolids look innocuous (e.g., no pieces of fast-food wrappers, condiment pouches, or personal sanitary products should be seen in the material).

HANDLING

GENERAL. While all wastewater solids and septage must be treated to meet the relevant federal, state, and local regulations, differences in processing methods can result in biosolids with widely varying consistencies, which will affect how they can be transported and beneficially used. Handling methods, for example, can greatly affect the consistency of biosolids: Screw conveyors can turn biosolids into a paste that is difficult to apply via manure spreaders. Belt conveyors alter the material less.

For example, two modifications to the solids treatment process at the Allegheny County Sanitary Authority in Pittsburgh, Pa., had unexpected results. Originally, the biosolids were dewatered via belt presses and then mixed with lime. This produced a crumbly mixture that was easily applied via standard manure spreaders. When plant staff replaced the lime-addition equipment with mixers and screw conveyors, the biosolids became a "pudding" that was difficult to spread. However, when staff replaced the belt presses with centrifuges, the material reverted back to the crumbly, spreadable mixture. (Each treatment plant's sludge is unique, so the best process train will be site-specific.)

CHEMICAL ADDITIVES. Any compound added during wastewater treatment typically ends up in the biosolids and may affect its physical, chemical, or handling characteristics. It also may affect the biosolids' permitted use and disposal options.

Lime and sodium bicarbonate, which are added during anaerobic digestion to control pH, should not be problematic; they only increase the concentration of compounds that occur naturally in biosolids and are typically harmless. Likewise, the acids and caustics used to control pH in aerobic digesters should not affect the biosolids' ability to meet regulatory standards. Calcium, on the other hand, can change the soil chemistry and nutrient uptake at land-application sites, so agronomists may recommend occasional soil tests (e.g., once every 3 years) to check the macro- and micronutrient levels at the sites.

Some treatment plants use organic polymers or inorganic chemicals to thicken or dewater sludge. Some regulators are concerned that nitrogen-based polymers may decompose to produce amines and other intensely odorous compounds. However, research has shown that the polymer may adsorb to particulate, making it less biodegradable and significantly less reactive—effectively, an inert material (Dental et al., 2000). The portions of the polymer that do break off are typically innocuous and biodegradable. So, polymer additions should not prohibit the biosolids from being land applied safely.

Solids-conditioning chemicals [e.g., lime, ferric chloride, ferrous sulfate, ferrous chloride, and aluminum sulfate (alum)], which may be added before or after thickening or dewatering processes, should not affect the biosolids' ability to meet regulatory standards. However, if the ferric chloride solution is a byproduct of another process (e.g., spent pickle liquor from an industrial source), then the solution should be analyzed for metals and possibly organics.

Some treatment plants use potassium permanganate to control odors; this also should not affect the biosolids' ability to meet regulatory standards.

TREATMENT PROCESSES. Most sludge-stabilization methods (e.g., anaerobic digestion, aerobic digestion, composting, lime stabilization, thermal treatment, and heat drying) produce land-applicable biosolids, but their products' characteristics and required handling methods will vary. Anaerobic digestion, for example, produces biosolids with low levels of organics and bacteria. However, the material may be somewhat odorous and difficult to dewater.

Aerobic digestion, which is mostly used at small treatment plants, produces a land-applicable biosolids that may be harder to thicken than other types of biosolids.

Composting, when done properly, produces a relatively dry, biologically stable, odor-free biosolids that may be stored outside without developing odors or attracting insects. Some treatment plants sell this material, thereby reducing solids-handling costs. Composted biosolids typically look better and emit less odor than other types of biosolids.

Lime stabilization produces biosolids whose quality some state regulators question, because they are not convinced that this method produces "stabilized" solids. Also, the biosolids are likely to be odorous (primarily ammonia). Research has shown, however, that if enough alkaline (or lime and heat) is added, then the resulting biosolids meet the pathogen-reduction and vector-attraction-reduction standards for Exceptional Quality (EQ) biosolids and are less likely to be odorous because the odorous gases are driven off during processing and can be collected and treated then.

Thermal treatment processes destroy pathogens, improve the resulting biosolids' thickening and dewatering characteristics, and greatly reduce its volume. Although odors are produced during treatment, the biosolids have little odor (as long as the material remains dry). However, the biosolids may have higher metals concentrations and could spontaneously combust.

Mechanical drying methods and drying beds have potential odor problems and may be costly if covers are needed to abate odors or because of temperature extremes.

Incineration destroys organic matter, reduces the sludge volume, and produces an ash that may be beneficially used if its metals levels do not exceed regulatory standards. At temperatures well above 816 °C (1500 °F), the ash may become a hard frit that can be used as a fill, roadbed material, or ceramics ingredient. This option may be attractive to larger wastewater treatment plants that have difficulty finding enough land for composting or land application.

Emerging sludge-stabilization technologies include a microwave technology and methods involving quicklime and heat. For more information on sludge-stabilization methods, see Chapter 32.

MANAGEMENT

USE OPTIONS. Biosolids that meet the requirements of U.S. EPA's Standards for the Use or Disposal of Sewage Sludge (40 *CFR* 503), as well as state and local standards, can be beneficially used. Metals levels in U.S. biosolids have dropped since U.S. EPA's pretreatment regulations were promulgated, and most treatment plants now have no trouble meeting 40 *CFR* 503's metals requirement, according to various studies. The pathogen and vector-attraction-reduction levels, however, depend on the processing method used.

Land Application. The most common method for using biosolids is land applying it on farmland. In 1988 (before ocean disposal stopped), 33% of sewage sludge was land applied, according to the preamble of 40 *CFR* 503. A more recent U.S. EPA study gives a rough estimate that 60% of biosolids are now land applied. Before a treatment plant can begin spreading (or injecting) biosolids on farmland, however, all federal, state, and local paperwork must be completed and approved. Some states require every site to be permitted, while others require the biosolids generator to obtain a general permit and maintain a register of individual sites.

To obtain a general permit, the biosolids generator may need the following:

- An open and ongoing relationship with regulators (they should be familiar with the treatment plant and its operations because they have toured the site at the plant staff's invitation);
- A database of biosolids test results (at least 3 years' worth, but preferably since plant startup because regulators will be more comfortable about letting a plant land apply biosolids if extensive physical, chemical, and pathogenic data demonstrate its safety);
- A history of the treatment plant's operations and a detailed description of its solids processes;
- A quality-control and quality-assurance plan, standard operating procedures for each analysis, and chain-of-custody forms or a logbook of all samples;

- A public relations plan and ongoing outreach efforts to inform the public about the biosolids management program;
- A written description of all land-application activities and personnel, along with the contact information for the treatment plant staff and regulators who should be notified if a question arises or emergency occurs;
- A spill prevention and control plan, a contingency plan, and a long-range plan for future improvements to the biosolids management program; and
- A written procedure (and form or logbook) for handling complaints from each land-application site's neighbors.

Some states have training programs for biosolids generators and land appliers. Biosolids personnel should take such programs (whether mandatory or optional) because they will learn how to interact with regulators and what their expectations are. Biosolids personnel also should become active members of biosolids-related professional organizations [e.g, the Water Environment Federation (WEF), its member associations (MAs), and regional associations], which are sources of useful information, help, and support. In addition to committees devoted to biosolids issues, WEF and its MAs also publish technical materials.

Once a treatment plant has met the general permit requirements, its personnel can establish the land-application program by doing the following:

- Find suitable farmland. The site must have enough acres to justify the expenditure of time and resources that go into obtaining a permit. The vicinity must be checked for wetlands, wind direction, remoteness, location of neighbors, local ordinances on biosolids use, and the general feeling about biosolids.
- Determine which farmers want the material, explain the approval requirements, verify ownership, obtain the necessary data and signatures, and notify the neighbors and any local officials (e.g., township or borough supervisors, county officials, conservation districts, and regional state regulators);
- Contact all of the relevant biosolids regulators; prepare the necessary paperwork; do the required field work [e.g., soil sampling every 10.1 ha (25 ac) or so] and lab tests; procure aerial photographs of the area and mark the fields, boundaries, and all water-related landmarks (e.g., waterways, wetlands, water supplies, and wells); determine the delivery truck's travel route; and complete any other work required by local agencies;
- Inform local agencies and the public about the benefits of beneficially using biosolids (especially if land application or the treatment plant is new to the area), ensure that all program-related personnel (e.g., generators, transporters,

and land appliers) understand the benefits of biosolids and can explain them properly to the public, and maintain an ongoing local outreach program for the benefit of anyone who inquires about land application; and

- Inspect the land-application sites regularly to verify that the work is done correctly (e.g., the trucks are not causing problems, mud is not tracked onto roads, odors are controlled, the site is well-maintained, and any unspread biosolids are neatly stored) and that a treatment plant representative will be able to answer all questions during regulatory inspections.

Land Reclamation. Land reclamation is similar to land application except that the biosolids-application rates are higher because the application is not just to provide nutrients for the current growing season but to establish long-term growth on disturbed and nutrient-poor soils. The land-reclamation sites are usually acidic, strip-mined areas (Sopper, 1993; Pennsylvania Organization for Watersheds and Rivers, 2003). However, biosolids also have successfully reclaimed rangeland in New Mexico by providing organic content that helps retain moisture in the soil.

Lime-stabilized biosolids work well on strip-mined ground where the pH may be low across the site—the lime content of the biosolids provides the pH adjustment needed to allow grasses to grow—but other types of biosolids are also effective as long as appropriate pH adjustments are made. The material's organic matter and slow-release nitrogen will provide a good base for most seed mixtures. However, if the seed mixture includes warm-season grasses, which develop slowly (over 2 to 3 years), they can be choked by faster-growing fescue and other grasses, so multiple applications of biosolids at lower rates may be necessary to avoid this problem.

Biosolids have also successfully revegetated capped cells at landfills. Once a cell has been filled, it is typically covered with a geomembrane, or filter fabric covered with soil to keep water from infiltrating into the cell and to minimize leachate from the cell. The biosolids are then applied in the same manner as for reclaiming strip-mined land.

Forestry. The King County (Washington) Wastewater Treatment Division has been applying biosolids to tree farms since 1987 and to state forests since 1995. The biosolids make an excellent soil amendment and source of nutrients for trees, as illustrated by tree rings from biosolids-fertilized trees, which are wider after the applications. The forestry projects help protect and enhance forests and wildlife habitat along the scenic highway that leads from Seattle to the mountains.

Commercial Products. Some treatment plants (on their own or with a private company) compost biosolids for use in landscaping and gardening. Biosolids that can be bagged and sold may be used by the public for their gardens and potted plants.

Incineration. In 1993, 381 wastewater treatment plants (2.8%) incinerated their sludge (16% of the total volume produced nationwide), and seven plants co-incinerated sludge with municipal solid waste in municipal waste combustors, according to the preamble of 40 *CFR* 503. Some treatment plants choose to incinerate biosolids because they are in colder areas and need an effective management method in winter, when land application is infeasible. Some plants in large metropolitan areas incinerate solids to avoid the odor complaints related to hauling Class B biosolids long distances through city neighborhoods. The incineration process is equipment- and energy-intensive and requires air-pollution-control devices; the leftover ash must also be used or disposed. (For more information on incineration processes, see Chapter 32.)

Some wastewater treatment plants recover the heat generated during incineration and use it to heat other treatment processes, to generate electricity, or to make steam for heating or use in other treatment processes. Incinerator ash is typically landfilled, but it could be beneficially used if its metal concentrations are within regulatory limits (all pathogens were burned off during incineration). For example, the ash could be used as

- An amendment to soil that will be dug up and sold by topsoil producers (the ash-and-soil mixture produced must meet regulators' criteria);
- A component of cement, concrete, or asphalt;
- An alkaline addition to sludge (with other alkaline additives, perhaps);
- A component of house shingles;
- A component of plastic;
- A ceramic-like material (if further treated at higher temperatures); and
- Landscaping bricks (if further processed at higher temperatures).

To qualify for most of these uses, the ash must meet certain criteria and be available on demand at specified volumes. Not all treatment plants can meet such requirements, and they must compete with other industries that produce large volumes of suitable ash.

Heat Drying and Other Themal Processes. Together, heat drying and pelletizing produce a marketable fertilizer that meets the 40 *CFR* 503 requirements for EQ biosolids, and so has fewer regulatory recordkeeping and reporting requirements if used for land application. This biosolids management option is a proven technology in which odors can be contained and controlled. The resulting biosolids pellets have much less volume and weight than the influent solids and are easily handled, conveyed, and stored. They can be delivered to consumers in bulk or in bags or other containers.

The disadvantages of heat drying and pelletizing include the dust's explosive potential and the potential for overheating and fires. Also, the equipment is expensive, complex, and maintenance-intensive, requiring qualified operators. Air-emissions-control equipment also is required, especially because drying certain types of solids can result in more odorous pellets.

Solids also may be treated via the following thermal processes:

- phased thermophilic digestion;
- heat pasteurization, which produces a marketable fertilizer;
- residuals gasification, which produces liquid, gaseous, and hydrogen-derived fuels;
- treating biomass thermo-chemically to produce a low- to medium-grade heat content gas;
- Enersligle™ (a process that produces a fuel-grade oil); and
- Cambi™ (thermal hydrolysis using temperature and pressure to heat and cool sludge).

DISPOSAL OPTIONS. Treatment plants typically decide whether to use or dispose of biosolids based on the cost of each evaluated option. Sludge that will ultimately be landfilled may need as much treatment as if it were to be land applied, so the related labor and trucking costs may be the overriding factors.

The disposal methods—"dumping", landfilling, monofilling, surface application, and co-disposal with municipal solids waste—all typically involve putting the biosolids in a hole in the ground. These holes are subject to federal, state, and sometimes local regulations, which require liners; daily and final covers; collection of leachate and methane gas; groundwater monitoring; control of odors, vectors, and nuisances; and caps and other closure methods.

DIVERSIFICATION AND CONTINGENCY PLANS. The Allegheny County Sanitary Authority's wastewater treatment plant in Pittsburgh, Pennsylvania, produces approximately 154 000 wet tonne/a (170 000 wet ton/yr) for the following purposes:

- Almost one-half is incinerated, producing steam for use in various plant processes as an energy-recovery method;
- Almost one-half is land applied on farms and strip mines by contractors; and
- The rest is landfilled.

Treatment plant staff chose this combination because the plant is within city limits, surrounded by businesses and residences, and cannot store solids onsite because of

potential odors. This diversity enables the treatment plant to operate efficiently and without odors, regardless of maintenance needs or weather conditions.

Treatment plants do not just process wastewater, and solids management is not a small part of the operation. It requires at least as much time, effort, and financial commitment as wastewater does. So, all treatment plants should have a contingency plan for unexpected events (e.g., severe weather). Planning for regulatory changes, however, is another matter. Plant staff should establish a good working relationship with regulators and keep abreast of the regulatory changes under development. Changes that will result in more solids treatment will involve more money and equipment, which can take months or years to secure, install, and start up.

FACTORS AFFECTING THE DECISION. The most important factor in choosing a biosolids management option is the applicable laws, regulations, and local ordinances. Check carefully: even if land application is technically allowed, obtaining permits and site approvals can be difficult and time-consuming. The regulators who permit generators and approve sites may have many duties and, therefore, little time for these tasks or for complaints from organizations that vehemently oppose land application. In some states, local governments have established local ordinances that impose fees and requirements doubling the cost and effort of land application. The current trend is that regulators want treatment plants to produce odorless Class A biosolids.

Another important factor is whether to treat the plant's solids to meet Class A or Class B biosolids requirements. Typically, Class A treatment processes cost more than Class B processes. Most land-application programs use Class B biosolids, which work well on farms and strip mines and are acceptable to farmers and miners. Class A biosolids have lower pollutant and pathogen levels, and can be sold or given away to the public. (The sale price typically does not cover the entire production cost, but does help defray it.)

Other factors that affect the choice of biosolids management option include:

- The treatment plant's location;
- Local weather conditions;
- Past solids-management practices (everyone is more comfortable with something they know);
- Distance from available beneficial use sites;
- The number and strength of local anti-biosolids groups;
- Support of local government officials;
- Estimated costs;

- Available funding; and
- Local landfill availability and pricing.

Each option has advantages and disadvantages, and plant staff should avoid making the decision based solely on cost. Choosing to land apply Class B biosolids, for example, may ultimately fail if the anti-biosolids groups complain daily to regulators, who then become overwhelmed with public relations efforts and cannot keep up with permit applications and site-approval requests. Also, switching from a long-used method to a new one will be stressful, especially if the old method was simple (e.g., landfilling) and the new one is complex (e.g., composting or heat drying). Treatment plant personnel also need to decide whether to manage solids in-house or to outsource the work.

OUTSOURCING. *Outsourcing* is the process of hiring another entity to perform some of an organization's work. It enables treatment plant personnel to decide how much of the solids management work they want to do and how much they prefer to let someone else do. For example, the treatment plant could produce the biosolids and then hire a contractor to land apply it (e.g., perform all the work related to permitting, transporting, land applying, reporting, and communicating with the public and regulators). Alternatively, the treatment plant could hire a contractor to handle all of the solids-management processes.

One advantage of outsourcing is that the treatment plant does not have to expand its workforce. Also, plant personnel can rely on the expertise of a biosolids management specialist rather than "starting from scratch" themselves. Nor does the plant have to invest in a fleet of specialized vehicles (e.g., tractors, spreaders, and front-end loaders) or—if the entire solids-management program is outsourced—any solids or biosolids handling, processing, or storage facilities.

One disadvantage of outsourcing is that the treatment plant is still responsible for its contractor's actions, because as far as regulators are concerned, the biosolids generator remains their owner. So, plant personnel should be familiar with all aspects of the contractor's work, monitor the operations, and confirm that the program is effective and meets all requirements. Plant personnel also should maintain a suitable public outreach program and keep in contact with contractor staff, beneficial-use site owners, and regulators.

Once treatment plant personnel have decided to hire a solids management contractor, they need to draft an agreement that covers all usual and exceptional matters affecting the services that they expect the contractor to perform. The bid specifications or request for proposal should be developed by a team that includes legal counsel, en-

vironmental scientists, engineers, and operations and maintenance staff, as well as input from regulators. (Most outsourcing treatment plants are willing to share their bid specifications.) Any contractor hired to manage a treatment plant's solids should be well-known in their field and have experienced staff, a good compliance record, and a good work history.

ODORS AND PUBLIC ACCEPTANCE. Another important factor is the problem of odor complaints. Some complaints may be justified. Others will have nothing to do with the treatment plant's biosolids; they may be the result of odors from neighbors down the road. The complaints may even be more general: "We don't want your sewage sludge here." Justified or not, these complaints will cost the treatment plant personnel much time and energy combating their effects on regulators and the news media.

Although odor complaints cannot be completely avoided, treatment plant personnel can address the problem by

- Producing as odorless a product as possible;
- Monitoring conditions at beneficial-use sites (e.g., remoteness, wind direction, possibility of inversions, humidity, topography, and occurrence of holiday weekends);
- Encouraging regulators to educate the public about biosolids;
- Supporting environmental programs in schools and teaching students about biosolids;
- Establishing and maintaining public outreach programs on biosolids;
- Inviting local government and media representatives to tour the sites so they become familiar with biosolids and their benefits for farms and strip mines; and
- Following the suggestions of biosolids organizations [e.g., WEF and the National Biosolids Partnership (NBP)] concerning the public and the media.

Making the public familiar with the beneficial use of biosolids will hopefully counteract their instinctive fear of and aversion to the material.

RECORDKEEPING. Treatment plant personnel should keep the required records for as long as the regulations dictate. All permits, lab analyses, and regulatory reports should be maintained in a well-organized file or bookshelf to help regulators or third-party verifiers when they inspect the solids facilities.

Plant personnel also should set up an archive system. For example, paper files could be copied onto new storage media (e.g., CDs or optical disks) and then stored off-site so the hardcopies are backed up, but the data remain at staff's fingertips. (For more information on management information systems, see Chapter 6.)

REGULATORS AND INSPECTIONS. Regulators and treatment plant personnel are "in this together": both answer to the public, their supervisors, and elected officials. The regulators who inspect facilities or approve permits want a treatment plant's solids management program to succeed because it makes their jobs easier. If regulators approve a permit and the treatment plant does a poor job, then both look bad. On the other hand, if the solids management program is a success, then both look good.

So, if regulators ask for information that is not "required" by the regulations, they probably need the data to help them approve the plant's paperwork. Treatment plants will get their work done faster if their personnel are cooperative.

EMS AND ISO 14001. The National Association of Clean Water Agencies (NACWA), U.S. EPA, and WEF formed the NBP in 1997 "to advance environmentally sound and accepted biosolids management practices". For example, the NBP encourages treatment plants and solids contractors to develop environmental management systems (EMSs) to improve their production and use of biosolids. The partnership's *EMS Guidance Manual*, which is based on ISO 14001, is designed to help treatment plants develop EMSs tailored for their solids management programs. The systems will help treatment plants do a good job, develop a good reputation, and improve working relations with regulators and environmental groups. However, they may or may not help public relations efforts, because some people will never accept any material that comes from a wastewater treatment plant.

OTHER SOLIDS

Other solids separated from wastewater may be beneficially used but are typically landfilled. The use of grit is being explored; it is washed to remove rubbish and slime, and then separated by size into sand and gravel for use as aggregate in asphalt mixtures and sub-base course materials.

COSTS

The costs of various solids management options are shown in Tables 27.1 through 27.4. These costs are from estimates, demonstration projects, and full-scale operations. Most are from 2002 or later, but costs from the 1990s are included for historical comparison. To make the figures comparable, some discretion was used (judgment as to number of days of operation per week, etc.).

TABLE 27.1 Costs of various biosolids process chains.

Process	Includes	Cost ($/wet ton)	Cost ($/dry ton)	Reference
Heat drying and pelletizing	Dewatering; privatized	92.47	462.39	Frankos, 2003
Composting in-vessel Paygro	Dewatering and trucking; privatized	105.36	526.80	Frankos, 2003
Land application	Privatized	32.69	163.45	Frankos, 2003
Class A lime stabilization	Thickening		1100	Leininger and Nester, 2003
Class A lime stabilization	Dewatering		900–920	Leininger and Nester, 2003
Class A ATAD	Dewatering		900–920	Leininger and Nester, 2003
Class A ATAD	No dewatering		770	Leininger and Nester, 2003
Class A indirect steam drying	Dewatering		980–1040 1600–1700 thru land application	Leininger and Nester, 2003
JVAP™ frame press and Class A heating/drying	Dewatering		820–1335 storage and land application	Leininger and Nester, 2003
Upgrading and keeping Class B process	Aerobic digestion		750	Leininger and Nester, 2003
Class A thermal drying process	Fully allocated costs; digestion, dewatering, land application		average: 257 range: 187–328	Bullard, 2002
Land application demonstration	Dewatering through land application; centrifuges		172–220	Sloan et al., 2002
	Dewatering thru land application; belt filter press		154–160	Sloan et al., 2002
Land application current system	Dewatering thru land application; gravity belt and belt filter press		202	Sloan et al., 2002
Land application and landfill daily cover	Aerated static pile composting		405	Van Der March et al., 2002
	In-vessel composting		399	Van Der March et al., 2002

BLE 27.1 Costs of various biosolids process chains (*continued*).

cess	Includes	Cost ($/wet ton)	Cost ($/dry ton)	Reference
	Rotary heat drying		93	Van Der March et al., 2002
	Pre-pasteurization and RDP-Cambi		224	Van Der March et al., 2002
	Chemical addition—Bioset		217	Van Der March et al., 2002
	Dedicated landfill		300	Van Der March et al., 2002
:lass A lime stabilization; re-1996 study survey of 0 facilities	Thicken-digest-dewater; En-Vessel Pasteur. (RDP-EVP)		312 – 10 mgd 228 – 20 mgd 158 – 40 mgd 139 – 60 mgd	Rothberg, Tamburini & Winsor Inc., 1996
	Thicken-digest-dewater; Biofix with lime only		~345 – 10 mgd ~250 – 20 mgd ~180 – 40 mgd ~160 – 60 mgd	Rothberg, Winsor Inc., 1996 Tamburini &
Aerated static pile composting; pre-1996 study survey of 14 facilities	Thicken-digest-dewater		360 – 10 mgd 277 – 20 mgd 204 – 40 mgd 184 – 60 mgd	Rothberg, Tamburini & Winsor Inc., 1996
Thermal drying; pre-1996 study survey of 9 facilities	Thicken-digest-dewater		493 – 10 mgd 372 – 20 mgd 276 – 40 mgd 247 – 60 mgd	Rothberg, Tamburini & Winsor Inc., 1996

ATAD = autothermal thermophilic anaerobic digestion.

TABLE 27.2 Unit cost snapshot for various processes.

Process	Cost ($/wet ton)	Cost ($/dry ton)	Comments/Reference
Belt filter press dewatering	76		3% to 23.5% total solids (Hagaman, 1998)
Belt press dewatering	30	187	to 15.9% (Lee et al., 2003)
Centrifuge dewatering	33.25	187	Lee et al., 2003
Anaerobic digestion	2.25 per gallon (4.25–1.90/gal)		Cost depends on size of digester (Potts et al., 2003)
	3.85 per gallon		Concrete egg-shaped digester (Potts et al., 2003)
	1.88–4.24 per gallon		Costs include everything but storage (Marx, 2002)
Centrifuge dewatering		172.63	Drury et al., 2002
Belt press dewatering		185.77	Drury et al., 2002
Aerobic digestion without thickening	6.07 per gallon	146	Curley et al., 2002
Aerobic digestion with thickening	6.23 per gallon	150	Curley et al., 2002
Anaerobic digestion without thickening	6.87 per gallon	165	Curley et al., 2002
Anaerobic digestion with thickening	7.31 per gallon	176	Curley et al., 2002
Composting	50 (38 after revenues)		Hogan, 2003
Heat drying and pelletizing		250–350 412	Hogan, 2003 with dewatering and bond repayment pelletizing (Hogan, 2003)
Multiple hearth incinerator		192.30	at 20.80% total solids (Leger, 1998)
Lime stabilization—RDP EnVessel process		41.33	at 22–25% total solids (Hagaman, 1998)
Composting	22-own facility 29-outside facility		Lee et al., 2003
Multiple hearth incinerator		183.78	Sherodkar and Baturay, 2003
Fluidized bed tray dryer and pelletizer		190 for O&M	Janses et al., 2003
Incinerate scum and grease		248	6-year average (Dominak and Stone, 2002)

ABLE 27.2 Unit cost snapshot for various processes (*continued*).

ocess	Cost ($/wet ton)	Cost ($/dry ton)	Comments/Reference
ind application of osolids	20 / ton – by facility 25 / ton – contractor 55 / ton – to landfill		agriculture application; Chambersburg, Pennsylvania (Hook, 2003)
	0.055 per gallon		Class B; North Carolina (Hagaman, 1998)
		88	includes lagoon drying and subsurface injection; Calgary, Canada (Tatem, 1998)
andfill biosolids	58	233	Hampton, New Hampshire (Berkel, 2003)
	approx. 59		by contractor; Cleveland, Ohio (Dominak and Stone, 2002)
Landfill ash		approx. 50	Cleveland, Ohio (Dominak and Stone, 2002)
Landfill grit and screenings	approx. 53		Cleveland, Ohio (Dominak and Stone, 2002)

TABLE 27.3 Sales value of biosolids.

Material	Value	Comments
Biosolids	$6–7 per percentage point of nitrogen	Florida (Maestri, 1998)
Compost	$10 per dry metric ton or $6.50 per cubic meter	Palo Alto, California (Nichols, 1998)
Bulk dry pellets	$63 per dry metric ton ($28.22 after marketing and distribution)	Palo Alto, California (Nichols, 1998)
Compost	$5.45 per cubic yard	Baltimore, Maryland

TABLE 27.4 Incineration costs.

Time	Operations and maintenance ($/dry ton)	Amortized capital installed capacity ($/dry ton)	Total ($/dry ton)	Reference
1990 actual(1)	70–90	100–125	170–215	Walsh et al., 1990
1990 actual(2)	180–200	200–230	380–430	Walsh et al., 1990
2003 estimate(3)	105–187	37–55	114–187(5)	Welp and Lundberg, 2003
2003 estimate(4)	135–247	37–55	144–247(5)	Welp and Lundberg, 2003

(1) Based on a well-operated sludge incineration system operating at capacity; starts with dewatered sludge and includes furnaces, heat recovery, air-pollution control, and ash disposal systems; includes some reserve capacity; 20 years for equipment, 40 years for buildings, and 8%.
(2) Same as 1 and also including thickening and dewatering.
(3) Does not include thickening and dewatering; fluid bed incinerator; 20 years, 6%.
(4) Does not include thickening and dewatering; multiple hearth incinerator; 20 years, 6%.
(5) Total includes $27–55 of energy credit.

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