ArrowBio Process for Municipal Solid Waste:
Recovery of Material and Energy Resources in a Single System

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Introduction.

After extensive development involving laboratory, pilot, and small commercial scale steps, a full-scale ArrowBio plant opened in early 2003 at the preexisting Tel Aviv, Israel, Municipal Solid Waste (MSW) transfer station (Figure 1).

Figure 1. The ArrowBio plant at the Tel Aviv, Israel, transfer station. The physical separation/preparation element of the plant is under the roof at the left, and the biological element is beyond the roof at the right. In the background is the Hiriya dump, now closed and being remediated as part of the future Ayalon Park.

The design capacity of a standard ArrowBio module is 200 tons/day or 70,000 tons/year. However, lack of space at the preexisting transfer station imposed two constraints. First, the two elements had to be apart, though this is not a major drawback as they are connected by pipelines. Second, there was space for only one 100 ton/day separation/preparation line rather than two lines as in a standard module. The biological element shown is sized for two lines as in a standard module.

System Integration. The physical and biological elements of the Process are integrated such as to make possible the recovery of both material (e.g., non-compliance food containers) and energy (methane-rich biogas) resources in a single facility. Typically, about 70% of unsorted MSW mixtures consist of biodegradable organics (food preparation wastes, plate wastes, diapers, incidental vegetative material, food tainted paper), yielding methane. Source-separated waste streams might be up to 90% biodegradable. Both types of input must undergo separation and preparation prior to anaerobic digestion.

Not only must the biodegradables be isolated and prepared for energy recovery, but the non-biodegradables must be sub-fractionated into the various types of secondary materials for recycling to the extent practicable, as well as residual to be landfilled. In initiating theses tasks, mixtures that are currently landfilled in their entirety are tipped directly into ArrowBio's special purpose separation/preparation water vats.

Roles of Water in ArrowBio's Physical and Biological Elements.
The water in the vat is in circulation with water newly freed from the waste through biological action at the back-end. That is, the source of the water in both elements is the moisture content of the waste, typically comprising around 30% of the weight of MSW.[1] The biological gasification of organic solids leaves behind the water in liquid form.

In the water vat, the non-biodegradable and biodegradable fractions are separated gravitationally. Separation in water is far more efficient than in air, owing to the comparative densities (relative buoyancies) of the two fluids. Thus, depending on their specific gravity and tendency to absorb water, items sink, float, or become suspended in the water.

A central feature of the system is that, because separation/preparation is in water, it is possible to use UASB digestion, which requires its organic feed in solution or fine suspension. Thus, both front - and back- ends of the system are frankly watery and function reciprocally.

Other benefits of tipping into water include dust suppression and the neutralization of odors delivered with "ripe" loads. Neutralization is immediate because odorous compounds are soluble in water. Their biodegradation soon follows in enclosed digesters, preventing downstream generation of nuisance odors. Also, being watery evens-out surges and regulates the rate of progression through the processing train, contributing to the system's overall resiliency.

Physical Element: Separation and Preparation. Figure 2 is a close-up of the exterior of the physical element. Its functions are two-fold -- to remove traditional recyclables (e.g., non-compliance bottles and cans) and other non-biodegradables, while simultaneously isolating the biodegradable for UASB digestion. Visible are a large settling tank (2a), cyclone at the terminal end of a film plastic removal system (2b) [leads to a baler (Figure 3)], large trommel screen (2c), and office and control room (2d). The separation and preparation functions, performed in unison, are inextricable.

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[1] Finstein, M.S. 2003. "Operational Full-Scale ArrowBio Plant Integrates Separation and Anaerobic Digestion in Watery Processing, With Near-Zero Landfilling." *Proceedings of WasteCon 2003, SWANA's 41st Annual International Solid Waste Exposition*, October 14-16 2003 St. Louis, Missouri, p. 290-296.

Figure 2. Visitor entrance to the physical separation/preparation element of the plant (bins in forefront remain from construction.

Figure 3 shows one of the material products recovered.

Figure 3. Bales of plastic recovered from mixed MSW

In the separation/preparation vat, the watery flow carrying the heterogeneous mixture of MSW materials follows multiple pathways that are, by design, complex, overlapping, and repetitious. As such, the agencies of solubilization, size reduction, screening, and gravitational separation are given diverse and repeated opportunities to complete their work. The multiplicity of pathways makes it impossible to describe events in a linear fashion. The interior of the physical element is shown in Figure 4.

Figure 4. Inside the physical separation/preparation plant element, viewed toward the visitor entrance (see Figure 2 for orientation). The tipping platform is in back of the viewer. For scale, the railing is waist high. (Photo taken in early testing.)

The load is tipped onto a walking floor (4a), from which it falls into the water vat immediately upstream of a partially submerged rotating paddle (4b). The paddle urges floaters and buoyancy-neutral items forward into the main body of water (4c). Sinkers are diverted to the left and passed sequentially to a bag breaker (4d), magnetic pickup (4e), eddy current device (4f), and a pneumatic (vacuum/forced draft) station (4g) from which film plastic is swept into ductwork (4h). Ducts from several such stations converge on the cyclone (see Figure 2). Thereby, metals and film plastic are removed. Items that escape this processing train the first time around reenter the water vat (4c) for another chance to dissolve, float or sink or, if buoyancy-neutral, be suspended in the forward-moving water column.

Overflow from the water vat, screened to exclude large items, passes though smaller enclosed trommel screens (4i) and thence, according to partitioning criteria, to large (see Figure 2) and small (4j) settlers. In the settlers grit is separated from organics and removed from the system.

Meanwhile, larger floaters and buoyancy-neutral items are lifted (4k) to a slow speed shredder (4L) and thence to the large trommel screen (4m). The “overs” from this trommel consist mostly of film plastic and are removed at a pneumatic station. The “unders” (material that passed through screen) are washed into a non-mechanical device for further solubilization and size reduction. Non-soluble substances are thus reduced to a suspension of fine particles whose surfaces are roughened to favor microbial colonization.

Thus non-biodegradables are recovered for recycling as secondary material commodities, and soluble and particulate organics come into solution or fine suspension, including food sticking to containers and the contents of unopened diapers. The latter are disrupted in the processing train, freeing the feces, urine and cottony absorbent. Insoluble biodegradable organics (e.g., non-source-separated food-tainted paper products, tough fruit rinds) get increasingly soggy and fragmented, ultimately to the point of passing screens of selected sizes. The organics, now in watery isolation, are pumped to the biological element. In turn, return water from the biological element refreshes the separation/preparation water vat.

Within half an hour after tipping the last load of the day, the work of the physical separation/preparation element is complete. This part of the plant is then shut down until deliveries resume the next working day.

Biological Element: Transforming Organics to Useful Products. The biological element is shown in Figure 5. The organic flow first enters acidogenic bioreactors (5a) for several hours of preliminary treatment. There, readily metabolized substances already in solution are fermented (e.g., sugars fermented to alcohols), while certain complex molecules are biologically hydrolyzed to their simpler components (cellulose to sugar, fats to acetic acid). The overflow, rich in such intermediate metabolites, then enters the UASB bioreactor (5b).

Fig. 5. Biological element of the plant (see text and box).

UASB digestion is a generic, mature technology specifically designed for the treatment of high strength *wastewaters*, such as in dairy and candy manufacture and other industries. Hundreds of such systems are in use worldwide – in the wastewater treatment domain. The ArrowBio Process, by rendering solid phase organics into a strong wastewater, makes UASB, with its superior performance characteristics, applicable to MSW.

UASB

Snapshot of Upflow Anaerobic Sludge Blanket (bed) digestion

While a full outline of UASB digestion is beyond the scope of this paper, its main features are described herein. Two terms as used in the field are first noted: *Solids* refers, in context, to the microbial community performing the work; *granules* refers to the particles formed spontaneously by that community. Other special terms are italicized on first use.

Each granule is a miniature, mature, complete ecosystem performing the complex stepwise transformation of organic waste to stabilized residue and biogas. Moreover, in gasifying the organic material, the water in the waste is liberated and left behind in liquid form. The granules are kept in watery suspension to a given "blanket" (or column) height by the bubbling of the gas, abetted by pumping.

Specific features setting UASB digestion apart from older, less efficient, forms of anaerobic digestion are two: the wateriness of the feed, and the *Solids* and *Hydraulic Retention Times (SRT and HRT).* In other MSW applications using conventional digestion the feed is a thick paste (up to 30% solids/70% water), and the SRT and HRT values are identical or nearly so (~ 15 days). In UASB digestion as used in the ArrowBio Process the feed is watery (~ 4% solids/96% water), and the SRT and HRT vastly different (~ 75 days and 1 day, respectively). The difference in the SRT and HRT is at the heart of UASB digestion.

It might seem at first that the watery nature of UASB is an uneconomic use of reactor volume. The opposite is true, however, because UASB digestion unleashes the power of microbes in a manner not otherwise possible. This is manifested in faster and more complete transformation of organics to biogas. The practical results include: less residual organics and their more complete stabilization; more biogas richer in methane; a modest facility footprint (two acres, inclusive, for a one-module 70,000 tpy plant).

Operationally, excess biological granules suspended in similarly excess water (both excesses represent growth at the expense of the waste) are transferred to a settling tank (5c). Supernatant is pumped to the physical separation/preparation element as needed for makeup water, or to an aerobic tank for polishing (5d) if necessary. Water may be stored (5e) or used immediately as in irrigation. The solids are dewatered for use as stabilized organic soil amendment.

Some of the biogas is used to fire boilers (5f) to maintain UASB digestion at its optimum temperature of ~ 95˚F (35˚C). Otherwise, depending on site-specific circumstances, the gas fuels an electrical generator (5g) via a storage tank (5h). Waste heat from the generator contributes to the maintenance of digestion temperature.

Simplicity, Economics, and Benign Processing Conditions. Because the ArrowBio Process is essentially based on two benign phenomena (gravitational separation in water and advanced anaerobic digestion), processing conditions are mild throughout. By involving only biological temperatures and ambient pressures, the system may be said to "work with nature."

Being based on these two phenomena implies, correctly, that the economics of construction, operation, and maintenance are favorable. Moreover, most of the components are "off the shelf," and construction is local. Another implication is that, unlike systems based on harsh non-biologic reactions at high temperatures and pressures, there is no generation of toxic or hazardous compounds with their potential release into the environment.

Broader Significance of the ArrowBio Process. The transition of municipal solid waste management from being a matter of mere disposal to one of material and energy management is irrevocable, yet still in a formative stage. We expect the ArrowBio Process to play an important role in that transition.
