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**ARROWBIO PROCESS INTEGRATES PREPROCESSING AND  
ADVANCED ANAEROBIC DIGESTION TO RECOVER RECYCLABLES  
AND GENERATE ENERGY**

**Melvin S. Finstein<sup>1</sup>**  
ArrowBio USA  
Haifa, Israel

**ABSTRACT**

The ArrowBio process integrates separation and preparation (preprocessing) and advanced anaerobic digestion (Upflow Anaerobic Sludge Blanket digestion) via the medium of water. The water is derived from the moisture content of the waste. Clean recyclables are recovered from mixed waste via gravitational separation in water, and biodegradable organics are extensively converted to methane-rich biogas.

**INTRODUCTION**

After extensive development at laboratory, pilot, and small commercial scale, a full-scale ArrowBio plant opened in 2003 at the preexisting Tel Aviv, Israel, Municipal Solid Waste (MSW) transfer station. The plant is shown in [Figure 1](#).

A 90,000 ton per year ArrowBio plant is on order for suburban Sydney, Australia.



FIGURE 1. THE ARROWBIO PLANT AT THE TEL AVIV, ISRAEL, TRANSFER STATION. THE FRONT-END PHYSICAL SEPARATION/PREPARATION STAGE OF THE PLANT IS UNDER THE ROOF AT THE LEFT, AND THE BACK-END BIOLOGICAL STAGE IS BEYOND THE ROOF AT THE RIGHT. THE BACKGROUND IS THE HIRIYA DUMP, NOW CLOSED AND BEING REMEDIATED AS PART OF AYALON PARK.

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<sup>1</sup> The author, Emeritus Professor of Rutgers University, resides in Wheeling, West Virginia, USA. Email: [Finstein@envsci.rutgers.edu](mailto:Finstein@envsci.rutgers.edu)

## SYSTEM INTEGRATION

The ArrowBio process achieves system integration by exploiting the moisture content of MSW. Moisture content levels are typically around 30% by weight (Finstein, M.S., 2003). Thus a ton of MSW consists of approximately 1,400 pounds of material and 600 pounds of water (or, 70 gallons of water per ton).

In the course of anaerobic digestion, moisture in MSW is liberated as liquid water. The mechanism is that, as organics are converted to methane and carbon dioxide, and the gases bubble out of solution, water originally imparting moistness is left behind in liquid form.

A portion of the water liberated at the back-end biological stage (upflow anaerobic sludge blanket digestion - UASB) is exchanged with vat water at the front-end physical separation/preparation stage. As such, the bioreactors receive fresh substrate, and the vat receives makeup water.

UASB digestion is outlined later in the text, and in APPENDICES 1 and 2. Among its benefits are extensive

conversion of organics to methane-rich biogas (i.e. energy), production of a relatively small amount of clean, stabilized, digestate, and a modest facility footprint. These characteristics stem from integration of the two stages.

## FRONT-END STAGE: PHYSICAL SEPARATION AND PREPARATION

Figure 2 shows the exterior of the front-end physical stage. Its functions are three: to remove grit and other “landfillables,” to recover traditional non-biodegradable recyclables (e.g., plastic soda bottles and milk jugs) and other secondary materials, and to isolate and prepare the biodegradables for UASB digestion at the back-end stage. These functions are performed in unison and are inextricable

Visible (Figure 2) 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).



FIGURE 2. VISITOR ENTRANCE TO THE FRONT-END PHYSICAL SEPARATION AND PREPARATION STAGE (BINS IN FOREFRONT REMAIN FROM CONSTRUCTION).

Figure 3 shows one of the material products recovered in the front-end operation.



FIGURE 3. BALES OF PLASTICS RECOVERED FROM MIXED MSW.

Figure 4 shows the interior of the front-end separation/preparation water vat. Here the non-biodegradable and biodegradable fractions are separated gravitationally in water as abetted by filter screens and size-reduction devices. 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 solubility or specific gravity and tendency to absorb water, items dissolve, sink, float, or become suspended in the water.

“Incidental” benefits of tipping into water include the suppression of dust, and the neutralization of odors. Neutralization is immediate because odorous compounds are soluble in water. Their biodegradation soon follows as vat water is continuously pumped to the back-end enclosed digesters. Also, because the system is watery throughout, any input surges are evened out, contributing to the system’s overall resiliency

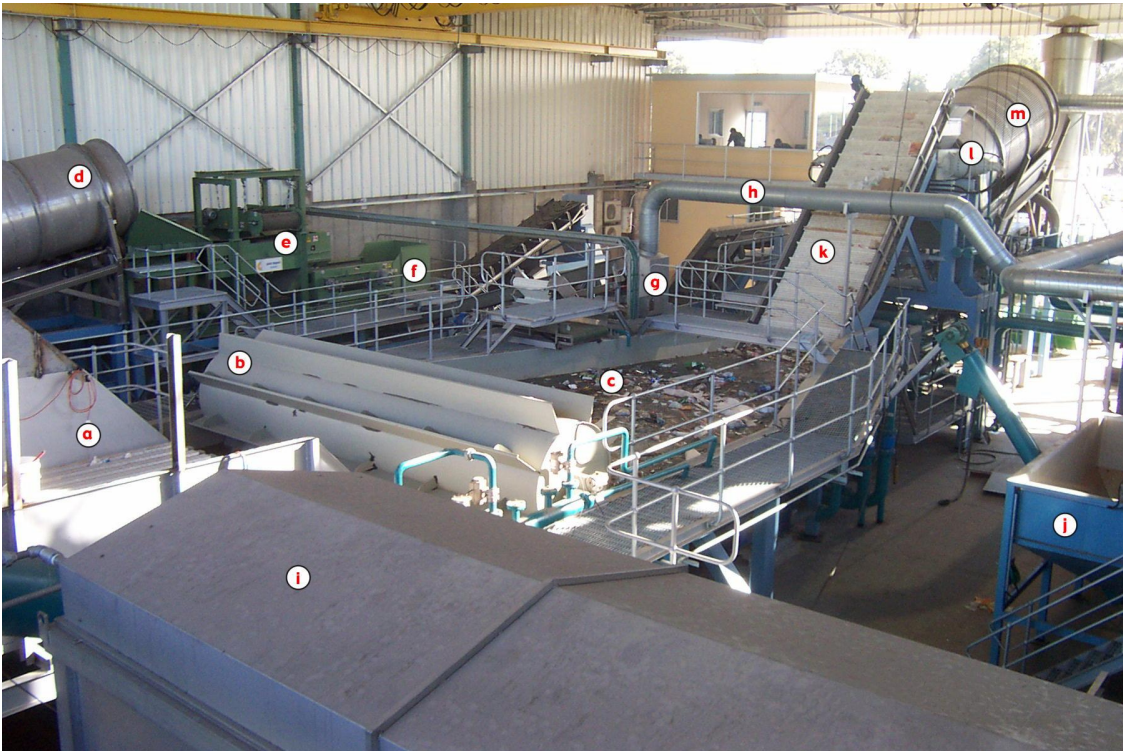


FIGURE 4. INSIDE THE FRONT-END PHYSICAL SEPARATION/PREPARATION STAGE, VIEWED TOWARD THE VISITOR ENTRANCE (SEE FIGURE 2 FOR ORIENTATION). THE TIPPING PLATFORM IS IN BACK OF THE VIEWER. FOR SCALE, THE RAILING IS WAIST HIGH. (PHOTO TAKEN IN EARLY START-UP.)

The load of mixed waste 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 through 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 and urine-soaked 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 stage. Reciprocally, return-water from the digester system 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.

### **BACK-END BIOLOGICAL STAGE: UPFLOW ANAEROBIC SLUDGE BLANKET (UASB) DIGESTION**

Figure 5 shows the biological stage. 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 upflow anaerobic sludge blanket (UASB) digestion bioreactor (5b).



FIG. 5. BACK-END BIOLOGICAL STAGE

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. More than a thousand such systems are in use worldwide – in the wastewater

treatment domain. Uniquely, the ArrowBio Process, by rendering solid phase organics into a strong wastewater, makes UASB, with its superior performance characteristics, applicable to MSW.

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.

When needed to maintain UASB digestion at its optimum temperature of ~ 95°F (35°C), some of the biogas is used to fire boilers (5f). Most of the gas is used to fuel a generator (5g), via storage in a reservoir (5h). Waste heat from the generator usually suffices to maintain digestion temperature.

## ECONOMICS AND BENIGN PROCESSING CONDITIONS

Because the ArrowBio Process is 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 system components are “off the shelf,” and construction is local. Another implication is that, unlike thermochemical 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.

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## APPENDIX 1: SNAPSHOT OF UASB DIGESTION

While a detailed discussion of UASB digestion is beyond the scope of this paper, its main features may be outlined. 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 (~ 80 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).

## APPENDIX 2: WHY WATERY PROCESSING? A METAPHOR

The ArrowBio Process for MSW utilizes a watery anaerobic digestion system, whereas other commercial processes are far less watery – let's say 96% water vs. 60-70% water (watery v. high-solids feeds). Since we are not treating water, but rather biodegradable organics, isn't a watery feed wasteful of bioreactor volume? Perhaps surprisingly, it is not! In fact, the opposite is true.

The question about the proportion of water may be usefully rephrased: Is more microbiological work done per unit reactor volume per time in a watery or a high-solids system? Given UASB digestion, the watery system comes out far ahead.

The work of anaerobic digestion is done by a community of microbes made up of different specialist populations, each population doing one biochemical operation. The metaphor of a bucket brigade putting out a forest fire may be a useful way of viewing events.<sup>1</sup>

Microbial population A pours its water (= its part of the work) into B's bucket, B into C's, C into D's.... and so forth.... until the work is completed (fire out, or fresh organics transformed into the end products methane, carbon dioxide, free liquid water, and depleted organic residue).

In the high-solids digester the bucket brigade is in a state of disorganization. It's as if population A first has to search for B, who is out there in the woods somewhere. Only on finding B can A can pour his/her work product into B's bucket. Now B's problem is to find C, and so forth. This type of bucket brigade, to continue our metaphor, is no way to fight a fire!

With UASB digestion, the bucket brigade is effectively organized into a straight, tight, line from water supply truck to the fire's edge. The fire is soon out. Or, back to MSW, the fresh organics in the feed have been efficiently transformed to the desired end products.

In technical terms this efficiency is the result of SRT>>>HRT (solids residence time>>>hydraulic residence time).<sup>2</sup> This separation of residence times is possible only with watery feed -- that is, with the UASB variant of anaerobic digestion.

The first step in the ArrowBio system, immersion of the waste in water, thus permits a train of downstream operations resulting in superior process performance.

### REFERENCE

Finstein, M.S., 2003, "Operational Full-Scale ArrowBio Plant Integrates Separation and Anaerobic Digestion in Watery Processing, with Near-Zero Landfilling," Proceedings, SWANA 41<sup>st</sup> Annual Conference (WasteCon), St. Louis, MO, pp.290-296.

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<sup>1</sup> An alternative metaphor is that of an assembly line in which each worker performs a unique task to ultimately produce a given end-product.

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<sup>2</sup> A more apt term would be culture, rather than solids, residence time.