

**Thumbnail Sketch of the ArrowBio Process**  
**Mel Finstein, Head ArrowBio USA ([finstein@envsci.rutgers.edu](mailto:finstein@envsci.rutgers.edu))**  
**(UK Contact: Stuart Gordon, Project Manager - [stuart@oaktech-environmental.com](mailto:stuart@oaktech-environmental.com))**  
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The defining characteristics of municipal solid waste (MSW) are heterogeneity, variability, abrasiveness, and wetness. The task of recovering materials and energy from such a problematic mixture has historically challenged both biological and thermal systems. The ArrowBio technology was conceived and developed specifically to overcome the difficulties posed by these characteristics, in a technically, environmentally and economically sustainable manner.

This system recovers material and energy from mixed ("un-MRFd") MSW and other difficult waste streams by using gravitational separation in water to recover hard to separate materials such as plastics, while also using water as a medium for efficient biological production of renewable energy. That is, in both its physical and biological aspects, ArrowBio is a watery system. The process water comes from the moisture in the waste.

Physically, gravitational separation in water more cleanly differentiates between non-biodegradable materials and biodegradable organics than is possible in air. Thereby, traditional recyclables are recovered for marketing, abrasive grit and other non-recyclable residual materials are segregated for landfilling. In parallel, organics are brought into solution and fine suspension in preparation for the production of energy via advanced anaerobic digestion.

Biologically, ArrowBio employs anaerobic digestion in sequential acidogenic and methanogenic stages. In both stages solid and hydraulic residence times (SRT and HRT) differ, with the following approximate values respectively (days): acidogenic, 4 and 0.25; methanogenic, 90 and 1. The methanogenic stage is of the upflow anaerobic sludge blanket (UASB) type. There are over 1,000 UASB installations worldwide in the wastewater treatment domain. Only ArrowBio links this technology to the recovery of materials and energy from MSW. We now focus on the principles underlying UASB digestion.

The cause of UASB's superior performance over traditional forms of anaerobic digestion (e.g., high solids) is well understood scientifically and technically. Basically, the selective pressure induced by a prolonged SRT (possible only in a watery system) prompts the self-organization of close-knit microbial consortia in the form of "granules." Each granule is a miniature, complete, methanogenic ecosystem, in which syntrophic populations are in close proximity. Since the reactor is dedicated to methanogenesis, a large inventory of granules can be maintained. In sum, this arrangement promotes speed and completeness in the conversion of organic waste to products. (Noteworthy papers: Thiele et al, 1988. *Applied Environ. Microbiol.* 54:10; Speece et al. 2006. *Water Environment Research*, 78:460.)

The products of the biological phase of treatment are water, digestate, and biogas. Their general characteristics and uses are as follows.

- Water overflowing the methanogenic digester is treated onsite in a wastewater treatment "package plant." Its effluent is used internally to make up evaporative and other losses incurred in separation/preparation, and in other uses (e.g., truck washing, landscape irrigation). Any excess is discharged for use off site or to the sewer.

- The digestates (acidogenic and methanogenic) are relatively small in amount and biologically stable. They may find higher uses such as in potting mixtures or general purpose compost, or lower ones like alternative daily landfill cover (ADC).
- The biogas is clean, large in amount and rich in methane. It may be used to generate electricity on site to satisfy internal ArrowBio needs (parasitic load) with export of the surplus (approximately 4/5ths of that generated). Alternatively, the methane may be converted to CNG or LNG to fuel refuse collection trucks.

These product characteristics are attributable to the staged organization of the microbial populations alluded to above (acidogenic followed by methanogenic UASB).

ArrowBio's physical (front-end) and biological (back-end) components are inseparable parts of the system as a whole. Thus, separation/preparation is *intrinsic* to the overall system. In contrast, in non-watery systems (all others), *pre*-processing is *extrinsic* to the overall technologies. The effect of ArrowBio's water-based functional integration is to make of it a M(E)RF, in which (E) stands for the recovery of energy; MRF, as usual, stand for materials recovery facility.

ArrowBio embodies the concept of pollution-prevention in contrast to after-the-fact pollution-control utilizing various "end-of-pipe" devices. The prevention of pollution relates to many aspects of the ArrowBio system. For example, water-based separation/preparation suppresses dust and odor – the latter because most odorous compounds are highly soluble in water and biodegradable. More fundamentally, prevention vs. control is illustrated through comparison of ArrowBio and thermal technologies as a class with respect to energy generation (Table 1).

Table 1. Pollution-prevention vs. pollution-control in converting MSW to energy

	Basic Phenomenon	Vessel Temperature	Gaseous Fuel Product	Options for Use of the Gaseous Product	Gas Suitability for Fuel Cell (Efficient Generation Electricity/ Ultra Low Emissions)
<b>ArrowBio (Pollution Prevention)</b>	Microbial Decomposition of Liquid-Phase Organic Matter, as in the Natural World	Body Temperature (37°C or 98.6°F)	Biogas: Methane, Carbon Dioxide and little else (like Natural Gas).	<p>Many Practical Options:</p> <p><i>Generating Electricity:</i> Internal Combustion; Turbine; Fuel Cell.</p> <p><i>Vehicle Fuel:</i> cf. CNG, LNG, HCNG</p> <p><i>Higher Synthesis:</i> Ammonia, Alcohols, Aldehydes etc.</p>	Yes - Suitable: Biogas needs Minor Cleanup; Many Applications Exist Using Dirtier Landfill Gas and Biogas Produced at Sewage Treatment Plants
<b>Thermal Technologies (Pollution Control)</b>	Thermal Decomposition of Solid-Phase MSW – Very Poor Fuel (Heterogeneous, Variable, Abrasive, Wet)	Representative Temperature (1100°C or 2012°F)	Syngas: Carbon Monoxide, Hydrogen, Methane – a Complex and Poorly Defined Mixture of Various Chemical Classes	<p>Few Practical Options:</p> <p><i>Generating Electricity:</i> Internal Combustion; Turbine.</p>	No - Not Suitable: Syngas Would Need Major Cleanup to Avoid Poisoning Catalyst; Applications Not Known

The differences summarized in Table 1 are profound. They are rooted in the contrasting basic phenomena at play, microbial action and thermal decomposition. The differences are not canceled out by end-of-pipe technological fixes.

Only ArrowBio produces a gas suitable for conversion to CNG, HCNG, or LNG. Moreover, the gas is clean enough to be a candidate for use in the most demanding application – that of the fuel cell. How the biogas is actually used is a complex issue, and one that is in a state of dynamic change. Best use must be determined within the context of local circumstances.

In summary, the source of ArrowBio’s strength in recovering materials and energy is that it overcomes the problematic nature of MSW noted at the top of this essay.