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The ArrowBio Process for Mixed Municipal Solid Waste (MSW):

Responses to "Requests for Information" (RFIs)

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Basis of this Paper

Governmental organizations when formally seeking information on available technologies typically issue documents entitled variously: Request for Proposal (RFP), Request for Information (RFI), Request for Qualifications (RFQ), Request for Expression of Interest (RFEOI), and so forth. The RFP is intended to result in a contract. It may be preceded by one or more preliminary 'Requests for Information' – whatever the term used. These are evaluated with the aim of narrowing the list of candidate vendors.

Reported herein is the experience of the authors in responding to various 'Requests' on behalf of the ArrowBio Process. This technology has been described in the open published literature (Finstein, 2003; Finstein, in press). A video showing a full scale plant in operation is available on request.

The 'Requests for Information' were issued by several organizations, including the State of California Integrated Waste Management Board (CIWMB); a California county; an association of local governments within a different California county; and independently by three different cities in the Province of Ontario, Canada. 'Requests' typically provide data on the composition of the waste stream, to the extent that it has been characterized, and address other circumstance-specific information such as facility siting.

Such 'Requests' tend to be lengthy. Present space limitation dictates selection of common recurrent themes, and collating and summarizing them to express the essence of the question originally posed. This is followed by a narrative, also abbreviated, reflecting the response given in representing the ArrowBio Process. The 'Request' is italicized; the response is in plain text.

What is being sought in distributing this Request for Information

This county (city, waste management district, or whatever the entity) seeks a municipal solid waste (MSW) processing technology, other than combustion (i.e., incineration), that maximizes materials and energy recovery thereby conserving the dwindling capacity of its existing landfill. The selected technology will have to meet high environmental quality standards, and be cost-effective and acceptable to the public. Financial arrangements, not considered here, are open to later discussion.

***'Requests'* and Responses**

1. Please indicate the name of your technology, its ownership, patent numbers if any, relevant web site, and regional contact persons.

The ArrowBio Process is a development of Arrow Ecology Ltd., Histadruth Avenue, 21, Haifa, Israel 31250, and is owned by that company. The technology received United States Patent No. 6368500, issued 9 April 2002. The web site is www.arrowbio.com. The regional contact persons are: USA, M. S. Finstein finstein@envsci.rutgers.edu; Israel and elsewhere, Y. Zadik yair@arrowecology.com; Ontario, Canada, danielb@esteelman.com; UK, A. Marshall alex@oaktech-environmental.com

2. Briefly describe the fundamental driving forces employed in your technology, indicate how these are exploited, and list the useful end products.

The ArrowBio Process is frankly watery throughout, to good effect. Thus, the MSW loads are tipped onto a walking floor which promptly deposits the material into a vat of circulating water. This approach is unique, and its logic is developed later. Meanwhile, to avoid misapprehension, it is noted that the water is derived from the moisture content of the waste.

The first stage of the Process exploits gravitational separation in water. Owing to its buoyancy, water is a superior separation medium. Aided by screening, size reduction, magnetic and eddy current and size-reduction devices, metal, glass, and plastic food containers, i.e. "recyclables," are recovered for use as secondary material commodities.

An equally important function of this first stage is the preparation of the biodegradable organic materials for subsequent advanced biological treatment. Thus, soluble substances (e.g., sugars) come into solution, while particulates (food tainted paper, pizza boxes) become soggy and fragmented, ultimately being reduced to a fine suspension. The prepared organic-rich flow is continuously pumped to the second, biological, stage of the process.

The flow is first briefly treated in a pair of acetogenic bioreactors, in which easily metabolized substances are fermented to intermediate products (e.g., acetic acid). The preliminarily treated flow then enters a methane-generating bioreactor for treatment through Upflow Anaerobic Sludge Blanket digestion.

The distinguishing characteristic of UASB digestion is that the Solids (or culture) and Hydraulic Residence Times differ widely. In this application the SRT and HRT are approximately 80 days and 1 day, respectively. Compared to conventional anaerobic digestion the lengthy SRT greatly enhances biological action with respect to both speed and extent. The short HRT minimizes the need for reactor volume, hence the facility footprint.

UASB digestion is a well proven generic technology in widespread use in the treatment of strong industrial wastewaters. The ArrowBio Process uniquely harnesses this advantageous technology to the treatment of organic solids in MSW.

The products of the second, biological, stage of the process are water, soil amendment, and biogas. Because the organic solids are transformed to gasses its entrained water, represented by its moisture content, is liberated in liquid form. The soil amendment consists of excess growths of the functional microbial community along with recalcitrant natural substances (lignin from paper, citrus rinds, etc). About four-fifths of the organic solids are transformed to biogas.

A portion of the water product is used internally in the first, physical separation/preparation, stage of processing. The excess is exported for various uses, such as irrigation, depending on circumstances. The excess solids are highly stabilized on removal from the UASB bioreactor, hence needs no further treatment before use as soil amendment. The biogas is unusually energy-rich, consisting of ~ 75% methane and 25% carbon dioxide. These characteristics reflect the UASB form of digestion.

The two processing stages are mutually supportive. Physical separation/preparation, in addition to recovering recyclables, provides the bioreactors with prepared organic substrate. In turn, the UASB bioreactor provides makeup water for the physical separation/preparation stage. Also, electricity generated from a portion of the methane powers the plant. Approximately 5 x more energy is produced than is consumed, with the rest being exported via the grid.

3. Characterize the status of your technology. Is it commercial, pre-commercial, pilot, bench-scale, or conceptual?

The status of the ArrowBio Process is commercial. A 70,000 tonne per year plant is currently in operation at the MSW transfer station of the Municipality of Tel Aviv, Israel. Development of this technology commenced in 1993, and progressed through laboratory, pilot, and small commercial/proof-of-concept stages. This led to the design and construction of the full scale plant.

Construction time for a new plant is about 16 months.

4. Is your technology modular and scalable?

It is modular, with each module designed for either 70,000 or 105,000 tonnes per year. Larger inputs require multiple modules. The footprint of a 70,000 tpy plant, inclusive of packer truck ingress and egress, is less than three acres.

5. What type of waste input is it capable of processing? Is the technology compatible with pre-existing MSW collection schemes? Is preliminary special preparation required? Can diapers ('nappies') be processed without special handling?

The ArrowBio system is capable of processing mixed MSW regardless of the extent, if any, of prior source separation. If an existing source separation program removes a portion of the recyclable metals, glass, plastics, and clean paper, the "leftovers," still comprising the bulk of the waste, are processed at the plant. Moreover, "non-compliance" recyclables are captured. Source separated organics (SSO fraction) are readily processed, but the input of select "clean" fractions is not necessary. The system thus offers the option of managing the entire mixed MSW stream as a single entity, without preliminary selection or preparation.

This is possible because all separation and preparation steps are intrinsic to the system, as performed in the first physical separation/preparation stage of processing. This involves certain types of equipment common to ordinary Material Recovery Facilities, (MRFs), such as trommel screens and magnetic pickups. But in the ArrowBio Process the equipment is oriented and the operations organized around the central role of water.

As an example of the inclusiveness of the process, diapers with their contents are processed along with the rest of the materials in mixed MSW. Moreover, the wetness or dryness of the waste has no effect on processing. The flexibility of this system, which fundamentally stems from its frankly watery nature, allows it to fit into and enhance any pre-existing collection scheme.

6. What is the proportion between useful products and residual material needing to be disposed of.

Approximately 90% by weight of the input exits as useful products, namely recyclables, water, organic soil amendment, and biogas (energy). The residual, amounting to some 10%, consists of stones, grit, and non-descript junk as expected in mixed waste. Being derived from MSW without chemical alteration, the residual is biologically inert and can be disposed of in ordinary landfills.

7. Other than MSW, what material and energy inputs (e.g., water, steam, electricity, natural gas) does your technology require?

Other than MSW no inputs are required because the system is autonomous with respect to non-waste materials, water and energy. The biological communities responsible for the acetogenic and UASB steps, respectively, organize themselves out of the myriad organisms introduced with the waste. Special cultures are not involved.

8. Describe the gaseous, liquid and solid emissions, from your technology, including dust and odor.

Please note that there is continuous circulation of water between the separation/preparation water vat and the biological stage. The former "sends" a flow of prepared organics, and the latter returns relatively clean water. The water is not stagnant, but rather is constantly circulated and refreshed.

Tipping directly into water has the effect of instantly quenching odors. This is because, being soluble in water, odorous compounds are sequestered in solution. Being easily metabolized, such compounds are quickly destroyed in the biological stage of treatment.

Similarly, any dust is immediately immobilized in water. Operations that would ordinarily generate dust, such as size fractionation in a trommel screen, do not do so in this watery system.

As described earlier, the prepared organic rich flow is pumped to enclosed acetogenic and then UASB bioreactor vessels. At the exit end of the biological train, the water and entrained solids removed from the UASB reactor, as dictated by the process control protocol, are separated gravitationally. The solids are then dewatered mechanically. If necessary, depending on local requirements, the water is polished though conventional aerobic treatment. These steps can be performed in enclosures. It is in the nature of UASB digestion, owing to its lengthy SRT, that the excess solids need not be treated prior to beneficial use as organic soil amendment.

The gas might be utilized variously, but direct use on site to generate electricity is often preferred. The turbine or reciprocating engine would be selected with low emissions a paramount consideration.

Thus, there is virtually no opportunity for troublesome emissions. In other systems, pollutants might be generated and then removed to control emissions. In contrast, in the ArrowBio Process pollutants are not generated in the first place. A characteristic of this technology, rather than after-the-fact control, is before-the-fact pollution prevention.

9. What toxic and hazardous substances are generated in processing, and how are their emission controlled.

The basic driving forces at work, being gravity and biological action, are benign. Absent are high temperatures and pressures and, with their potential to generate hazardous/toxic substances. Operation at mild, ambient, temperatures and pressures confers many advantages in terms of human and environmental hazards, costs, and public perception.

10. How does your technology fit into the universe of approaches to the management of MSW?

The main features of the ArrowBio Process are compared with those of other emerging technologies as well as with more established approaches to the management of MSW (Table 1). The limitations of this analysis should be made explicit. It is not possible for it to be symmetrical. With respect to the ArrowBio Process, the entries are based on the specific proprietary process represented herein. Otherwise, the references are to general practice and generic approaches based on publicly available information. In responding to this RFI's question # 10, the intent is to craft composite, least common denominator, general statements.

TABLE 1. MAJOR FEATURES OF DIFFERENT APPROACHES TO THE MANAGEMENT OF MUNICIPAL SOLID WASTE (adapted from Finstein, 2003)[a]

Factor or Function	**ArrowBio Process**	**Other Anaerobic Digestion Processes**	**Pyrolysis/ Gasification[b]**	**Incineration**	**Composting[c]**	**Landfilling**
Basic driving force	Biological - UASB digestion[d]	Biological - anaerobic digestion of thick slurry	Thermo-chemical pyrolysis/O_2-starved combustion	Combustion	Biological – aerobic self-heating	Biological - little or no process control
Moisture in MSW[e]	Not problematic	Problematic	Problematic	Problematic	Differs	Differs
Up-front separation of recyclables[f]	Intrinsic [g]	Extrinsic	Extrinsic	Extrinsic	Extrinsic	Extrinsic
Driving force speed	Fast	Intermediate[h]	Very fast	Very fast	Intermediate to slow[i]	Very slow
High pressures and/or temperatures	No	No	Yes[j]	Yes[j]	No[k]	No
Energy produced	Yes, biogas ~75% methane	Yes, biogas 50-60% methane	Yes, synthetic gas (syngas) mixture	Yes, heat used to make steam	No, consumed in process control (powering fans)	Yes, landfill gas (~ 50% methane) but only portion captured [l]
De-novo generation of hazardous/toxic compounds	No	No	Yes[m]	Yes[m]	No	No
Air emissions: prevention or	Prevention	Prevention[n]	Control	Control	Control	Control

control						
Track record	Short	Moderately lengthy	Short	Lengthy	Moderately lengthy	Very lengthy
Process residue	Stabilized organics ("mulch")	Non-stabilized organics[n]	Char	Bottom and fly ash	Compost – stabilized?	N/A
Permitting difficulty/Public acceptability	More acceptable	More acceptable[n,o]	Less acceptable	Essentially not acceptable	Less acceptable[o]	Varies

Footnotes on next page.

[a] Limitations of analysis are noted in the text.

[b] Pyrolysis (destructive distillation) involves only O_2-free reactions. Gasification can be seen as pyrolysis with an overlay of a small, metered, amount of O_2 supportive of combustion to a controlled extent.

[c] Refers to composting with purported process control (excludes passive "yard waste" variant).

[d] The UASB digestion follows an acetogenic stage (see Appendix II).

[e] See Appendix I.

[f] For example, separation of non-compliance containers from biodegradable organics. Separation may not be practiced in landfilling and other approaches.

[g] Intrinsic in that gravitational separation in water is part of the overall process. Where extrinsic a source of clean organics may be necessary, as in the anaerobic digestion of thick slurries of MSW organics.

[h] Problem of mass transport – see text and Appendix II.

[i] Not fast because process control is often deficient (c.f., Finstein, M.S. 1989. ASM News). See footnote **k**.

[j] e.g., Tens of atmospheres; temperatures of over 1,000^{o}C.

[k] Optimum <60^{o}C; usual maximum ~ 80^{o}C (induces severe self-limitation), though spontaneous ignition possible.

[l] Even in the "bioreactor landfill" the escape of methane (greenhouse gas) over the dispersed area is unavoidable. It has been estimated that, at best, only about 2/3 of the gas can be captured http://www.UNDP.org.in/programme/GEF/September/pages5-9.htm.

[m] Gases generated in pyrolysis include carbon dioxide, carbon monoxide, hydrogen, and methane along with other more complex gaseous, liquid, and solid phase hydrocarbons. Such compounds are doubtless also formed in gasification, though they may be destroyed in the limited combustion supported by the metered injection of O_2. In combustion (both

incineration and gasification), dioxins and furans are formed. Some gasification technologies combat this by rapid cooling of the exhaust gas. This is not feasible in incineration, owing to the large volume of gas. Incinerators may be equipped with devices to trap the particulates bearing these compounds in the flue gas.

[n] Prevented in the anaerobic digestion process per se. However, the residual solids, owing to incomplete digestion, needs to be composted. Control of emissions from the composting varies.

[o] Composting has been plagued by odor nuisance problems, for reasons that are well understood but rarely fully exploited in designing facilities (see footnote l).

Table 1 is considered to provide only a framework for a more detailed, rigorous, comparative analysis of specific alternative offerings. We would be pleased to provide further information on the ArrowBio Process, and also suggest that the county (city, waste management district, or whatever the entity) have its technical experts visit the operating ArrowBio plant in Tel Aviv, Israel.

References

Finstein, M. S. (2003). Operational Full-Scale ArrowBio Plant Integrates Separation and Anaerobic Digestion in Watery Processing, With Near-Zero Landfilling. *Proc. Of the Solid Waste Association of North America Conference (WasteCon 2003)*, St. Louis, Missouri, U.S.A. p. 290-296.

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