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Critique of URS Corporation Reports to Los Angeles on Solid Waste Technologies [1, 2, 3]

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By,

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[1] **"Conversion Technologies Evaluation Report," 18 August 2005** http://ladpw.org/epd/tf/subs.cfm **prepared by the URS Corporation for the County of Los Angeles Solid Waste Management Committee/Integrated Waste Management Task Force/Alternative Technology Advisory Subcommittee.**

[2] **"Evaluation of Alternative Solid Waste Processing Technologies," September 2005,** *http://www.lacity.org/san/alternative-technologies-final-City-report.pdf,* **prepared by the URS Corporation for the City of Los Angeles, Department of Public Works, Bureau of Sanitation.**

[3] **With respect to technology evaluation the two reports are really one and can only be reviewed as one, notwithstanding the vast difference between City and County. Non-technological aspects are outside the scope of this study.**

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PRELIMINARIES

WHY THIS CRITIQUE WAS WRITTEN

The City and County of Los Angeles separately commissioned the URS Corporation to evaluate solid waste processing technologies. Because California is such a pacesetting state, and URS such a large and powerful engineering firm, the influence of the resulting reports may extend far beyond the immediate region. Many complicated issues are raised by the reports. It is appropriate that they be reviewed independently and, if indicated, challenged. That is the purpose of this critique.

THE PROBLEM TO BE SOLVED

The success of City and County recycling programs in controlling the amount and type of municipal solid waste disposed of in landfills brings into relief the thousands of tons per day still landfilled. Much of it is black bin post-source separated MSW and residuals from MRFs and transfer stations.[4, 5] Both City and County seek to divert their waste streams from landfilling toward material and energy recovery.

The plan is to identify a technological approach, or perhaps more than one, that appears to be promising, and then build a limited number of facilities of modest size yet large enough to evaluate their performance under real conditions with an eye towards wider applicability. Many aspects of process performance are at issue such as materials recovery effectiveness, emission of air pollutants, generation of solid pollutants themselves needing disposal, economics including local job creation, flexibility to respond to changes in market conditions, and public acceptability.

The initial selection of technology will, for better or worse, start the region down a difficult to reverse path having major impacts on the economic and environmental health of the Los Angeles region.

CHRONOLOGY AND AUTHORSHIP OF THE REPORTS

On 13 January 2005 the County of Los Angeles, Solid Waste Management Committee/Integrated Waste Management Task Force, Alternative Technology Advisory Subcommittee issued its “Questionnaire for Conversion Technology Suppliers,” with a response deadline of 14 February 2005 later extended to 28 February 2005. The resulting

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[4] MSW is municipal solid waste. A MRF is where source-separated recyclable materials (blue bin) are sorted, leaving residual to be landfilled. Transfer stations are where street collections are consolidated for hauling to distant landfills, while often also functioning as MRFs.

[5] Information from the URS reports on composition is simplified as follows (MRF residues and black bin contents respectively): biodegradable materials, 69% and 62%; plastics, 14% and 17%; with the reminders being inorganic materials (e.g., glass, metal, indefinable grit).

report prepared by URS Corporation "Conversion Technologies Evaluation Report" is dated 18 August 2005 (http://ladpw.org/epd/tf/subs.cfm).

On 05 October 2004 the City of Los Angeles, Bureau of Sanitation issued its "Alternative Technology Request for Qualifications [RFQ]," with a response deadline of 08 November 2004. The resulting report prepared by URS Corporation "Evaluation of Alternative Solid Waste Processing Technologies" is dated September 2005 (*http://www.lacity.org/san/alternative-technologies-final-City-report.pdf*).

Two URS Corporation persons authored the County report, and a third was an author of the City report. Other URS persons participated in the evaluation. Additionally, the City report acknowledges the assistance of three other consulting firms.

HOW THE REPORTS ARE CITED IN THE CRITIQUE

In analyzing the reports it is often necessary to cite specific pages. It is simplest to assume use of their online versions and utilize the page numbers appearing at the bottom of the computer screen.

The online County report totals 333 pages in two separate files. The key file (report "Body") in which conclusions and recommendations arise is named "Conversion Technologies Evaluation Report." A citation to this file might be (CT 101/118), meaning page 101 of its 118 pages. A separate file named "Appendix" includes responder supplied technical information. A citation might be (CA 201/215), meaning page 201 of the 215 page County Appendix file.

The online City report totals 499 pages in one file only. There are a number of sections in which conclusions and recommendation arise. An Appendix lists information provided by the responders. An example citation is (City 401/499).

In addition to technology evaluation, both reports cover other topics. These are outside the scope of the critique.

THE TWO REPORTS ARE FUNCTIONALLY ONE

With respect to technology evaluation (sole subject under review), the two reports are functionally one. It could hardly be otherwise considering their common tasks and authorship. The titles of the reports reflect their commonality in using the synonymous terms "Conversion" and "Alternative" (County and City report, respectively) to circumscribe the subject array of solid waste technologies. Consequently, when the critique takes a cue from one report the ensuing analysis pertains equally to the other. Many manifestations of the oneness of the reports will be encountered as the critique unfolds

DISCONNECT BETWEEN THE BODIES AND THE APPENDICES

By “Bodies” is meant everything in the reports but the Appendices. It is in the Bodies that conclusions and recommendations arise. The Appendices summarize information provided by the responders. The particular technology represented by the critique’s author is adequately summarized in the Appendices of both reports (CA 90-92/215, CA 129/215; City 391-403/499).[6]

However, with respect to this technology, the information in the Appendices does not cross over for consideration in the Bodies. Consequently, its exceptional features have no discernable effect on the conclusions and recommendations of the reports.

METHODOLOGY DETERMINES OUTCOME

Both reports narrow the field down to two classes of technologies - thermal and anaerobic digestion. Both recommend that thermal treatment be considered further, but not anaerobic digestion. The recommendation arises inevitably out of the evaluation methodology used, or *modus operandi*, which may be described as follows.

● Individual members of the thermal technology class are differentiated according to significant differences.

● Individual members of the anaerobic digestion technology class are not differentiated according to significant differences.

● A series of broad prejudicial generalizations is made about anaerobic digestion, without differentiation among individual technologies. Like most such generalizations, these may contain some grains of truth but have major, inherent faults that lead the reader to false conclusions.

● Thermal treatment is exempted from such generalizations, no matter how numerous, serious, and undesirable its characteristics.

The methodology used cannot but lead to the recommendation reached.

RECOMMENDATIONS OF THE REPORTS

The County report recommends against further consideration of anaerobic digestion based on five generalized reasons. Thermal treatment is recommended for further consideration, seemingly by default. Both classes are ranked according to fitness (Table 1).

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[6]As noted in the title page and elsewhere, the author represents the ArrowBio process.

Table 1. URS Recommendations to the County of Los Angeles (CT 47-48/118)[a]

Thermal Technologies Recommended for Further Consideration			Anaerobic Digestion Technologies Found "Credible" but not Recommended for Further Consideration[b]	
Company name	**Process name**	**Significant variant within thermal class**	**Company name**	**Process name[c]**
Interstate Waste Technologies	Thermoselect	Pyrolysis/Gasification Fixed Bed	Waste Recovery Systems Inc.	Valorga
Primenergy LLC	PRM Energy gasification	Gasification Fixed Bed	Organic Waste Systems Inc.	Dranco
Whitten Group International	Entech Renewable Energy System	Gasification Fixed Bed	Arrow Ecology Ltd.	ArrowBio
Gravesend Energy Management	GEM High-Speed Conversion Technology	Flash Pyrolysis	Canadian Composting Systems Inc. (CCI)[c]	BTA

[a] Listed in the order ranked.
[b] Significant variants within anaerobic digestion class not noted.
[c] Despite the company name, the BTA process employs anaerobic digestion.

Starting early on (CT 08/118; City 19/499) and throughout the Bodies of the reports, individual technologies within the thermal class are differentiated. This is seen in the third column of Table 1 under thermal technologies. The absence of a sixth column, under anaerobic digestion technologies, reflects the omission of fundamental distinctions that nonetheless exist within the class.[7]

The City report's recommendation for the further consideration of thermal technologies only arises implicitly from its Body. Without explicitly ranking members of either class, complete combustion (incineration) is favored. It is termed "Advanced Thermal Recycling," or "ATR," and further described as a "second generation" technology (City 31/499) based on presumed stricter emission controls and more extensive up-front recovery of recyclables than usual.

[7] In Part 3 it is argued that the class consists of first and second generation members.

Statements favoring thermal technologies are found throughout the City report, notably in two identical tables: "Table ES-1 Key Findings" in the Executive Summary section (City 15-18/499), and "Table 8-1 Key Finding" in the Conclusion and Recommendation section (City 159-162/499). The explicit recommendation is as follows:

> *"The technologies best suited for processing black bin post-source separated MSW on a commercial level are the thermal technologies. These include advanced thermal recycling and thermal conversion (pyrolysis and gasification)."* (City 158/499),
>
> *"It is recommended that the City of Los Angeles proceed with the activities shown in Table 8-2 for continued development of an alternative MSW processing facility for black bin post-source separated MSW utilizing a thermal technology*." (City 163/499)

Part 1 addresses both reports. Part 2 focuses on the City report.

PROCESS INTEGRATION: KEY UNEXAMINED ISSUE

A common theme throughout the critique is that the reports omit consideration of the exceptional capacities of the ArrowBio process. A pattern of omission is evident at the outset in the inclusive disqualification of the anaerobic digestion class over the issue of preprocessing. Yet ArrowBio's preprocessing capacity is unique, with respect to both the other members of its class and also the thermal technology class.

The more general issue, however, is the integration, or lack thereof, of preprocessing with the other major unit sub-processes. Altogether, they are: preprocessing, conversion per se, and post-conversion operations. What sets the ArrowBio process apart is its integration of the three (Part 3).

In the course of the critique, omissions in the reports are noted in place.

ABOUT THE AUTHOR OF THE CRITIQUE

Melvin S. Finstein (B.S. 1959 and M.S. 1961, Cornell University; Ph.D. 1965, University of California, Berkeley) served as Professor in the Department of Environmental Sciences, Rutgers, The State University of New Jersey, from 1965 to 1999, and is now Emeritus Professor. He is author or coauthor of many scientific and technical publications on microbial aspects of pollution control, with emphasis on solid waste treatment.

In 2000 while giving guest lectures at the Israel Institute of Technology, Haifa, Dr. Finstein chanced upon a developmental version of the ArrowBio process for unsorted MSW. Its unique approach to preprocessing, use of advanced anaerobic digestion, and integration of the two, was so intriguing that, upon further investigation, he came to represent the system in the USA and elsewhere. Since then, a full scale ArrowBio plant came into operation at the Tel Aviv transfer station. A contract was recently signed for a plant to serve suburban towns to the west of Sydney, Australia.

PART 1

ANALYSIS OF THE REASONS GIVEN FOR RECOMMENDING AGAINST ANAEROBIC DIGESTION

INTRODUCTION: THE FIVE REASONS

The report to the County gives five generalized reasons for recommending against the further consideration of anaerobic digestion. These are analyzed in the order given. The recommendation is for the further consideration of thermal technologies only. Generalized reasons for this positive recommendation are not given.

The generalized negative reasons applied to anaerobic digestion are not exactly reproduced in the City report, but they clearly form its underlying premise. The City report also recommends only thermal processing.

Part 1 of the critique takes many of its leading cues from these five generalizations, or propositions. Subsidiary cues are taken from both reports. The method is to reproduce the stated reasons in ***italics bolded***, and relevant statements in the reports in *italics not bolded*. Analysis and discussion of the statements is in plain text.

Reason #1: *"Anaerobic digestion requires extensive preprocessing of the feedstock, therefore MRF residues may not be suitable for anaerobic digestion."* (CT 12/118).[8]

Preprocessing defined. The term "preprocessing" encompasses two overlapping purposes: separation of materials of value for recycling, and preparation of the reactor feed so that it is suitable for treatment. What determines suitability depends in part on the particular technology, but a factor of universal concern is the presence of potentially damaging abrasive material (i.e., grit).

Reason #1. This proposition stipulates that a requirement for extensive preprocessing is grounds for disqualifying anaerobic digestion. Absent is any such stipulation for thermal technologies, implying an exemption. The contradictions inherent in this position, and the omission of contradictory facts, lead to a three-fold breakdown in the logic of the reports.

● First, the implicit exemption is self-refuted in numerous passages cautioning that preprocessing is needed in thermal treatment (with the intermingling of a few tentative expressions of possible exceptions). A single cautionary passage is applied to anaerobic digestion.

● Second, having thus negated its implicit exemption, the report then executes a second reversal by top-ranking a costly, failed thermal technology that lacks preprocessing.

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[8] The proposition is expressed more strongly in its repetition: "***Anaerobic digestion requires <u>very</u> extensive preprocessing…***" (CT 109/118 – underline added.)

● Third, the report omits consideration of the unique preprocessing system integral to the ArrowBio process. This omission is addressed briefly here and exhaustively in Part 3.

Before outlining the breakdowns in logic, it is to be made clear that the report's cautionary statements on the need for preprocessing are valid and of great practical importance. The problem is in the multiple inconsistencies and omission of contradictory information.

The reports assigns certain cautionary passages to either thermal treatment or anaerobic digestion, but in fact most (though not all) are applicable to both classes. For present purposes these assignments are followed pending later distinction.

First breakdown in logic. In contradiction to the implied exemption granted by Reason #1, many reasons are given for the importance of preprocessing in thermal treatment.

CAUTIONARY STATEMENTS APPLIED TO THERMAL TECHNOLOGIES

> *"Municipal Solid Waste (MSW) is too heterogeneous for pyrolysis and other thermal conversion technologies and therefore requires preprocessing in most cases*." (CT 21/118)
>
> *"Depending on the specific pyrolysis process, pre-processing may include sorting, separation, densification, etc."* (CT 21/118)
>
> *"MSW is not a homogeneous waste stream. In order to make the pyrolysis product more efficient, pre-processing of MSW is required. The pre-processing includes the separation of thermally non-degradable material like metal, glass, and concrete debris. Also, for some pyrolytic processes, size reduction and/or densification of the feedstock may be required. If MSW has a high moisture content, a dryer may be added to the pre-processing stage to lower the moisture content of the MSW to 25% or lower."* (CT 24/118; City 41/499)
>
> *"Thermal conversion technologies often incorporate pre-processing subsystems in order to produce a more homogeneous feedstock; this provides the opportunity to remove chlorine-containing plastics (as recyclables), which could otherwise contribute to the formation of trace organic constituents."* (CT 25/118; City 42/499; City 141/499)
>
> *"Prior to entering the gasifier, some preprocessing will likely be required, as described above in the section on pyrolysis. Some gasification (primarily fixed-bed designs) may accept a minimum amount of preprocessing, such as removal of large appliances, shredding and sorting. Others may require a significant amount of removal of recyclables, sorting, shredding, and drying in order to provide a homogeneous feedstock."* (CT 27/118)
>
> *"Due to the heterogeneous nature of MSW, significant pre-processing is often required. While some systems state that they can operate with little or no pre-processing, most include manual picking for large appliances, followed by primary and secondary rotary/stationary trommel screens, primary and secondary shredders, and magnetic and eddy-current separators to remove glass and metals and reduce the feedstock size. Sizing/shredding varies, with feedstocks ranging from 2 to 12 inches.*

Many systems incorporate an auger or ram feeder that compacts the processed MSW feed to as little as 1/10th of the original volume. In order to increase efficiency, many systems incorporate drying to 10-20% moisture content, using steam or engine exhaust. Depending on the supplier, as much as 2/3 of the raw MSW may be removed prior to being fed to the gasifier." (CT 30/118; City 48/449)

"Drying to less than 12% moisture is typically accomplished through the use of forced-draft air. Steam from an adjacent boiler can be utilized if RDF is being combusted on-site in a waste-to-energy facility. Additional sieving and classification equipment may be utilized to increase the removal of contaminants. After drying, the material often undergoes densification processing such as pelletizing or cubing to produce a pellet or cube that can be handled with typical conveying equipment and fed through bunkers and feeders." (City 53/499).

CAUTIONARY STATEMENT APPLIED TO ANAEROBIC DIGESTION

"Microorganisms convert biodegradable matter. They do not convert minerals or nonbiodegradables like plastic. From the standpoint of the microorganisms that perform theconversion, it does not matter if non-degradable materials are present in the fermenting mix. The presence of non-biodegradables do matter from a materials handling perspective, as some extraneous materials like metal debris, plastic stringers, etc. can wreak havoc on the fermentation equipment. Additionally, if the resulting compost has to be marketable, it is important that as much as possible of these extraneous materials be removed before entering the process. The ideal feedstock is nearly pure biodegradable material, with as few inorganics or plastics as possible." (City 60/499; CT 38/118 except lacks last sentence).

DISCUSSION OF THE CAUTIONARY STATEMENTS

Reason #1 would disqualify anaerobic digestion on the grounds of requiring extensive preprocessing, while implicitly exempting thermal treatment. In the above passages the report contradicts its own implied exemption. This is the first breakdown in logic.

Before addressing the second breakdown, certain additional comments are in order.

As was noted earlier, the report assigns many cautionary passages to thermal treatment and only one to anaerobic digestion. In fact, most of the cautions are universally applicable without distinction of whether the technology is thermochemical or biochemical. Of special interest, however are those cautions that are truly technology-specific. These are now discussed.

> "… [the need to] *remove chlorine-containing plastics (as recyclables), which could otherwise contribute to the formation of trace organic constituents."* (CT 25/118; City 42/499; City 141/499).

This statement properly attributes the generation of hazardous/toxic substances (i.e., *trace organic constituents*) solely to thermal processing. The problem is that biological processing receives no credit for its <u>non</u> generation of such substances, and thermal processing receives no demerit.

To similar effect, in the City report the distinction between thermal and biological processing as emission sources is lost in a "Key Finding" that merges consideration of the two classes (Part 2, Rows 2 and 11).

The reports note the sensitivity of thermal technologies to water, and that preprocessing might have to include a step to dry the feed (CT 24/118; CT 27/118; CT 30/118; City 41/499; City 53/499). Not noted in the reports is that, for reasons that are different and less onerous, moisture content can be a concern for three of the anaerobic digestion technologies. The fourth technology, ArrowBio, is not affected by the feed's wetness or dryness.

The cautionary passage directed to anaerobic digestion (CT 38/118) is in part specific to that class, and in part universally applicable. Specific to anaerobic digestion are the cautions respecting compost quality, and the non-biodegradability of materials such as plastics. The caution about the damaging effects of abrasive inclusions such as metal fragments and grit is universally applicable, however. It might be thought that the potential for damage to pressurized high temperature vessels and appurtenances would be of special concern.

One further comment is that, of all the technologies examined, whether thermochemical or biochemical, the ArrowBio process addresses the ever-present, critically important need for preprocessing with unparalleled effectiveness (Part 3). From this perspective, the last sentence of a previously quoted passage might be reexamined:

> "*The <u>ideal</u> feedstock is nearly pure biodegradable material, with as few inorganics or plastics as possible."* (City 60/499). [Underline added.]

The implication is that the utility of anaerobic digestion is linked to the pursuit of the *"…ideal…"* In effect, that anaerobic digestion as a limited, "boutique," technology, best shunned by practical-minded people. The proposition is falsified by ArrowBio's non-discriminating appetite for real-world mixed, very non-ideal, MSW.

Second breakdown in logic. Dwelling upon preprocessing is fully justified by practical experience. It is all the more surprising that a pyrolysis/gasification system which lacks preprocessing was top-ranked.

> *"No preprocessing is required with the Thermoselect technology, other than removal of large objects."* (CA 51/215). (Reminder, CA = County report Appendix file.)

The supplier of this technology may not require preprocessing, but experience suggests that it is needed.

The report claims to accept supplier information without verification as a preliminary screening device (CT 09/118).[9] But the top-ranking of Thermoselect is so notable that the critique's author sought clarification of the status of the then flagship plant in Karlsruhe, Germany, from an independent international expert stationed in that city.[10] His response is summarized by the author as follows:

> During a troubled startup lasting about four years, the Thermoselect plant gradually reached a throughput of half its design capacity. A permit for regular operation was finally granted in January 2004. The plant was shut down at the end of 2004, purportedly because of a financial loss to the owner (EnBW Power) equivalent to over 500 million in U.S. Dollars. Other projects in Germany were cancelled, but contractual matters appear to be unresolved.

The shutdown of the Karlsruhe plant occurred about nine months prior to publication of the report to Los Angeles County. Its Appendix includes the statement that the plant:

> *"…recently shut down for economic reasons"* (CA 125/215).

But nonetheless, Thermoselect was assigned a grade of 100% for:

> "*Existing Operational Experience*" (CA 125/215).

The later-published report to Los Angeles City similarly states, with a parenthetical insertion, that:

> *"Due to economic (but not technical) reasons, EnBW has decided to shut down the Karlsruhe facility by the end of 2004."* (City 252/499).

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[9] That this acceptance is selective is demonstrated in the repeated omission from consideration of the exceptional features of the ArrowBio process, summarized in the term "process integration."

[10] Dr. Jurgen Vehlow, Ph.D., Head of the Chemistry Department, Division of Thermal Waste Treatment, Karlsruhe Research Centre, Germany. Personal communication received 05 September 2005.

The idea that economic and technical performances are somehow unconnected is not an easy one to accept.

This second breakdown in logic, the top-ranking of the Thermoselect plant in Karlsruhe, is both substantive in its own right and also representative of a larger point. This is that a technology evaluation arriving at such an unsupportable recommendation lacks realness.

Third breakdown in logic. This breakdown refers to the evidently unexamined assumption that preprocessing is necessarily extrinsic to conversion per se, whether thermochemical or biochemical. The author would phrase the unexamined assumption as follows:

> Separation and preparation of the MSW mixture is necessarily unidirectional, hence not integral to the overall system. That is, the prepared feed goes forward to the conversion reactor, but there is no return loop from it. The work done in conversion thus has no bearing on preprocessing.

This assumption is in fact true of both thermal and anaerobic digestion technologies – with the sole exception of the ArrowBio process. In this technology alone, separation and preparation, or "preprocessing," is integral to the overall system.[11] Yet consider the sole reference to the issue of process integration found in the reports:

> *There is room for improvement in most designs that would better integrate the three major components of a system (pre-processing, combustion/conversion, and post-processing/byproduct production). This would increase efficiency and reduced cost/ton.* (City 16/499 and City 160/499 – underlining added).

The underlined phrase weakening the statement is curious. It is as if the reader is left to his/her own devices to connect the dots in the Appendices, or to analyze the original vendor submissions, to discover that in the ArrowBio process the three major components are in fact integrated.

The capacity to integrate up-front separation/preparation and back-end biological stages in ArrowBio, indeed the necessity to do so according to its basic design philosophy, arises out of the central role of water in both stages. Some of the benefits of this approach to process integration follow:

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[11] "Preprocessing," the conventional term for the functions of separation and preparation, correctly expresses the fact that these operations are extrinsic to the overall process – with the exception that in the ArrowBio process the functions are necessarily part of an integrated system. With respect to ArrowBio, the term "separation/preparation stage" is preferable for its implication of process integration. Nevertheless, both terms, preprocessing and separation/preparation, are used interchangeably herein.

● Operational indifference to the feed's moisture content

● Ability to exploit the exceptional effectivenss of gravitational separation in water, sparing downstream equipment and reactor vessels from grit and other abrasive materials.

● Production of relatively small amounts of well-stabilized digestate ("compost"), owing to anaerobic digestion of the UASB type.

● Near-freedom of the digestate from "Man-made Foreign Matter."

Neglect of ArrowBio's integrated design is further exemplified in the City report's tabulation of preprocessing equipment (City 110/499). The ArrowBio process, like other anaerobic digestion as well as thermal systems, is credited with a trommel for fractionation according to size. Omitted is any reference to its unique preprocessing via gravitational separation in water. Thus is bypassed ArrowBio's paramount characteristic – process integration, only one manifestation of which is effective preprocessing.

Bottom Line on Reason #1

● It is valid to stipulate inadequate preprocessing as grounds for rejecting anaerobic digestion.

● It is not valid to award an exemption to thermal technologies.

● The breakdown in logic detailed above feeds into the ranking scheme, helping to explain the top-ranking of a thermal technology that failed technically and financially.

● The exceptional preprocessing capacity of the ArrowBio process is omitted from consideration.

Reason #2*: "Anaerobic digestion requires more acreage for development because of its larger footprint."* (CT 12/118)[12]

Rephrasing the Proposition. Discussion of the original proposition would be awkward owing to its defective phrasing.[13] The following articulation is meant to retain what appears to be the original intended meaning.

> Biochemical decomposition is slower than thermochemical decomposition. Therefore, anaerobic digestion facilities require a larger area per unit throughput.

Presumptively, this seems a reasonable expectation. Surprisingly, the presumption is not confirmed in comparing specific pyrolysis/gasification and anaerobic digestion systems. The comparison is developed later; meanwhile some general observations are made.

Footprint and the quantity and quality of work. All waste processing facilities occupy land. Within the anaerobic digestion class there are differences in the area required. The same is true of the thermal class. Footprint is one of many factors to be considered.

Throughput is the amount of waste processed per area in a given time period. It may be seen as the quantity of work done per unit area, expressed in terms of tons per acre-day. This is a simple and useful formulation. However, it does not address the issue of the quality of the work done. This is a complex matter not easily quantified. It may be usefully considered in reference to footprint (Table 2 – next page).

[12] A later version differs only slightly *"Anaerobic digestion requires larger area because of a larger footprint."*(CT 109/118).

[13] Both versions of the proposition have the same flaws in logic. First, they are tautologies, or self-fulfilling confirmations of an idea by its repetition in different words. They essentially say: 'Anaerobic digestion requires more acreage because it requires more acreage.' Second, the statement conflates two different things: the phenomena involved, whether microbial or thermal, and the total area of the facility. But the facility area must accommodate more than just the reaction vessels.

Table 2. Qualitative Aspects of Work Done in Reference to Facility Footprint

Smaller footprint (presumptively pertains to thermal processing) [a]		Larger footprint (presumptively pertains to anaerobic digestion) [a]	
Gain	**Loss**	**Gain**	**Loss**
More throughput per acre	--	--	Less throughput per acre
Less residual material	Residual material burdened by toxic/hazardous issues	Residual material not burdened by toxic/hazardous issues	More residual material
--	Needs elaborate emission control devices	No need for elaborate emission control devices	--
--	Special disposal requirements for residuals, including material captured by control devices	No special disposal requirements	--
Less selective feeding of reactor where this favors power production	Strong disincentive for materials recycling (i.e., high Btu content of plastics)	Strong incentive for materials recycling	More selective feeding of reactor; more pre-separation required
Consistent with centralized mega facilities	Longer distances to centralized facilities	Shorter distances to decentralized facilities	Consistent with decentralized facilities
--	Costlier construction and operation	Less costly construction and operation	--
--	Not consistent with local job creation	Consistent with local job creation	--

[a] The presumptions are probably correct in relation to large complete combustion incinerators vs. anaerobic digestion facilities. The presumptions are not confirmed, however, in comparing specific pyrolysis/gasification and anaerobic digestion systems (see text).

Some of these qualitative aspects have a philosophical character, such as facility centralization vs. decentralization, and the attendant implication of local job creation. Regardless, the proposition to disqualify anaerobic digestion on quantitative grounds of footprint/throughput may lead to neglect of important qualitative considerations.

Specific comparison. Available information on throughput/footprint for the Thermoselect (pyrolysis/gasification) and ArrowBio (anaerobic digestion) systems permits a comparison of the two.[14] The history of a Thermoselect facility (Reason #1, Second breakdown in logic) is put aside for present purposes.

The information in the County report (CT 40-42/118) indicates a Thermoselect plant with a footprint of 3.3 acres, a throughput of 100,000 tons per year, based on a single module rated at 13.3 tons per hour. This translates on average into productive operation for 86% of the time, or 20.6 hours per day, 7 days per week, 365 days per year. The time available for maintenance is 3.4 hours per day.

The City report gives a slightly different footprint for a Thermoselect plant, that of 4.5 acres for a 100,000 ton per year throughput (City 252/499). Otherwise the above pertains, including 3.4 hours per day available for maintenance.

A 100,000 ton per year ArrowBio plant calls for approximately 4.5 acres in a single module housing three separation/preparation (preprocessing) lines. Each line is rated at 10-15 tons per hour. Taking the lower throughput figure, on average this translates into productive operation for 38% of the time, or about 9 hours per day, 7 days per week, 365 days per year. This leaves about 15 hours per day for maintenance.

This economy of footprint combined with a realistic production schedule in a biological system is attributable to the process integration embodied in the ArrowBio process. Thus, based solely on the quantitative aspect of work (throughput), generalization #2 regarding footprint does not hold true for all anaerobic digestion technologies relative to all pyrolysis/gasification ones. For qualitative aspects see Table 2.

Bottom Line on Reason #2

● Footprint is an important consideration that can, however, simplistically divert attention from complexity.

● Footprint is a useful point of reference in analyzing complexity and in the balancing of the many tradeoffs involved.

● The footprint of anaerobic digestion systems varies according to basic design attributes.

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[14] The information about footprint in the ArrowBio submissions, or in their transcriptions into the Appendices of the URS reports, or both, was confused. The present example is based on a contracted for 90,000 ton per year plant (see Reason #3), prorated to 100,000 tons per year.

Reason #3: ***"An anaerobic digestion technology vendor (WRSI/Valorga) is in the process of building a commercial facility in Southern California, and, therefore there is no need for a demonstration facility."*** (CT 12/118, CT 109/118)

Explanation. The project noted above is under the aegis of the Coachella Valley Association of Governments (CVAG) in Riverside County.[15] The planned site of the WRSI/Valorga plant is the closed Edom Hill landfill near Cathedral City. Currently, CVAG seeks agreement from its fourteen constituent political entities so that the project may proceed.

CVAG tasked Waste Management of the Desert (subsidiary of Waste Management, Inc.) with the evaluation of technologies. An initial field of 44 potential vendors was successively narrowed to 16, 4, and 2 – the Valorga and ArrowBio technologies. Valorga's formal bid is not public information, but whatever it was CVAG translated it into $45/ton.[16] ArrowBio's formal bid was $53 per ton, apparently leading to its elimination from consideration.

Regardless of whether the CVAG project ever comes to fruition in its present form, the proposition that "*... there is no need for a* [anaerobic digestion] *demonstration facility"* in Los Angeles County should be considered in the light of the comparative analysis involving the two finalist systems, among others, which shows distinct differences (Part 3). Also to be considered is the projected tip fees.

Tip fee. The County questionnaire requested various types of financial information, not including a proposed tip fee. But the report includes a table having a column labeled:

> *"Tipping Fee or Break Even Tipping Fee ($/ton)"* (CT 78/118).

For WRSI/Valorga, the County report lists a figure of $67/ton (CT 78/118). Whether this figure was provided by the responder company or calculated by URS is not clear. For whatever its significance, it differs substantially from that of $45/ton as per CVAG's internal analysis (footnote 16). In the eventuality of a bid to Los Angeles City or County, ArrowBio's would be similar to that made to CVAG of $53/ton (see also accepted bid in Australia below).

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[15] Hater, G., R. Green and F. Orlett. July 2005. "Conversion Facility Chosen for Palm Desert, California. BioCycle, p.63-66.

[16] Edom Hill Waste Conversion Facility, CVAG Report, 14 July 2005

Arrow Ecology answered all the questions on finance asked by the County questionnaire. A proposed tip fee was not requested and none was given. The report nonetheless indicates a tip fee of $93/ton for the ArrowBio process (CT 78/118). This grossly misrepresents the company's position.

As noted, ArrowBio's formal bid to CVAG was $53/ton. A similar bid to a consortium of suburbs of Sydney, Australia, for a 90,000 ton per year plant was accepted.[17,18] The design of this facility is currently being finalized and equipment is being ordered. Construction is to start in mid-2006.

Sources of ArrowBio's cost-effectiveness. ArrowBio's cost-effectiveness is attributable in large measure to its process integration, mediated though watery processing. Benefits include the innate superiority of water-based gravitational separation compared to the norm of air-based separation; the easy flow of a 4% solids feed compared to more viscous feeds having 10% - 40% solids; and the rapidity and completeness of anaerobic digestion via the Upflow Anaerobic Sludge Blanket (UASB) digestion compared to thick solids digestion as in other technologies.

The benefits of water-based process integration, particularly as it concerns preprocessing, are not available to thermal technologies. Rather, thermal processing often suffers from the feedstock having too high a moisture content.

Bottom Line on Reason #3

● The premise that all the anaerobic digestion technologies perform alike is incorrect. This is shown in a comparative analysis of the technologies (Part 3).

● Compared to other anaerobic digestion technologies, ArrowBio is at least competitive with respect to costs, and is superior with respect to its capacity to treat mixed MSW.

● Process integration accounts in large measure to ArrowBio's efficiencies.

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[17] Campbelltown City Council news release, 06 December 2005.

[18] Melbourne Age, 08 December 2005.

Reason #4: "*Anaerobic digestion generates a larger percentage of residue, and therefore has a lower diversion rate.*" (CT 12/118, CT 109/118).

Design differences. The percentage of the feed exiting an anaerobic digestion facility as residue to be landfilled depends on many factors. Not least is the particular system's fundamental design as it pertains to the recovery of recyclables and its capacity to produce high quality compost. Contrary to the proposition's generalization, all members of the anaerobic digestion class are not alike with respect to these capacities, or to diversion rate.

Value of plastics: materials recycling vs. electricity generation. The issue of diversion rate is brought into focus by plastics, which comprise an estimated 17% and 14% of the Los Angeles City and County waste streams, respectively. As noted in the City report, the value of plastics is greater as secondary material than as electricity generated through its thermal destruction (City 18/499; City 162/499).[19]

At all anaerobic digestion facilities regardless of the particular design, there is no ambiguity about the desirability of maximizing the recovery of plastics as secondary materials. Being non-biodegradable, plastics do not contribute to the generation of methane. Therefore, to the extent that plastics escape capture they either enter into the compost and degrade its value, or exit the facility as residue to be landfilled at a cost.[20] This amounts to both positive and negative incentives to continually upgrade the capacity to capture recyclables. Positive incentives are the revenues to be realized from sales of secondary materials and higher quality compost. The negative incentive is to avoid the cost of landfilling. All motivations point in the same direction: to recovery plastics.

The situation at thermal plants is different. There, plastics are the best component of the waste stream for electricity generation. Consisting mostly of carbon and hydrogen, plastics contribute disproportionately to the generation of syngas in reactors of the pyrolysis/gasification type, and to heat generation in the case of complete oxidation in incinerators. Either way, the amount of electricity product to export is diminished to the extent of prior removal for the purpose of recycling as secondary material. This constitutes an inescapable conflict between capture and thermal destruction in feeding the reactor. Feeding is operationally easier and consistent with the main product, electricity.

Bottom Line on Reason #4

● With anaerobic digestion there is a set of unambiguous interlocking incentives to recover plastics among other recyclables as secondary material commodities.

● With thermal processes there is an unavoidable conflict between materials recovery and electricity generation, especially for plastics with their high Btu content.

● Recovered plastics as secondary commodities have more value than the electricity generated in their thermal destruction.

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[19] Owing to gravitational separation in water, ArrowBio excels in plastics recovery.

[20] While not burdened by toxic/hazardous issues, the cost is still potentially large.

Reason #5: ***"Anaerobic digestion generates mostly compost and soil amendment with a small amount of biogas to generate electricity. The marketability of the compost is questionable."*** (CT 12/118, CT 109/118).

Introduction. The amount and makeup of the compost and biogas products is a key issue with respect to the utility of anaerobic digestion in managing MSW. We use the term "production parameters" to signify the quantity and quality of these two products.

Technology evaluation understandably tends to emphasize direct measurements of production parameters as supplied by vendors. The problem is that such information can confuse the issues as much as clarify them. Reason #5 exemplifies the problem in a sweepingly disqualifying proposition.[21]

Lack of comparative analysis. It might be supposed that Reason #5 is supported by a comparative analysis of the anaerobic digestion technologies with respect to production parameters. No such analysis is found, however. Moreover, as outlined below, it would be extremely difficult to develop such an analysis based directly on quantitative and qualitative measurements of compost and biogas produced at the different plants.

The City report offers certain unexplained conclusions that have the appearance of being based on a comparative analysis. The conclusions are in the form of two rows of numbers attributing compost and electricity production to the different systems (City 110-111/499). That these numbers put ArrowBio in a fairly good light does not ameliorate the absence of procedural explanation.

The problem of comparison. To compare production parameters validly, a way would have to be found to normalize, or render comparable, information provided by vendors.[22] The following are some of the barriers to normalization.

● The real feeds are characterized as either source-separated organics or mixed unsorted MSW (see Table 3, Part 3). Though rudimentary, these characterizations are indicative of substantial quantitative and qualitative differences in composition with respect to both the organic and inorganic fractions.

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[21] A minor problem is that for consistency the *"...generates mostly compost..."* statement would have to cover the 15% to 40% range that later describes the disparity in compost outputs as percentages of inputs (City 18/499; City 162/499). This is a rather wide range for *"...mostly..."* to cover comfortably.

[22] The City report (City 132/499 - section 7.1) alludes to assumptions made to "levelize" (i.e., normalize) technical data, and refers the reader to section 5.2.1. That section, however, does not exist. Certain levelizing assumptions are shown in support of financial comparisons (City 103/499 - Section 5.3.1), but that is not relevant to the technical issue at hand.

● The moisture contents of the two types of feeds would differ substantially. Reasonable figures for moisture contents of source-separated and mixed unsorted wastes are 60% and 40% respectively (wet weight basis of expression). This translates into a considerable difference in the dry matter input per reactor volume.

● Similarly, the moisture content of the compost product is highly variable. The amount produced cannot be judged without knowing this (changeable) datum.

● Different systems differ with respect to their capacity to keep foreign inclusions out of the compost.

● Different systems differ with respect to their capacity to yield stabilized compost.

● Both foreign inclusions and stability enter into the question of compost quality.

There is no obvious way to normalize these various factors as necessary for valid comparison, and attempts to do so in the technical literature are not known.

The problem of making comparisons based on production parameters may be summarized as follows:

> For comparisons to be valid, the external variables have to be controlled so that the isolated "experimental" variable is solely the performance of the facilities themselves.

It is an intractable problem. Failing to address it suffices to invalidate Reason #5.

How a meaningful comparison might be performed. The problem of non-comparable production information can be entirely avoided by basing the comparison on fundamental design attributes having a direct bearing on production. That is, certain key design attributes can serve as surrogates for, or indicators of, the quantity and quality of compost and biogas produced. Comparability is preserved because, unlike actual measurements, the design attributes are operative independent of external variables (e.g., waste composition and moisture content). Thereby, facility performance is isolated as the sole ("experimental") variable. This use of surrogates is the premise of Part 3.

Bottom Line on Reason #5

● The disqualifying generalization about the quantity and quality of compost and biogas (production parameters) is not supported by a comparative analysis.

● The reports do not address the intractable difficulties in constructing a comparison based on production parameters.

● A valid comparative analysis can be constructed based on fundamental design attributes serving as surrogates for the production parameters.

PART 2

“KEY FINDINGS” OF THE REPORT TO THE CITY

INTRODUCTION: COLLECTIVE TREATMENT OF THE KEY FINDINGS

As noted in the Preliminaries section of the critique (The Two Reports are Functionally One), and as evidenced in Part 1, the report to Los Angeles City is built upon the one to the County. The five clearly stated disqualifying statements in the County report, though not exactly repeated in the City report, clearly form its underlying premise.

The City report is examined principally through its two identical twin tables both labeled “Key Findings.” One, “Table ES-1 Key Findings,” is in the Executive Summary section (City 15-18/499), and the other, “Table 8-1 Key Findings,” in the “Conclusions and Recommendations” section (City 159-162/499).

The tables have twenty rows, nine of which are reproduced for discussion. The material in rows not reproduced is either tangential to technology evaluation, or is covered elsewhere within Part 2, or in Part 1 or Part 3. Repetition cannot be entirely eliminated, however. The rows are assigned numbers corresponding to the sequence in the original tables, but that sequence may not be followed.

The Key Finding of each row is applied to the three classes of technologies: “*Advanced Thermal Recycling”* (incineration), *Thermal Conversion”* (pyrolysis/gasification), and *Biological Conversion”* (anaerobic digestion). The treatment is collective in the sense that different members of a given class are not distinguished (no intra-class distinction). Collectives are also organized more broadly in that a Key Finding may refer to all three classes (no inter-class distinction). The different organizational modes may be summarized as follows:

● Each technology class is treated as its own collective (no intra-class distinction).

● The two thermal classes are gathered into a common collective (no inter-class distinction), while maintaining the anaerobic digestion class as a separate collective.

● All three technology classes are gathered into a common classless collective.

As before, material taken from the reports is *italicized* and discussion is in plain text.

Row 1. Diversion Rate (City 15/499 or 159/499)

Key Finding Description **(of the report)**	***Advanced Thermal Recycling*** **(incineration)**	***Thermal Conversion*** **(pyrolysis-gasification)**	***Biological Conversion*** **(anaerobic digestion)**
Diversion rate, the percentage of black bin post-source separated MSW that is diverted from landfilling, is an important objective for this project. (7.2.1.5)	*At least ninety percent diversion expected, with a worst-case rate of 80%.*	*At least ninety percent diversion expected, with a worst-case rate of 80%.*	*Eighty percent diversion rate expected with a worst-case rate of 50%.*

Discussion of Row 1. The diversion rate of a standard ArrowBio plant is at the high end of the range indicated for anaerobic digestion (approximately 80%). Diversion was discussed in Part 1, Reason #4.

Row 2 Upper Panels (four): Air Emission Characteristics (City 15/499 or 159/499)
Row 11 Lower Panels (two): Air Emission Control Devices (City 16/499 or 160/499)

Key Finding Description **(of the report)**	***Advanced Thermal Recycling*** **(incineration)**	***Thermal Conversion*** **(pyrolysis-gasification)**	***Biological Conversion*** **(anaerobic digestion)**
Air emissions characteristics will differ among the alternative technology groups evaluated. All technology groups will meet regulatory limits. (7.2.2.1)	*Air emission control systems are available to limit emissions to well below regulatory limits.*	*Thermal conversion systems are expected to result in emissions well below regulatory limits.*	*Emissions from biological systems will be lower than thermal technologies due to lower operating temperatures.*
Air emission control systems are commercially available to limit air emissions to below regulatory levels for all technologies. (2.2)	*Applies to all technology groups.*		

Discussion of Rows 2 and 11. None of the elements that make up rows 2 and 11 is false. Stringing them together gives a false and misleading impression.

These Key Findings (statements in the first column) blend together very different sets of considerations such that their individuality is lost. That *"Air emission characteristics will* *differ among the technology groups"* (row 2, column 1), and that *"[A]ir emission control systems are commercially available…"* (row 11, column 1) is a rather casual treatment of a critically important distinction. This is that thermal processing generates de novo hazardous/toxic organic compounds, and anaerobic digestion does not. The distinction is non-trivial. It deserves serious consideration.

As noted before (Part 1, p.12), insofar as concerns conclusions and recommendations, just as anaerobic digestion is given no credit for its non-generation of hazardous/toxic substances, thermal processing is given no demerit for its generation. The same pattern is applied to the respective non-need vs. need for elaborate emission control devices.

It is odd to attribute lower emissions from biological processing to "… *lower operating temperatures"* (row 2, column 4). This trivializes the profound difference between biological and physiochemical action, contributing to the overall obscurantism of rows 2 and 11.

Elsewhere in the City report, differences among the technology classes with respect to meeting emission limits are listed frankly. Yet these differences get collectivized in the Key Findings, and do not seem to influence conclusions and recommendations. The listings are examined class by class, and then the Findings of rows 2 and 11 are revisited.

The incineration class is addressed first (City 35-36/499).

> *"The South Coast Air Quality Management District (SCAQMD) would be likely to require a number of emission control and processing systems that would include some or all of the following:*
>
> *●Automated combustion controls and furnace geometry designed to optimize residence time, temperature, and turbulence to ensure complete combustion.*
>
> *● Selective non-catalytic reduction (SNCR) system in the boiler for reduction of oxides of nitrogen (NO_x) emissions. Selective catalytic reduction (SCR), which is more efficient than SNCR, would be evaluated for potential feasibility.*
>
> *● Baghouse (fabric filter) with activated carbon injection for removal of trace metals and trace organics concentrated on the particulate matter.*
>
> *● Scrubber for chlorides/HCl (may produce saleable HCl – a commonly used commercial and laboratory chemical).*[23]

[23] Optimistic sales projections appear now and again in reference to thermal processing only.

• Scrubber for SO_2 (may produce saleable gypsum – a material routinely used in the cement industry).

• Secondary activated carbon for trace organic and metals.

• Final baghouse for removal of fine particulate after scrubbers."

All of these emission control systems are well-demonstrated technologies that would be able to control emissions to levels well below regulatory limits in California."

With respect to the several variants of pyrolysis and gasification, the following measures to meet the air pollution regulatory limits are listed (City 42-43/499).

"Air emission control and processing systems that are likely to be required by South Coast Air Quality Management District (SCAQMD) include some or all of the following:

• When the syngas is combusted in a boiler, reciprocating engine, or gas turbine, automated combustion controls and furnace geometry (for boilers) designed to optimize residence time, temperature, and turbulence to ensure complete combustion.

•For combustion of syngas in a boiler, low-NO_x burners and/or a Selective Non-catalytic Reduction (SNCR) system for reduction of NO_x emissions. Selective Catalytic Reduction (SCR) is typical for exhaust gases from reciprocating engines and gas turbines.

•Baghouse (fabric filter) for removal of particulate matter from flue gases."

•Activated carbon injection (followed by a baghouse) for removal of trace metals (such as mercury).

• Wet scrubber for removal of chlorides/HCl (may produce saleable HCl).

• Wet, dry, or semi-dry scrubber for SO_2 (may produce saleable gypsum).

•Final baghouse for removal of fine particulate matter after dry or semi-dry scrubbers.

Air emission control equipment to accomplish this syngas and/or flue gas cleanup is commercially available, and is able to reduce air emissions to levels well below regulatory limits in California."

With respect to anaerobic digestion, the following measures to meet the air pollution regulatory limits are listed (City 61/499).

> *"Combustion and flaring of the biogas would result in emissions of NOx, CO, VOC, PM10, PM2.5, and SO2. Typical combustion and post-combustion process controls (such as SNCR or SCR) may be required."* [Underline added.]

The significance of "*Typical...*" is noted elsewhere in the report:

> *"Biogas combustion has emissions similar to those of any natural gas combustion process, which can be controlled to meet any air quality regulations."*
> (City 142/499 – section *7.2.2.1.3*).

That is, utilization of biogas generated in anaerobic digestion is under the same constraints as the commonplace utilization of natural gas. The constraints applied to biogas are far less onerous that those applied to thermal processing.

"Key Findings" revisited. In light of the above, it is seen that the Key Findings of rows 2 and 11 bear little relationship to the distinctions made by the regulatory authority regarding air emissions. Rather, the Findings collectivize very different sets of constraints.

As noted at the outset, none of the entries is itself false, but blending them together gives a false and misleading impression.

Technological fix vs. prevention. Air emission regulation is not the only issue involved. The following must also be taken in to account:

● Capital and operating costs of the control devices.

● Costs of monitoring the performance of the control devices.

● Costs of maintaining the devices as they age, to prevent loss of reliability.

● Environmental impacts other than the emissions themselves, such as those associated with use of concentrated ammonia in reducing NOx emissions through SNCR or that of precious metals in SCR, and the disposal of the captured pollutants.

Finally, the issues raised by rows 2 and 11 boil down to the issue of Pollution Prevention before the fact vs. Pollution Control after-the-fact. The URS reports would preclude the Prevention approach in favor of the Control approach, via numerous complicated "technological fixes." The short- and – long terms implications of these alternative approaches are very substantial.

Row 4 Upper Panels: Solid Residue (City 15/499 or 159/499).
Row 13 Lower Panels: Solid Residuals (City 17/499 or 161/499)

Key Finding Description **(of the report)**	***Advanced Thermal Recycling*** **(incineration)**	***Thermal Conversion*** **(pyrolysis-gasification)**	***Biological Conversion*** **(anaerobic digestion)**
Solid residue will be generated from material rejects, process waste, and air emission control systems. (7.2.2.3)	*Advanced thermal recycling systems will generate bottom ash, boiler ash, and fabric filter ash. Assuming the bottom ash is recycled, about 5% of the incoming material will be landfilled.*	*Similar to advanced recycling systems.*	*Biological systems will typically generate unmarketable residuals consisting of 15-40% of the total throughput.*
Solid residuals generated by these technologies differ in composition. (7.2.1.4)	*Residuals include boiler and fabric filter fly ash (assumes bottom ash is recyclable).This material, although small in terms of quantity (about 7500 tons/yr for a 400,000 TPY facility), may be classified as hazardous.*	*Residuals for low temperature gasification and pyrolysis include boiler and fabric filter fly ash, and bottom ash (if not recycled). These materials, although small in quantity (1000-6000 tons/yr for a 100,000 TPY facility), maybe classified as hazardous. Residuals (slag) from high temperature gas-ification will be non-hazardous and inert.*	*Residuals primarily will consist of unmarketable rejects, which will be landfilled. Quantities will range from 15,000 to 40,000 tons/yr for a 100,000 TPY facility.*

Discussion of rows 4 and 13. The performance of the ArrowBio process puts it at the lower end of the range for residuals noted for anaerobic digestion. Otherwise, two features of rows 4 and 13 are both noteworthy and consistent with the reports overall.

One is the optimistic assumptions, or projections, associated with the possible use of residues from thermal processing, and the unfailingly pessimistic ones associated with anaerobic digestion (see also row 18 and elsewhere).

The other noteworthy feature is that, again, the distinction between thermal and anaerobic digestion processing with respect to hazardous substances is not carried through into conclusions and recommendations.

Row 10. Process Optimization (City 16/499 or 160/499) (cryptic allusion to process integration.)

Key Finding Description **(of the report)**	***Advanced Thermal Recycling*** **(incineration)**	***Thermal Conversion*** **(pyrolysis-gasification)**	***Biological Conversion*** **(anaerobic digestion)**
Facility designs are relatively new; therefore, current facility designs generally have not achieved the desired level of optimization.	*There is room for improvement in most designs that would better integrate the three major components of a system (pre-processing, combustion/conversion, and post-processing/byproduct production). This would increase efficiency and reduced cost/ton.* [Underlining added.]		

Discussion of Row 10. It was noted in the critique's Preliminaries section that the reports neglect the subject of process integration. Row 10 is the sole exception, in its collective statement about possible design improvement. The cryptic insertion "…in *most designs*…" is perhaps intended to leave open, barely, the possibility of an exception. But the reader himself/herself would have to discover the exception by "connecting the dots" in the Appendices, or by examining the original ArrowBio submissions.

Row 12. Thermal Efficiency and Financial Performance (City 17/499 or 161/499)

Key Finding Description **(of the report)**	***Advanced Thermal Recycling*** **(incineration)**	***Thermal Conversion*** **(pyrolysis-gasification)**	***Biological Conversion*** **(anaerobic digestion)**
Thermal efficiency, the amount of net electricity generation per ton of feedstock processed, varies by technology. Higher efficiencies result in better financial performance. (7.2.1.3) [Underline added.]	*Thermal technologies that use a steam turbine for electricity production have thermal efficiencies in the range of about 500-600 kWh/ton. If a reciprocating engine is used, the efficiency will increase to about 800-900 kWh/ton.* [Underline added; this figure comes from City 137/499.]		*Thermal efficiency is in the range of 150-200 kWh/ton using recip-rocating engines.Thermal processes recover more energy than biological ones because they convert essentially all organics to energy, not just the biodegradable organics.*

Discussion of Row 12. The electricity yield of the ArrowBio process is approximately 300 kWh/ton. The disadvantage of converting plastics (non-biodegradable organics) to electricity is discussed under Reason #4.

But the main Key Finding of row 12 needing discussion its assertion that thermal efficiency and financial performance are positively related. Examination shows the relationship to be negative.

Note that the figure "*..800-900 kWh/ton"* with a reciprocating engine (and presumably that of *"…500-600 kWh/ton"* with a steam turbine) is based on a proposal by Interstate Waste Technologies (IWT) to build a 370,000 ton per year capacity Thermoselect plant (City 137/499). The example falsifies the assertion.

Earlier (Part 1, Reason #1, Second breakdown in logic), the technical and financial failure of the then flagship Thermoselect plant in Karlsruhe, Germany was analyzed. This experience indicates, not a positive relationship between power production and financial performance, but rather a negative relationship between the two.

Unlike the County report, the City one refers, not to the Karlsruhe plant, but primarily to one in Chiba, Japan. As of a few years ago this plant was treating 'light industrial waste having perhaps half the inerts of MSW,' and the cost of waste processing in Japan 'was said in the early 2000s to be on the order of $550/ton.'[24]

Bottom Line on Row 12: Unspoken perspective of the reports. The author of this critique sees in Row 12, even in its infelicitous example, an indication clearer than elsewhere of what appears to be the mind-set expressed in the reports. The author suggests that, more than the management of waste, the perspective is that of power production. Whatever the merit of the suggestion, it is consistent with the overall thrust of the reports.

Power production is an important objective in processing waste; it is not the exclusive goal. Rather, numerous objectives must be balanced (Part 1, Reason #2), while not losing sight of the "core goal." It is to "jump-start" economically and environmentally sustainable, forward-looking, management of waste.

[24] Paraphrased from personal communication, 05 September 2005, Dr. Jurgen Vehlow, Ph.D., Head of the Chemistry Department, Division of Thermal Waste Treatment, Karlsruhe Research Centre, in Germany.

Row 18. Byproduct Marketability (City 18/499 or 162/499)

Key Finding Description **(of the report)**	***Advanced Thermal Recycling*** **(incineration)**	***Thermal Conversion*** **(pyrolysis-gasification)**	***Biological Conversion*** **(anaerobic digestion)**
Byproduct marketability is an important issue. Significant uncertainty with regard to some materials may impact economic viability. (7.2.1.5)	*Advanced thermal recycling gains most of its revenue from the sale of electricity. This is a well-developed market. Although only small amounts of bottom ash are presently recycled/reused, this is expected to increase as designs isolate the potentially hazardous fly ash from the bottom ash.*	*Thermal conversion gains most of its revenue from the sale of electricity, a well developed market. Another significant revenue source for some designs are the recyclables recovered from pre-processing the inlet black bin post-source separated MSW. The market for glass, metals and paper is also well-developed.*	*Biological conversion facilities produce both electricity and compost. The compost is produced in large quantities (15,000-40,000 tons/yr for a 100K TPY facility). California compost quality regulations are complex. Extensive testing is required to ensure acceptability. In addition, the market for this material is uncertain*

Discussion of Row 18. Previously, in rows 4 and 13, anaerobic digestion was burdened with "*…15,000 to 40,000 tons/yr…of unmarketable rejects…"* (or *residues*) per 100,000 tons input. The exact same range now appears in row 18 in regard to compost. Whether this is coincidence or an inter-changeable use of the terms rejects/residues and compost is unclear.

Regardless, in examining row 18 it can be seen that its Key Findings are highly prejudicial. Suffice to point out the row credits at least some pyrolysis/gasification systems with the capacity to recover recyclables through preprocessing, while not similarly crediting anaerobic digestion facilities with this capacity.

This aspect of row 18 again illustrates that process integration was omitted from consideration (Row 10). One capacity thereby neglected is that imparted by gravitational separation in water, which significantly enhances the recovery of marketable secondary plasics.

Row 20. Value of Plastics (City 18/499 or 162/499)

Key Finding Description **(of the report)**	***Advanced Thermal Recycling*** **(incineration)**	***Thermal Conversion*** **(pyrolysis-gasification)**	***Biological Conversion*** **(anaerobic digestion)**
Pre-processing to remove recoverable recyclables increases revenues. The value of uncontaminated recyclables in the black bin post-source separated MSW is higher as a recyclable material than as a feedstock to produce electricity.	*Applies to all technology groups.*		

Discussion of Row 20. Whereas in row 18 anaerobic digestion was denied the capacity to recover recyclables, in row 20 this capacity is shared among all technology classes. Again, although none of the elements of this Key Finding is false, their collective application gives a false impression.

Row 20's Key Finding that recycled material is more valuable than the electricity potentially generated comes into relief in connection with plastics, as was developed previously (Part 1, Reason #4) These remarks about differing sets of incentives and disincentives at thermal and anaerobic digestion plants pertain to row 20.

PART 3

COMPARATIVE ANALYSIS OF ANAEROBIC DIGESTION TECHNOLOGIES

INTRODUCTION: SURROGATES FOR PRODUCTION PARAMETERS

For reasons developed earlier (Part 1, Reason #5), there are intractable difficulties to the development of a valid comparative analysis of anaerobic digestion technologies based directly on production parameters (quantity and quality of compost and biogas). Basically, this is because of the inability to normalize differences in the input waste streams and output composts, to make technological performance stand out as the sole variable.

A valid comparison is possible, based on key fundamental design attributes serving as surrogates for, or indicators of, actual production parameters. It is possible because the design attributes operate independently of differences in the waste inputs and compost outputs, yet have a determinative effect on both. Thus, process performance stands out as the sole variable. Part 3 is premised on this use of surrogates.

THE DIFFERENCES REVOLVE AROUND WATER

The factor from which all design attributes stem is the solids content, or wateriness, of the digester feed. This factor sets in motion the distinction between the first generation (BTA, Dranco, Valorga) and the second generation (ArrowBio) anaerobic digestion systems.

Water comprises roughly one-third the weight of mixed municipal solid waste (MSW), and two-thirds that of source separated organics dominated by food waste. Water is often the unacknowledged "tail that wags the dog" of MSW processing. Even though processing relatively dry mixed waste, the ArrowBio system exploits the properties of water at both its front- and back-ends. In contrast, the other systems can be said to "fight water."

At the front end of the ArrowBio system, biodegradable and non-biodegradable materials are separated gravitationally in water. Water-based separation is superior to air-based separation -- the norm for MSW. Additionally, the biodegradables are prepared for digestion in the water. The process water is generated internally, being freed from the waste at the back-end through advanced, Upflow Anaerobic Sludge Blanket (UASB), digestion. Altogether, exploitation of water allows the integration of front- and back-ends of the system.

WATER CONTENT OF DIGESTER FEED:
KEY DETERMINANT OF PROCESS DESIGN, OPERATION AND PERFORMANCE

How the microbial community is organized, whether by design or default, is the central issue. And the single factor of feed thickness at the outset of the processing train determines the organizational options and limitations. All else with respect to facility design and operation follows, including the quantity and quality of the compost and biogas products. In this light, the four anaerobic digestion technologies of interest fall into two categories: High Solids Feed (thick slurry or paste) and Watery Feed (Table 3).

Table 3. Thickness of Digester Feed as the Key Determinant of Anaerobic Digestion Technology Design, Operation, and Performance (the attributes in the left-hand column follow the operational sequence)

Attribute	**Valorga (high solids)**	**Dranco (high solids)**	**BTA (high solids)**	**ArrowBio (low solids-watery feed)**
MSW or fraction delivered to facility	SSO (MMSW?)[a]	SSO (MMSW?)[b]	SSO[c]	Mixed unsorted MSW[d]
In-facility separation ("pre-processing)	In air[e]	In air[f]	In air[g]	In water[h]
Mechanical resistance to mixing and pumping	High	High	Moderate	Low
Thickness of feed to digester (% dry matter)	30-40%[i]	40%[j]	~ 10%[k]	4%[l]
Biological process control	Convent-ional digestion; low rate conversion	Convent-ional digestion; low rate conversion	Convent-ional digestion; low rate conversion	UASB digestion; high rate conversion[m]
Digestate (amount, condition)	Large, poorly stabilized, considerable M-mFM[n]	Large, poorly stabilized, considerable M-mFM[n]	Large, poorly stabilized, considerable M-mFM[n]	Small, well stabilized, little M-mFM[n]

Definitions: SSO = Source Separated Organics (or biowaste); MMSW = Mixed MSW; Biological Process Control: Conventional, SRT~ = HRT; UASB, SRT>>>HRT (see Appendix: "Why Watery Processing? A Metaphor").

(Citations on next page.)

Citations to the County report:
[a] CT 105/218; [b] CT 102/118; [c] CT 96/118; [d] CT 90/118; [e] CT 106118; [f] CT 103/118; [g] CT 97/118; [h] CT 91/118; [i] CT 105/118; [j] CT 102/118; [k] Not given in the URS report, but ~10% is based on <http://www.bta-technologie/de/files/short_information.pdf>; [l] A91; [m] see Appendix; [n] Man-made Foreign Matter (glass, ceramic, metal, film plastic, rigid plastic, synthetic fabric (plus stones and grit).

Citations to the City report:
[a] City 418/499; [b] City 405/499; [c] City 430/499; [d] City 392/499; [e] City 422/499; [f] City 407/499; [g] City 434/499; [h] City 396/499; [i] City 417/499; [j] City 404/499; [k] Not given in the URS report but ~10% is based on <http://www.bta-technologie/de/files/short_information.pdf>; [l] City 403/499; [m] see Appendix; [n] Man-made Foreign Matter = glass, ceramic, metal, film plastic, rigid plastic, synthetic fabric (plus stones and grit).

Table 3 bottom line. Table 3 identifies the wateriness of the digester feed as the factor which determines what is possible, or not possible, in downstream facility design and operation. High solids feeds (10-40% dry matter) limit the possibilities with respect to all three major facility functions (Pre-Digestion, Digestion, and Post-Digestion). In contrast, a watery feed (4% dry matter) opens up possibilities for integration and expansion of what a facility can accomplish.

It is also important that immersing the solid waste in water at the outset greatly decreases the friction to be overcome throughout processing, decreasing the mechanical effort needed for all subsequent operations such as mixing and translocation (Table 3 third entry down). This spares the amount of power consumed in running the plant (parasitic load).

In what follows, the implication of Table 1 are discussed in operational sequence.

PREPROCESSING, OR SEPARATION AND PREPARATION

Functions. Operations prior to digestion, or "preprocessing," involve the separation of the non-biodegradable and biodegradable fractions of mixed waste, and preparation of the biodegradables for biological action. Other purposes are the recovery of traditional recyclables, protection of downstream equipment from abrasive grit, and exclusion of Man-made Foreign Matter (M-mFM) from the post-digestion digestate (i.e., compost).

High Solids Technologies (Valorga, Dranco, BTA). In these technologies the refuse (e.g. black bin contents or MRF residual) is sorted through some combination of mechanical and manual means in ambient air, as is the norm. Water-based separation/preparation would be incompatible with the forms of anaerobic digestion that follow. Prior to feeding the digester, adjustment may be necessary to bring the feed's solid content to the particular design level (10-40%).

Watery Feed (ArrowBio system). In the ArrowBio system the refuse is immersed in water at the outset, in a special separation/preparation vat. In a continuous process, the organic-rich vat water is pumped to the digesters, to be replaced with relatively clean return water. The logic of basing the system on water is best explained starting at the back-end of the plant and then working upstream to the front-end.

● UASB digestion is superior to older forms of digestion (see Table 5 and Appendix).

● UASB digestion requires a watery feed preferably dominated by organics in solution, but tolerant of finely divided particulates.

● Separation in water based on differential specific gravity is superior to air-based separation, owing to the large difference in the buoyancy of water vs. air.

● The two factors (biological action and physical separation/preparation) are mutually supportive, and together form a highly integrated whole.

● The water comes from the moisture content of the waste.

These matters are summarized in Table 4.

Table 4. Separation and Preparation in High Solids Technologies and the Watery ArrowBio Process[a]

Attribute	High Solids Technologies	Watery ArrowBio Process
Separation medium	Air	Water[b]
Accepts mixed MSW	Varies	Yes
Absorbs dust	No	Yes
Absorbs odor	No	Yes
Isolation of biodegradable organics	Incomplete	Nearly complete
Integrated with anaerobic digestion (subsequent function – see Table 5)	No[c]	Yes[d]
Burden of M-mFM in prepared feed	Large	Small

[a] High Solids refers to the category of technologies represented by Valorga, Dranco, and BTA, while ArrowBio is based on Low Solids (watery) feed.
[b] The water comes from the waste.
[c] Front-end separation/preparation is a stand alone unit process
[d] Front and back-end functions (separation/preparation and digestion) are integrated in that the front-end supplies the prepared feed to the back-end, which reciprocally supplies feed-derived makeup water and electrical energy to the front-end.

Table 4 bottom line. Industrial scale separation technologies generally utilize, where possible, water as the separation medium rather than air. This is because water's far greater density results in much more effective separation of materials differing in specific gravity. In this special case of MSW, in connection with UASB digestion, water also serves pre-preparation in that soluble organics are brought into solution.

Other anaerobic digestion technologies cannot exploit water-based separation, basically because it is prohibited by the high-solids designs of their digestion reactors. (Thermal processes obviously cannot take advantage of water-based separation.)

In other digestion technologies, the pre-digestion stage, or separation/preparation, is not intimately connected to the overall processing scheme, and there is a strong preference for source-separated organics (SSO, or biowaste). In the ArrowBio technology the pre-digestion stage is integral to the overall system, hence the integrated processing of mixed MSW.

ANAEROBIC DIGESTION PER SE

Functions. The essential function of an anaerobic digestion plant is to transform biodegradable organic material to biogas and depleted digestate, while also recovering non-biodegradable recyclables. The more gas produced and the higher its methane content, the better. Equally, the less digestate produced and the more highly stabilized its condition, the better. The two are reciprocals of one another in that the more complete the transformation of organics to methane, the less compost produced and the more stabilized its condition.

The digestion also results in the production of liquid water, through two mechanisms. The major one is that the moisture entrained in the waste is freed as the solid phase organic carbon is converted to methane and carbon dioxide. (The gases evolve out of the water phase while what was originally entrained in the solids remains behind in liquid form.) A minor mechanism is that certain biochemical steps generate *de novo* water.

High Solids Technologies (Valorga, Dranco, BTA). The moisture content of the organic material in high solids technologies is adjusted as needed by the particular digester design (~10-40% solids). The prepared material is transferred to a single stage (methanogenic only) high-solids digester.

Watery Feed (ArrowBio). In the ArrowBio system the watery stream of well-isolated organics in solution and fine suspension (~ 4% solids) is pumped to a two-stage digester system (acidogenic stage followed by methanogenic stage of the UASB type).

These matters are summarized in Table 5 next page.

Table 5. Anaerobic Digestion in High Solids Technologies and the Watery ArrowBio Process

Attribute	High Solids Technologies	Watery ArrowBio Process
Feed	High Solids (thick slurry), or Very High Solids (thicker paste)	Watery
Organization of microbial community[a]	As in conventional digestion	As in advanced UASB digestion
Efficiency in use of bioreactor volume[b]	Low	High
SRT/HRT (days)[c]	Little difference, if any	~ 80/1
Rate of biological action	Slow	Fast
Extent of biological action	Slight	Considerable
Biogas methane/CO2 ratio (%)	~ 55/45	~ 75/25
Amount of biogas	Smaller	Larger
Amount of digestate	Larger	Smaller
Condition of digestate	Poorly stabilized, substantial M-mFM	Well stabilized, little M-mFM
Amount of work done per facility footprint area[d]	Smaller	Larger

[a] *See Appendix.*
[b] *The UASB microbial community does much more work per unit reactor volume.*
[c] *Solid and hydraulic residence times, respectively (see Appendix).*
[d] See text below.

Table 5 bottom line; and a comparison of footprints. Not surprisingly for a class of technologies called "anaerobic digestion," bacterial action is the centerpiece. Similarly, the central issue is how the microbial community is (or can be) organized. It is the manner of organization (Conventional or UASB) that determines the amount of microbiological work accomplished. The practical implications radiate back to the pre-digestion functions (Table 4), and forward to the post-digestion function including the quantity and quality of the finished compost (Table 6).

Early on, in Part 1, Reason #2, the footprints of a thermal system and ArrowBio were compared. Here, the footprints of two anaerobic digestion systems, Valorga and ArrowBio, are compared.

The footprint of a proposed 28,600 ton per year Valorga plant was listed as 7 acres (CA 106/215). The ArrowBio footprint for a 31,000 ton per year is incorrectly listed as 3 acres (CA 91/215); the correct area for that throughput is 2.5 acres. It is possible that the report also erred with respect to the Valorga offering. What is clear is that the smallness of ArrowBio's footprint is attributable to more rapid and complete biological action and the high degree of system integration, both made possible through the exploitation of water.

POST-DIGESTION

Functions. The post-digestion stage typically involves composting to advance stabilization of the digestate to the point of a finished compost product.. The magnitude of the composting operation depends on the thoroughness of the preceding anaerobic digestion (Table 5).

High Solids Technologies (Valorga, Dranco and BTA). In high-solids digestion the digestate exiting the reactor may, or may not, be dewatered, depending on the needs of the composting system. The composting operation, onsite or elsewhere, may be large.

Watery Feed (ArrowBio system). The digestate exiting the digester in the ArrowBio system is dewatered employing, for example, a belt-filter press. A portion of the water is recycled as makeup water to the front-end separation/preparation unit. Because the preceding microbial action is thorough, any need for composting is slight (Table 6).

Table 6. Digestate Characteristics in High Solids Technologies and the Watery ArrowBio Process

Attribute	High Solids Technologies	Watery ArrowBio Process
Amount of digestate	Large	Small
Condition of digestate	Poorly stabilized	Well stabilized
Need for composting	Major unit process[1]	Minor passive system – if any
Presence of M-mFM in final product	Substantial	Slight

[1] The composting component may be as large as the rest of the plant put together, and is potentially odorous.

Table 6 bottom line. The entries in Table 6 reflect the relative effectiveness of separation/preparation (Table 4) and the anaerobic digestion per se (Table 5). Both determine the quality of the compost product, in terms of inclusion of foreign matter and stability (Table 6). Thus, the ArrowBio digestate is nearly free of Man-made Foreign Material (attributable to water-based separation), and a modest amounts and is sufficiently well stabilized to need little composting (attributable to UASB digestion). The composting operation, if any, is minor and involves only passive aeration.

APPENDIX TO PART 3: 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 way 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.[25]

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).[26] 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.

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[25] An alternative metaphor is that of an assembly line in which each worker performs a unique task to ultimately produce a given end-product.

[26] A more apt term would be culture, rather than solids, residence time.