HEATING VALUE OF REFUSE DERIVED FUEL

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ABSTRACT

Resource recovery systems have been, and are being, developed as environmentally acceptable solutions for solid waste disposal. Fuel derived from solid waste is an important product of these systems, and in many instances represents the bulk of revenue received. The fuel revenue is a function of the quantity and heating value of the fuel produced from the solid waste. The important fuel characteristic, which is heating value, may not be consistent because it is derived from solid waste which varies in composition and heating value. A methodology is presented which can predict the heating value, and the circumstances and factors which impact on heating value are discussed.

INTRODUCTION

The traditional methods of solid waste disposal, dumping, and incineration, as previously practiced, are no longer acceptable because of their unfavorable environmental impact. The search by many communities for a satisfactory alternative has led them to consider resource recovery. Such a solution, although environmentally acceptable, is capital intensive and can significantly increase the cost of waste disposal as compared to the traditional methods. Therefore, to make the concept economically attractive, revenues from the recovered products are used to offset some of the increased cost.

An examination of revenues for such a system [1] shows that fuel can account for approximately 80 percent of the revenues while ferrous contributes 10 percent, glass 5 percent and aluminum 5 percent. This relationship pretty much holds true for revenues either from the direct sale of fuel or from the sale of steam produced from the firing of the fuel. Therefore, for any such proposed project it is important to develop a high degree of confidence in the projection of fuel revenue. This revenue, in turn, depends on the heating value of the fuel produced.

PROBLEM DEFINITION

Fuel produced from solid waste is generally referred to as RDF (from Refuse Derived Fuel). It is a new evolving product development which does not define a particular product but a class of product. RDF is available as a large or small type "confetti," powder and in densified form. Within each category the solid waste can be processed through various process designs which could produce RDF at different levels of purity. Coupled with these possible variations in RDF is the realization that the input material or solid waste is heterogeneous and will vary in composition on a daily and seasonal basis. Although several studies have characterized solid waste composition, much more remains to be done under generally accepted testing and reporting procedures before a standard composition(s) is recognized.

In the meantime, state and municipal officials must proceed with the planning and implementing of solid waste management programs based on limited data. For those systems where fuel will be the most important source of revenue, a procedure is required to evaluate competing process designs and to validate revenues. The text which follows describes such a procedure which can be applied to the different forms of RDF.

INPUT MATERIAL

The performance criteria of a resource recovery system is a function of its output in relation to the input. The success of any such system is contingent on the completeness and reliability of the data base. With respect to an RDF type system, it is important to specify the composition and higher heating value (HHV) of the input material.

COMPOSITION

A review of the several studies which examined solid waste composition reveals a lack of uniformity in the reporting process. Some include a detailed breakdown on a dry weight basis [2], others are on a wet weight basis [3], some exclude yard waste [4], while others include a less detailed breakdown of constituents [5]. These same reports identify variation in composition which can occur due to seasonal changes, regional area, commerce (industrial, commercial, agricultural), character (urban, surburban, farm) and city neighborhoods.

Although the referenced studies identify the variations in waste composition that can occur, additional studies are required to update earlier information, determine waste composition change for a broader range of factors and to validate the data base.

The more reliable the data base of input material and output product, the greater is the confidence in proposing and specifying systems. However, decision makers are faced with the reality of moving ahead in an environment of uncertainty because, for a variety of reasons, the data base unique to their circumstances is not available. Under such conditions an educated construction should be made from the information available which most closely represents local conditions. While this may not represent conditions in absolute terms, it does establish a base line for comparison purposes and a uniform criteria which is important to a resource recovery system.

In order to evaluate RDF, the composition of the input material should have as detailed a breakdown of constituents as is practicable. The presentation of the waste composition should be such that the combustible, noncombustible and moisture components of waste are identified or can be determined. For illustration purposes, a representative waste composition is shown in Table 1 for the northeast area which is subject to seasonal changes.

TABLE 1 [4] * REFERENCE WASTE COMPOSITION

Constituent	% Weight (dry)
Paper	35.14
Plastics	1.08
Leather, rubber	1.47
Textiles	1.80
Wood	2.29
Food waste	6.33
Yard waste	7.05
Sub total	55.16
Glass	8.62
Metal	8.53
Miscellaneous	1.76
Moisture	25.93
Total	100.00

*Data taken from Table 8 of reference and adjusted for moisture in accordance with the "as-discarded" criteria of Table 9 from the same reference.

HIGHER HEATING VALUE

To complete the definition of the input material, an HHV must be determined for the waste composition shown. A review of the literature shows various HHV's for waste generally in the range of 4500-6500 [6] Btu/lb (10,467-15,119 kJ/kg) of waste. Therefore, to determine the HHV of our reference composition, it will have to be calculated from the HHV of its constituents. Table 2 lists the range and selected HHV for each waste constituent. Using the data from Table 2 and applying it to Table 1, we can calculate the HHV for the reference waste composition as shown in Table 3.

HIGHER HEATING VALUE – REFUSE DERIVED FUEL

With the constituents and the HHV of the ref-

TABLE 2 [7] HIGHER HEATING VALUES

	RANGE OF VALUES		SELECTED VALUES	
Constituent	Btu/lb dry	kJ/kg	Btu/lb dry	kJ/kg dry
Paper products	7000-8000	16,282-18,608	7600	17,677.6
Plastics	11,000-18,000	25,586-41,868	14,600	33,959.6
Leather, rubber	10,000-16,000	23,260-37,216	11,300	26,283.8
Textiles	8000	18,608	8000	18,608
Wood	8000-9000	18,608-20,934	8300	19,305.8
Food waste	8000-9000	18,608-20,934	8400	19,538.4
Yard waste	6500-7500	15,119-17,445	7300[4]	16,979.8

TABLE 3 HIGHER HEATING VALUE REFERENCE WASTE COMPOSITION

Constituent	% Weight (Dry) [4]		HHV (Dry) [7] Btu/lb	HHV (Dry) [7] kJ/kg		Btu	kJ
Paper	35.14	x	7600	17,677.6	=	2670.69	6212.02
Plastics	1.08	x	14,600	33,959.6	=	157.68	366.76
Leather, rubber	1.47	x	11,300	26,283.8	=	166.11	386.37
Textiles	1.80	x	8000	18,608	=	144.00	334.94
Wood	2.29	x	8300	19,305.8	=	190.07	442.10
Food waste	6.33	x	8400	19,538.4	=	531.72	1236.78
Yard waste	7.05	x	7300	16,979.8	=	511.00	1188.59
Subtotal	55.16					4371.27	10,167.56
Glass	8.62	x	65		=	5.60	13.03
Metal	8.53	x	840		=	63.12	146.82
Miscellaneous	1.76						
Moisture	25.93						
Total	100.00					4439.99	10,327.41

erence waste composition defined, we have established a baseline from which to estimate the HHV of the prospective RDF. Before we estimate or validate a prospective RDF, we need some information about the output from the system. This information is available from the proposals submitted by each contractor. Generally, the proposal includes a description of the process design proposed with either a material balance, fuel analysis or both. The HHV of RDF can be estimated using either the material balance or fuel analysis data; however, each requires a different approach.

MATERIAL BALANCE

The material balance provided as part of the process design documentation should identify the combustible, noncombustible and moisture fractions of the RDF. It should be recognized that the so-called "noncombustible" term can and has been reported as inorganics, inerts, etc. For purposes of this paper, the term "noncombustible" will be used to include those materials such as metals, glass, dirt, etc. which adhere to and form the impurity portion of RDF and are not usually considered combustible.

Before calculating the HHV of RDF, we must first convert the combustible fraction of our reference waste composition to a 100 percent weight basis of combustibles as follows:

$$HHV_C = HHV_{WC}/\frac{C}{100} \qquad (1)$$

where

HHV_C = higher heating value of dry combustibles in reference waste composition on a 100% weight basis; see Table 3.

HHV_{WC}	=	higher heating value of the dry combustible fraction in the reference waste composition.
C	=	percent combustible fraction in the reference waste composition.

therefore

$$HHV_C = 4371.27/\frac{55.16}{100} = 7924.7$$

Btu/lb of dry combustible

$$10{,}167.57/\frac{55.16}{100} =$$

18,432.88 kJ/kg

Having determined HHV_C we can now calculate the HHV of RDF as follows:

$$HHV_{RDF} = HHV_C(1 - \frac{N+M}{100}) \qquad (2)$$

where

HHV_{RDF}	=	higher heating value of refuse derived fuel.
HHV_C	=	higher heating value of dry combustible in reference waste composition on a 100 percent weight basis.
N	=	percent of noncombustible from material balance.
M	=	percent of moisture from material balance.

Therefore, substituting the values for HHV_C, N and M, the HHV of RDF can be determined for any range of compositions. Calculations of HHV for RDF based on various compositions can be plotted, for convenience, into a series of curves as shown in Fig. 1. Therefore, using a defined input and a specified output, the HHV of RDF can be estimated.

FUEL ANALYSIS

As previously stated, a fuel analysis may be presented as part of the process design documentation. For our purposes, a breakdown into combustibles, ash and moisture is sufficient. The introduction of ash, in light of our discussion relative to the material balance, presents a complication in analysis and definition of terms. The combustibles listed in a fuel analysis are on an ash-free basis and therefore are different than the combustibles listed in a material balance. In addition, the ash listed in a fuel analysis consists of two constituents, ash contributed from the 55.16 percent combustible fraction plus the noncombustible portion of fuel shown in the material balance. Therefore, to calculate HHV of RDF from a fuel analysis, it is necessary to determine the combustible in the reference waste composition on an ash free basis as shown in Table 4 and to modify Eqs. (1) and (2) as follows:

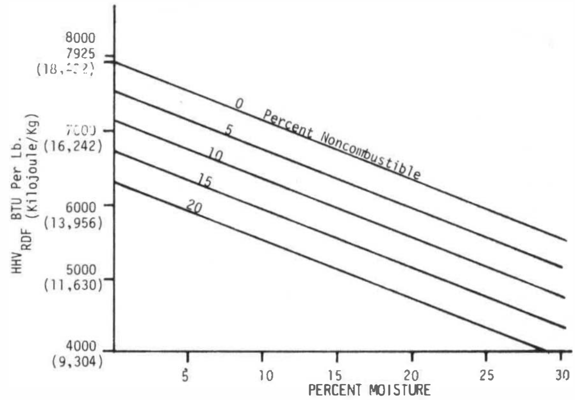

FIG. 1 HHV_{RDF} VERSUS NONCOMBUSTIBLE AND MOISTURE CONTENT

$$HHV_{AC} = HHV_{WC}/\frac{CA}{100} \qquad (3)$$

where

HHV_{AC}	=	higher heating value of combustibles in reference waste composition on a dry ash free and 100 percent weight basis.
C_A	=	percent of combustible fraction in the reference waste composition on an ash free basis.

therefore

$$HHV_{AC} = 4371.27/\frac{52.37}{100} = 8346.9$$

Btu/lb of dry ash free combustibles in waste.

TABLE 4 PERCENT ASH FREE COMBUSTIBLES IN REFERENCE WASTE COMPOSITION

Constituent	% Weight (dry) [4]		% Ash in [7] Combustibles		% Weight in Ref. Waste	% Weight Ash Free Combustible
Paper	35.14	x	5.0	=	1.76	33.38
Plastics	1.08	x	1.5	=	.02	1.06
Leather, rubber	1.47	x	15.0	=	.22	1.25
Textiles	1.80	x	3.0	=	.05	1.75
Wood	2.29	x	3.0	=	.07	2.22
Food waste	6.33	x	5.0	=	.32	6.01
Yard waste	7.05	x	5.0	x	.35	6.70
Total	55.16				2.79	52.37

$$10{,}167.57/\frac{52.37}{100} =$$

$$19{,}414.87 \text{ kJ/kg}$$

Having determined HHV_{AC}, we can calculate the HHV of RDF as follows:

$$HHV_{RDF} = HHV_{AC}\left(1-\frac{A+M}{100}\right) \qquad (4)$$

where

A = percent of ash in RDF.
M = percent of moisture in RDF.

With correction made for ash in the equations, the HHV of RDF can be calculated from a fuel analysis. The same procedure that was performed to produce Fig. 1 can be repeated on an ash free basis to produce Fig. 2.

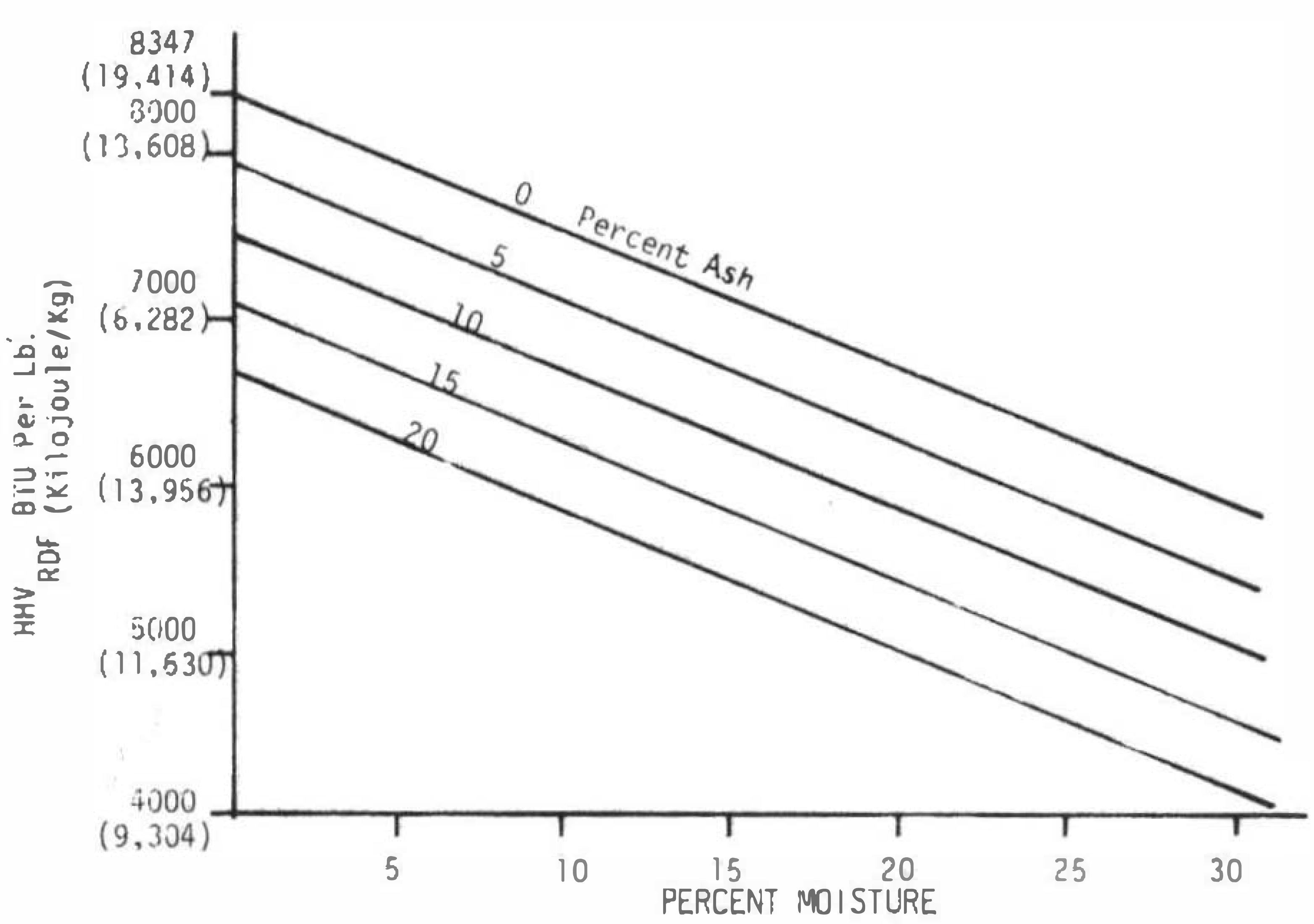

FIG. 2 HHV_{RDF} VERSUS ASH AND MOISTURE CONTENT

It is recognized that on occasion proximate and ultimate analyses are provided as part of a fuel analysis. HHV of RDF can be calculated using this information; however, a discussion on the use of this method is beyond the scope of this paper.

DISCUSSION

The analytical method of deriving the HHV of RDF has been presented; however, before concluding, it will be useful to make a few observations on the prepared material.

An examination of Table 3 will show it can be used for sensitivity analysis on the effect of changes in constituents on RDF. It shows the ranking and contribution of each constituent to the HHV of RDF. With this information one can assess the impact on resource recovery systems of such diverse developments as institution of paper source separation programs, significant increases of plastics, in waste, etc.

Equation 1 as illustrated by Fig. 1 is interesting in that it determines the upper limit of the HHV for RDF. In addition to establishing the process design limit, it provides a guide to the assessment of experimental results. Figure 1 shows the relationship of moisture and noncombustible removal on the HHV for RDF. For more on this subject, the reader is directed to reference eight listed at the end of this paper.

The application of the analytical method presented should be used with some discretion. It is necessary to analyze the process design to determine if by its nature a combustible constituent is eliminated. Such a possibility could occur if RDF was produced by an aerobic process in which plastics are not affected and therefore could be eliminated from the fuel.

SUMMARY

For state and municipal officials planners and practitioners concerned with RDF as a resource recovery product, a method has been presented for an orderly evaluation of such a system. A need has been demonstrated for specifying a reference waste on which to establish a comparable basis for the evaluation of systems. A need has also been demonstrated for a uniformity in the definition and use of terms as well as in the presentation of experimental results. The importance of treating RDF in the complete context of input, process, and output, that is, a systems approach, has been illustrated. As the work on standards and current experimental studies come to fruition, greater precision and confidence will develop in improved methods for the evaluation of resource recovery systems.

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Key Words

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Standard

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The authors' concern that a procedure be developed to effectively evaluate competing RDF producing processes is shared by many. Therefore, it may be helpful to elaborate on the authors' findings in three separate areas:

1. Constituent analysis of RDF
2. Heating value of combustibles in RDF
3. The quantity of RDF produced from solid waste.

The authors propose an evaluation of RDF based on either a material balance or on a fuel analysis of the RDF produced. During the evaluation of the St. Louis Demonstration, a material balance of the RDF was determined [A] *. Because of the shredding process, a large quantity of material could not be characterized. Therefore, up to 30 percent of the material was characterized as miscellaneous. It may also be difficult to develop a moisture figure separate from the various material categories. However, it should not be difficult to develop a fuel analysis for RDF consisting of percent moisture, percent ash and noncombustibles, and percent combustibles. Therefore, the analysis resulting in Fig. 2 would probably be the more likely to be of practical use.

In developing this paper, the authors drew on prior work by Hollander [7] ** and Niessen [4]. Hollander drew on the same work by Niessen. However, an interesting phenomenon can be observed as one follows the output from Niessen to Hollander to the present authors. There is an erosion of heating value. Thus, Niessen's 7930 Btu/lb of dry paper has been eroded to 7600 Btu/lb. Niessen's 3500 Btu/lb for dry miscellaneous material has been eroded away to nothing. Within the present paper, 68.7 Btu/lb disappeared somewhere between Table 3 and Equation 3. Thus, the heating value for the reference waste composition falls below the general range of 4500 to 6500 Btu/lb quoted by the authors. Further, the heating value of combustibles with zero ash and zero moisture is given as 8347 Btu/lb. The heating value on the same basis for precisely the same refuse composition can be derived from either Hollander or Niessen as 8750 Btu/lb. By way of comparison, the average moisture and ash free heating value based on 97 samples at St. Louis is 8840 Btu/lb [A] and the moisture and ash free heating value based on 14 samples at Ames is 9450 Btu/lb [B]. Therefore, it would seem that Fig. 2 would be a more accurate representation if the zero ash, zero moisture point was 8750 or perhaps even a higher number like 9000 Btu/lb.

In the Abstract, the authors point out that fuel revenue is a function of the quantity of fuel produced from solid waste. But in the body of the paper, the importance of determining the pounds of RDF produced from a ton of raw solid waste is not stressed. The curves should contain advice to the evaluator for determining the amount of heat energy that is available from the incoming unprocessed solid waste.

Otherwise, Fig. 2 could be a valuable tool for the process evaluator if:

1. It was increased in size.
2. A background grid was provided for ease of use.
3. Percent moisture was extended to 40 percent as moisture contents this high have been experienced [A].
4. The percent ash curves was extended to 20 percent as ash percentages this high have been experienced [A].
5. Kilojoules per kilogram was indicated on a separate ordinate on the right hand side of the plot.

* Letters in brackets refer to references at the end of this discussion.

** Numbers in brackets refer to references in the paper under discussion.

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AUTHORS' REPLY

The authors wish to express their appreciation to Mr. Hecklinger for his comments and this opportunity to elaborate on our paper.

The experience of the authors has required the use of both the fuel analysis and material balance methods for determining the heating value of RDF. It is expected this will continue to be a common occurrence for others, and therefore each method will have its application as the need arises.

Mr. Hecklinger notes an interesting phenomenon whereby an erosion of heating value appears to occur from the referenced Niessen paper to that of the authors. Equally interesting to the authors is that we can find no quoted heating values in the referenced paper other than a passing comment that the heating value of refuse will continue to rise toward the year 2000. The referenced paper is entitled "The Nature of Refuse" and deals exclusively with the testing and determination of Refuse Composition for the reference year of 1968 and goes on to project refuse composition changes to the year 2000. In the referenced paper, the miscellaneous category in refuse is defined as inorganic ash, stones, and dust. The authors assume that Mr. Hecklinger must be quoting data from a source other than the referenced Niessen paper.

Mr. Hecklinger goes on to suggest that, based on some operating data, the zero moisture zero ash heating value of RDF should be higher than that determined in our paper, perhaps as high as 9000 Btu/lb. To make such a suggestion misses the point of our paper. The authors have presented a methodology and a recommendation to use the systems approach for determining the heating value of RDF. This requires relating a heating value of RDF to an input refuse composition as outlined in our paper before one can say whether the heating value should be higher.

An additional point to be made is the observation from Table C of our paper that the bulk of RDF is cellulosic in nature. The material with the higher heating value contributes less than 8 percent to the overall value. It would require a 100 percent increase or more of these constituents in the input waste to result in zero moisture, zero ash heating values over 9000 Btu/lb. Considering the above and recognizing the refuse composition in the Niessen paper as fairly typical, the authors were unable to resolve the anomaly of the reported data. Thus the motivation for developing a methodology which we also thought would be helpful to the solid waste community.

It should be recognized that the Niessen work is now a decade old and significant changes have taken place which place the projections in the reference work in question. Therefore, the authors simply used the Niessen and Hollander works as vehicles to illustrate the methodology without regard to the current applicability of the data because, as acknowledged in our paper, the determination of heating value with greater precision and confidence will have to await the results of current experimental work and the effort on standards.

The determination of the quantity of RDF produced from a ton of raw solid waste, while critically important, is a subject for another paper.