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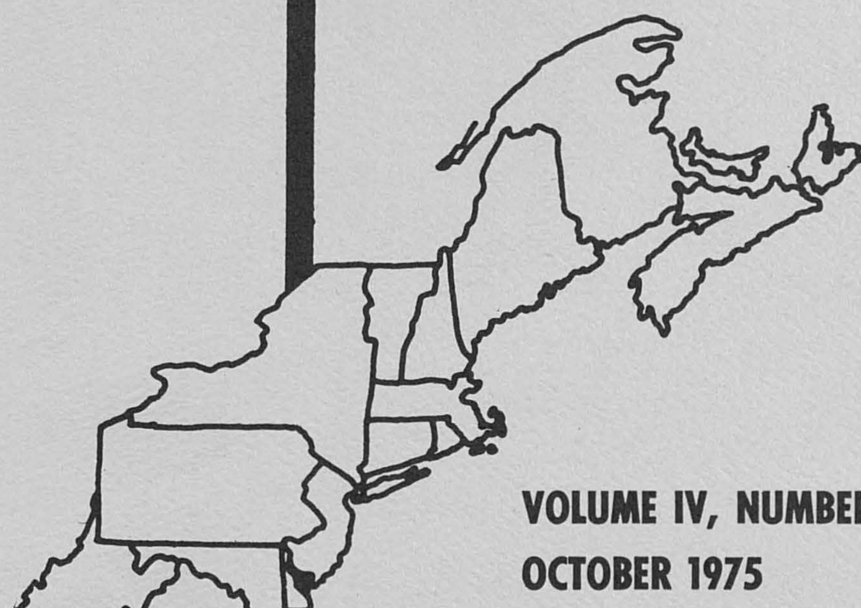

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IN-PLANT COSTS FOR A SMALL RURAL TOWN RECYCLING PLANT[1/]

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Introduction

In the past, open dump burning has been the solid waste disposal method used by many small rural towns because from a strict monetary perspective, it was the least cost alternative available to them. Now, due to environmental legislation prohibiting open dumps, they must establish new disposal facilities. The traditional environmentally acceptable alternatives of incineration and/or sanitary landfill necessarily involve increased disposal costs for these towns, with the increases being especially pronounced for towns in areas like New Hampshire where fuel oil prices are high and suitable sites for sanitary landfill are scarce.

As ways are sought to reduce the overall increase in disposal costs, many towns in New Hampshire, and perhaps elsewhere, are actively considering the recycling of some materials. Their evaluation of this course of action is hindered though by the lack of data from operating systems of the type being considered by these towns. Aside from the small operations of ecologically motivated volunteers, most recycling experiments in the past have been large scale capital intensive systems involving expensive in-plant separation processes and serving large metropolitan populations. The large capital investments required for these systems obviously would not be justified by the relatively small quantities of waste generated in small rural towns, and such systems are not

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being considered by these towns. In general, the systems being considered involve source separation (segregation of waste materials at the point of generation: in homes, businesses, etc.) and processing plants requiring relatively small capital investments.

What is believed to be the first opportunity to obtain data from a functioning system designed for a small rural town was presented by the operation of the system that has been serving Nottingham, New Hampshire (estimated year round population @ 1200) since January, 1974. That system, which was designed and subsidized by Recycling and Conservation, Inc., a non-profit resource recovery research foundation in Kittery, Maine, and adopted as the official town disposal system by the vote of Nottingham residents attending a special town meeting, consists of a small recycling-incineration plant and mandatory source separation.

As the first rural town solid waste disposal system in the state, and perhaps the country, to include recycling as a key component, it was certain from the inception of the system that other small towns would look to Nottingham's experience as an indication of the economic desirability of including recycling in their own systems. It was also obvious, however, that Nottingham's actual costs and revenues could be misleading guides for most towns. Apart from the fact that the first year's operation would involve many "start up" and "learning" costs, the actual cost figures would also include the costs of incinerating non-recyclables. Incineration is not necessarily the best disposal method to accompany recycling in other towns, and in any case its inclusion in cost data obscures the cost of recycling. It would also be impossible to discern the processing costs for individual recycling processes from the actual operating costs for the plant, and many of the factors determining costs and revenues (e.g., prices of outputs and inputs, costs of transporting or shipping materials to market, the quantity and composition of waste, etc.) are variable both between towns and over time.

All of the above considerations pointed to the need for an economic model that would permit an evaluation of the economics of this type recycling plant for the differing circumstances (prices, quantities, etc.) that prevail in different towns and of the impact of possible changes in any of the circumstances. Since so many of the important determinants of annual net cost or profit for the plant are location and time specific variables, the overall model needed to be primarily a framework in which values of the variables appropriate for specific towns could be combined in a systematic manner with estimates of plant parameters. The model also needed to be relatively simple and decomposable into even simpler terms to increase its potential usefulness to planners and decision makers for small rural towns.

Production relationships being the fundamental plant parameters, the plant was modeled on the assumption that input-output relationships observed at Nottingham were adequate approximations of those that would be achieved in other towns with the same plant. These relationships are the core of the in-plant cost model which is the basic equation of the overall model and the primary concern of this article.

Description of Recycling Processes

Before turning to the cost model itself, a brief description of the production processes being modeled is probably in order. The mandatory source separation regulations call for all materials brought to the plant to be separated according to the following categories: newspaper, corrugated cardboard, clean mixed paper, glass, metal and rubbish. The rubbish is incinerated and the ash is spread on the old dump site. Large salvageable items are stored behind the plant for eventual sale. Newspaper, cardboard, mixed paper, glass, "tin" cans (all small ferrous metals), and aluminum all undergo some type of "processing" at the plant before being marketed, and it is the processing of these materials that is modeled here.

The "process" for each material recycled was defined to include all activities normally required to get the material from its point and condition of reception at the plant to its point and condition for shipment from the plant. Space limitations prohibit a complete description of all the activities involved, but hopefully the following will give the reader a general understanding of each material process.

Each recycled material is received through a window which is labeled as the receiving point for the particular material. As newspaper is received it is stacked in a wooden frame which is specially constructed to aid the manual stacking and strapping of newspaper bales weighing approximately 1/2 ton. Cardboard is fed through a small shredder. When the bin receiving the shredded material is full, it is emptied into a larger shipping bin. Clean mixed paper is processed in the same manner. As glass is received, it is manually sorted according to color. When a sorting bin is full, it is emptied into a glass crusher which is elevated and mobile along metal tracks permitting it to be situated over a shipping bin for the particular color being crushed. As small metals are received, they are emptied onto a small magnetic conveyer and those few items which should not be crushed or marketed as either "tin" cans or aluminum are manually removed. Aluminum falls into a container at the end of the conveyer while the magnetic property carries "tin" cans under the conveyer where a crosspiece rakes them off into a different container. Full containers are manually dumped into the hopper of a can crusher which drops the crushed material into a shipping bin for that material located under the body of the crusher. In all processes, a forklift is used to move full shipping bins (completed bales in the case of newspaper) to a storage area. It is also used for intra-process movement of bins in the cardboard, mixed paper, and glass processes, and for switching the shipping bins under the can crusher between "tin" can and aluminum processing.

The Model of In-Plant Costs

Preliminary observation of these processes indicated that it would not be possible to obtain data appropriate for a rigorous statistical estimation of the actual technical production functions for the various processes, but that it was possible to obtain data that would permit the calculation of the average man and machine-hour usage per ton for the processing of each recycled material. From June 8, 1974 through September 1, 1974, we timed the activities of each recycling process with stop watches, and were provided the shipping weights of these monitored materials by Recycling and Conservation, Inc. These times and weights were used to calculate average man-hour and machine-hour usages per ton as estimates of the production coefficients for each process. R & C, Inc. also provided us with estimates of the electrical usage of each machine per machine hour based on the horsepower of the machine's motors.

These fixed coefficient approximations of input requirements provide the basis for the following linear cost function for the plant's recycling operations.

$$C = F + WAMQ$$

and, perhaps of greater interest, the corresponding cost per ton or average cost function:

$$C/Q = F/Q + WAM$$

where:

- C, F and Q are scalar values of total annual in-plant cost, annual fixed cost, and total annual tonnage recycled, respectively;
- M is a 6x1 vector in which each m_{i1} is the proportion (by weight) that the ith material is of total recycled material;
- A is a 2x6 matrix where a_{1j} is the man-hour requirement per ton of the jth material and a_{2j} is the kilowatt-hour requirement per ton of the jth material.
- W is a 1x2 vector where w_{11} is the wage rate and w_{12} is the electrical rate per kilowatt-hour.

This simple cost model is in essence a refinement of the methodology already in use by the "solid waste committees" of some of the New Hampshire towns which have been trying to estimate annual recycling cost without the benefit of information on production relationships. Their methodology consists primarily of determining the capital costs at their location and applying simple amortization formulas. Other costs are necessarily estimated by rather ad hoc annual allowances. The model refines their methodology by relating production labor and electrical costs to output, composition, and wage and electrical rates via the estimated production coefficients while retaining their simple amortization and annual allowance approach for other costs all of which are included in the fixed cost term. Only production labor and electrical costs are treated as variable costs because they appear certain to be the dominant components of in-plant variable cost and on the basis of currently available data it is not possible to relate other costs to output in a simple but meaningful way.

Input Requirements and Cost Implications

Our findings as to the average man-hour and machine-hour requirements per ton of each category of material recycled in a Nottingham-type plant are presented in Table 1. The estimated electrical usage of each machine per machine-hour is as follows: 3.0 kilowatt-hours for the shredder, 1.5 kilowatt-hours for the glass crusher, 5.0 kilowatt-hours for the can crusher, 0.5 kilowatt-hours for the conveyer and 0.5 kilowatt-hours for the forklift. Together Table 1 and these electrical usage estimates imply the man-hour and kilowatt-hour requirements per ton of each recycled material category, matrix A in the model, given in Table 2. Table 3 itemizes the capital stock which yields the flow input requirements given in the first two tables.

Table 1
Man-hour and Machine-hour Requirements
Per Ton for Each Recycled Material Category

Input \ Output	Newspaper	Cardboard	Mixed Paper	Glass	"Tin" Cans	Aluminum
Man-hours	4.7	16.2	8.6	2.3	7.0	17.8
Shredder hours	0	9.1	6.5	0	0	0
Glass Crusher-hrs.	0	0	0	.5	0	0
Can Crusher-hrs.	0	0	0	0	3.3	5.4
Conveyer-hrs.	0	0	0	0	3.6	9.1
Forklift-hrs	.1	2.7	1.2	.5	.3	1.6

The dependence of amortizations and annual allowances on judgments and circumstances in individual towns would make any general estimate here of the model's fixed cost term rather artibrary. Amortizations will vary due both to different judgments regarding appropriate procedures, interest rate, etc., and to differences in the initial cost of the same building and set of equipment at different locations and times. However, the costs of the capital stock in Nottingham at the time the study plant was built and equipped (Table 3) should give the reader a rough idea of the required capital investment.

Table 2
Matrix A: Man-hour and Kilowatt-hour Requirements
Per Ton of Each Recycled Material Category

Input \ Output	Newspaper	Cardboard	Mixed Paper	Glass	"Tin" Cans	Aluminum
Man-hours	4.7	16.2	8.6	2.3	7.0	17.8
Kilowatt-hours	0.05	28.65	20.10	1.00	18.45	32.35

Table 3
Recycling Capital Costs at Nottingham, N. H. (1973-1974)

Item	Cost
Paper Shredder	$ 2,390
Glass Crusher	1,000
Can Crusher	3,900
Magnetic Conveyer	800
Forklift	3,800
Battery Charger	150
30 Batteries	1,500
Paper Baling Frame	15
Paper Baling Equipment	50
3 Glass Sorting Bins	300
12 Glass Shipping Bins	360
12 Metal Shipping Bins	300
Paper Shredding Bin	30
6 Paper Shipping Bins	300
Building (30x66x16)[a]	18,400
	$33,295

[a] At Nottingham, this building houses the incinerator operation in addition to its recycling operation.

The variable cost term also contains elements that depend on circumstances in each individual town, but the estimated plant parameters given by matrix A, (Table 2) permits some general analysis of how average variable cost, will be affected by those factors. As can be seen in Table 2, aluminum and cardboard are the heaviest users of both labor and electricity per ton of output, followed by mixed paper and "tin" cans. The newspaper and glass processes are relatively small users of both of these inputs per ton of output. Varible costs per ton for these individual materials (the coefficients of WA) and their sensitivity to changing input prices will differ accordingly. The specific per ton variable costs implied by the input requirement findings for the individual materials have been disaggregated into their labor and electrical components and are presented for selected ranges of wage and electrical rates in Tables 4 and 5. In addition to being of interest for its own sake, the information for the individual processes also indicates that variable cost per ton of recycled material (WAM) and its responsiveness to input price changes can be quite sensitive to the composition of recycled materials. This follows from the substantial differences that are evident in the corresponding values for the individual processes.

Table 4
Estimated Labor Cost Per Ton for Each Recycled Material
at Selected Wage Rates

Hourly Wage Rate	Newspaper	Cardboard	Mixed Paper	Glass	Cans	Aluminum
Dollars	Dollars					
2.00	9.40	32.40	17.20	4.60	14.00	35.60
2.50	11.75	40.50	21.50	5.75	17.50	44.50
3.00	14.10	48.60	25.80	6.90	21.00	53.40
3.50	16.45	56.70	30.10	8.05	24.50	62.30
4.00	18.80	64.80	34.40	9.20	28.00	71.20

Table 5
Estimated Electrical Cost Per Ton for Each Recycled Material
at Selected Average Electrical Rates[a/]

Average Rate Per Kilowatt-Hour	Newspaper	Cardboard	Mixed Paper	Glass	"Tin" Cans	Aluminum
Dollars	Dollars					
.02	.001	.57	.40	.02	.37	.65
.04	.002	1.15	.80	.04	.74	1.29
.06	.003	1.72	1.21	.06	1.11	1.94
.08	.004	2.29	1.61	.08	1.48	2.59
.10	.005	2.87	2.01	.10	1.85	3.24

a/ We are abstracting here from the analysis complicating fact that electrical rates vary with total electrical usage.

The composition estimates of Table 6 together with an additional estimate of the relative proportions of "tin" cans and aluminum in the can category suggest the following vector M for recycled materials from rural households: M' = [.200 .038 .100 .469 .186 .008], implying labor cost per ton of recycled material of $4.94 for each one dollar of the wage rate and electrical cost per ton of recycled material of a little over seven cents for each one cent of the average electrical rate. Different compositions can yield significantly different average variable costs though and as with any case study there is no guarantee that the composition estimates made here have direct applicability to other towns. They are presented as one bit of evidence as to the composition of source separated waste from rural households, and not as a substitute for composition studies in individual towns. In any case, individual towns must also consider the waste from any commercial and industrial activities within their boundaries in addition to household waste.

Concluding Remarks

The recycling system at Nottingham, New Hampshire, offers a functioning example of methods which will allow small rural towns to recycle a substantial proportion of their solid waste for a relatively modest capital investment. As might be expected,labor costs appear certain to be the dominant component of in-plant variable cost. The per ton man-hour requirements (and for that matter, electrical requirements) vary significantly between processes making in-plant variable cost per ton of recycled material heavily dependent on the composition of recyclables in the particular town.

Ultimate conclusions as to the economic desirability of recycling must rest on a comparison of net recycling costs and the cost of disposing of the same materials by the particular town's least-cost alternative. The costs of alternatives and the other components of net recycling costs, market prices and shipping costs, are town specific and beyond the scope of this paper on in-plant costs. However, it may help to put the in-plant costs in perspective to note that during the time the study plant has been in operation, the per ton prices at their markets have ranged from $40 to virtually zero for both newspaper and cardboard, $20 to virtually zero for mixed paper, from $20 to $30 for glass and "tin" cans, and from $200 to $300 for aluminum.

All things considered (i.e., in-plant costs at reasonable input prices, the level and stability of experienced market prices for recycled materials, shipping weight per unit of volume, and the apparent prevalence in rural household waste streams), the glass process appears to be the backbone of a Nottingham-type system. The "tin" can process also seems likely to involve net costs that will be less than disposal alternatives for many towns, and the extremely high prices seem certain to make aluminum process profitable despite relatively high per ton processing costs and light weight. Unfortunately, aluminum is a very small percentage of total recyclables. Newspaper fares well in terms of processing costs and shipping weight, but has suffered from erratic prices that drop very low. Cardboard and mixed paper suffer from high processing cost and light weight as well as erratic prices that have fallen to virtually zero. The processing of the latter two materials has been discontinued at Nottingham

Composition is a function of town characteristics rather than plant characteristics. However, in addition to providing the opportunity for estimating the plant parameters for one type of small recycling plant, the operation of the Nottingham system also provided an opportunity to obtain data on the quantity and composition of waste that might be expected from rural households under a source separation system. During the period from August 3, 1974 through September 11, 1974, the materials brought to the plant by a sample of 62 households were weighed and recorded by category along with the number of days each category had been accumulating.[2/] At the end of the study period, an average daily weight was calculated for each household by dividing that household's total poundage for each category by its total number of days accumulation. The means of the resulting 62 average daily weights for each category are given in Table 6 as are composition estimates based on those means. Glass is clearly the predominant recyclable followed by newspaper, cans (all small metals, "tin" and aluminum), mixed paper, and cardboard in that order.

Table 6
Composition of Rural Household Waste Based on Means
of Average Daily Weights for a Sample of Nottingham Households

Category	Mean[a/] (lbs.)	% of Total Recycled	% of Total
Newspaper	.64	20.0	10.5
Cardboard	.12	3.8	2.0
Mixes Paper	.32	10.0	5.2
Glass	1.50	46.9	24.6
Cans	.62	19.4	10.2
Total Recycled Materials[b/]	3.20	100	52.5
Rubbish	2.89		47.4
Total[b/]	6.10		100.0

a/ t - ratios for all means have values in excess of 3

b/ Parts may not sum to totals due to rounding

2/ The sample is a cooperative subset of a larger random sample of Nottingham households which were interviewed regarding their attitudes and reactions to the recycling system (see [1]). The time period over which the weighing was performed may introduce some seasonal bias into the estimates.

and the materials will be incinerated for the duration of the current low prices.

Finally, it should be noted that since our examination of recycling production relationships was necessarily limited to a single pilot plant which is not necessarily an optimal plant for all (or any) small towns, the costs implied for an individual town should not be viewed as the minimum recycling costs achieveable for that town. Modifications of the basic plant may well reduce per ton costs for some or all towns. In particular, the variable input requirements for the shredder operation imply unduly large variable costs. While we do not have specific data of the type gathered on the Nottingham equipment for balers, it seems certain that in towns with significant quantities of cardboard and mixed paper per ton costs can be reduced by substituting a baler for the shredder thereby accepting higher fixed cost but gaining lower variable cost. Of course, if the current low prices for these materials become their normal prices, the best modification in regard to those processes might be complete elimination. Still other cost reducing modifications are undoubtedly possible. Nevertheless, the Nottingham-type plant provides a valuable benchmark for the analysis of rural recycling plants.

References

[1] Tichenor, Richard, Edmund F. Jansen, Jr., and Judy Pickering, Economics of a Small Rural Town Recycling System: Implications of a Case Study, New Hampshire Agricultural Experiment Station, Research Report No. 43, June 1975.