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HOUSEHOLD ENERGY CONSERVATION SYSTEM STUDY

Final Report

April 1978

Work Performed Under Contract No. EY-76-C-02-4058

General Electric Company
Valley Forge Space Center
Philadelphia, Pennsylvania

MASTER

U. S. DEPARTMENT OF ENERGY

Division of Buildings and Community Systems

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I SUMMARY

This report details the areas investigated, and the procedures used to develop the preliminary design for a cost effective household energy conservation and reclamation system for waste product energies.

The selected design recovers sufficient energy from household wastes to provide up to 50% of the heating energy for a domestic hot water system. In addition it ameliorates energy expenditures associated with trash collection and disposal, sewage collection and processing, and conserves fresh water usage and the energy associated with providing it. Secondary benefits are available from the increased potential for the use of marginal lands for residential construction. The design is shown to be compatible with existing life styles and to be cost competitive when viewed against competitive systems, and only a modest investment is required to demonstrate the system's feasibility.

In accomplishing the study, household energy and water use patterns were reviewed and a baseline model established. Solid waste generation along with sewage and waste water flows were determined for the model. The areas of solid wastes and liquid wastes processing were examined for potential techniques and systems applicable to energy reclamation for a household.

A number of household energy reclamation systems were then conceptualized using the most attractive elements of the individual waste processing systems. These systems were then evaluated and screened for further analysis and development.

An integrated solid and liquid waste energy recovery and conservation concept was subsequently selected and a design baseline established and evaluated.

An assessment of barriers to implementation has been made together with a market penetration analysis. Recommendations for phased development and dissemination are included.

II INTRODUCTION

A typical American family of two adults and two children generates an average of 8.34 pounds of thermally convertible solid waste a day, equivalent to 17.7 MBTU's per year. Sewage from this same home may account for additional 3300 BTU's per day. The combined potential for energy recovery for these primary waste outputs amounts to more than 18.9 MBTU's per year. This is equivalent to the energy content almost of 5 barrels of oil assuming the energy conversion efficiency factor of 70% associated with home heating system. Household energy conservation in the use of hot water may account for an additional 1.2 MBTU/year without impacting acceptable life styles.

Energy estimates to dispose of a family's solid and liquid wastes are extremely difficult to estimate, however, a minimum of 5 MBTU (Page IV-1) appears reasonable per year. The sum of these energies as shown in Table II-1 represents the energy conservation potential associated with present day usages and systems.

Table II-1. Energy Values For Various Categories Of Wastes & Waste Disposal
For Individual Households

<u>Category of Waste</u>	<u>Item</u>	<u>Value in MBTU/Year</u>
Waste Products	Solid Waste	17.7
	Sewage	1.2
Waste Product Processing	Sewage	4.9
Water*	Water	
	Water Heating	5.8
	Total	29.6

*Assumes 20% Reduction of Present Usage Rates

Converting or conserving this quantity of potential energy to useable energy in 1% of the single family residences in the United States could result in an equivalent oil savings of 1-3/4 million barrels of oil per year in 1980.

The study is divided into six major sections covering:

- a) Residential Baseline Model which examines and defines energy usages and waste energy availabilities.
- b) Solid Wastes treatment and energy recovery mechanisms.
- c) Liquid Waste treatment and energy recovery mechanisms.
- d) Integrated System Concepts for solid and liquid waste treatment and energy recovery.
- e) Selected System Concept describing a recommended system design for waste treatment and energy recovery.
- f) Development and Plan and Policy Recommendation for implementation of the selected system.

III RESIDENTIAL BASELINE MODEL

A single family residential model was developed in order to determine and analyze energy usage, water usage, waste flows and characteristics, and the resulting benefit potentials for candidate systems.

A. CHARACTERISTIC DWELLING AND ENERGY CONSUMPTION

Information on the characteristic dwelling and the baseline energy usage was obtained from Reference 1. The source was chosen for information on the characteristic dwelling because of the depth of definition provided. The baseline dwelling from that study is a two story frame house located in the Baltimore/Washington area and is occupied by four people - two adults and two children. The characteristics of the house are detailed in Table III-1, and the floor plan is shown in Figure III-1.

Heating of the dwelling is via a gas-fired forced air furnace and cooling is provided by an electrically driven central air conditioning unit. A year round thermostat setting of 75°F was assumed for that study. The resulting heat load of 710 therms and cooling load of 282 therms produced a total annual primary energy requirement of 1432 therms. See Table III-2.

The overall efficiency of gas utilization for heating was approximately 68 percent including pipeline losses and combustion efficiency. Primary energy requirements at the power plant were 10,910 BTU per Kw-hour of electrical consumption at the house. This value included a six percent electrical transmission loss. The central air conditioning unit was assumed to have a performance of eight BTU/watt-hour, which, when overall efficiencies were considered, resulted in one BTU of cooling requiring 1.36 BTU of primary energy at the power plant. (See Footnote*)

* 10,910 BTU @ Plant = 1000 Watt-Hr at Home
or 10.9 BTU @ Plant = 1 Watt-Hr at Home
but 1 Watt-Hr at Air Conditioner Provides 8 BTU Cooling
10.9 BTU @ Plant = 1 Watt-Hr at Home = 8 BTU Cooling
and
$$\frac{10.9 \text{ BTU @ Plant}}{8} = \frac{8 \text{ BTU Cooling}}{8}$$
$$1.36 \text{ BTU @ Plant} = 1 \text{ BTU Cooling at Home}$$

1. "Residential Energy Consumption Single Family Housing", Final Report; Hittman Associates, Inc., Columbia, Maryland, for Department of Housing and Urban Development, Report Number HUD-HAI-2, September 1975.

Table III-1. Design Parameters For Characteristic Single-Family Detached Dwelling
In Baltimore/Washington Area

STRUCTURAL PARAMETERS:

Number of stories	Two
Basement	Full (unfinished)
Garage	Attached, open carport
Floor area, ft ²	1695 finished
Construction type	Wood frame
Exterior walls:	
Outside surface	Wood shiplap
Sheathing	Plywood, 1/2 inch
Insulation	R-7 batting*
Inside surface	Drywall, 1/2 inch
Ceiling insulation	Loose fill blown-in, 5 inches
Attic	Ventilated, unheated
Roof	Asphalt shingles
Windows:	
Type	Aluminum casement
Glazing	Single
Area, ft ²	180
Exterior doors:	
Type	Wood panel
Number	3
Total area, ft ²	60
Patio door:	
Type	Aluminum frame
Glazing	Single
Area, ft ²	40

* R7 equivalent to 2-1/4 in. fiberglass batting.

ENERGY CONSUMPTION PARAMETERS:

Energy consuming equipment:

Heating system	Forced air, gas
Cooling system	Forced air, electric
Hot water heater	Gas
Cooking range	Gas (90 therms/year)*
Clothes dryer	Gas
Refrigerator/Freezer	Electric (1830 Kw-hr/year)*
Lights	Electric (2000 Kw-hr/year)*
Color TV	Electric (500 Kw-hr/year)*
Furnace fan	Electric (394 Kw-hr/year)*
Dishwasher	Electric (363 Kw-hr/year)*
Clothes washer	Electric (103 Kw-hr/year)*
Iron	Electric (144 Kw-hr/year)*
Coffee maker	Electric (106 Kw-hr/year)*
Miscellaneous	Electric (1200 Kw-hr/year)*

* Energy input to structure due to use of item.

Factors affecting heating/cooling load: (Base case)

Exterior glass areas	70% draped 20% shaded 10% open Patio door on south wall No awnings, no storm windows No shading effect
External landscaping	North
Dwelling facing	White roof and walls
External colors	Two adults, two children
People	Data for 1954 from Baltimore, Md. weather station
Weather	West side
Garage location	

*(From Page 13, Reference 1)

SECOND FLOOR

SCALE .1" = 1'

NORTH

BASEMENT

Figure III-1. Floor Plan of Characteristic House (From Page 13a, Reference 1)

Table III-2. Heating and Cooling Requirements and Primary Power Usage For Characteristic Dwelling*

	Net Loads		PRIMARY POWER	
	Heating Therms	Cooling Therms	Heating ^(a) Therms	Cooling ^(b) Therms
January	147.1	0.0	216.0	0.0
February	100.7	0.0	148.1	0.0
March	103.2	0.0	152.1	0.0
April	43.3	- 10.4	63.7	14.2
May	31.6	- 14.9	46.6	24.0
June	3.0	- 50.7	4.4	69.0
July	0.0	- 73.7	0.0	101.0
August	0.0	- 58.3	0.0	79.4
September	5.4	- 46.3	7.9	63.1
October	38.6	- 27.5	56.7	37.4
November	95.4	0.0	140.3	0.0
December	<u>141.4</u>	<u>0.0</u>	<u>208.0</u>	<u>0.0</u>
TOTAL	709.7	-281.8	1043.8	388.1

(a) Including three percent pipeline loss.

(b) Based on power plant input of 10,910 Btu/Kw-hr consumed in house and a nameplate coefficient of performance of eight Btu/w-hr for the air conditioner.

(c) 1 Therm equals 10^5 Btu

(d) See Table III-1 for parameters

*(From Reference 1, Page 31)

Energy utilization of major appliances for the characteristic house is shown in Table III-3, as derived from Reference 1. Where an appliance was available in either an electric or gas model, that study made a determination of the resultant primary power usage for each device. The appliance requiring the lower amount of primary energy was then selected. In general, the source found that gas appliances were lower primary energy users. An exception was the outside light. However, it should be noted that an assumption was made that for convenience the gas light would burn continuously whereas the competing electric lamp was operated only at night.

B. SOLID WASTES GENERATION AND CHARACTERISTICS

The term "solid wastes" as referred to in this report includes all non-liquid waste products generated within the home excepting toilet wastes. The solid wastes chargeable to a household for the purpose of this study include the general categories of (a) garbage - wastes resulting cooking and serving of food, (b) rubbish - paper and paper products, yard wastes, metals, tin cans, glass, rags, etc. It does not include street refuse, demolition wastes, industrial wastes, commercial or office wastes and construction wastes which would normally appear as part of a municipal dump solid waste composition. Energy recovery values for an average household's solid waste is equivalent to more than 18 MBTU/year as described in the following.

The per capita generation of solid wastes varies greatly as reported by various sources and is dependent upon location and economic status. Source 2 reports an average value for solid wastes of 2.51 pounds per capita day for a U.S. total and 2.48 for urban areas. Data from Reference 3 is shown in Table III-4 and displays the variance in waste generation. For the purpose of this study, an average value of 2.5 pound per capita per day will be assumed, which for the baseline household of 4 people results in a daily solid waste generation of 10 pounds per day. This compares favorably with the national average of 3.2 pound per person per day cited in Reference 4, when adjusted for non-combustibles.

2. Municipal Refuse Disposal, prepared by Institute for Solid Wastes, American Public Works Association, Public Administration Service, 3rd Edition, 1970, Page 32.
3. Technical-Economic Study of Solid Waste Disposal Needs and Practices, Municipal Inventory, Volume 1, U.S. Department of HEW, Public Health Service, 1969, Page 11.
4. Energy in Solid Waste, Citizens Advisory Committee on Environmental Quality, Washington, D. C., 1974.

Table III-3 Appliance Energy Consumption

<u>Component</u>	<u>Load Therms</u>	<u>Primary Power Therms</u>
Hot Water Heating (G)	150.2	270
Lights (E)	68.2	218
Range (G)	40.0	50
Refrigerator/Freezer (E)	62.6	200
Clothes Dryer (G)	33.8	40
Color TV (E)	16.9	54
Furnace Fan (E)	13.5	43
Dishwasher (E)	12.5	40
Clothes Washer (E)	3.4	11
Iron (E)	5.0	16
Coffee Maker (E)	3.4	11
Outside Light (E)	28.2	90
Miscellaneous (E)	<u>41.0</u>	<u>131</u>
Total Annual Energy Consumption (Excluding Heating and Cooling)	478.7	1174

(E) Electric

(G) Gas

* One Therm = 10^5 Btu

** Electric power based on power plant energy consumption of 10,910 Btu/Kw-hr.

Because of the inherent variations in refuse composition and in heat value, by location and time of testing, a comprehensive gathering of data to characterize refuse in fine detail would be of marginal value. Instead, available characteristic data were examined and a representative composition was then developed. Several of these representative composition samplings are shown in Tables III-5, 6, and 7.

As the previous tables suggest there is considerable variation in solid waste composition from location to location and also with the time of year. In order to establish a common standard for evaluation of concepts, an average composition was developed as shown in Table III-8.

Various methods have been used to project changes in municipal refuse composition. While these estimates vary in their details, the following trends are evident:⁸

<u>Constituent</u>	<u>Trend (% Weight)</u>
Paper	Increase
Garbage	Decrease
Yard Wastes	Slight Decrease
Glass and Ceramics	Decrease in Late 1990's
Metals	Decrease
Plastics	Increase

The projected increase in paper products and plastic waste coupled with a decrease in the noncombustibles such as glass and metals would indicate an increase in the heating value of solid wastes when considered as a fuel. In fact such is the case, as shown by Figure III-2, derived from Reference 8. Therefore, the heating value of household solid wastes may be expected to increase substantially in the future. As a reference point, the HHV, as received, from Reference 8 varied between 4280 and 4917 Btu/lb.

8. "Solid Waste Management", Op. Cit., Page I-1.

Table III-4. Residential Solid Waste Generation (3)

Pounds per Capita per Day	
City ^a	Residential solid waste
Niagara Falls, NY	2.70
Los Angeles, CA	2.59
Philadelphia, PA	2.10
New York City, NY	2.42
St. Petersburg, FL	2.14
San Francisco, CA	3.16
Miami, FL	1.75
Wilton, CT	2.40
Weston, CT	2.10
Average	2.37
Standard Deviation	0.41

Table III-5. Suggested Refuse Composition As Received (5)

Constituent	Weight (%)
Paper	37.0
Glass	9.0
Ferrous Metals	7.6
Nonferrous Metals	0.8
Plastics	1.4
Leather, Rubber; Textiles, and Wood	6.0
Garbage and Yard Waste	10.0
Moisture	25.0
Miscellaneous	3.2
	<u>100.0</u>

5. "Solid Waste Management", Technology Assessment, Section 1, General Electric Company, Schenectady, N. Y., 1973, Page I-3.

Table III-6. Refuse Composition And Moisture Contents (6)

Hempstead, New York

Category	Test 1 June 1, 1966		Test 2 June 23, 1966		Test 3 Feb. 21, 1967		Test 4 April 5, 1967	
	Weights Per Cent	Moisture Per Cent	Weights Per Cent	Moisture Per Cent	Weights Per Cent	Moisture Per Cent	Weights Per Cent	Moisture Per Cent
Cardboard	1.59	23.78	6.75	13.22	5.78	16.10	6.81	14.27
Newspaper	8.88	37.77	11.27	19.20	21.35	18.00	12.75	19.05
Misc. paper	22.25	36.93	21.78	24.68	26.20	21.90	24.70	21.88
Plastic film	1.76	18.80	1.77	20.47	1.20	2.85	1.09	12.43
Other plastics, etc.	0.69	20.50	1.67	29.60	2.34	4.38	7.73	6.26
Garbage	9.58	65.25	10.21	73.45	16.70	59.80	7.23	55.75
Grass, dirt, leaves	33.33	62.20	19.00	44.80	0.26	21.08	17.89	23.69
Textiles	3.00	31.40	3.33	22.40	2.24	26.05	3.97	15.30
Wood	1.22	24.98	6.58	8.70	1.46	13.20	3.47	14.80
Mineral (glass, etc.)	9.74	6.00	9.49	1.99	11.87	1.64	7.13	2.23
Metallic	7.96	10.83	8.15	2.76	10.60	4.46	7.23	8.35
	100.00		100.00		100.00		100.00	
Avg. moisture, % weighted		42.10		27.06		21.18		19.57

Table III-7. Percentage Composition Of Residential Refuse (7)

1966 - 1969

Material	Percent
Paper and Paper Produces	43.8
Food Waste	18.2
Glass	9.0
Metals	9.1
Plastics, Leather, Elastomers	3.0
Wood	2.5
Plants and Grass	7.9
Woven Textile Products	2.7
Dust, Dirt, and Miscellaneous	3.8
	100.0

6. Municipal Refuse Disposal, Op. Cit., Page 46.7. Handbook of Environmental Control, Volume II, "Solid Waste", CRC Press, Cleveland, Ohio, 1972, Page 7.

Table III-8. Solid Waste Model

Item	Quantity (LB/Day)	Percent By Weight	Typical Household
Paper	4.09	40.9	Newspaper, Magazines
Glass	0.86	8.6	Bottles
Ferrous Metals	0.73	7.3	Cans, Nails, Bottle Tops
Non-Ferrous Metals	0.07	0.7	Cans, Foils
Plastics	0.16	1.6	Gallon Containers, Pens, Vinyls
Leather, Rubber, Wood	0.66	6.6	Saw Dust, Pencils, Shoes
Yard Wastes	1.40	14.0	Glass Clippings, Leaves
Food Wastes	1.68	16.8	
Misc. Including Textiles	0.35	3.5	Rags
	10.00	100.0

Figure III-2. Projected Heating Value of Mixed Municipal Refuse

C. HOUSEHOLD WATER USAGE

Water consumption rates have been found to vary widely in previous studies. Some of the parameters which have a direct impact on water use rates have been assessed by Reference 9 as the following:

- a. Economic Standard of the Home/Community
- b. Number of Dwelling Unit Occupants and their Ages
- c. Regional Location (Environmental Conditions)
- d. Type of Domestic Wastewater Removal System
- e. Water Pricing Policy - Measurement Method
- f. Dwelling Type and Provisions

9. Murray, R. W., "Water Recovery and Solid Waste Processing For Aerospace and Domestic Applications", General Electric Company, May 1973, Page I-8.

In the future, as water becomes in more critical supply, political and legislative pressures may also be exerted, as well as increased social pressures by citizens awakening to the limitations of the natural resource. The recent water shortages in the California area and the resultant response may become more commonplace in the future.

The type of domestic water removal system and water prices have been shown to be definite influences on water consumption rates. Reference 10 found that the per capita use in areas served by septic tanks was 47 gpcd, while apartment dwellers used 62 gpcd. Also, areas in the east served by metered public water supplies used 51 gpcd, similar areas in the west used 67 gpcd and that in areas of flat rates the usage was 66 gpcd.

The assumed baseline model for this study follows the recommendations of Bailey, et al (Reference 11) and is shown in Table III-9.

Data from other sources, while showing some variation in individual appliance usage, generally agree with Reference 11 as to the total daily household usage. Reference 12 cited data on domestic water use in the city of Denver as shown in Table III-10, and also information developed by the United States Geological Survey as shown in Table III-11.

A hypothetical water use pattern is shown in Figure III-3 for the baseline model. This is patterned after that developed by Reference 13 and incorporates the following assumptions. The dishwasher is used 1.5 times per day at an average water usage of 10 gallons of water per use. The washing machine is operated once per day at 35 gallons per use. Toilet flushing has been assumed to use 5 gallons per flush corresponding to 20 flushes per day. Other water uses and number of uses per day were directly incorporated into the hypothetical water use pattern.

10. Guarnei, C. A., A. Reed, and R. E. Renman, "Study of Water Recovery and Solid Waste Processing for Aerospace and Domestic Applications", Volume II, Grumman Aerospace Corporation, Bethpage, New York, December 1972, Page 1-14.
11. Bailey, J. R., et al, "A Study of Flow Reduction and Treatment of Waste Water From Households", Department of the Interior, Federal Water Quality Administration, December 1969.
12. Murawczyk, C., and D. C. Ihrig, "Water Recovery and Solid Waste Processing For Aerospace and Domestic Applications", Martin Marietta Corporation, January 1973, Page 10.
13. Murray, R. W., Op. Cit., Page I-7.

Table III-9. Domestic Water Usage Model

	FAMILY WATER* USE GPD	HOT WATER USE GPD
DISH WASHER	15	15
GARBAGE DISPOSAL UNIT	3	0
OTHER KITCHEN	9	9
UTILITY SINK (CLEANING)	5	4
LAUNDRY	35	26
BATHING	80	60
LAVATORY	8	1
TOILET	<u>100</u>	<u>0</u>
	255	115

*SOURCE: J. R. BAILEY et al - A STUDY OF FLOW REDUCTION & TREATMENT
OF WASTE WATER FROM HOUSEHOLDS, DEPT.
 OF INTERIOR, FWQA 1969

Table III-10. City Of Denver Household Water Use (11)

Item	Family (4 members) Use (Gallons Daily)	% of Total
Drinking and Kitchen	10	4.3
Dishwasher	16	6.9
Toilet	80	34.3
Bathing	72	30.9
Laundering	40	17.1
Miscellaneous	15	6.5
Total	<u>233</u>	

Table III-11. U.S. Geological Survey Information (11)

Usage	Family (4 members) Use (Gallons Daily)	% of Total
Toilet	100	38.5
Bathing	80	30.7
Laundry	40	15.4
Kitchen	28	10.8
Lavatory	8	3.1
Utility	4	1.5
Total	<u>260</u>

Figure III-3. Daily Household Water Demand

D. SEWAGE

The term "sewage" implies inclusion of all materials flowing from the house through a sewer pipe connection. However, as water becomes more valuable and waste disposal more difficult, it will become more common to differentiate the waste water sources, as has been done in this study.

The heavily contaminated portion of sewage termed "black water" is made up predominantly of toilet wastes and includes urine, feces, and the associated waters used for flushing these waste products. Food wastes and flushing waters from a garbage disposal are also considered in this category¹⁴.

The more lightly contaminated portion of sewage is made up of effluents from the dishwasher, kitchen and utility sinks, clothes washer, bath and shower, and the lavatory. This contribution is referred to as "grey waters" to indicate the reduced amount of contaminants present. The effects of separating out only the toilet wastes from the household wastewater substantially improves the effluent quality as shown in Table III-12 and is important to the selection of design concepts for the disposal or treatment of these materials.

Table III-12. Effect Of Toilet Waste Segregation on House hold Wastewater¹⁵.

Parameter	% Reduction
BOD ₅	22-49
Suspended solids	36-67
Total Phosphorus, P	14-42
Total Kjeldahl Nitrogen, N	68-99

14. Fair, G. M., Geyer, J. C., and Okun, D. A. Water and Wastewater Engineering, Volume 2, Water Purification and Wastewater Treatment and Disposal, John Wiley and Sons, Inc., New York, 1968.

15. Otis, R. J., et al, "On-Site Disposal of Small Wastewater Flows", University of Wisconsin, Madison, Wisconsin, 1977, Page 47.

Human body wastes, which constitute a major source of the black water contaminants, are excreted in quantities which vary according to sex, health, age, and nutrition. Urine is excreted in amounts which range from 500 grams for females to 1,500 grams for males. (Reference 16) This information agrees reasonably well with that from source 17 which is presented in Table III-13 below.

Table III-13. Urine Output For Various Subjects

<u>Subject</u>	<u>Urine Volume/24 Hours</u>
Children 1 - 3 Years	500 - 600 ml
3 - 5 Years	600 - 700 ml
5 - 8 Years	650 - 1,000 ml
8 - 14 Years	800 - 1,400 ml
Adults	600 - 1,600 ml

The HECSS baseline for urine was derived from the above table considering the household to be composed of 2 adults and 2 children - one child in the 8-14 year old classification and the second in the 3-5 year old category. Using the average value for each the resultant daily production was found:

$$\begin{aligned}
 2 \text{ Adults} &= 2 \times 1200 &= 1200 - 3200 \text{ ml} \\
 1 \text{ Child (8-14 Year Old)} &= &800 - 1400 \text{ ml} \\
 1 \text{ Child (3-5 Year Old)} &= &\underline{600} \quad \underline{650} \text{ ml} \\
 &&2400 - 5300 \text{ ml or} \\
 &&.63 - 1.49 \text{ gallons per day}
 \end{aligned}$$

Feces production shows a similar variability as that experienced for urine. Reference 17 cites mean values of 150 grams per day for those on mixed intake of up to 370 grams per day for vegetable diets. These values are in agreement with the general range of those found in Reference 18 from which the following table was drawn.

16. Muraurzyk, C., Op. Cit., Page 16.

17. Webb, P., Bioastronautic Data Book, National Aeronautics and Space Administration, Washington, D. C., 1964, Page 219.

18. Handbook of Environmental Control, Op. Cit., Page 81.

Effective conversion of potential energy to useful energy it is critically dependent upon the efficiencies of the conversion process, and the end form of the energy. Restated, the second law of thermodynamics implies that energy has a "quality" about it and that this quality can only be consumed as energy is used to perform work. The real measurement of available work in a system is an index that takes into account the quantity and quality of energy.

Accordingly, while the overall quantity of potential energy available for household conservation is significant its quality is a critical constraint that must be carefully considered. For example, the waste heat from hot water, while available, is of moderate quality because of its low temperature difference for various applications such as hot water heating. Alternatively it could be highly effective for reverse cycle air conditioning. The same is true with various techniques for energy extraction. For example sewage under aerobic conditions has a conversion efficiency of less than 60%. As methane the output would provide approximately 3 cubic feet of low grade gas per family day or the equivalent of a 100 watt light burning for 3 hours.

A major aspect of this study has been the attempt to relate the sources of energy and their quality to a system that is maximally compatible with both. Consideration has been given for example to the benefit of a single system that operates year round, rather than seasonally for heating which might require stock piling. Emphasis has also been placed on defining an integrated process that provides good conversion for the wide variety of energy sources within the home.

While the study has concentrated on energy availability, transformation and usage consideration has also been given to the economics and societal impacts of the design solution. Without these considerations a meaningful design must surely run afoul of barriers to implementation in these areas. To that extent, benefits directly related to economic and societal factors have been considered. For example, the opportunity and value of utilization of lands not presently considered suitable for sewerage or conventional septic tanks has been considered and utilized in an economic benefit analysis.

Table III-14. Human Fecal Output

<u>Diet</u>	<u>GM/Day</u>
Adults	
Mixed Diet	60 - 250
Vegetable Diet	370
Meat Diet	54 - 64
In Disease	500 - 1,200
Infants	4 - 120
Young Children	60 - 150

Using the above information for the four person household, the following baseline was formulated:

2 Adults = 2 x 160	=	320 grams
1 Child (8-14 years)	=	150 grams
1 Child (3-5 years)	=	<u>100</u> grams
570 grams or 1.26 pounds per day or the equivalent of 1.2 mbtu/year (dry)		

By integrating the fecal, urine, and food waste information into the water usage model, the baseline shown in Figure III-4 was established. This figure also displays the sources of black water waste and grey water wastes.

A household hydrograph developed by Reference 9 is shown in Figure III-5. This figure, which is representative of a 255 GPD water use mode, displays the ultimate use of the water supply by breaking it down into hot and cold grey and also black water.

The makeup of wastewaters as delivered from the various contributing sources is presented in Table III-15, as drawn from Reference 19. This table also presents the temperature of these wastewaters, the majority of which are low in terms of their energy content.

19. Otis, R. J., et al, Op. Cit., Page 45.

Figure III-4. Baseline Water Use Model *

255 GPD

Bailey et.al.; FKQA, 1969 (modified)

Figure III-5. Household Hydrograph - 15 Minute Flows

Table III-15. Mean Wastewater Contributions From Household Events, MG/Capita/Day (18)

Event Parameter	Fecal toilet flush	Nonfecal toilet flush	Garbage disposal	Kitchen sink usage	Automatic dish washer	Clothes washer- wash	Clothes washer- rinse	Bath/shower
BOD ₅ U	4340	6380	10900	8340	12600	10800	4010	3090
BOD ₅ F	2340	3980	2570	4580	7840	6970	2840	1870
TOC U	3530	4250	7320	5000	7280	7700	2610	1750
TOC F	1580	3170	3910	4110	4690	5380	1910	1130
TS	10700	17800	25800	13800	18200	37500	10900	4590
TVS	7760	12000	24000	9730	10500	14700	4800	3600
TSS	6240	6280	15800	4110	5270	7930	3040	2260
TVSS	5090	5120	13500	3840	4460	4700	1810	1580
TOT-N	1500	2640	630	420	490	580	150	310
NH ₃ -N	590	520	9.6	32.3	54	19.4	11.4	40
NO ₃ -N	6.3	21.1	.2	1.8	4.1	17	10.3	7.4
TOT-P	270	280	130	420	820	1600	550	36
ORTHO-P	120	190	90	180	380	410	110	20
Temp. °F	66	66	71	80	101	90	83	85
Flow (gal)	4.3	4.3	3.8	4.8	12.0	15.7	14.4	13.0
No./samples	32-40	24-37	4-7	7-11	13-15	24-27	24-28	18-24

U = Unfiltered Sample

F = Sample was filtered through Whatman No. 2. Filter Paper prior to analyses.

E. ENERGY VALUES FOR THE RECOVERY/DISPOSAL OF WASTES

Any evaluation of household waste energies for conservation or reclamation must consider the energies that may be required for their ultimate disposition. Accordingly, the energies associated with solid waste include the energy potential in the waste for reclamation and the energies required to transport, process and/or ultimate dispose of residues.

This is equally true for liquid waste. Here, the number of energy variables to be considered is impacted by water usage since it is the most generally accepted form of transport. Also related to energy values of liquid wastes is the use/recovery of the energy values associated with hot water.

The purpose of this section is to assess the energy required for the disposal of waste products, principally sewage and solid wastes, to identify the potential energy value of wastes and wasted energy, i.e. hot water and water and to compile these values for the baseline model. This will then serve as a starting point to measure the worthiness of candidate household energy, conversion systems. Since it may be argued that in order to be a viable alternative to a homeowner, the recommended device/subsystem/system must show a benefit in terms of dollar savings, cost data is also included to provide guidelines for economic factors affecting system design alternatives and implementation.

The first area to be examined is the water supply to the household. The baseline model shows a flow of 255 GPD. Previous studies have shown that water savings are possible by using water conserving devices and techniques. Typical water conserving devices include reduced flush toilets, restricted flow shower heads, and automatic faucet shut-offs. Many techniques for water saving are available, however, a conservative approach as taken by this study, is to limit the applicable technique to use of grey water for toilet flushing. Other techniques not considered include reuse of treated grey water for the laundry and utility areas, as well as recycling of rinse waters to be used as wash water for the laundry and dishwashing functions. Recirculation of grey water for toilet flushing would save approximately 100 GPD or 36,500 gallons per year. Assuming that this is reduced somewhat by vacations, time spent away from the home and water lost during processing, a conservative value might be 30,000 gallons per year. If a value were placed on water of \$1.00 per 1,000 gallons, then the recirculation technique presents a potential cost savings of \$30 per year. (20)

20. Personal Communication, George Kraft, Technical Director American Water Works Association, February 1978.

Hot water usage is a second area which previous studies have shown to hold a potential for reduced usage. Typically after a hot water faucet is opened, the user then opens the cold faucet to modulate the temperature to a comfortable level. The fact that present hot water temperatures of 140°F are excessive was affirmed when a doctor warned on local radio that water temperatures of 130°F for several seconds could cause burns on small children. Water saving devices also effect a reduction in hot water usage as well as total water usage.

From Table III-9, Page III-12, the baseline water model for this study, it can be seen that the amount of hot water required per day is 115 gallons. The energy requirement is then:

$$115 \text{ GPD} \times 365 \text{ days} \times 8.3 \frac{\text{pounds}}{\text{gallon}} \times 1 \frac{\text{Btu}}{\text{pound}} \times 80^{\circ}\text{F temp rise} = 27.9 \text{ MBTU}$$

In order to arrive at a potential for energy savings at this point, it is necessary to make some assumption as to how much hot water savings can be obtained. It will be assumed, at this point, that a 10% reduction in hot water usage may be accomplished through water saving devices and techniques. Thus, the hot water requirements will be 104 gallons per day for this assumed savings. Secondly, a drop in water use temperature from 140°F to 130°F results in another potential savings.

The potential savings then for:

- (a) Reduced hot water flow (10% reduction)
- (b) Reduced end use hot water temperature (10°F)

is calculated by:

$$\begin{aligned} \text{Original Energy Required (115 FPD \& 80}^{\circ}\text{F rise)} &= 27.9 \text{ MBTU} \\ 104 \text{ GPD} \times 365 \text{ days} \times 8.3 \times 1.0 \times 70^{\circ}\text{F} &= \underline{22.1} \\ &5.8 \text{ MBTU} \end{aligned}$$

In terms of percentage, the potential assumed savings of energy is $\frac{5.8}{27.9} \times 100 = 20.8\%$

The model described on Page III-3 utilized a gas hot water heater. The potential cost savings for the assumed hot water savings as generated by the gas fired hot water heater is shown. However, due to the short supply of natural gas and restrictions on new use, the cost savings for oil and electricity hot water heaters are also presented.

Gas Cost/MBTU = \$1.69 (21)

Conversion Efficiency = 70%

1 MBTU $\approx$ \$2.41

Using this rationale, the 5.8 MBTU assumed energy savings is approximately equal to an annual cost savings of \$14.00.

In relating energy to costs, the following approach for oil is utilized:

Fuel Oil Heating Value = 19,376 BTU/lb (22)

Conversion Efficiency = 70%

Fuel Oil Cost = \$.40 per gallon

$19,376 \frac{\text{BTU}}{\text{lb}} \times 7.43 \frac{\text{lb}}{\text{gallon}} \times 0.70 = 100775 \frac{\text{BTU}}{\text{gallon}}$

1 MBTU $\approx$ \$4.00

Using this rationale, the 5.8 MBTU assumed potential energy savings is approximately equal to an annual cost savings of \$23.

The cost to the homeowner using electrical energy for hot water heating may be computed as follows:

$\frac{5.8 \text{ MBTU}}{3,415 \text{ BTU/KWH}} = 1698.4 \text{ KWH}$

@ \$.04/KWH, the cost is \$68 per year

21. Gas Facts 1975, American Gas Association, 1515 Wilson Blvd., Arlington, Virginia, Page 115.

22. Baumeister, T., Marks' Standard Handbook For Mechanical Engineers, Seventh Edition McGraw-Hill Book Company, New York, N. Y., Page 7-22.

For electrical heat, this is not the entire story, however, as the inefficiencies in generation and transmission end up costing approximately 10,500 BTU/KWH. Therefore, back at the power plant:

$$1698.4 \text{ KWH} \times 10,500 \frac{\text{BTU}}{\text{KWH}} = 17.83 \text{ MBTU}$$

Or, stated another way, the heating value at the home required to produce 5.8 MBTU for hot water heating requires the expenditure of 17.83 MBTU at the power plant in order to provide the electrical power for such heating.

The energy value as feces may be calculated using the baseline model.

Feces generated per day	=	1.26 pounds
Solids content	=	34% or 0.43 pounds/day
Energy content	=	7668 BTU/pound of solids

$$0.43 \frac{\text{pounds}}{\text{day}} \times 365 \frac{\text{days}}{\text{year}} \times 7668 \frac{\text{BTU}}{\text{pound}} = 1.2 \text{ MBTU/year}$$

At \$4.00/MBTU, the maximum energy value from feces, considering 100% conversion in a combustion process and ignoring the moisture, is \$5.00/year.

If we consider moisture vaporization for this combination process, then the energy value is considerably less:

$$(1.26 - 0.43) \text{ pounds moisture} \times 1040 \frac{\text{BTU}}{\text{pound}} = 863.2 \text{ BTU/day}$$

$$863.2 \frac{\text{BTU}}{\text{day}} \times 365 \text{ days} = 0.315 \text{ MBTU/year (Required for Moisture)}$$

$$1.2 \text{ MBTU} - 0.315 \text{ MBTU} = 0.885 \text{ MBTU/year Gross Energy}$$

If we now assume a 70% combustion efficiency, then the net energy is:

$$0.885 \text{ MBTU/year} \times 0.70 = 0.62 \text{ MBTU/year}$$

At \$4.00/MBTU, the energy value is

The energy value of solid wastes and food wastes may be estimated by using the baseline model, the solids content of the specific item and the heating value of the various materials. Table III-16 was derived for the baseline using calorific values for each of the various categories. Metals and glass are assumed to have no value as to convertible energy content at the household level, although they have salvage value. From the resultant 50,811 BTU/day must be subtracted the energy required to vaporize the attendant moisture, in order to arrive at a net available energy figure.

A combustion process, as yet undefined, is considered at this point for the disposal/energy recovery of solid wastes. Drying of the material of normal moisture is considered to be accomplished thermally, since other approaches potentially have serious impacts.

Air drying of the wastes could be accomplished at a reduced loss of net available energy over that for thermal drying. This would require, however, that a separate area be set aside for drying with attendant storage of drying materials, pest control, etc. If the air drying were to be accomplished in a bin, for example, then mechanical agitation and forced ventilation would be necessary which would require additional equipment and energy expenditure as well as increased involvement by the homeowner. Air drying was not considered therefore to be feasible because of the equipment and operator involvement necessary as well as the power required to process the small quantity of waste involved.

1040 BTU per pound is the energy required to vaporize moisture in this combustion process at approximately 95°F.

$$\frac{2.302 \text{ pounds moisture} \times 1040 \text{ BTU}}{\text{pound}} = 2,394 \text{ BTU/day}$$

$$(50,811 - 2,394) \times 365 \text{ days} = 17.7 \text{ MBTU}$$

year

Assuming this combusted at an efficiency of 70%, then the resultant available energy content is:

$$17.7 \times .7 = 12.39 \text{ MBTU, which at } \$4.00/\text{MBTU} \text{ has a value of approximately } \$50.$$

Table III-16. Energy Values Of Solid Wastes

	Total Weight <u>lb/Day</u>	Dry Weight <u>lb/Day</u>	Moisture <u>lb/Day</u>	Calorific Value <u>BTU/lb</u>	Energy <u>BTU/Day</u>
<u>Trash</u>					
Paper	4.09	3.673	0.417	7,572	27,812
Plastics	0.16	0.157	0.003	14,368	2,256
Leather, Rubber, Wood	0.66	0.594	0.066	9,598	5,701
Miscellaneous Including Textiles	0.35	0.315	0.035	7,652	2,410
<u>Food Wastes</u>					
Garbage	1.40	0.392	1.008	8,484	3,326
Fats	0.28	0.28	-----	16,700	4,676
<u>Yard Wastes</u>					
Grass	0.467	0.163	0.304	7,693	1,254
Brush	0.175	0.105	0.070	7,900	830
Greens	0.175	0.067	0.108	7,077	474
Leaves	0.583	0.292	0.291	7,096	2,072
	<hr/> 8.34	<hr/> 6.038	<hr/> 2.302		<hr/> 50,811

Urine contains approximately 5% solids with a nominal energy value. While theroretically it would be possible to extract the solids using natural evaporation, any means employing heat energy would be self defeating because of the large quantities of water involved. Natural evaporation on a year round basis is not considered practical at this time.

Waste waters from the household have an energy value in that the waste temperature, in several cases, are above ambient and could therefore be used for processes requiring lower quality energy, such as hot water preheating. Utilization of waste water energy for space heating has limited applications. The supply temperature for hot water used for space heating is generally 150-200°F with a temperature drop of 20° in the heating panel considered as a norm. Thus the lowest system temperature is 130°F, well above any waste temperatures. Warm air furnaces generally have a bonnet supply temperature of 150°F up to a maximum of 200°F, with the return air temperature at room temperature. Thus, some potential exists for using waste waters for preheating air in a warm air furnace, but the low temperatures of wastes present a small potential for this application. The highest waste water temperature, as shown in Table III-15, is 101°F. Possibly the wastewater temperatures would be advantageous for use with a heat pump in homes so equipped.

Domestic hot water is currently supplied at approximately 140°F. As previously noted, this is an excessive and wasteful practice. Reference 23 recommends a 120°F supply temperature, with a 80°F temperature rise, and assumes the temperature of the incoming water at approximately 40°F. Integrated over a year temperatures may be somewhat higher, however, this figure has been used as a design baseline.

If it assumed that the energy in the wastewater may be recovered down to approximately 75°F, allowing for losses and system inefficiencies, then the potential may be estimated through the use of Table III-15.

23. "Installation Standards for One and Two Family Dwellings and Multifamily Housing Including Solar", The Better Heating & Cooling Bureau, Sheet Metal and Air Conditioning Contractors' National Association, Inc., Vienna, Virginia, 1977.

<u>Event</u>	<u>Wastewater Temp.</u>	<u>ΔT</u>	<u>GPD</u>	<u>BTU/Day</u>
Kitchen Sink	80°F	5°F	12	498
Dishwasher	101	26	15	3,237
Clothes Washer-Wash	90	15	18	2,241
Clothes Washer-Rinse	83	8	17	1,129
Bath/Shower	85	10	80	6,640
				<u>13,745</u>

Over a year period, the energy potential is:

$$13,745 \text{ BTU/day} \times 365 \text{ days} = 5 \text{ MBTU}$$

At the cost of \$4.00 per MBTU, this represents an annual value of \$20.

A survey of local trash disposal services for suburban areas showed a range of from \$4 per month to \$12 per month. One service charged \$4 per month for a pickup at the curb of once per week. Two services charged \$8 per month for that same service. A further service charged \$10 per month for a twice per week pickup, while a fifth charged \$12 per month. An average value of \$10 per month was assumed for this service, with the knowledge that this cost may vary widely depending upon the service, the proximity to a dumping area, the availability of land-fill operations, and inflationary factors for fuel, machinery, etc.

A summary of the above which reflects a potential annual baseline value of an integrated system is shown in Table III-17. Note that these are not absolute values, but rather a relative figure which can be used to gauge the economic viability of systems. The values are also variable, depending on the final system derived. For example, if no solid waste were recovered in the final system, then no value would be recovered, and disposal would be required for a cost, not a credit, of \$120. If the system recovered the energy in the solid wastes and in so doing produced a group of non-combustibles high in value (composed of reclaimable metals, glass, etc.), then the trash pickup could possibly be at no cost to the homeowner. The net value under this scenario would be \$170.

Table III-17. Waste Value

	<u>Potential Value</u>		<u>Disposal Cost</u>	<u>Total</u>
	<u>BTUM</u>	<u>\$</u>	<u>\$</u>	<u>\$</u>
Solid Waste	17.7	50	120	170
Sewage	1.2	2.5-5	60-120	65
Water (Reduction Recycling)	-	30		30
Water Heating - (20% Reduction)	5.6	23		23
Waste Water - Energy Reclamation	5.0	20		20
				\$308

F. GUIDELINES

When deriving alternate systems and subsystems for household use, it is mandatory to have a "set of rules" as to what may or may not be acceptable. The goal of this study has been to create an effective system which would be acceptable for integration into the "typical" single family residence by current standards of aesthetic and socially amenable habits. While realizing that this is a highly subjective topic, the following guidelines have been formulated and used on this study:

1. The life style will be minimally impacted where aesthetics are not affected and the change can be rationalized as "reasonable" to achieve resultant savings.
2. Public acceptance would probably be lacking for any change which would involve direct reuse of waste waters where direct body or oral contact is involved.
3. Source separation of solid waste into combustibles and noncombustibles by the home occupants is acceptable.
4. The residential baseline model is a starting point. Water savings devices, etc. which cause a reduction in energy and supply requirements may impact the baseline to a reasonable level, so far as item #1 is achieved.

IV SOLID WASTE ENERGY CONSERVATION

Commercial solid waste systems provide a base for examining existing techniques for the reclamation/conversion of solid waste energies. While some of these disposal systems are limited in applicability - some have enjoyed success and offer a starting point for evaluating single family applications and these processes have been examined for that purpose.

A. COMMERCIAL SOLID WASTE SYSTEMS

For energy recovery, solid waste processes may be broken down into three energy conversion methodologies; thermal, mechanical and biological. Table IV-1 summarizes the major alternative processes presently in use.

It will be noted that no potential for energy recovery exists for mechanical solid waste treatment processes. Likewise the complexity and limited state-of-the-art knowledge mitigate against serious consideration of the pyrolytic processors.

Incineration as used in this study is defined in terms of systems for the disposal of solid wastes only. It is recognized that many such systems do employ heat recovery. Even so, such systems are geared to reducing the total energy for the destruction of wastes rather than effecting a net energy recovery. As such they are not considered further.

In summary, the examination of conventional practices employed in the treatment of solid wastes provides an understanding of the

- Major alternatives for waste energy recovery.
- Multiple steps of the process, i.e. of preparation of materials for energy recovery, transport to the energy converter, and energy conversion.
- Necessity to preprocess materials by segregating combustibles for direct thermal and/or biological conversion from salvagable scrap.
- Necessity to pre-treat combustibles for purposes of improved handling or transport and good decomposition, or burning.

Table IV-1. Major Large Scale Solid Waste Processing Systems

<u>Classification</u>	<u>Process</u>	<u>Description</u>	<u>Reference</u>	<u>Primary Objective</u>	<u>Secondary</u>	<u>Critical Energy Impact Parameters</u>
Thermal	1. <u>Shredding</u> Combustibles segregated, shredded and fired with secondary fuel.		3	Energy Recovery	Waste Disposal	Presence of Moisture
	2. <u>Pulping</u> Combustibles segregated, wet pulped, dewatered fluffed and fired with a secondary fuel.		4	Energy Recovery	Waste Disposal	Presence of Moisture
	3. <u>Incineration</u> Combustibles segregated, waste fired with or without secondary fuel.		9	Waste Destruction	Energy Utilization	Presence of Moisture
	4. <u>Pyrolysis</u> Combustible segregation, shredded and fired at high temperature in absence of air for volatile gas or liquid fuel recovery.		5, 8	Energy Recovery	Useful Energy Form	Process Control
Biological	1. <u>Aerobic-Passive</u> Biodegradables segregated and composted in open air rows with manure inoculant.		7	Non Polluting Waste Destruction	Product Recovery	Heavy Metals
	2. <u>Aerobic-Active</u> Biodegradables segregated and composted in rotating drums with thermophillic bacteria inoculant.		9	Rapid Non Polluting Waste Destruction	Product Recovery	Heavy Metals
	3. <u>Anerobic</u> Methane taps of old solid waste dumps.			Energy Recovery	Useful Energy Form	Heavy Metals
	4. <u>Anerobic</u> Feed lot and farm product wastes composted as agitated slurry for methane production and fertilizer.			Non Polluting Waste Destruction	Energy Recovery	Heavy Metals
Mechanical	1. <u>Area Method</u> Open dumping with light earth cover.			Waste Disposal	Landfill	
	2. <u>Trench Method</u> Waste compaction, trench cut and fill.			Non Polluting Waste Disposal	Landfill	

The applicability of each of the solid waste energy recovery processes and the multiple activities associated with each relative to household systems is described in the following.

B. SOLID WASTE SYSTEM CONCEPTS FOR SINGLE FAMILY RESIDENCE

In developing concepts for a household solid waste energy recovery system the following guidelines were developed and employed. Concepts must:

- Provide for a net energy return.
- Have potential economic effectiveness.
- Provide options for use in combination with liquid wastes.
- Not be dependent upon liquid wastes for operation since they may not be available.
- Assume that "wasteheat" from other sources such as stack is potentially a capturable resource and as such must be accounted for in determining net energy return.

The functional requirements of a solid waste system are shown in Figure IV-1. Waste products are initially separated based upon their suitability in the ultimate energy conversion in the ultimate process. Combustibles are separated from noncombustibles, and large bulky items such as discarded furniture, are set aside for bulk disposal off-site. The degree of separation required will depend upon the downstream processes. For example, glass bottles, if inadvertently placed with combustibles could cause jamming or breakage in a shredder, could fracture in or jam the mechanisms of an automatic incinerator, but might pass thru a compost process without damaging the equipment or causing mechanical problems.

WASTE PRODUCT EXAMPLES**KITCHEN WASTE**

BONES
EGGSHELLS
COFFEE GROUNDS
CORN COBS
BANANA SKINS
BAGS

HOUSEHOLD WASTE

TEXTILES
SHOES
NEWSPAPERS
MAGAZINES
PENCILS
OVERSHOES
GALLON PLASTIC JUGS
BOTTLE CAPS
ALUMINUM FOIL

YARD WASTE

LEAVES
TWIGS
GRASS
BRANCHES

BULK DISPOSAL WASTE

BELT BUCKLES
NAILS
BOTTLES
CANS
WOOD 72"
LARGE OBJECTS

Figure IV-1. Solid Waste System Functional Requirement

The functions after initial separation are concerned with transport and processing. The transport function may vary from simple manual involvement, as in carrying the refuse to an on-site incinerator to an automate vacuum transport system. Preliminary and final preparation involve elements such as shredding, grinding and pulping to reduce the size of the refuse particles for ease of storage, transport and processing and may also include steps to dewater or dry shredded refuse which has been transported by a liquid system to the final processing area. The use of two stages in preparation provide the opportunity to design for both large and small waste products, i.e. garden and kitchen.

Energy utilization from the energy conversion step may take the form of electrical power or fuel, steam or hot water generation for space heating and/or heating or pre-heating of domestic hot water. The residue from the conversion process must be disposed of either on-site or placed with the bulk disposal items separated in the first step.

Transportation and preparation of the solid wastes may be handled either wet or dry. Parasitic energy is essentially equivalent. The wet system utilizes less power for size reduction in pulping and permits the use of more economic devices to transport solids. However, this type system incurs a penalty if the refuse is to be fired, since an additional dewatering and drying step is required.

The interactive variations of the foregoing are shown in Figure IV-2. The dashed line indicate the interfaces that are capable of being quantized over preliminary screening reflecting the basic alternatives has been accomplished. These relationships shown by the solid lines in Figure IV-2.

Waste Preparation

Table IV-2 summarizes the major alternatives for solid waste preparation prior to the energy recovery/conversion step.

Figure IV-2. Waste Preparation Concept Development Relationships

Since the efficiency of net energy conversion depends not only on the energy conversion process but also on the handling and preprocessing of materials. The information has been categorized in these terms, i.e. wet or dry preparation. Within these categories exist major alternatives relative to wet processing, i.e. water, oil or hot wax each of which has further implication for materials preparation.

The term shred is used to identify a method for reducing the size of waste products thereby providing a material with greater surface area and size uniformity to aid in such storage, transport and energy conversion. Similarly, pulp denotes material size reduction and by cutting, tearing or grinding in the presence of a liquid.

The nature of the preparation process also dictates to a degree the potential or requirement for manual or automatic transport of both raw materials or processed materials. For example, trash may be bagged manually for temporary convenience and then compacted and manually transported to a combustor. Alternatively trash might be placed directly into a compactor, and after compaction transferred automatically for conversion. The "USE" column distinguishes relationships with automatic manual handling. In addition it suggests major limitations or application for employment of the waste in energy conversion.

Table IV-2. System Concepts - Solid Waste - Preparation

Category	Concept	Use	Applicability	Pro's	Con's
DRY SYSTEM	Compact and Package	Manual, fire within 3-5 days	Minimum wet material organics	Conventional	Decomposition of materials, Bag Cost
	Shred and Package	Manual, fire within 3-5 days	Same	Potential for Biocide addition improved	High parasitic energy load
	Bag Combustibles	Manual, fire immediately	Same	Simple	Decomposition of materials, lack of uniformity for firing
	Shred or bag shred	Compost (aerobic) feed stock with energy recovery	Accepts wet materials	Simple	Minimum
	Bag Combustibles with special combustion bag	Manual, fire within 2-3 days	Same	Improved firing and ash reduction	Bag cost, Decomposition
	Direct fire combustibles	Real time manual firing	Same	Convenient	Combustibility, safety hazards, sanitation
	Bag, shred with UV light	Automatic, fire as needed	Minimum wet material moderate organics	Convenient, good sanitation	UV effectiveness, cost and energy requirements
	Shred compact	Automatic, fire as needed	Minimum wet material	Convenient	High parasitic energy load
WAX SYSTEM	Compact and Package Combustible with Wax/Biocide	Manually store and fire as needed	Minimum wet material and organics	Storability, Combustibility	Partial biocidal mixing only
	Shred, Compact and Package with Wax/Biocide	Manually store and fire as needed	Moderate wet material and organics	Dense, stable package, good combustibility	Two step system
	Shred with hydrocarbon/biocide (Bulk Storage)	Bulk store and fire as needed	Moderate wet materials and organics	Stable materials	Containers handling storage and feed equipment complexity

Table IV-2. System Concepts - Solid Waste - Preparation (Continued)

Category	Concept	Use	Applicability	Pro's	Con's
WET SYSTEM (WATER)	Bag, Wet Shred/pulp with Biocide, spin and press dry (50%), break. Fire with progressive drying or	Automatic; fire as needed Store as slurry	May accept wet material and glass/cans, which may be settled out, and removed	Clean, sanitary, low manual involvement	Storage container Dewatering cost. New equipment developments
	Compost, (anerobic)	Compost (anerobic) feed stock with heat recovery			Low energy recovery potential
WET SYSTEM (OIL)	Bag, dry shred, pulp with oil and biocide, fire as a slurry	Automatic - store as slurry, fire as needed	May accept glass, cans and moderate wet materials	Clean, maximum energy extraction	Storage container, new equipment development
	Dry shred, pulp with oil, fire as a slurry	Automatic - store as slurry, fire as needed	Glass and cans may be settled out or removed	Low manual involvement	Shredder sanitation. New nozzle design

Major conversion constraints for each prepared waste are shown under "applicability". The primary distinctions are with regard to moisture content and waste not readily converted in a household system. This information has been used as a guide to aid in segregation of more detailed preparation scenarios discussed under component concept.

In an effort to overcome this disadvantage, a wet system using a combustible oil may be considered. The resulting slurry may be stored in a manner similar to fuel oil and fired as required. However, fine reduction of the refuse is required and a new firing nozzle design is required.

Dry processes introduces minimal additional equipment, but may incur problems with material decomposition in storage. While sterilization techniques such as ethylene oxide or elevated temperatures could be used to avoid these problems, both add significant penalties. To overcome this problem and to increase the caloric content of the fired material, a system using wax encapsulation may be considered. This minimizes the decomposition process but adds storage and handling complexities.

C. COMPONENT CONCEPTS FOR SOLID WASTES

For each of the functional requirements shown in Figure IV-1, alternative mechanisms for the processing of solid wastes were defined as shown in Table IV-3. A description of each mechanism is provided following together with power requirements and cost estimates.

Where no mechanism was readily identifiable as off-the-shelf, a design concept was developed and estimates prepared for power and cost. (Energy requirements are shown later in Table IV-4 where they are developed based upon operating times or duty cycles.)

Once the mechanisms were defined and estimated certain decisions were made regarding their applicability. It was immediately obvious that the automatic separation of wastes (1.0) was impractical for the small loads generated by a household and that source separation by the occupants would be required. The next conclusion as a result of this was that the feed/transport step to the preliminary preparation process should be manual, i.e. the householder would manually move the refuse to the first processing step. (2.0)

Table IV-3. Mechanisms For Processing Solid Wastes

1.0 Waste Segregation	2.0 Transports & Feed	3.0 Preliminary Preparation		4.0 Transport & Feed	5.0 Final Preparation	6.0 Energy Conversion
		Process	Vehicle			
Manual or Automatic	Manual or Automatic	Compact	Air	Gravity Blower	Compact	
		Shred	Oil	Vacuum Pump	Shred	Fire as a Slurry
		Pulp	Water	Auger	Pulp	Fire as a Solid
		Soak & Pulp	Wax	Ram	Deoil	Fire as a Solid
		Shread & Pulp		Conveyor Flipper Vibrator	Dewater Various Combinations	Anerobic Compost
		Compost None transport only			None transport only	Aerobic Compost

It will be recalled that the two step processing approach is based on the potential to accommodate bulky yard wastes as well as kitchen waste, generally the preliminary processes required for systems that include yard waste. As a result pulping, was deleted as a preliminary process (3.0) since it was determined that at least a coarse shredding would be required to avoid very high pulping power requirements. A combination of a coarse shred and pulping operation was added that coarse shreds the material, allows it to soak and then pulps with a liquid at low power.

Composting the material directly as received, was also eliminated since some size reduction and mixing was determined to be required in order to allow intimate contact between the required elements to obtain reasonable decomposition periods.

Wax as a vehicle during preliminary preparation was also eliminated. No such system presently exists, while it offers potential benefits in controlling bacteria, facilitating processing and transport and utilization of a low cost fuel significant development work would be necessary.

Various mechanisms for the transport function (4.0) were also deleted including vacuum, air, gravity, vibration and flipper. These were considered to add an unacceptable degree of complexity and the potential for low system reliability. Firing as a slurry was also rejected within the energy convenience function (6.0). No burner nozzle could be located which would function satisfactorily in this application. This is an area of ongoing interest and slurry firing should be reexamined for applicable equipment in the future.

The use of air to transport fuel for firing was also rejected because of lack of existing state-of-the-art on home size systems and limited experience in larger systems.

For the 28 mechanisms that remained after the initial evaluation process, daily duty cycles were estimated based on processing the average daily household output at 8.34 pounds of waste materials. The processing times were translated into energy utilization based upon the power requirements. A summary of this data is presented in Table IV-4.

Table IV - 4

Equipment Summary Table

Item No.	Description	Cost \$	Power HP	Duty Cycle Min/Day	Energy BTU/Day
3.1	Shredder	500.00	3	5	1000
3.2	Pulper	100.00	0.5	10	260
3.3	3.1 and 3.2	600.00	3.5	15	1260
3.4	Compactor	190.00	0.33	5	130
3.6	Composter	463.00	0.033 Avg.	Fan-cont Motor-60	1966
3.7	3.1 and 3.4	690.00	3.33	5	1130
3.8	3.1 and 3.6	963.00	0.048 Avg.	Fan-cont Motor-60 Shredder-5	2966
4.1.1	Air Transport	150.00	0.25	10	106
4.1.2	Vacuum Transport	265.00	1.8	10	763
4.1.3	Pump	65.00	0.25	5	53
4.2.1.1	Conveyor	278.00	0.25	10	106
4.2.1.2	Auger	200.00	1/6	60	424
5.2	Fine Shredder	150.00	1	10	425
5.3	Same as 3.1	180.00	1.5	5	500
5.4	Fine Pulper	100.00	0.25	10	130
5.4.1.1	Dewater - Mechanical	250.00	0.75	15	317
5.4.1.2	DeWater - Thermal	210.00	0.125	140	731
5.4.2	Deoil	250.00	0.75	15	317
6.2.2.1	Stoker	200.00	1/6	60	424
6.2.2.2	Ram	175.00	1/3	40	565
6.2.2.3	Conveyor	350.00	1/4	40	424

Table IV - 4

Equipment Summary Table (Continued)

Item No.	Description	Cost \$	Power HP	Duty Cycle Min/Day	Energy BTU/Day
6.2.2.5	Gravity	75.00	0	0	0
6.2.2.6	Shredder/Feeder	180.00	0.5	120	2544
6.2.2.6a	Shredder/Feeder	125.00	1/6	120	845
6.3.1	Compost (3.6)	463.00	0.033 Avg	Fan-cont Motor-60	1966
6.3.2	6.3 and 6.2.2.5	538.00	0.033 Avg	Fan-cont Motor-60	1966
6.3.3	6.3 and 6.2.2.6	616.00	0.074 Avg	Fan-cont Motor-60 Shred-120	4510
6.3.3a	6.3 and 6.2.2.6a	561.00	0.046 Avg	Fan-cont Motor-60 Shred-120	2811

3.1

SHREDDER

Equivalent to common garden model.

Cost: \$500.00 3.0 HP (electric)

3.2

PULPER

Equivalent to household garbage disposal

Cost: \$100.00 1/2 HP

3.3

SHREDDER & PULPER

Combination of 3.1 and 3.2

3.4

COMPACTOR

Equivalent to household compactor

Cost: \$190.00 1/3 HP

3.6

MECHANICAL COMPOSTOR

Cost: \$463.00 1/30 HP (average)

4.1.3 CENTRIFUGAL SLURRY PUMP

Cost: \$65.00 1/4 HP

4.2.1.1 CONVEYOR

Cost: \$280.00 1/4 HP

Web Belt

Bicycle

Housing

Vinyl Covered

Chain

Metal Duct

Nylon

Drive

13" x 12"

12" Wide

4.2.1.2 AUGER

Cost: \$200.00 1/6 HP

Duct Dia. = 4"

4.2.2 VACUUM-DRY SYSTEM

Similar to 4.1.2 - Concept deleted for low reliability.

4.2.3 AIR-DRY SYSTEM

Similar to 4.1.1 - Concept deleted for low reliability

4.3 WAX PROCESS

Eliminated because of complexity

Extra storage tank and wax washer.

3.7 SHRED & COMPACT
Combination of 3.1 and 3.4

3.8 SHRED AND COMPOST
Combination of 3.1 and 3.6

4.1.1 AIR TRANSPORT - WET SYSTEM
Cost: \$150.00 1/4 HP

4.1.2 VACUUM TRANSPORT - WET SYSTEM
Cost: \$2,000.00 1.8 HP

5.2 FINE SHREDDER

Similar to 3.1 except less power.

Cost: \$150.00 1 HP

5.3 COARSE SHREDDER

Same as 3.1

Cost: \$500.00 3 HP

5.4 FINE PULPER

Similar to garbage disposal.

Cost: \$100.00 1/4 HP

5.4.1.1 DE-WATER, MECHANICAL

Cost: \$250.00 3/4 HP

5.4.1.2 DE-WATER, THERMAL

Cost: \$210.00

1/8 HP

5.4.2 DE-OIL

Same as 5.4.1.1

6.2 FIRE

Combination primary and secondary fuel furnace/boiler similar to Riteway Company.

Cost: \$1,800.00 - Hot Air; \$2,800 - Hot Water.

6.2.2.1 STOKER

Cost: \$200.00 1/6 HP

6.2.2.2 RAM

Similar to 5.4.1.1 except cone, wringer and cake breaker are removed.

Cost: \$175.00 1/3 HP Duty Cycle: 40 min.

6.2.2.3 CONVEYOR

Similar to 4.2.1.1 but incorporating fire door.

Cost: \$350.00 1/4 HP

6.2.2.4 PUMP (Deleted)

Associated with Items 4.3 (Wax Process)

6.2.2.5 GRAVITY

Chute connected to furnace, incorporating manual fire door at furnace.

Cost: \$75.00 0 HP

6.2.2.6 SHREDDER/FEEDER

Modification to 3.1

Cost: \$500.00 3 HP

6.2.2.6a SHREDDER/FEEDER

Modification to 6.2.6

Cost: \$125.00 1/6 HP

6.2.2.7 MANUAL FEED

Cost: 0 0 HP

6.3.1 MECHANICAL COMPOSTER

Similar to 3.6

Cost: \$463.00 0.033 HP (AVERAGE)

6.3.2 COMPOST WITH GRAVITY FEED

3.6 + 6.2.2.5

COST: \$538.00 0.033 HP (AVE)

6.3.3 COMPOST WITH SHRED & FEED

3.6 + 6.2.2.6

COST: \$610 0.074 HP (AVE)

6.3.3 (a) COMPOST WITH SHRED & FEED

3.6 + 6.2.2.6 (a)

COST: \$561 0.046 HP (AVE)

The next step in the analysis was to compute the levelized annual cost to operate each component.

In so doing a measure of potential acceptability for alternative systems is established based upon varied component groupings. This measure also provides a yardstick against which other economic indications may be evaluated including such items as impacts caused by escalating fuel/energy costs.

The method used is based on amortizing equipment costs as equivalent annual mortgage payment plus the cost of electricity. The mortgage payment was calculated assuming a 9%, 25 year mortgage by a homeowner is a 25 percent tax bracket. Since interest is tax deductible, the effective after-tax cost is reduced to 6.75%. Table IV-4 lists the annual mortgage payments for each component, which merely represent an additional cost in their basic home mortgage. The levelized cost of electricity was computed by assuming a 6% annual price escalation rate over the 25 year life, from a current price of 5¢/kw hour. The levelized cost is equivalent to that amount which, if placed yearly in an account earning 6.75% interest, would permit annual withdrawals to pay all future electricity costs. It is an effective way to account for future escalation and the time value of money. Summing the mortgage payment and the levelized cost of electricity gives the levelized annual cost in the last column of Table IV-5.

D. EVALUATION

The components were coded according to the flow diagram of Figure IV-3. Various combinations of the components were grouped in the form of potentially viable systems as shown in the matrix of Table IV-6.

For each of these possible system combinations, the component levelized annual costs were then accumulated to arrive at a system annual cost. These system costs were then rank ordered for comparison purposes. These are shown in Table IV-7.

The most obvious fact from this ranking is that maximum manual involvement reduces the overall system costs, as would be expected. As the systems became more complicated, by the addition of shredders, pumps, conveyors, de-oilers, etc. the cost increased accordingly. No complexity or reliability factors were factored into the ranking for the various systems, however, it is felt that the overall cost structure did in fact weigh the results in the same manner as if these factors had been accounted for, i.e. the simpler (and therefore more reliable systems) were highest in overall ranking.

Table IV-5. Component Levelized Annual Costs

	<u>COST</u>	<u>HP</u>	<u>MIN DAY</u>	<u>KW HRS YR</u>	<u>MTG.PMT.</u>	<u>LEVELIZED ELECTRICITY</u>	<u>LEVELIZED ANNUAL COST</u>
3.1	\$500	3	5	68.0	\$ 41.94	\$ 6.52	\$ 48.46
3.2	100	0.5	10	22.7	8.39	2.17	10.56
3.3	600	3 0.5	5 10	90.7	50.33	8.69	59.02
3.4	190	0.33	5	7.5	15.94	.71	16.65
3.6	463	.026 .125	cont 60	209.2	38.84	20.04	58.88
3.7	690	3 0.33	5 5	75.5	57.88	7.24	65.12
3.8	963	3 .026 .125	5 cont 60	277.2	80.78	26.56	107.34
4.1.1	150	.25	10	11.3	12.58	1.09	13.67
4.1.2	265	1.8	10	81.7	22.23	7.83	30.06
4.1.3	65	.25	5	5.7	5.45	.54	5.99
4.2.1.1	278	.25	10	11.3	23.32	1.09	24.41
4.2.1.2	200	1/6	60	45.4	16.78	4.34	21.12
5.2	150	1	10	45.4	12.58	4.34	16.92
5.3	180	1.5	5	34.0	15.10	3.26	18.36
5.4	100	.25	10	11.3	8.39	1.09	9.48
5.4.1.1	250	.75	15	51.0	20.97	4.89	25.86
5.4.1.2	210	.125	140	79.4	17.62	7.60	25.22
5.4.2	250	.75	15	51.0	20.97	4.89	25.86
6.2.2.1	200	1/6	60	45.4	16.78	4.34	21.12
6.2.2.2	175	1/3	40	60.5	14.68	5.80	20.48
6.2.2.3	350	1/4	40	45.4	29.36	4.34	33.70
6.2.2.5	75	-	-	-	6.29	-	6.29

Table IV-5. (Cont'd)

	<u>COST</u>	<u>HP</u>	<u>MIN DAY</u>	<u>KW HRS YR</u>	<u>MTG. PMT.</u>	<u>LEVELIZED ELECTRICITY</u>	<u>LEVELIZED ANNUAL COST</u>
6.2.2.6	\$180	.5	120	272.2	\$ 15.10	\$ 26.08	\$ 41.18
6.2.2.6a	125	.06	120	90.7	10.49	8.69	19.18
6.3.1	463	.026 .125	cont 60	209.2	38.84	20.04	58.88
6.3.2	538	.026 .125	cont 60	209.2	45.13	20.04	65.17
6.3.3	610	.026 .125 .5	cont 60 120	481.4	51.17	46.12	97.29
6.3.3a	561	.026 .125 .06	cont 60 120	299.9	47.06	28.73	75.79

[illegible]

Table IV - 7. Relative Ranking of Solid Waste Processing Concepts

RANK	PROCESS NO.	LEVELIZED ANNUAL COST	DESCRIPTION
1	26	\$ 16.65	COMPACT/MANUAL TRANSPORT/MANUAL FIRE
2	9	48.46	DRY SHRED/MANUAL TRANSPORT/MANUAL FIRE
3	48	48.80	COMPACT/MANUAL TRANSPORT/GRAVITY FIRE
4	27	56.13	COMPACT/MANUAL TRANSPORT/COARSE SHRED/STOKER FIRE
5	25	57.83	COMPACT/MANUAL TRANSPORT/SHRED & FIRE
6	29	65.12	DRY SHRED & COMPACT/MANUAL TRANS./MANUAL FIRE
7	10	67.64	DRY SHRED/MANUAL TRANS./SHRED & FIRE
8	33	68.94	DRY SHRED/MANUAL TRANS./RAM FIRE
9	2	69.58	DRY SHRED/AUGER TRANS./MANUAL FIRE
10	11	69.58	DRY SHRED/MANUAL TRANS./STOKER FIRE
11	1	72.87	DRY SHRED/CONVEYOR TRANS./MANUAL FIRE
12	49	73.40	DRY SHRED & COMPACT/MANUAL TRANS./GRAVITY FIRE
13	36	82.16	DRY SHRED/MANUAL TRANS./CONVEYOR FIRE
14	12	86.50	DRY SHRED/MANUAL TRANS/FINE SHRED/STOKER FIRE
15	4	88.76	DRY SHRED/AUGER TRANS./SHRED & FEED FIRE
16	34	90.06	DRY SHRED/AUGER TRANS./RAM FIRE
17	6	90.70	DRY SHRED/AUGER TRANS./STOKER FIRE
18	22	90.87	SHRED & OIL PULP/PUMP/DE-OIL/MANUAL FIRE
19	3	92.05	DRY SHRED/CONVEYOR TRANSPORT/SHRED & FEED FIRE
20	35	93.35	DRY SHRED/CONVEYOR TRANSPORT/RAM FIRE
21	5	93.99	DRY SHRED/CONVEYOR TRANSPORT/STOKER FIRE
22	47	97.16	SHRED & OIL PULP/PUMP/DE-OIL/GRAVITY FIRE
23	14	97.91	SHRED & OIL PULP/AIR TRANSPORT/DE-OIL/MANUAL FIRE
24	37	103.28	DRY SHRED/AUGER TRANS/CONVEYOR FIRE
25	30	104.60	DRY SHRED & COMPACT/MANUAL/TRANS/COARSE SHRED/STOKER FIRE
26	39	104.84	SHRED & OIL PULP/AIR TRANS/DE-OIL/GRAVITY FIRE
27	28	106.30	DRY SHRED & COMPACT/MANUAL TRANS./SHRED & FEED FIRE
28	32	107.34	SHRED & COMPOST/MANUAL TRANS./MANUAL FIRE
29	50	107.34	DRY SHRED/MANUAL TRANS./MANUAL COMPOST
30	8	107.62	DRY SHRED/AUGER TRANS/FINE SHRED/STOKER FIRE
31	21	110.05	SHRED & OIL PULP/PUMP/DE-OIL/SHRED & REED FIRE
32	7	110.91	DRY SHRED/CONVEYOR TRANS./FINE SHRED/STOKER FIRE
33	45	111.35	SHRED & OIL PULP/PUMP/DE-OIL/RAM FIRE
34	38	111.57	DRY SHRED/CONVEYOR TRANS/CONVEYOR FIRE
35	51	113.63	DRY SHRED/MANUAL TRANS/GRAVITY COMPOST
36	52	113.94	COMPACT/MANUAL TRANS./SHRED & FEED COMPOST
37	18	114.94	SHRED & OIL PULP/VACUUM TRANS/DE-OIL/MANUAL FIRE
38	24	116.09	SHRED & WATER PULP/PUMP/MECH & THERMAL DEWATER/MANUAL FIRE
39	13	117.73	SHRED & OIL PULP/AIR TRANS./DE-OIL/SHRED & FEED FIRE

Table IV - 7. (Continued)

RANK	PROCESS NO.	LEVELIZED ANNUAL COST	DESCRIPTION
40	41	\$ 119.03	SHRED & OIL PULP/AIR TRANS./DE-OIL/RAM FIRE
41	44	121.23	SHRED & OIL PULP/VAC TRANS./DE-OIL/GRAVITY FIRE
42	16	123.77	SHRED & WATER PULP/AIR TRANS./MECH & THERMAL DEWATER/MANUAL FIRE
43	46	124.57	SHRED & OIL PULP/PUMP/DE-OIL/CONVEYOR FIRE
44	31	128.46	SHRED & COMPOST/MANUAL TRANS./STOKER FIRE
45	40	132.25	SHRED & OIL PULP/AIR TRANS./DE-OIL/CONVEYOR FIRE
46	17	134.12	SHRED & OIL PULP/VAC TRANS./DE-OIL/SHRED & FEED FIRE
47	23	135.27	SHRED & WATER PULP/PUMP/MECH & THERMAL DEWATER/SHRED & FIRE
48	42	135.42	SHRED & OIL PULP/VAC TRANS./DE-OIL/RAM FIRE
49	20	140.16	SHRED & WATER PULP/VAC TRANS./M & T DEWATER/MANUAL FIRE
50	58	142.25	SHRED & WATER PULP/PUMP/M & T DEWATER/MANUAL COMPOST
51	15	142.95	SHRED & WATER PULP/AIR TRANS/M & T DEWATER/SHRED & FIRE
52	55	148.54	SHRED & WATER PULP/PUMP/MECH DE-WATER/GRAVITY COMPOST
53	43	148.64	SHRED & OIL PULP/VACUUM TRANS./DE-OIL/CONVEYOR FIRE
54	56	149.93	SHRED & WATER PULP/AIR TRANS./MECH DE-WATER/MANUAL COMPOST
55	53	156.22	SHRED & WATER PULP/AIR TRANS./MECH DE-WATER/GRAVITY COMPOST
56	61	159.16	SHRED & WATER PULP/PUMP/MECH DE-WATER/SHRED & FEED FIRE
57	19	159.34	SHRED & WATER PULP/VAC TRANS/M & T DEWATER/SHRED & FIRE
58	57	166.32	SHRED & WATER PULP/VACUUM TRANS/MECH DE-WATER/MANUAL COMPOST
59	59	166.84	SHRED & WATER PULP/AIR TRANS/MECH DE-WATER/SHRED & FEED COMPOST
60	54	172.61	SHRED & WATER PULP/VAC TRANS/MECH DE-WATER/SHRED & FEED COMPOST
61	60	183.23	SHRED & WATER PULP/VAC TRANS./MECH DE-WATER/SHRED & FEED COMPOST

No interactions with sewage were accounted for in these systems at this time. The processes shown involve only solid wastes. Energy reclamation was assumed equal for each system and the furnace cost was assumed constant. Any concepts for integrated systems accommodating sewage is postponed pending the results of the liquid waste tradeoffs and evaluation. At this point the most favorable solids waste processing concept is by manual disposal and firing in a modified home furnace.

V LIQUID WASTES

The use of fresh water to transport human wastes goes back at least to the Minoan civilization in Crete, around 1600 B.C. (1) The only major improvements to this have been the invention of the water flush toilet and the central sewer facility. The water flush toilet, a symbol of modern convenience, uses approximately 40% of the fresh water supplied to an average household, to flush away approximately $1\frac{1}{2}$ gallons of human waste products. Additional waste waters, relatively innocuous in nature, accumulated from baths, sinks, and other appliances, are then co-mixed and befouled with the stronger wastes from the toilet. This mixture is then discharged to either central systems or on-site individual systems where effort must be exerted to recover the useful waters from this mixture in a form that is suitable either for reuse or for harmless discharge into the environment.

The large expenditures currently required for sewer lines and central waste treatment plants has generated interest in alternative systems for non-sewered small communities and individual homeowners. A recent EPA survey of planned new facilities for communities under 10,000 population found that the local cost portion for operation and maintenance plus debt retirement represents on the order of 1.5 - 2.3 percent of an average family's annual income. (2) It is not uncommon to find the true cost of such systems, including state and federal subsidies, at between \$5,000 and \$10,000 per household, particularly in rural areas. (3) The present study is concerned with the individual dwelling and energy recovery alternatives for water born wastes. In considering the implications for such systems it is evident that there are a number of areas impacted that provide energy conserving potential.

Such items include the quantity of water used as well as energy costs for its recovery and/or treatment. The first is sewage treatment itself. Determination of energy conservation potential is difficult to estimate in this area because of the tremendous variety and type of sewage processing techniques. One authority (4), however, indicates that for an aerobic treatment plant, energy utilized for treatment of a single family residence effluent would approximate 465 KWH per year, or 4.9 MBTU.

1. Proceedings of the National Home Sewage Disposal Symposium, 1974, American Society of Agricultural Engineers, St. Joseph, Michigan, Page 9.
2. Russell E. Train, "Encouraging Less Costly Waste Water Facilities for Small Communities", Letter to Regional EPA Administration, Washington, D. C., December 1976.
3. Randolph, J., "The Next Steps In Protecting The Environment", In: Individual On-Site Wastewater Systems, Proceedings of the Third National Conference 1976, National Sanitation Foundation, Ann Arbor, Michigan, Page 4.
4. Harold Stone, Technical Editor, Water and Sewage Wastes, personal conversation February 1978.

System implications of the foregoing have been considered in the analysis that follows as well as the recovery of waste energy from excreta and hot water.

A. REQUIREMENTS

Proper disposal of wastes containing or consisting of human excreta is mandatory if transmittance of diseases from person to person through the contamination of food and water products and contact surfaces is to be avoided. The manual of Septic Tank Practice recommends that to accomplish satisfactory results, such wastes must be disposed of so that: (5)

1. They will not contaminate any drinking water supply.
2. They will not give rise to a public health hazard by being accessible to insects, rodents, or other possible carriers which may come into contact with food or drinking water.
3. They will not give rise to a public health hazard by being accessible to children.
4. They will not violate laws or regulations governing water pollution sewage disposal.
5. They will not pollute or contaminate the waters of any bathing beach, shell-fish breeding ground, or stream used for public or domestic water supply purposes, or for recreational purposes.
6. They will not give rise to a nuisance due to odor or unsightly appearance.

Several additional requirements on waste water treatment systems are added as a result of the purposes of this study aimed at energy conservation and reclamation and utilization. These are discussed in the following.

5 Manual of Septic Tank Practice, PHS Publication No. 526, U.S. Department of Health, Education and Welfare, Public Health Service, Rockville, Maryland, 1969, Page 1.

1. Maximum energy recovery is a prime consideration. To meet this goal, not only must energy be captured and reused at and when possible, but input energy must be minimized - i.e. parasitic energy should be minimized. It also follows that minimizing water usage results in energy saving.
2. The system should be compatible with present life styles. The interface between the user and appliance should be conventional to aid acceptance and utilization. Unusual maintenance not presently commonly accomplished should be avoided.
3. System designs should reflect potential for cost effectiveness as well as energy savings. Consideration must accordingly be given to operating and maintenance costs.
4. The waste water system either singularly or in conjunction with a solids waste system shall be an optimized concept if no energy recovery is possible.

In order to evaluate the potential for liquid waste energy recovery and/or water conservation and sewage reductions (and thus energy conservation) a review of the options and alternatives in these areas was conducted. The results and preliminary analysis and conclusions follow.

B. COMBINED PROCESSES

In the area of waste water treatment there are customarily three general categories of systems based upon the degree of contamination of the incoming material. The "black water" systems handle human waste products such as urine and feces, and for the purposes of this study, garbage disposal effluents. "Grey water" systems treat the more lightly contaminated waste waters from sinks, baths, showers, dishwashers, clothes washers, etc. Combined systems, as the name implies, mingle and treat wastes of grey and black water contributors. Some overlapping between systems is inevitable. For example, a septic tank will handle a) black water only, b) grey water only, or c) combined black and grey waters. Since there is less water in a grey water only system, then the septic tank and drain fields will be considerably reduced in size over that required for a combined system. This is based on the conservative approach of reducing the system size based on the required quantity only, even though the quality is also improved.

Table V-1 Combined Black Water & Grey Water Processes

<u>ITEM</u>	<u>COMPONENTS</u>
1. CONVENTIONAL ANEROBIC (SUBSURFACE DISCHARGE)	SEPTIC TANK & SUBSURFACE ABSORPTION A) DRAIN FIELD B) DOSING C) PRESSURIZED DISTRIBUTION D) ALTERNATING BEDS E) SAND MOUND F) EVAPOTRANSPIRATION G) SEWAGE OSMOSIS
2. CONVENTIONAL ANEROBIC (SURFACE DISCHARGE)	SEPTIC TANK & SURFACE DISCHARGE A) SAND FILTRATION B) OXIDATION LAGOON A OR B + CHLORINATION ULTRAVIOLET LIGHT IRRADIATION OZONE TREATMENT
3. AEROBIC TREATMENT SYSTEM (SUBSURFACE DISCHARGE)	AEROBIC UNIT + SUBSURFACE ABSORPTION A) DRAIN FIELD B) DOSING C) PRESSURIZED DISTRIBUTION D) SAND MOUND E) EVAPOTRANSPIRATION
4. AEROBIC TREATMENT SYSTEM (SURFACE DISCHARGE)	AEROBIC UNIT + SURFACE DISCHARGE A) SAND FILTRATION B) SAND FILTRATION + DISINFECTION C) DISINFECTION CHLORINATION ULTRAVIOLET LIGHT IRRADIATION OZONE TREATMENT
5. AEROBIC TREATMENT W/FLUSH WATER RECYCLE	AEROBIC UNIT + FILTRATION + DISINFECTANT + PUMPING + STORAGE → FLUSH RECYCLE + SUBSURFACE OR SURFACE DISCHARGE → EXCESS

Figure V-1 Septic Tank

Source: Home Sewage Disposal
 Special Circular 212, Page 8
 Pennsylvania State University
 College of Agriculture Extension Service
 University Park, Penna.

Figure V-2 Aerobic Treatment Tank

Source: Home Sewage Disposal
 Special Circular 212, Page 9
 Pennsylvania State University
 College of Agriculture Extension Service
 University Park, Pa.

A summary of the combined processes is shown in Table V-1. In general, the processes break down into two general categories - anerobic treatment and aerobic treatment, with each followed by varying degrees of secondary treatment prior to surface or sub-surface discharge.

1. Primary Treatment

Anaerobic

Bacteria, which live without oxygen, digest some of the grease and heavy solids to cause a partial breakdown to liquid and gas. The anerobic process is typified by the septic tank, which is a tank which receives raw sewage from the household. (See Figure V-1) In the tank, three things occur - (a) solids are separated from the liquid, (b) Anaerobic bacteria partially decompose the solids and (c) the resulting sludge and scum are stored. About half of the particulate solids in the sewage settle out and are retained in the septic tank. The partially conditioned liquid flows out of the tank and into the disposal area where it is absorbed by the soil. (6) No matter how efficient the digestive process may be, sludge, the residual products of solids and bacteria, settles in the bottom of the tank and must be eventually removed and disposed of. If not removed, the sludge will eventually overflow into the downstream disposal process and damage this process.

Aerobic

This process, which is more efficient in terms of solids breakdown than the anaerobic processes, requires oxygen utilizing bacteria to breakdown a portion of the sewage. Free air is combined with the liquid mass by various techniques including air compressors or blower. See Figure V-2. The oxygen in the air supports the activity of the aerobic bacteria which digest the sewage and liquify most of the solids. Some packaged models utilize a mechanism to stir or circulate the sewage to ensure good contact between the sewage and the air. The biological activity and digestive process are much more efficient than that of a septic tank, and will produce a reduction of solids of up to 90% cleaner effluent with little or no odor (6). However, just as in the septic tank, some organic materials resist digestion, so that there is a gradual buildup of solids which must be removed to prevent a periodic discharge of sludge particles to the downstream processing step (7).

6. Home Sewage Disposal, Special Circular 212, The Pennsylvania State University, College of Agriculture Extension Service, University Park, Pennsylvania.
7. Bailey, J. R. et al, "A Study of Flow Reduction and Treatment of Waste Water From Households", Department of the Interior, Federal Water Quality Administration, December 1969, Page 48.

2. Secondary Treatment (SUBSURFACE ABSORPTION)

Drainfield

The drainfield, or absorption field, is the ground area used for subsurface disposal of anaerobic or aerobic treated effluents. The field serves to discharge this effluent into the soil so that any remaining nutrients may be oxidized and any remaining particles and microorganisms may be filtered out in the soil before the water returns to the ground water reservoir. (8) If the soil absorption system should fail, inadequately treated sewage can reach the ground surface. Area requirements for absorption fields have been recommended by Reference 9 based upon the ability of the soil to absorb fresh water (percolation test). (See Figure V-3)

Dosing

Liquid flow into the absorption field by gravity is the most common method of distribution. The liquid trickles out the drain holes at the lowest elevation or nearest the inlet. Thus the soil at these points receive a nearly constant flow of fluid while the rest of the bed may be dormant. This heavy loading accelerates clogging effects in this area. After this area becomes clogged, liquid is forced further down the bed and the sequence is continued until the entire bed is clogged.

In an attempt to overcome this drawback, periodic dosing of the field with large volumes of effluent has been used. Distribution is improved and between applications the soil infiltrative area is exposed to air, which serves to rest the area. (10)

Pressurized Distribution

Small diameter pipes with small drain holes are used in a pressurized distribution system. The entire pipework fills with liquid before very much passes thru the holes so that the entire infiltrative area is utilized and thus the net loading per area is more evenly distributed than in a gravity system. Since the loading is more even, the soil remains well aerated, and the chances of field clogging are substantially reduced. (11)

8. Ibid, Page 33.
9. Manual of Septic Tank Practice, OP. Cit., Page 9.
10. Otis, R. J., et al, "On-Site Disposal of Small Wastewater Flows", University of Wisconsin, Madison, Wisconsin, 1977, Page 41.
11. Ibid, Page 42.

Figure V-3 Drain Field

Source: Home Sewage Disposal
Special Circular 212, Page 11
Pennsylvania State University
College of Agriculture Extension Service
University Park, Pa.

Alternating Beds

This system utilizes two absorption beds with a diverter valve between the beds and the outlet of the septic tank so that one or the other bed may be selected for disposal. Research has shown that a clogged bed will rejuvenate itself if rested for a period of time. (12) The beds are alternated in use so that each bed is used one year and then rested one year. The life span of alternating is believed to be substantially greater than if two fields were used to exhaustion consecutively. Apparently aerobic bacteria are able to breakdown the clogging material at the infiltrative surface of the unused bed and open up the soil structure.

Sand Mound

Many soils are not suitable for utilization with conventional absorption beds. These include soils of low permeability, excessively permeable soils, and soils over shallow bedrock or high groundwater. (13) To overcome these limitations, a mound of sandy fill material is placed on the ground surface, the drainage piping laid in gravel fill over the sand, and the top covered with a soil mound. (14) This ensures proper filtration of fluid prior to its entry into the original grade of excessively permeable soils. The process also aids absorption by the remaining soil types by spreading the effluent over a larger area where it can move out laterally until absorbed by the less permeable soil. See Figure V-4.

Evapotranspiration

The evapotranspiration system is a shallow bed which utilizes the evaporation of effluent to the atmosphere and transpiration of effluent by plants. Their system utilizes a impermeable liner to prevent absorption into an unsatisfactory soil type. This makes the system almost entirely dependent upon climatic factors. Two such units installed in Pennsylvania have experienced at least periodic failure. (15) While this system has met with limited success in the climatic conditions of Pennsylvania, it may prove satisfactory in arid or semiarid regions.

12. Winneberger, J. H. T., "Ryon's Septic-Tank Practices Corrected", In: Home Sewage Disposal, Op. Cit., Page 218.
13. Otis, R. J., et al, Op. Cit., Page 53.
14. "Alternate Methods of Effluent Disposal For On-Lot Home Sewage Systems", Special Circular 214, The Pennsylvania State University, College of Agriculture, University Park, Pennsylvania, Page. 5.
15. Mauer, G. E., "Field Application: Sand Mound and Evapotranspiration Systems", In: Individual On-Site Wastewater Systems, Proceedings of the Third National Conference 1976 Op. Cit., Page 100.

Figure V-4 Elevated Sand Mound - Seepage Bed Distribution

Source: Alternate Methods of Effluent Disposal
 For On-lot Home Sewage Systems
 Special Circular 214, Page 5
 Cooperative Extension Service/College of Agriculture
 Pennsylvania State University
 University Park, Pa.

Sewage Osmosis

This process uses the principal of electroosmosis to move water through otherwise slowly percolating soils such as clay and silt. An anode of rock high in minerals and oxides is constructed on one side of the drainage area and a cathode of high-carbon material on the other. By burying these dissimilar materials on opposite side of the drainfield, an electric potential is developed in the soil-water complex. The anode attracts negatively charged ions, such as oxygen, phosphates and nitrates. The positively charged hydrogen ion is attracted to the cathode, allowing the removal of the water layer from the clay particles. As this outer water layer is removed, it is replaced by free water from the capillary waters, producing water movement from the anode to the cathode. While this system is not in wide use, approximately 50 systems have been installed, many where other systems have failed, and have enjoyed good operating experience. (16)

3. Secondary Treatment (SURFACE DISCHARGE)

Secondary treatment by surface discharge has been limited primarily to municipal systems. However, increased in such treatment for household systems has been found in the literature and is reported here for completeness.

Sand Filtration

Two types of flow configuration have been successfully tested in the field; the recirculating sand filter and the intermittent sand filter.

The recirculation sand filter system doses wastewater from the septic tank onto and open sand bed filter. A portion of the dose is flowed out of the system to discharge while a larger portion is recycled to mix with the incoming septic tank effluent and sent to a recirculation tank from where the process is repeated. When the recirculation tank is filled the filter effluent is discharged directly from the system. Approximately 1 inch of sand is removed from the sand bed each year to avoid ponding. After 12 inches of sand are removed from the 36 inch deep bed, new sand is added. (17)

16. Coolbroth, F. P., "The Sewage Osmosis Concept For Onsite Disposal Systems - Clay Soils", In: Ibid, Page 131.

17. Otis, R. J. et al, Op. Cit., Page 61.

In the intermittent sand filter process, the wastewater is applied directly over a 2-3 foot deep bed and the filtrate collected by under drains. Two filters are recommended so that service may be alternated between them. As one filter is ponded, it is taken out of service, and raked to a depth of 2-4 inches. Alternatively the top crust is replaced with fresh sand. The resting period is essential to allow the lower portion of the bed to aerate and regenerate (18). The resting period was also noted as being beneficial for the ordinary soil absorption field.

Oxidation Lagoon

Oxidation lagoons, requiring large land areas, are open ponds where septic tank or aerobic system effluent is discharged. Some aerobic treatment occurs along with soil absorption and evaporation. A BOD reduction of 75% has been reported (19). However, COD and phosphorous reduction were not significant. Regular maintenance is required to prevent the areas from becoming overgrown with weeds and bottom vegetation and developing into mosquito-breeding areas.

Disinfection

Effluents from sand filtration units and oxidation lagoons in most instances require further polishing prior to surface discharge. Dry feed chlorinators will produce EPA standards, but lack control of the dosage amount to the wastewaters. Periodic high chlorine concentrations were determined to be effective over an extended field testing program (20). Ultraviolet irradiation has proven promising, but high initial capital investment has been a major drawback at this time (21). Experience with iodine disinfectant has been excellent, but iodine costs are high. Ozone treatment involves relatively complex equipment and bromine salt feeding has proven to be too complex for small flows application (22).

18. Sauer, D. K., "Treatment Systems Required For Surface Discharge of Onsite Wastewater", In: Individual On-Site Wastewater Systems, Op. Cit., Page 119.
19. Karikari, T. J., et al, "Treatment of a Residential Septic Tank Effluent In An Aerobic Lagoon", In: Home Sewage Disposal, Op. Cit., Page 149.
20. Otis, R. J. et al, Op. Cit., Page 65.
21. Ibid., Page 66.
22. Ibid., Page 67.

C. BLACK WASTE PROCESSES

Black wastes may be handled by all the processes discussed in the previous section and these processes will not be restated here. The focus of this section will be on the uncommon and innovative process and/or singular devices which handle concentrated fecal and urine wastes and/or food wastes. A summary of these are shown in Table V-2.

Composting System

The composting process is typified by the Clivus Multrum marketed in the United States by Clivus Multrum, USA, Inc., of Cambridge, Massachusetts. See Figure V-5. The equipment will take as its input urine feces, toilet paper, kleenex, tampons, sanitary napkins, disposable diapers (not the plastic part) and similar bathroom wastes. Organic kitchen and household wastes such as cooking liquids, paper towels, grease and fat, dust pan and vacuum cleaner refuse, vegetable and meat scraps, peelings, bones and eggshells. Newspaper used for pet litter may also be included. (23)

The equipment includes a large decomposition chamber to which is attached a toilet stool, garbage chute, and air vent. No water flushing is utilized. The aerobic process decomposes waste materials over a two year period to form an end product that is reportedly useful as a soil conditioner. Occasional additions of water are required to maintain the desired moisture content of the decomposition pile. Freezing temperatures stop the decomposition process, so it is suggested that the equipment be installed in a warm area. The costs of this system run between \$1500-\$1700 depending upon size and accessories. No operating power is required in normal installations. Unusual vent stack problem may require a fan to provide a draft for air to the aerobic process. Emptying of the residue is accomplished manually. Grey wastewaters must be separately treated and disposed.

23. "Questions and Answers - Clivus Multrum Organic Waste Treatment System; Clivus Multrum USA, Inc., Cambridge, Mass.

Table V-2. Black Water Processes

<u>ITEM</u>	<u>COMPONENTS</u>
1. COMPOSTING SYSTEM (EXAMPLE - CLIVUS MULTRUM)	AEROBIC TREATMENT UNIT + TOILET + GARBAGE HATCH
2. COMPOSTING TOILET (EXAMPLE - ECOLET)	AEROBIC TREATMENT TOILET + FAN + VENT + HEATER
3. INCINERATING TOILET (EXAMPLE - INCINOLET)	INCINERATING TOILET + VENT
4. DIGESTION TOILET (BIO-FLO TOILET)	BACTERIAL/ENZYME DIGESTIVE TOILET + FAN + VENT

Figure V-5 Composting System

Source: Questions and Answers
 Clinis Multrum Organic Waste Treatment System
 Clinis Multrum USA, Inc.
 Cambridge, Mass.

Composting Toilet

A number of dry toilets which compost urine, feces, toilet paper and some food wastes are produced by European manufactures and several are marketed in the United States. Although relatively common in the European countries, as an acceptable alternative for unsewered areas, such devices are extremely rare in the U.S. A typical composting toilet is the Swedish "Mullbank" toilet marketed in the U.S. as the Ecolet. See Figure V-6. The toilet device accumulates material on an aerating/heating coil. Air is passed thru the pile by the action of an air vent which contains a fan. The process is aerobic decomposition which is accelerated through the use of a continuous air flow. Since the toilet may be placed in unheated areas a heating coil is provided to maintain temperatures in the uninsulated container to acceptable levels for composting.

The compost pile is reduced in bulk over a six month time period and the residue manually removed. A heating coil of 125 watts is thermostatically controlled to provide the proper temperature for rapid decomposition in unheated areas. The air vent fan removes water vapor and promotes air flow and requires approximately 20 watts of continuous power. The cost of such units are approximately \$750 plus installation, which involves routing and insulating on air duct and locating the toilet. Usual capacity for this toilet is approximately 4-6 people when used on a year round basis.

Incinerating Toilet

The incinerating toilet heats human wastes to a temperature sufficient to reduce this waste to a odor-free ash. Several versions are produced, some utilize fuels, several have oxidizing catalysts to reduce or prevent odors, and others utilize electrical energy for heating. A typical electrical model is the Incinolet produced by Research Products of Dallas, Texas.

The incinerating toilet uses a waxed paper bowl liner to accumulate wastes as well as for carrying wastes from the bowl to the incinerator chamber below. A radiant heater mounted above the waste evaporates the urine, dries and fires the solids to leave only an ash. A vent line carries off heat as well as moisture generated

Figure V-6 Composting Toilet

Source: Ecolet-Self-Contained Toilet:
Recreation Ecology Conservation of United States, Inc.
Milwaukee, Wisconsin

during evaporation of liquid wastes. An airflow generator is required - a turbine type vent cap is recommended. A heat activated catalyst between the incinerator chamber and the exhaust blower is used to remove odor and smoke from the effluent. The cycle is automatic, and each use requires approximately one KW of electrical energy. The catalyst requires replacement 2-3 times per year, and the ash residue must be removed about once per week. The cost of such toilets are in the area of \$850 - \$1,000 for home size units.

Digestive Toilet

The Bio-Flo is digestive toilet utilizing a patented re-circulating process that enhances bacterial/enzyme digestion and insures high evaporation. See Figure V-7. The toilet utilizes a three-section tank for waste disposal, water flushing, waste breakdown, and water purification. The largest compartment, receives the waste, is a water chamber to which gravel and activated charcoal have been added. Waste liquid flows thru this bed into a second smaller chamber which is predominately activated charcoal. Overflow water from this chamber passes into a third chamber which is used for flushing water supply. An excess is drained from the unit to an external field.

A weekly addition of a digestive powder is used to supply the bacteria and enzymes used for waste and paper decomposition. No additional water is supplied to the unit over that required for an initial filling. The unit uses a manual flush from the self contained flush chamber. Literature on the unit notes that an absolute updraft vent is required. This apparently necessary to aid in evaporating the excess moisture from the unit. Unit costs are approximately \$500 plus vent and installation. The manufacturer places costs of operation at 25¢ per week when used continually to insure digestion. An additional 23¢ per week is required of the effluent must be disinfected prior to discharge.

D. GREY WATER PROCESSES

The processes described in Section B will also handle grey waters, and in most cases the required absorption areas, tank sizes, etc. may be reduced in size to handle the more lightly contaminated wastewaters. Therefore these systems will not be restated here. The processes discussed here are, in most instances, sufficient to purify wastewaters to

Figure V-7 Digestive Toilet

Source: Bio-Flo Recycling Toilet
Pureway Corporation
Madison, Wisconsin

the state that they may be reused for toilet flushing, etc. In several instances, the purity of the water meets potable requirements, however, under the guidelines of this study as stated in Section III, F, 2, this use is not considered since public acceptance would be difficult to obtain. Thus while the processes of Sections B and C were predominately aimed at treatment and disposal, the processes of this section relate to treatment and reuse. These processes are summarized in Table V-3.

Multi-Filtration

Waste waters are forced through progressively finer filters under high pressures under this process. The waste water may be made as pure as desired by the use of sufficient filters and pressures. The system will not handle urine as urea will usually pass thru the filters and consequently pretreatment is required if urine is considered. Recovery efficiency is good, but expendables cost and requirement for pump energy is high.

Reverse Osmosis

Reverse osmosis is a process whereby a contaminated waste product is placed next to a dialyzing membrane and subjected to hydrostatic pressures exceeding the osmotic pressure of the solution. Under these conditions, water will pass out of the solution depending upon the selective properties of the membrane.

Air Evaporation

The waste water is brought into a wick evaporator after a series of pretreatment and filtration processes, and it is distributed through wicks in the evaporator where a hot air stream evaporates the water, leaving the solids in the wicks. The air stream is then passed through a condenser, where the vapor is cooled to condense out the water, and through a water separator where the gas and liquid separation takes place. The condensed water is then post-treated and stored. The air stream is reheated and returned to the evaporator.

Vapor Compression Distillation

Mechanical compression is employed to provide for re-use of heat in the vapor compression distillation process. In this technique the temperature of the stream is increased by increasing the pressure of the stream mechanically. The temperature is increased sufficiently to permit transfer of the heat of condensation of the steam to evaporate additional water.

Table V-3 Grey Water Processes

<u>ITEM</u>	<u>COMPONENTS</u>	<u>COMMENTS</u>
1. MULTI-FILTRATION	FILTER ELEMENTS OF INCREASING FINENESS, PUMP, STORAGE TANKS	
2. REVERSE OSMOSIS	PREFILTERS, R-O MEMBRANE CELLS, HIGH PRESSURE PUMP, STORAGE TANKS	
3. AIR EVAPORATION	WICK EVAPORATOR, BLOWER, CONDENSER, PREFILTER, AIR HEATER, STORAGE TANKS	
4. VAPOR COMPRESSION DISTILLATION	EVAPORATOR, COMPRESSOR, CONDENSER, STORAGE TANKS, PREFILTER, VACUUM SOURCE	
5. VACUUM DISTILLATION	EVAPORATOR, CONDENSER, STORAGE TANKS, VACUUM SOURCE	
6. DISTILLATION	EVAPORATOR, CONDENSER, STORAGE TANKS	
7. VACUUM DISTILLATION/ CATALYTIC OXIDATION	EVAPORATOR, CATALYTIC OXIDIZER, CONDENSER STORAGE TANKS	SYSTEM WILL ALSO HANDLE URINE WITHOUT PRETREATMENT

Vacuum Distillation

This process utilizes low pressure evaporation to reduce the volatiles driven off during boiling. Steam is produced at approximately 120°F and 1.2 psia. This is then condensed at approximately 60°F and .25 psia. The low temperatures involved reduce the contaminants found in the product water, but do not eliminate them. As with any change of phase process, the energy requirements are high unless waste heat sources are available.

Distillation

This process is similar to that above except that the distillation step is carried out at ambient pressure, which increases the temperatures involved as well as the volatiles carried with the water.

Vacuum Distillation/Catalytic Oxidation

As stated in Table V-3, this system is capable of handling not only grey wastewaters, but also urine without pretreatment. Wastewater and/or urine is charged into the evaporator where it is evaporated continuously under reduced pressure. The vapors are then processed further by passing them over a catalyst bed and pyrolyzing them at 1200°F with oxygen. The vapor is condensed and waste gases vented. The resultant product water meets or exceeds the potable water requirements even when the input is a combination of urine, feces and wash water. In addition, the product is entirely bacteria free.

E. SPECIAL TRANSPORT METHODS

Three special transport methods are reported here. All have the purpose of reducing the amount of water utilized by a household for the toilet flushing functions. These systems are summarized in Table V-4.

Vacuum Toilet System

The vacuum toilet system was developed in Sweden and is commonly referred to as the Liljendahl system. This system relies on vacuum to transport wastes rather

Table V-4 Special Transport Methods

<u>ITEM</u>	<u>COMPONENTS</u>	<u>COMMENTS</u>
1. VACUUM TOILET (LILJENDAHL SYSTEM)	TOILET ASSY., COLLECTION TANK, VACUUM TANK, VACUUM PUMP, DISCHARGE PUMP, FLUSH VALVE & CONTROL MODULE	1/3 GALLON/FLUSH
2. PRESSURE FLUSH (MICROPHOR)	TOILET ASSY., COMPRESSED AIR SOURCE	2 QTS./FLUSH
3. NON-AQUEOUS RECIRCULATION SYSTEM (SARMAX)	TOILET, HOLDING TANK, PUMP, FILTER, DISINFECTANT, FLUID	NO WATER USED IN FLUSH

than water and gravity. The amount of water required is limited to that necessary to clean the bowl - approximately 1/3 to 1/2 gallon. The plumbing for a vacuum system is shown in Figure V-8. On flushing, the contents of the bowl are pushed by atmospheric pressure into the vacuum plumbing, which contains a trap to permit transport of wastes in slug form. At the time of flushing, water sprays from a ring to wash the bowl. A timer closes an outlet valve, while water flow continues to fill the bowl to the required level. A typical vacuum system is produced by Colt Industries under the name "Envirovac".

Pressure Flush

The pressure flush system operates on air pressure to move waste materials from the bowl. The system requires a source of compressed air between 60 and 100 psi and water at normal household pressures. Activation starts a flow of water into the bowl and opens a valve in the toilet. The valve automatically closes and a charge of compressed air ejects the waste material into the discharge line. Typical water usage is 1½ - 2 quarts per flush. A typical unit is produced by Microphor of Willits, California.

Non-Aqueous Recirculation

This system is shown schematically in Figure V-9. This system uses a mineral oil type fluid to transport wastes from the toilet to an on-site holding tank. In the tank, the waste materials rapidly separate out, leaving the transport fluid on top. When the toilet is flushed, this fluid is recovered, filtered purified, and reused for flushing. The cycle repeats until the holding tank is filled at which time controls prevent further use. The toilet is conventional in appearance with a teflon lined bowl to retard solids buildup and discoloration. Typical systems are produced by Chrysler, Sarmax and Monogram Industries.

F. SPECIAL DEVICES

A multitude of devices and equipment currently exist which are aimed at reducing water usage within the home. This section covers the more common devices as well as some in development or use in the aerospace field where water usage has been of great concern due to the high cost of transport and use in manned space vehicles. The section is broken down into two subsections - one covering black water devices and the second reporting grey water devices.

Figure V-8 Vacuum Toilet System (24)

24. Bailey, J. R., et al, Op. Cit., Page 58.

Teflon® is a Registered Trademark of E.I. DuPont de Nemours & Co

Figure V-9 Non-Aqueous System (25)

25. "Magic Flush Toilet Systems", Monogram Industries, Inc., Monterey Park, CA.

1. Black Water Devices

A summary of black water devices is shown in Table V-5.

Low Flush Toilet

A shallow trap toilet as produced by American Standard and others has the same basic principles of operation and appearance of standard toilets. However, it has a more efficient trap design which allows it to use less water resulting in a smaller flush tank. Water usage is approximately 14 quarts per flush versus the 21 quarts for standard appliances.

Direct Flush Toilet

Direct flush toilets utilize the water pressure directly from the supply system to effect a more efficient flush. A mechanically activated slide valve performs the sewer isolation function. This valve is opened only during the flush cycle and the resultant water use can be reduced to nearly one pint of water. A second type utilizes a more convention water trap. (26)

Recirculating Toilet

Recirculating toilets are used in aircraft, marine and other various mobile and recreational applications. These recycle the flush waters by filtering and chemical treatment to kill bacteria and retard odor generation prior to reuse which is effected by a recirculating pump to the bowl flush. A slide valve isolates the bowl from the waste chamber or sewer. Home units are installed so that the accumulated wastes may be pumped into a conventional sewer systems by a second pump. The flushing fluid is usually colored by a dye to reduce objections of an otherwise urine colored flush fluid. A typical recirculating toilet is "Clean Flush" aircraft toilet produced by Sherwood Products of San Antonio, Texas. See Figure V-10.

26. Guarnei, C. A., A. Reed, and R. E. Renman, "Study of Water Recovery and Solid Waste Processing for Aerospace and Domestic Applications", Volume II, Grumman Aerospace Corporation, Bethpage, New York, December 1972, Page III-10.

Table V-5 Black Water Devices

<u>ITEM</u>	<u>COMPONENTS</u>	<u>COMMENTS</u>
1. LOW FLUSH TOILET (AMERICAN STANDARD)	SHALLOW TRAP TOILET	14 QT. FLUSH VS. 21 QTS.
2. DIRECT FLUSH TOILET (MONOGRAM)	TOILET ASSY. - UTILIZES WATER DIRECTLY FROM SUPPLY SYSTEM	1/3 GALLON/FLUSH
3. RECIRCULATING TOILET (MONOGRAM)	TOILET ASSY., RECIRCULATION PUMP, FILTER, HOLDING TANK, CHEMICALS, FLOOR PUMP	
4. DUAL FLUSH CONVERSION (WATER SAVER, INC.)	WATER DISPLACEMENT TANKS, CYCLE SELECTION MECHANISM	LOW FLUSH MODE REDUCES WATER CONSUMPTION BY ONE GALLON/ FLUSH
5. ANAL WASH/AIR DRY TOILET (HYDRO-JOHN)	TOILET ASSY., BLENDER, WATER PUMP, BLOWER	4 LBS./FLUSH, URINE COLLECTED SEPARATELY
6. DEHYDRATION/VACUUM DRYING TOILET (DRY-JOHN)	TOILET ASSY., ROTATING SHREDDER, VACUUM SOURCE OR BLOWER, GERMICIDE & PUMP	NO WATER USED, URINE COLLECTED SEPARATELY

Figure V-10 Recirculating Toilet

Source: Clean Flush Aircraft Toilets
Sherwood Products
San Antonio, Texas

Dual Flush Conversion

This is a device for conversion of a standard toilet to a dual flush unit. It consists of water displacement tanks and a cycle selection mechanism. A downward handle movement permits all of the toilet tank water to flush the bowl. An upward movement prevents water contained within the displacement tanks from entering the bowl (approximately one gallon). The device is designed to fit into standard toilet tanks and is compatible with common ball floats and refill valves. (27)

Anal Wash/Air Dry Toilet (Hydro-John)

This is a waste collection system developed for spacecraft applications, utilizing a manually initiated, automatically controlled anal wash and air dry cycle. Transport air draws the feces into a pump/blender. The anal wash water is blended with the fecal material and pumped out to disposal. Urine is deposited and collected separately. No toilet paper is used. Flush water continues during the pump out cycle to wash the user and rinse the pump/blender. The user is then dried by warmed transport air. The system utilizes approximately $\frac{1}{4}$ pint of water per flush.

Dehydration/Vacuum Drying Toilet (Dry-John)

This is a second waste collection system developed by General Electric and is currently being produced for use on the Space Shuttle. Fecal wastes are transported in zero gravity by a transport air flow into a container. A slinger with rotating tines break up the fecal material and toilet paper and sling it against the container walls where a thin coating is created. After the user is done, the interface valve between the seat and container is closed and a vacuum valve to the container is opened. The feces are dehydrated to reduce microbial growth and reduce the resultant weight and volume.

27. Ibid, Page III-11.

A second version of this system uses an air flow instead of the vacuum vent to dehydrate feces. The air flow is then passed through bacteria filters and charcoal containers to reduce odors and eliminate bacteria.

2. Grey Water Devices

A summary of grey water devices is shown in Table V-6.

Flow Restrictors

Flow restrictors take the form of flow regulators which regulate the pressure at the outlet point to a preset point and orifice restrictors which provide an increased pressure drop regardless of the upstream pressure. These devices provide maximum water savings with showers and may be purchased as part of the shower head assembly. For showers, the flow rate is usually limited to 2 gpm or less. These same devices may also be used in kitchen sink faucets and bathroom lavatories. The net water savings are dependent on many factors, the major one being the habits of the user.

Mixing Valve

The mixing valve uses a bi-metallic sensing coil to regulate the flow proportions of hot and cold water to maintain a set temperature of dispensed water. Variations in pressure and temperature of incoming flows are automatically compensated for so that a bather, for example, will not be scalded when a toilet is flushed in another bathroom. Water savings is enhanced as a bather may turn off the shower when soaping up and when the water is turned on for rinsing, he may be assured of the same temperature water without the need for wasteful readjustment, with the consequent wasting of water while the temperature reaches the proper steady state point.

Self Closing Lavatory Valves

These type valves are common equipment in institutional and commercial buildings. The spring loaded handle reduces waste by closing the valve when the user releases the handle. Thus, the flow of water is shut off automatically if a user walks away, forgetting to shut off the water prior to leaving.

Table V-6 Grey Water Devices

<u>ITEM</u>	<u>COMPONENTS</u>	<u>COMMENTS</u>
1. FLOW RESTRICTORS (AMERICAN STANDARD)	FLOW REGULATOR OR ORIFICE RESTRICTOR	
2. MIXING VALVE (BEACON)	THERMAL SENSOR MIXING VALVE	
3. SELF CLOSING LAVATORY VALVES (SPEAKMAN)	WATER REGULATING FAUCET	
4. PHOTOELECTRIC CONTROL OF FAUCETS	LIGHT, PHOTOELECTRIC CELL, RELAY, SOLENOID VALVES	
5. WHOLE BODY SHOWER (ZERO-G)	HAND-HELD SPRAY NOZZLE, BLOWER, PUMP, STORAGE TANK, PHASE SEPARATOR	0.35 GPM & 0.6 GALLONS/SHOWER
6. "SUD SAVER WASHER"	UTILITY TANK FOR USED WATER & DETERGENT	
7. DISHWASHER RINSE REUSE	HOLDING TANK, VALVING & PLUMBING	

Proximity Control

A surgeon scrub sink may utilize photoelectric control to activate the water faucets only when the user is in a close proximity of the sink. Flow and water temperature are preset. While the original purpose of such a device was to prevent a surgeon from contaminating his hands, the idea is useful to prevent water waste in a home. The foot actuated water faucet is a similar device spring loaded, the actuating lever or bar requires constant pressure to produce flow. When the user leaves, flow is automatically stopped.

Whole Body Shower

This system was originally designed for the Skylab space missions. Reduced to the requirements of earth, the shower is a hand held water dispenser similar to the kitchen sink sprayer. This allows the user to wet down and then shut off the water while he soaps up. Wasteful excess water usage is avoided. Rinsing is accomplished then by using the hand held water dispenser. The typical shower used in Skylab required only approximately 0.6 gallons of water.

Sud Saver Washer

Washing machines capable of reusing washwater have been commercially available for some time. Water and detergent are pumped to a utility sink next to the machine after the wash cycle. During the next cycle, the majority of this stored washwater is pumped back into the machine. Some is not recycled to permit removal of settled solids. These machines were originally promoted for their detergent saving ability rather than the water savings involved. Customer reaction has been nearly totally negative. (28)

Dishwasher Rinse Reuse

Reuse of the dishwasher rinsing waters has been advocated by reference 29. A typical wash cycle uses 9 gallons of water while a rinse cycle requires approximately 6 gallons. The 6 gallons could be stored in a tank under the machine to augment the next washing cycle. The self contained dishwasher heater serves to increase the stored water temperature to a level sufficient for washing. The net savings per cycle would be approximately 6 gallons.

28. Ibid, Page III-18.

29. Ibid, Page III-26.

G. EVALUATION

A preliminary evaluation of liquid waste system and water devices is required in order to prioritize concepts. The conclusions of Baily, et al, (30) are useful in screening candidates and are shown below:

1. Reduction of water usage appears to be economically the most feasible means of reducing waste flow from the home.
2. Flow control faucets are of marginal value when replacing workable faucets, but are definitely warranted for new homes and for necessary replacements. Faucet aerators would apparently be a useful addition to all faucets for convenience as well as water savings.
3. Flow control showers are an inexpensive means of economically saving considerable quantities of water.
4. The use of pressure flush valves to reduce water flow does not appear as advantageous as the redesign of the toilet bowl to allow adequate flushing with less water.

The pressure flush valve could be advantageously used with the redesigned toilet bowl. Siphons, as used in the English water closets, would also provide better volume control than the system presently used in the United States.

5. The vacuum flush toilet for the individual home is too expensive because of the high cost of the accompanying equipment when used for single homes.
6. The major economic disadvantage of the recycle toilets is the high cost of the chemical used for disinfecting the recycled flush water. Development of a suitable, lower cost disinfectant could make their use much more practical. There could be a problem with acceptance of reused flush water in the home, but this objection does not appear insurmountable.

30. Bailey, J. R., et al, Op. Cit., Page 85.

7. Incinerator toilets are excessively costly to operate and maintain for family use. For certain applications, such as weekend cabins which are used sporadically, the incinerator may be the most economical system, but for normal continuous use, the incinerator toilet can not economically compete with conventional systems.
8. The analysis of the system to reuse wash waters for toilet flushing reveals several very significant facts. The treatment and the quality standards required for flushing water are minimal and the costs are thus relatively low in comparison with those for any other reuse. Yet this treatment and reuse is economical only in fair and poor soil areas.
9. The additional treatment of the non sanitary waste waters by distillation, reverse osmosis, carbon adsorption, or a multifilter system for use as laundry and bathing water as well as toilet flushing does not appear economically feasible.
10. The treatment of all waste waters by distillation and reuse for all purposes but drinking is also economically unattractive.
11. Aerobic treatment is competitive with anaerobic systems in poor soil areas. In such poor soil areas, some reuse may also be warranted.
12. Electrolytic treatment for disposal is not economical for most areas because of the low conductivity of the water.

The study done by Baily did not consider the oil transport system, black water processes such as composting, and the aerospace dry and vacuum toilets. For those systems and devices that were considered, however, the conclusions might be summarized as:

- a. Common water savings devices, such as flow control faucets, flow restrictors, etc. are useful and cost effective.

- b. The vacuum/pressure transport systems are too expensive for single house use, as are the incinerator toilet and recycling water toilet.
- c. Low flush toilets are an economical alternative.
- d. It is not economical to recycle waters for general use excluding drinking. Recycling of water for toilet flushing is marginal, being attractive only where disposal is a problem.

A selected alternative for combined black and grey water processing is dependent upon the soil conditions of the individual building lot. This choice is determined by the lowest cost system to the homeowner as required by those known soil conditions. This is true if grey water only is disposed or grey and black waters are disposed. The lowest cost option for on-site disposal will be the conventional septic tank and soil absorption field. If soil conditions are a problem, then the builder will go to the next series of options - sand mound, aerobic treatment with conventional soil absorption field, etc. Only if these options are impossible will the owner go to the more expensive surface discharge process, where extensive post treatment devices will be required. Reprocessing of waste waters to eliminate completely on-site water disposal has proven to be too expensive and is not considered an option.

Recycling of waste water for toilet flushing may be economical as the complexity of the required disposal system increases. For the purposes of this study then, it is assumed that there will be waste waters to be disposed of on-site, that these waters may be black and/or grey, and that the disposal system will be a function of the soil absorption characteristics. Therefore, further trades and evaluations in this areas are of little ultimate value. Efforts should be directed to modifying and evaluating the upstream equipment which produces these wastes, and to evaluating the possibilities of combination with the solid waste systems for energy savings and/or recovery.

A summary of liquid waste system evaluations is shown in Table V-7. The special devices and systems such as the composting toilet, composting system and digestive toilet lack acceptability because of the poor aesthetics of such devices. The potential for energy recovery in combination with solid wastes energy recovery systems is also lacking. The composting toilet also has a high energy use with a continual fan operation and an intermittent heat coil operation. Some recovery potential is reportably available with the composting system (Clivus Multrum) but is not available as part of the system at the present time.

The grey water reuse possibilities are limited to that for toilet flushing since under the guidelines of this study, reuse is limited to non-contact, non-potable areas.

Special transport methods discussed in this report included the vacuum, pressure, and non-aqueous recirculation system. The vacuum and pressure system have been shown to be uneconomical for a single family household but have potential for multi-family units. The esthetics of such systems have judged poor-good as concerns were noted in the literature of possible accidents involving vacuum and pressures in the toilet. The energy requirements are high. The non-aqueous transport system has good esthetics as the toilet is conventional appearing. A plus factor is that the wastes appear in a concentrated form which may then be processed with solids wastes for energy recovery. Pumping power is similar to that required for water flush toilets.

Special black water devices have been previously discussed. The low flush toilet and the dual flush conversion unit both are adaptable to homes now with little impact and good water savings potential. The direct flush toilet presents a source of back contamination to the water supply and is not recommended. The recirculating toilet, as previously mentioned, requires costly chemicals and is useful more as a vacation home device than as a continued use household toilet. The aerospace dry toilet and vacuum drying toilet are lacking in development at this point for household use.

Table V-7 Liquid Waste System Evaluation

<u>SYSTEMS</u>	<u>COSTS</u>	<u>STATE OF ART</u>	<u>ESTHETICS</u>	<u>ENERGY RECOVERY</u>
<u>SPECIAL DEVICE/SYSTEMS</u>	1000-	YES	POOR	NEGATIVE
ECOLET	3000-			
<u>SPECIAL TRANSPORT</u>	3-8000	LIMITED	POOR TO	NEGATIVE
VACUUM/PRESSURE			GOOD	
<u>VEHICLE (TRANSPORT MEDIA)</u>				
WATER	--	YES	EXCELLENT	POOR
DRY	--	YES	POOR	POTENTIAL
OIL	1000	LIMITED	GOOD	POTENTIAL
<u>PROCESSES</u>				
ANEROBIC (WET)	1000	YES	GOOD	NO
ANEROBIC (DRY)	3000	YES	POOR	LOW
AEROBIC (WET)	2000	YES	GOOD	NO
AEROBIC (DRY)	3000	YES	FAIR	POTENTIAL
CHEMICAL	8000	NO	----	NO
WET OXIDATION	8000	NO	----	POTENTIAL
THERMAL		YES	FAIR	NO

Useful grey water devices include flow restriction, mixing valves, and self closing lavatory valves. Photoelectric control is too complicated and self closing valves will accomplish the same function. The whole body shower, in its simplest form is commercially available in a hand held dispenser and is recommended. The suds saver washer has met with public rejection although water savings potential is available. The dishwasher rinse reuse is not currently available. As concern for water conservation increases, perhaps these last two devices will become more acceptable.

In summary, liquid waste concepts should be developed to reduce water usage and waste generation, and should make use of the aforementioned common water saving devices such as flow restrictors, self closing faucets, low flush toilets, etc. Combined waste treatment processes will be determined by factors outside the scope of this study, i.e. soil and surface conditions. As complete recycling is uneconomical, waste waters treatment will be required and the process will be determined on a lot by lot basis. Non-aqueous transport is held open as an option since it provides wastes in a concentrated form which may prove useful for combination with solid wastes processing. This is the only transport method which avoids at least some dilution with water. Recycling of waste waters for toilet flushing is also held open as an option as the economics have proven to be dependent upon soil conditions, which cannot be forecast for ultimate utilization at this point.

H. LIQUID WASTE SYSTEM CONCEPTS

The domestic water usage model originally discussed in Section III is reiterated in Table V-8 and Figure V-11. This baseline water model serves as a departure point in discussing the liquid waste system concepts. The baseline system utilizes no low water devices and requires 255 gallons per day of potable water. The wastes from the baseline system are 248 gallons per day.

Based on evaluations as discussed in the previous section, three concepts were generated. The first uses only low water devices, the second uses low water devices in conjunction with recycling of grey waters for toilet flushing only, and the third uses low water devices and an oil transport system for toilet wastes. Reuse of grey waters for purposes other than for toilet flushing was considered and rejected. Reuse for such non-potable and non-contact areas as laundry and utility sink functions was also rejected since the amount of treatment required is nearly that necessary to produce potable water and therefore too costly.

Table V-8 DOMESTIC WATER USAGE MODEL

	FAMILY WATER USE GPD	HOT WATER USE GPD
DISH WASHER	15	15
GARBAGE DISPOSAL UNIT	3	0
OTHER KITCHEN	9	9
UTILITY SINK (CLEANING)	5	4
LAUNDRY	35	26
BATHING	80	60
LAVATORY	8	1
TOILET	<u>100</u>	<u>0</u>
	255	115

*SOURCE: J. R. BAILET et al - A STUDY OF FLOW REDUCTION & TREATMENT OF
WASTE WATER FROM HOUSEHOLDS, DEPT. OF
INTERIOR, FWQA 1969

Figure V-11

BASELINE WATER USE MODEL*
255 GPD

Bailey et.al.; FWQA, 1969 (modified)

Low water devices were shown to be cost-effective items and consequently these are utilized by the three concepts. Water use by a low flush toilet is approximately 14 quarts versus 21 quarts for a conventional toilet. Thus the baseline which required 100 gallons for a conventional toilet is reduced to 66 gallons for a shallow trap toilet, under the low water usage model, assuming the same number of flushes occurs daily. Bailey, et al, reduced the bathing water requirements from 80 gallons to 60 gallons per day through the use of flow control showers. It was estimated that an additional 10 gallons per day may be saved if thermostatically controlled valves were incorporated into the bathing areas, for a total water usage of 50 gallons per day. Laundry water requirements were reduced from 35 gallons per day to 30 gallons per day by considering utilization of the selectable cycle washing machines which more closely match the machine water levels to the load. Lavatory water usage was reduced from 8 gallons per day to 6 gallons per day by use of proximity or self closing taps to prevent water waste. The resultant low water use model is shown in Figure V-12. Potable water input requirements are reduced by 71 gallons per day to 184 gallons. Waste flows to the on-site disposal treatment process is reduced by the same amount.

Low water use, combined with recycling for toilet flushing is shown in Figure V-13. This system utilizes filtration combined with disinfection to treat grey water wastes to a level acceptable for toilet flushing. While grey water direct reuse for toilet flushing may be acceptable, it was deemed advisable to treat these waters to reduce bacteria levels and remove solids in order to reduce the likelihood of a small child becoming sick from ingestion of same. Of the 118 gallons of grey waste waters collected, only 66 gallons is required for recycling for toilet flushing. Consequently a high rate of bypass in the filtration unit is possible, and solids buildup in the effluent should be minimal. This concept reduces the amount of fresh water required by 66 gallons per day over the low water use only system. Waste flows to the on-site waste treatment process are reduced by the same amount. The primary energy resource available for combination with a solid waste system feces - are still extensively diluted in this concept, however.

Figure V-12 LOW WATER USE MODEL
184 GPD

Figure V-13 Low Water and Recycling for Toilet Flushing Model
118 GPD

A concept utilizing non-aqueous transport of toilet wastes is shown in Figure V-14. This utilizes low waterA concept and toilet paper to a holding tank. The fecal and urine wastes are held in a concentrated form in the holding tank.

A garbage disposal was considered in the oil transport system. Since disposal wastes are considered as black waters. It should use the same disposal method as the toilet. A concept was developed for such using a batch type disposal operating with an oil flush. Use would be similar to the conventional batch disposal except that oil would be recirculated internally rather than water being admitted through the partially open top as in the current practice. Such a unit would be located outside, but adjacent to the sink area to prevent excess amounts of water from being added to the oil system. While the system itself would permit such water flows, the dilution effect upon the wastes would downgrade the desired potential for later combination with the solid waste system. However, there was some doubt as to whether the finely chopped food particles would adequately settle out in the oil system holding tank. Because of this unknown, the oil garbage disposal was eliminated from the system.

The disposal waste could be added to the water side of the system and would be adequately handled by the grey waste treatment and disposal systems. This, however, would cause high contamination of the grey water wastes and result in loss of an energy source and it would negate the desirability of having only a grey water system which could then utilize a smaller septic tank/waste treatment process and a smaller soil absorption field, and was therefore rejected. Thus, the oil system, in conjunction with grey water waste on-site treatment and disposal assumes that food wastes be collected in the same manner as the other solid waste.

This system requires a potable water supply of 115 gallons per day and produces a waste flow for on-site disposal of 107 gallons per day. The holding tank may be pumped out annually if no other system combination is used, or alternatively the concentrated wastes may combined with the solids waste system for energy utilization.

POTABLE SUPPLY - 115 GPD

Figure V-14 . Low Water Use and Non-Aqueous Transport Model

115 GPD

A summary of the various water systems as to water usage, component water requirements, and resultant on-site waste disposal requirements is shown in Table V-9. The reduced flow system reduces water requirements and waste treatment flows over that of the baseline system, but not substantially. The greatest reduction is seen in the last two systems - reduced flow with recycling grey water for toilet flushing and the reduced flow with oil transport systems. The greater difference between the last two systems is in (a) the type of waste treatment system required on-site, combined or grey water only and, (b) the form in which the wastes are available for further processing or combination with a solid waste energy recovery system - dilute or concentrated. For this latter respect, the oil transport system holds the greatest potential. These two systems will be carried forward and re-examined as to applicability with the total combined liquid and solid waste system.

Table V-9 Liquid System Flows

<u>Component</u>	<u>Baseline</u>	<u>Baseline with reduced flow devices</u>	<u>Reduced flow devices plus recycling for flush</u>	<u>Reduced flow devices plus oil transport</u>
Dishwasher	15 GPD	15	15	15
Garbage Disposal	3	3	3	-
Other Kitchen	9	9	9	9
Utility Sink	5	5	5	5
Laundry	35	30	30	30
Bathing	80	50	50	50
Lavatory	8	6	6	6
Toilet	<u>100</u>	<u>66</u>	<u>66</u>	<u>-</u>
Weather Demand	255	184	184	115
Potable Supply	255	184	118	115
Waste Flows to On-Site System	248	177	110	107
On-Site Treatment for wastes	Combined	Combined	Combined	Grey water only

VI INTEGRATED SYSTEM CONCEPTS

A. SOLID WASTE FUEL FIRING

The lowest cost option developed for solid waste processing in Section IV was manual transport and manual firing. The liquid waste concepts developed under Section V were grey water recycling for toilet flushing and oil transport of fecal and urine wastes, both using low water usage devices. The obvious next step was to combine the possible variations of these processes to obtain an integrated system.

Solid waste fuel firing may be accomplished in a special device such as an incinerator, wood/garbage burning furnace/stove or a modified furnace. The purpose generally of an incinerator is to destroy waste, no energy recovery is attempted. Wood/coal/waste burning furnaces are available, but extremely limited in current usage and expensive as compared to a conventional furnace. The obvious application then would be a modified home furnace.

The combination of the solid waste with liquid wastes in order to form an integrated system was examined. The liquid waste system using recycled water for toilet flushing presents those wastes in a form too dilute to be burned in a conventional furnace even when the solid wastes are combined. The oil transport system substantially reduces the amount of liquid present with the solids, but even the urine only imposes a substantial energy input requirement, as shown below:

Fecal Solids Energy Available:

$$1.26 \text{ LB/DAY} \times (.34) \text{ SOLIDS} \times 7668 \text{ BTU/LB} = 3285 \text{ BTU/DAY}$$

Minus Energy Required to Evaporate Fecal Water:

$$1.26 \text{ LB/DAY} \times (.66) \text{ Water} \times 1040 \text{ BTU/LB} = -865$$

(1040 Btu/lb is the energy required to vaporize water at a nominal temperature of 95°F)

Minus Energy Required to Evaporate Urine Water:

$$1.1 \text{ GPD} \times 8.3 \text{ LB/GAL} \times (.95) \text{ Water} \times 1040 \text{ BTU/LB} = -9020$$

**Energy Required = -6600 BTU/DAY
(NET LOSS TO SYSTEM)**

This represents only the energy required to evaporate the fecal and urine waters, over that furnished by the fecal solids. If the combustor is operating at a temperature in excess of 212°F, then additional sensible energy is also required to heat the steam to the appropriate temperatures in the combustion chamber.

Further development of slurry firing concepts may improve firing techniques, but the net energy available is still negated by the moisture requirements. The concept for combination of liquid wastes and solid wastes for combustion leads to reduced net energy recoverable over a concept which combusts only solid wastes. Therefore, the possibility for an integrated system is not feasible for this concept.

A modified home furnace for solid waste firing was considered. Solid wastes would be placed in removable containers such as that shown in Figure VI-1. The container would be encased in an outer cover and would appear much like a wastebasket in the home living areas. The liner has a lower sidewall which is solid in order to retain liquids and wet food wastes as might be disposed of in kitchen garbage. An open gridwork sidewall permits air circulation and good flame contact for rapid drying and combustion when fired in the furnace. A centercore provides an increased surface area and circulation path for drying and subsequent firing. The metal sidewall also retains ashes left in the firing process for disposal.

The solid waste firing concept utilizing a modified furnace in conjunction with these containers is shown in Figure VI-2. An entry port permits loading of the container into an initial loading/drying position which is located in the cooler portion of the furnace. The container is keyed to the guiderods so that the ash retention partition is located properly. An entry port similar to that for a night deposit box prevents combustion gases from escaping during loading as well as preventing the user from inadvertent injury through contact with the hot interior.

As other containers are loaded, the first progresses from the original loading/drying zone, into the firing zone and then into the rejecting area. This last zone is pitched such that when a container is forced into the zone, it rolls down a chute into a cooling/unloading chamber. As it rolls, the ashes are dropped into an integral ash container which is periodically emptied. The unloading/cooling position has a door similar to that of the entry position to prevent combustion gases from escaping and also to prevent user injury.

Figure VI-1. Solid Waste Container.

Figure VI-2. Solids Disposal Concept

The solid waste system could be implemented in the warm air furnace by utilization of the area of the inspection port. See Figures VI-3 and 4. The sidewall penetration required for the unloading chute could also be accommodated. However, retrofit to a hot water system is not easily accomplished as the water jacket would have to be penetrated. Water boilers would be in the same category as to retrofit.

The potential for such a system is limited. While the maximum use of the solid wastes is accomplished as to energy recovery, the system is not integrated and consequently no energy recovery is possible from the liquid wastes. Retrofit capability is limited to warm air furnaces and new installations since hot water systems and boilers are not easily adaptable because of the locations of the water tubes. There are, however, a number of piggy-back devices coming into the market place similar to that shown in Figure VI-5. Reclamation is limited to periods when the furnace is operating which restricts the potential both in climatic regions and periods. The problems of increased soot generation with the furnace, resulting in lowered combustion efficiency and pollution controls must also be dealt with. In summary, the limitations of this concept are significant and further consideration of such is not warranted.

B. SOLID WASTE THERMOPHILIC DIGESTION

The concept of thermophilic digestion of solid wastes was derived from the composting toilet and the composting system. The prime objections to those type systems were the poor esthetics involved, the lack of energy recovery, and the required fan power in the case of the composting toilet. The fact that several reports on municipal composting systems reported windrow temperatures of 50°C or higher, in windrows open to the weather, meant that there was energy being generated in this decomposition process, and that a potential existed for energy recovery. Consequently a review of this process, in combination with the liquid waste systems, was accomplished.

Composting requires a moisture level of approximately 55% for most efficient operation. While the system using recycled grey water for toilet flushing provides wastes diluted with entirely too much water for composting, the wastes provided by the oil transport system are more concentrated and are very near the optimum when mixed with the solid wastes. The oil transport system provides a plus factor which is lacking with the composting toilet and composting system - good aesthetics. The conventional appearance of toilet should reduce many of the objections to the composting toilet and system.

Figure VI-3. Furnace Configuration

Figure VI-4. Furnace Dimensions

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Figure VI-5. Piggy-Back Wood Fuel Furnace Device.

While the composting toilet has the drawback of continual fan power, the composting system does not, as the latter relies on gravity circulation. Because of its smaller size, the composting toilet must rely on accelerated decomposition and therefore requires heat and increased air flows to accomplish this, while the larger composting system can operate without parasite energy loss although requiring longer periods for decompositions.

Composting of wastes has long been used in the agricultural sector to produce humus and to reduce the volume of waste materials. In the residential area, Europeans for a number of years have used similar techniques, and at the present time, there are more than twenty manufacturers of composting systems for household toilet wastes. In virtually all cases aerobic composting is utilized because it provides a reduction in solids of up to 95%, freedom from noxious odor and faster reaction times. See Reference VI-1.

These systems generally operated in the 50° - 80°F temperature range and are most widely used on an intermittent basis where such temperatures can be obtained even on an intermittent basis.

Such systems are also capable of being operated at elevated levels of 140° - 150°F and function effectively at these high levels under adverse conditions. Figure VI-6 shows the temperatures reached within a windrow type compost pile which was exposed to the elements. Shielding of the pile and insulating of the compost area both serve to maintain these temperatures. As can be observed in Figure VI-6, the temperature gradually decreases as the compost matures. This may be avoided in a home system, since new material is continually being added while the mature product gravitates to an emptying tray.

The combination of the oil transport system with a composting process utilizing both solid wastes and liquid wastes in a high temperature thermophilic digestion process offers the advantages of low power requirements, system integration, and energy recovery potential combined with good aesthetics. Such a system is shown conceptually in Figures VI-7 and VI-8.

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1. "21 Biological Toilets", Extracted from Consumer Report No. 10., Microbiological Institute, Agricultural College of Norway.

Figure VI-6.
(From Reference 2)

Toilet wastes are flushed to a holding tank where the solid and liquid wastes settle out to the bottom of the tank. The mineral oil comprises the top layer in the tank. A floating pickup recirculates the mineral oil when required through filters back to the toilet. The black wastes in the sludge tank are periodically pumped to the compost tank. When this pump is actuated it also causes an arm within the compost tank to rotate, thereby spreading the load over the entire area. Yard wastes and food wastes are admitted to the compost tank via a shredder which serves to reduce the particle size. Paper and other combustibles are loaded in a pulper where they are allowed to soak in water from the dishwasher rinse in order to reduce the power required in the subsequent pulping step.

2. "Composting at Johnson City", Volumes 1 and 2, Final Report on Joint USEPA-TVA Project, U. S. Environmental Protection Agency, 1975, Page 70.

Figure VI-7. Integrated Solid Waste/Liquid Waste Concept

Figure VI-8. Thermophilic Digestion Concept

An integral heat exchanger serves to absorb energy for use in heating the domestic hot water, a combination cake breaker and leveler aerates and aids in spreading the compost pile as the arm is turned. A natural circulation vent draws air through the pile to provide air for the aerobic process.

This natural circulation vent also facilitates evaporation of moisture generated by decomposition and excess moisture present in the as-received material. Periodically, once or twice per year, the residue of the composting process is removed from the lower compartment and disposed of. This may be accomplished by utilizing plastic liners in the lower section which are simply gathered up in a bag like fashion, thereby eliminating shoveling or other material handling.

The positive features of this concept include:

- a. State-of-the-art components and techniques - The oil transport system is well developed and utilized in many recreational areas where on-site drainage is a problem. Composting is a technique utilized to a large extent in foreign countries, with several plants in the U.S.
- b. The system is climate compatible As this concept does not depend on firing for energy recovery, but rather composting in conjunction with recovered heat for hot water heating, it is independent of the house heating junction.
- c. Water consumption is reduced Since no water is used for toilet flushing, approximately 66 gallons per day is saved in addition to that credited for the use of low water devices.
- d. Conventional appearance - The oil transport toilet is a conventional appearing low flush toilet which differs only in a Teflon lined bowl which reduces soiling buildup.
- e. Common processing of solid and liquid water - The system is integrated, disposing of the combustible solid wastes with the concentrated liquid wastes.

- f. Reduced on-site disposal requirements - Since the liquid waste system is now handling only grey water wastes, the on-site disposal system can be simplified and its size reduced accordingly. Also, because of the greatly reduced liquid loads to the on-site system, land areas which might otherwise be marginal in respect to soil absorption are now viable building areas.
- g. Trash pickup and processing reduced - Since the majority of wastes are disposed of in the compost tank, the garbage and trash volume is considerably reduced. The non-compostable items such as metals, plastics, and bulky items have a salvage value which may prove to be an incentive for no cost pickup.

The several negative features are listed below:

- a. The system is inoperative without electricity. - While this may be a drawback to those accustomed to the never-failing township water supplies, the situation is similar to that experienced by suburban and rural homeowners with on-site wells. Electrical failure in those areas leaves the user with perhaps several toilet flushes available, depending upon the capacity of the pressurized water tank. The oil system still has one flush available as the toilet tank is filled with oil for gravity flushing.
- b. Regular maintenance is required - Periodic emptying of the compost residue is required as well as occasional filter changing. Although the maintenance required is minimal, some will be required. Therefore, the benefits must outweigh the negative aspects if acceptance is to be gained.
- c. The average homeowner is unfamiliar with the oil transport system and the composting process. While both processes are simple, they are new to the homeowner and therefore unknown. Some learning process will be involved as that required for any new equipment, device or appliance.

The potential benefits of this concept are sufficiently attractive that it will be carried forward and more extensively defined and investigated.

VII SELECTED SYSTEM CONCEPT

Perhaps one of the greatest polluters in our present society is the water flush toilet where 5 gallons of potable water is used to transport away approximately one pint of wastes. The problems thus presented by these otherwise concentrated wastes are thus magnified 40 fold. This practice results in significant expenditures of energy to provide a method of disposing of a potential source of energy that is subsequently subjected to far energy expenditures to render it useless. Beyond the expenditure of energy, additional losses are incurred in another limited resource - water. As a result of present practice, systems that reduce energy loss or expenditures will become increasingly desirable.

The concept selected maximizes energy recovery from solid and liquid wastes, minimizes energy usage for providing water and sewage and utilizes minimum parasitic expenditures of energy to accomplish this. The basic premise of the system is to keep wastes concentrated while utilizing conventional appearing facilities.

A. SYSTEM DESCRIPTION

The system is comprised of a black waste collection subsystem, a solid waste collection subsystem and a processing subsystem, with necessary control and monitoring equipment. The integrated system functional schematic is shown in Figure VII-1 and the component arrangement is shown conceptually in Figure VII-2.

The black waste collection subsystem is composed of one or more toilets, a sludge collection tank, recirculating flush filters, water separators, pump, interconnecting piping and fluid inventory. The toilet is a conventional appearing low volume flush apparatus modified to incorporate a Teflon lined bowl and a tank fluid level float switch. Toilet wastes are flushed using mineral oil to a sludge collection tank. In this tank, the difference in density between the mineral oil, urine and solid wastes cause the separation of the transporting fluid from the waste products. The mineral oil floats on top of the wastes, thus sealing in orders and permitting reuse of the transport fluid. A pickup tube permits the flushing fluid to be withdrawn from the sludge tank when required for appliance flushing. The fluid passes thru a water separator where any entrained water is separated and returned to the sludge tank. The flushing fluid then passes through a filter to remove any small particles which may be present before passing through the pump to the appropriate appliance.

Figure VII-1. System Schematic

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Figure VII-2 Component Arrangement

Controls are provided in the black waste collection subsystem to direct flush fluid flow to the appropriate appliance, to monitor filter condition (pressure drop) and to monitor tank level. If an equipment malfunction should prevent sludge removal from the sludge tank for an extended period of time, the high level switch will prevent overfilling and backup by inhibiting the flow of the transport fluid to any appliance.

Urine, feces, and toilet paper are pumped from the sludge tank setting area onto a table in the compost tank when the level switch at the sludge tank fluid interface verifies that a sufficient amount of wastes has accumulated. The compost tank is part of the processing subsystem which also includes the domestic hot water heater, a water pump, and a temperature controller. When the pump is operated to move material from the sludge tank into the compost tank the motor also turns a leveling and cakebreaker arm in the compost tank. This permits deposited material to be evenly spread over the table as well as breaking up and turning the crust of the compost pile to facilitate aeration.

The material deposited on the table quickly builds up to surround a heat exchanger of stainless steel tubing Teflon coated to reduce adherence of composted materials. This aids heat exchange between the materials and tubing since a thick layer of dried out material is not allowed to accumulate on the tubing.

The domestic hot water heater is connected to the heat exchanger to extract energy from the compost pile. The hot water heater is located near the compost tank to take advantage of the thermosyphon effect. (See calculations in Appendix C)

A water pump and temperature controller is provided so that the pile may be brought up to temperature quickly after vacations, or other periods of low input/or microbial activity. A humidity readout is provided on the compost tank to provide monitoring of the compost pile status. This may be coupled to a warning device or automatic water addition equipment to prevent drying out the pile with subsequent reduction in microbial activity.

The solid waste collection subsystem is provided to handle materials such as food wastes, paper, wood chips, lawn clippings, leaves, etc. A shredder is used to chip and cut primary yard wastes. These are fed directly into the composter. A wet pulper is included to handle paper wastes. Hot waste water such as from the rinse cycle of a dishwasher is temporarily stored in a holding tank. Waste papers are loaded into the pulper and when full the lid is closed and the hot waste water is admitted. The material is left to soak and then wet pulped at minimum energy utilization. The resulting wetted material is then fed into the compost tank.

The composting process is adaptable to a relatively wide range of carbon/nitrogen ratio. However, to prevent abuse of the system some gross monitoring method may be added if tests show such a device to be required. This could take the form of comparing toilet flushes (the primary source of nitrogen) against wet pulping operations (the primary source of carbon). A suitable alarm or inhibit function might be employed to protect the system against an obvious overloading of one or the other elements. While it is not envisioned that such would be required at the present time, provisions are available for such if testing shows that a monitoring system is required.

The integrated waste management system concept, in addition to producing usable energy for hot water heating, reduces the amount of potable fresh water utilized by a household. A typical household requires 255 gallons per day of fresh water of which 100 gallons is required for toilet flushing. In addition, the waste water disposal field must accommodate a daily flow of 248 gallons of highly contaminated wastes.

Water requirements for the same household using the proposed system in conjunction with low water consumption devices are lowered to 115 gallons per day. The waste water flows from the household are also reduced, to approximately 103 GPD. In addition, as these waste waters are not contaminated by fecal and urine wastes, the effluent may be handled with a reduced drain field area.

Maintenance of the system is limited to emptying the residue compartment twice a year and changing of the fluid filter yearly. The experience of oil system manufacturers has indicated that the yearly filter change may be more frequent than required. However, this is in line with their current recommendations and will be retained for now. To avoid potential problems or objections from home owners and/or health officials, the compost residue will be emptied by scrapping into a impervious Kraft/Paper bag which may then be disposed of in the segregated salvagable wastes or by burying. In the later case the bag will decompose in the ground so all residue will eventually return to the soil. The bag may be formed to the shape for the lower compartment so that no transfer of material from an emptying tray to another container will be required.

The compost residue is a good soil conditioner as it is high in organic matter as well as containing some small amount of plant nutrients. Chemical analysis of samples from composting toilets show that the amounts of potentially toxic metals are well below those levels considered acceptable for composted sewage sludge that is to be applied to agricultural soils. The level of bacterial content in the residue is similar to that of soil. The residue of human waste obviously will be objectionable to many. The low levels of harmful bacteria, chemical constituents, and lack of parasites in such material may help to calm such fears. For that reason, results of bacteriological, chemical and parasitic tests on residues taken from composting toilets presented as Tables VII-1, 2 and 3. Also, a letter reporting analysis of several Ecolet scrappings is presented.

B. COMPONENT DESCRIPTION

Toilet

The toilet is a conventional shallow trap toilet modified with a Teflon lined bowl to retard soiling. The toilet tank utilizes a float switch which provides an electrical signal to turn the oil pump on and off, and also to actuate the proper solenoid valve to direct oil flow to the appropriate toilet.

Sludge Tank Assembly

The sludge tank assembly is shown in Figure VII-3. The tank is a mild steel container with three compartments. Wastes are transferred into the large lower compartment where the difference in densities causes the wastes to settle to the bottom, while the mineral oil floats to the top. A volume of 60 gallons are provided in this compartment. This provides a sufficient room for waste settling, to accommodate simultaneous flushing of three toilets, and provides approximately 10 days storage for emergency periods.

Table VII-1. Presence Of Bacteria In Samples From The Different Ecolets¹

Toilet	No. of bacteria/g air-dry sample		
	Total 22°C	Total coliform 35°C	Thermostable coliform 44°C
1	4.2.10 ⁵	1.0.10 ²	< 10
2	3.0.10 ⁷	< 10	< 10
3	1.2.10 ⁵	< 10	< 10
4	6.3.10 ⁵	2.0.10 ²	< 10
5	2.7.10 ⁵	1.7.10 ³	1.5.10 ³
6	1.2.10 ⁷	1.0.10 ²	< 10
7	3.5.10 ⁶	3.2.10 ⁵	2.74.10 ⁵
8	6.2.10 ⁶	7.0.10 ⁵	5.0.10 ⁵

Table VII-2. Results Of Bacteriological, Chemical And Parasitic Tests On Ecolet Compost Samples In Sweden²

	Ecolet in use for		
	3 Months	6 Months	9 Months
Eschorichia coli (per 100 g waste)	240,000	0	0
Coliform	460,000	360	10,500
Faecal streptococci	240,000	2,100	360
ph value	6.1	6.8	6.8
Dry substance (%)	88	89	92
Mineral substance (% dry subst.)	32	53	46
Organic substance (% dry subst.)	68	47	54
Total nitrogen (% dry subst.)	2.89	1.56	2.34
Carbon/Nitrogen	12.5	12.8	10.3
Phosphorus (P % dry subst.)	0.85	1.7	1.9
Potassium (K % dry subst.)	2.1	3.1	2.7
Calcium (Ca % dry subst.)	0.6	1.5	1.1
Parasitic examination	Negative	Negative	Negative

These results are very similar to those obtained in a laboratory of the Royal Swedish Agricultural College in UPPSALA concerning samples from installations which had been in use for corresponding periods.

1. Extracted From Reports Submitted by Drs. Coin and Legarde to the French Ministry of Public Health, Water, Drainage, and Sewage Section, May 7, 1973, regarding request for approval of Mullbank decomposition toilet.
2. Valdmaa, Dr. Kalju; "Function of the Ecolet Biological Compost Toilet", The Royal Agricultural College of Sweden, Uppala, Sweden.

Table VII-3 CONTENTS OF DIFFERENT SUBSTANCES IN THE FINAL PRODUCT OF DIFFERENT ECOLETS,
IN COMPARISON WITH DIGESTED SLUDGE AND FARMYARD MANURE 2

8-IIA	Substance	Toilet no.								Mean	Digested sludge	Farmyard manure
		1	2	3	4	5	6	7	8			
	Dry matter (dm)	88.8	69.9	79.0	84.9	86.6	91.0	94.1	95.2			
	pH	6.6	8.0	7.0	6.9	6.9	6.6	6.7	6.6	6.6	6.9	8.5
	KJ.-N in % of dm	3.16	2.76	3.06	2.13	1.70	3.21	2.22	1.93	2.5	4.9	2.2
	NH ₄ -N --	1.70	1.44	1.80	0.33	0.35	0.73	0.26	0.42	0.9	1.0	0.3
	NO ₃ -N --	0.11	0.33	0.09	0.06	0.05	0.08	0.11	0.10	0.1	0.1	0.1
	Tot.-N --	3.27	3.09	3.15	2.19	1.75	3.29	2.33	2.03	2.6	5.0	2.3
	Org.-N --	1.46	1.32	1.26	1.80	1.35	2.48	1.96	1.51	1.6	3.9	1.9
	Org. C --	16.2	24.7	23.5	28.5	20.7	28.7	21.0	18.1	22.7	34.2	44.1
	Org. matter in % of dm	44.2	51.9	51.2	47.8	40.2	57.9	45.2	41.9	47.5	59.0	76.0
	Phosphorus (P) "	2.88	0.66	2.19	1.33	1.00	1.26	1.49	1.12	1.5	1.5	0.6
	Potassium (K) "	3.86	1.90	6.80	2.17	2.00	4.40	1.95	1.88	3.1	0.4	2.1
	Calcium (Ca) "	0.46	0.79	0.55	2.53	1.36	1.24	3.19	2.95	1.6	2.5	1.5
	Magnesium (Mg) "	0.03	0.09	0.04	0.33	0.22	0.12	0.64	0.59	0.3	0.4 ^{x)}	0.1
	Zinc (Zn) mg/kg dm	51	37	18	154	60	96	247	184	106	1700 ^{xx)}	80
	Lead (Pb) --	56	14	14	53	37	15	30	22	30	180 ^{xx)}	10
	Cadmium (Cd) --	1.1	0.7	0.8	0.6	0.4	0.8	0.9	0.8	0.8	6.0 ^{xx)}	0.2
	Mercury (Hg) --	0.12	0.15	0.07	0.35	0.20	0.31	0.50	0.41	0.3	6.0 ^{xx)}	0.04
	C/N ratio (org. N)	11.1	18.7	18.7	15.8	15.3	11.6	10.7	12.0	14.2	8.8	23.2

x) mean value of 25 Swedish sewage plants

xx) mean value of 90 Swedish sewage plants, in cooperation with S. Odén

KJ.-N : Kjeldahl-nitrogen

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March 8, 1977
Project #5857

Attn: Dr. Lepley

Scrapings from Ecolet Composting Toilet

Two samples of scrapings from Ecolet biological toilets were delivered to the lab for chemical and bacteriological testing. The results are tabulated below.

Sample	Baldurn Ecolet #3 Installed Jan. 1976 Scraped down Jan. 6, 1977	Baldurn Ecolet # 2 Installed Dec. 24, 1975 Scraped down Jan. 6, 1977
pH Value*	8.00	7.15
Dry Substance	43.7 %	58.2 %
Mineral Substance D. B. **	34.6 %	44.5 %
Organic Substance D. B.	65.4 %	55.5 %
Total Nitrogen D. B.	4.24 %	3.71 %
Carbon/Nitrogen	7.4	7.5
Phosphorus D. B.	1.8 %	4.5 %
Potassium D. B.	0.50 %	2.70 %
Calcium D. B.	0.46 %	2.06 %
Escherichia Coli	less than 100/100gm.	less than 100/100gm.
Coliform	less than 100/100gm.	less than 100/100gm.
Fecal Streptococci	3000/100gm.	less than 100/100gm.

*pH of a 5% suspension of the scrapings in water

** D. B. means Dry Basis, thus all the values given with this notation are on the basis of the material remaining after the moisture is driven off.

Edward J. Carroll, Asst. Mgr.

Figure VII-3 Sludge Tank Assembly

Mineral oil passes thru a screen between the two lower compartments. The screen functions to remove large solid particles from the mineral oil as a first filter. A floating pickup in the smaller lower compartment permits the oil to be drawn up through a tube into the pump. Two level sensor systems are located in the smaller lower compartment. One system utilizes interface floats which are weighted to float on mineral oil - urine interface. This system serves to turn on and off the sludge pump which moves wastes from the sludge tank into the compost tank.

The second level sensor system is comprised of conventional floats which give warnings of high and low fluid levels. A high level inhibits further addition of wastes to the sludge tank by preventing operation of the oil pump. The low fluid level gives a warning that a leakage has occurred or that the system is otherwise malfunctioning.

The top compartment contains the mineral oil pump, electrical controls, a coalescer which serves to remove water from the flushing fluid, and a filter which removes solids. The pump is an Oberdorfer gear pump which utilizes a 1/3 HP motor. The coalescer is a Monogram Industries unit as is the filter. Both of these latter units are utilized in the Monogram Industries mineral oil transport system, after which this design is patterned.

The top of the sludge tank assembly is removable to permit easy servicing of components such as the filter and pump. The tank interfaces need not be disturbed when the cover is removed and replaced.

Sludge Pump

The sludge pump serves to transfer concentrated wastes from the sludge tank to the compost tank. The motor provides a second function which is to turn a leveling arm in the compost tank. The sludge pump is a Oberdorfer helical rotor pump which utilizes a 1/2 HP motor with a double shaft motor in order to provide the means for driving the compost tank leveling arm.

Compost Tank Assembly

The compost tank assembly is composed of a tank, a gridwork table, a set of leveling arms with drive mechanism, a heat exchanger, a vent stack, humidity sensor and insulation. The compost tank is fabricated in two parts, a top and lower half, so that the tank may be moved through a 30" door opening. See Figure VII-4.

The lower half of the tank is a mild steel assembly which contains a structure to carry the loads imposed by the compost pile on the gridwork table. Two removable trays are provided in this part of the tank to permit removal of the compost residue. Bag liners are placed in these emptying trays so that the residue may be easily removed and disposed of. Air vents are located under the table level to permit air flow through the composting material and then into the vent.

The upper half of the tank houses a heat exchanger which serves to heat water using the energy given off by the compost pile. A leveling arm is mechanically driven through gear boxes and shafting from the sludge pump motor. This leveling arm serves to distribute the waste materials over the heat exchanger area and also serves to breakup the crust, thereby improving aeration of the compost pile. The top of the tank provides the interfaces for the sludge inlet, shredder input, pulper input, the vent stack outlet and the humidity sensor mounting.

The heat exchanger uses gravity circulation to heat water received from a stratified water tank. After dormant periods, such as vacations or shutdowns, the compost pile may be quickly brought back to temperature by utilizing energy from the hot water in the water heater. A three-way valve and pump are operated to permit hot water to be drawn from the top of the water heater, through the heat exchanger and back into the lower portion of the hot water heater. Normal circulation is resumed after the pile is at temperature and the valve and pump are shut off.

The heat exchanger is a 14 foot coil of stainless steel tubing with a 0.5 inch O.D. and a 0.35 wall thickness. The surface area presented by this coil is sufficient to transfer the heat given off by the pile. See calculations in Appendix C for the sizing information of this heat exchanger, and for the flow head developed.

Figure VII-4 Compost Tank Assembly

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The entire compost tank is covered with an insulation jacket to reduce heat losses and maintain internal temperatures.

The size of the compost tank was derived using the information of Table VII-4 as a starting point. The top compartment was sized to maintain a load equivalent to 2 months volume. The compost process initially undergoes rapid volume buildup, and then levels out, after which the volume is maintained.

The daily generated volume of 0.5206 ft^3 contains 7.59 lb/day of moisture which is evaporated to maintain the proper moisture level in the compost pile. This results in a net volume after moisture evaporation of 0.399 ft^3 /day of material. Over a sixty day period this accumulates to approximately 24 cubic feet.

If a tank diameter of 4.5 feet is assumed, the required height is 18 inches. An additional 4 inches is left for air flow and safety factor, and thus a design height of 22 inches is provided.

The volume required for the receiving tray was calculated using information derived from reference 6 and 8. The residue reported by these sources varies between 6.7% and 7.2% of the original volume. Assuming a density of the composted residue at 40 lb/ft^3 , a year's accumulation was calculated:

$$\begin{array}{rcl} \text{Daily Weight} & = & 22.74 \text{ LB} \\ \text{Moisture Evaporated} & = & - \underline{7.59 \text{ LB}} \\ & & 15.15 \text{ LB} \end{array}$$

$$\frac{15.15 \text{ LB}}{\text{DAY}} \times 365 \text{ DAYS} = 5529.8 \text{ LB}$$

Assuming the higher value of 7.2%, the residue is 398 LB.

@ 40 LB/FT^3 , the required volume is 9.95 ft^3 .

Assuming a tank diameter of 4.5 feet, the required height is 7.5 inches. The actual height was set at 8 inches, which provides a 100% safety factor since the trays are programmed to be emptied every six months while the volume available is sufficient for one year.

Table VII-4. Waste Volumes

	Density <u>LB/FT³</u> (3)	Total Weight <u>LB/Day</u>	Volume <u>FT³/Day</u>
A. <u>Trash</u>			
Paper	33	4.09	0.124
Leather, Rubber, Wood	22	0.66	0.030
Miscellaneous, Including Textiles	22	0.35	0.016
B. <u>Food Wastes</u>			
Garbage	30	1.40	0.047
Fats	50	0.28	0.0056
C. <u>Yard Wastes</u>			
Grass	22	0.467	0.021
Brush	22	0.175	0.008
Greens	22	0.175	0.008
Leaves	22	0.583	0.027
D. <u>Sewage</u>			
Feces	62.4	1.32	0.021
Urine	62.4	9.15	0.147
E. <u>Water for Pulping</u>	62.4	4.09	0.066
Total		22.74 LB	0.5206 FT ³

3. Paroni, J. L., J. E. Heer, Jr., D. J. Hagerty, Handbook of Solid Waste Disposal, Materials and Energy Recovery, Van Nostrand Reinhold Co., New York, N. Y., 1975, Page 72.

Shredder

The shredder is a conventional shredder-grinder produced by Amerind-MacKissic, Incorporated with a 2 HP electric motor. The shredder reduces the size of input material to approximately 1 inch. The loading hopper is modified to incorporate a self closing door in order to prevent risk of injury and also to eliminate unwanted air flow into the system.

Pulper

The pulper is an EPA developed item, which was developed for transmission of household refuse in pressurized sewer lines. The item is described more fully in Reference 4. A 2 HP electric motor is used. Wastes are loaded in the hopper and when a sufficient load is accumulated, the user closes and seals the lid, and presses a start button. This activates a solenoid valve from a holding tank which then admits hot rinse water stored from the dishwasher use. If sufficient water is not present in the holding tank, water from the potable supply is admitted for makeup. The wastes are then allowed to set in the water for several hours, in order to help break down the paper wastes. After this period, the pulper is operated for a given time period and the pulped wastes pumped to the compost tank. Appropriate interlocks are provided to prevent entry into the pulper loading hopper when the pulper is in the operational cycle.

C. CONCEPT VARIATIONS

Three concept variations were conceptualized and these are discussed here. No development or evaluation of these concepts was accomplished as these were felt to require significantly greater study which might be accomplished as part of a hardware development phase.

1. Integral Hot Water Heater

The concept is relative to enlarging the designed heat exchanger within the compost tank assembly such that it contains the entire hot water volume. The enlarged unit would then serve as both the water heater and water container. Some method of preheating of inlet water would be required in order to bring the cold water to an acceptable temperature which would otherwise thermally shock the composting. A post heater would also be required to provide makeup energy as the compost energy is less than that required for the total hot water requirements.

4. Fisk, et al, "Preliminary Design of a Household Refuse Grinder", Foster-Miller Associates, Inc., For USEPA, EPA-670/2-74-020, Page 116.

2. Waste Water for Preheating

The potential for use of waste liquids for heat reuse was previously described as limited for home heating. The potential for use as hot water preheating either with the integrated system or with number 1 above is greatly improved as the lower grade waste temperatures are, in many cases, above the incoming water temperatures. With the integral hot water heater concept, the waste liquids could be used to preheat the incoming potable water. A separate tank would be required to accumulate both the waste liquids and a suitable volume of potable water in order to allow sufficient time for heat transfer. The same idea could be used in the integrated system by preheating the water prior to its entry into the hot water tank.

3. Combination Composting and Firing System

This concept is shown in Figure VII-5. Combustible solid wastes are separated and fired in a converted furnace as previously discussed in Section VI. The energy is utilized for space heating and/or hot water heating. Dilute wastes, such as urine and feces, and wastes with high moisture contents, such as yard wastes and food wastes are composted. No energy recovery is attempted in the compost tank in this concept. This system preserves the high temperature potential of the combustible solid wastes, disposes of the liquid wastes and non combustible solid wastes and still preserves the advantages of grey water only on-site disposal. The disadvantages of this system is that two systems are required, a modified furnace and a composter, which increases costs. Also the system is climate dependent if space heating is the energy recovery method.

D. ENERGY REQUIREMENTS

Energy requirements for operation of the major components was estimated based on the equipment horsepower requirements and estimated operating periods.

Flush Pump

A period of 1.5 minutes was estimated for each toilet tank filling. A total of 24.5 toilet tank fillings was estimated based on 21 urinations per day and 3.5 defecations per day. A motor efficiency of 70% was assumed for the 1/3 HP motor.

Figure VII-5 Combination Composting and Firing System

$$24.5 \text{ fillings} \times 1.5 \text{ minutes/filling} \times \frac{1}{60} \text{ hr} = 0.6125 \text{ hour use}$$

$$\frac{746 \text{ watts}}{\text{hp}} \times \frac{1}{3} \text{ hp} \times \frac{1}{0.7 \text{ (efficiency)}} = 355 \text{ watts}$$

$$355 \text{ watts} \times 0.6125 \text{ hour} \times \frac{1}{1000 \text{ KW}} = 0.22 \text{ KWH}$$

Sludge Pump

The selected pump can pump 8 GPM with a 10 psi head. The amount of wastes to be pumped per day equals 1.32 pounds of feces plus 1.1 gallons of urine or approximately 1½ gallons of wastes. In order to be conservative, a pumping period of one minute per day is assumed for the ½ HP motor.

$$\frac{746 \text{ watts}}{\text{hp}} \times \frac{1}{2} \text{ hp} \times \frac{1}{0.7} \times \frac{1}{60} \text{ hr} = 8.9 \text{ watts hour}$$

$$\text{or } 0.0089 \text{ KWH}$$

Pulper

From Reference 4, a total of 12 minutes is required to grind and pulp the household wastes. Since this system does not pulp all the wastes, this figure is conservative.

$$\frac{746 \text{ watts}}{\text{hp}} \times 2 \text{ hp} \times \frac{1}{0.7} \times \frac{12}{60} = 426 \text{ watt hour or } 0.43 \text{ KWH}$$

Shredder

A conservative value of 12 minutes operation is estimated for the shredder. This shredder also uses a 2 HP motor, which therefore requires the identical power requirement of the pulper.

$$\text{energy requirement} = 0.43 \text{ KWH}$$

Solenoid Valves and Monitoring Equipment

The flow directional solenoid valves require only 10 watts per valve and are operated intermittently. The power consumption by the solenoid valves and monitoring equipment is negligible.

A summary of the parasitic power requirements is shown in Table VII-5. This includes power required for normal operation. The power required for the hot water pump which is used during startup is not included as this use is not required for normal use.

E. ENERGY POTENTIAL

Of the waste generated by the household, approximately 2 pounds per day is composed of metals, glass, and plastics which are not compostable. Table VII-6 shows the amount of material generated along with the breakdown as to which is compost material and which is refuse. Once this source separation is accomplished, the refuse has a greater reclamation value than unsorted material. The amount of recycable materials in the sorted refuse constitutes a major portion.

For aerobic composting a high carbon to nitrogen ratio of compost materials (18-22:1) is desirable as is the presence of at least equal amounts by weight of water and solids. The addition of pulped paper, kitchen and yard wastes provides the necessary C:N ratio for rapid and odorless aerobic decomposition of sewage materials. Table VII-7 provides a breakdown of the chemical makeup of those compostable materials from a single family residence and shows a favorable C:N ratio of 21.1:1.

Studies of liquid to solids ratios in aerobic piles indicate effective composting is accomplished with moisture levels varying between 8 to 1, 1 to 1 by weight to solids. Manufacturers of composting toilets, for example, are uniform in their claims for a slightly damp end product resulting from composting a combination of approximately one pound of fecal and urine solids and eight pounds of fecal and urine liquids (5, 6, 7). Larger, more varied aerobic composting studies have suggests 1.2 to 1 of liquids to solids by weight works well. (8)

5. Ecolet Advertising Bulletin, Recreation Ecology Conservation of United States, Inc., Milwaukee, Wisconsin.
6. "Clivius Multrum Organic Waste Treatment Systems", Clivius Multrum USA, Inc., Cambridge, Mass.
7. "21 Biological Toilets", Extracted from Consumer Report No. 10., Microbiological Institute, Agricultural College of Norway.
8. "Composting at Johnson City", Volumes 1 and 2 Final Report on Joint USEPA-TVA project, U. S. Environmental Protection Agency, 1975, Page 70.

Table VII-5 Parasitic Power Requirements

<u>ITEM</u>	<u>CHARACTERISTICS</u>	<u>KWH/DAY</u>
FLUSH PUMP	1/3 HP FOR 37 MINUTES	0.22
SLUDGE PUMP	1/2 HP FOR 1 MINUTE	0.01
PULPER (1)	2 HP FOR 12 MINUTES	0.43
SHREDDER	2 HP FOR 12 MINUTES	0.43
CONTROLS	SOLENOID VALVES AND MONITORING EQUIPMENT	NEG
TOTAL		<hr/> 1.09 KWH/DAY

Table VII-6 SOLID WASTE SEPARATION

	<u>Amount Generated</u> <u>LB/DAY</u>	<u>Amount Compostable</u> <u>LB/DAY</u>	<u>Refuse</u> <u>LB/DAY</u>
A. <u>TRASH</u>			
Paper	4.09	4.09	-
Glass	0.86	-	0.86
Ferrous Metals	0.73	-	0.73
Non-Ferrous Metals	0.07	-	0.07
Plastics	0.16	-	0.16
Leather, Rubber, Wood	0.66	0.66	-
Misc., Including Textiles	0.35	0.35	-
B. <u>FOOD WASTES</u>			
Garbage	1.40	1.40	-
Fats	0.28	0.28	-
C. <u>YARD WASTES</u>			
Grass	0.467	0.467	-
Brush	0.175	0.175	-
Greens	0.175	0.175	-
Leaves	0.583	0.583	-
TOTALS	10.00	8.18	1.82

Table VII-7. Calculated Materials Breakdown

	<u>TOTAL WEIGHT LB/DAY</u>	<u>DRY WEIGHT LB/DAY</u>	<u>MOISTURE LB/DAY</u>	<u>NITROGEN LB/DAY</u>	<u>CARBON LB/DAY</u>	<u>ENERGY BTU/DAY</u>
A. <u>TRASH</u>						
PAPER	4.09	3.673	0.417	0.011	1.59	27,812
LEATHER, RUBBER, WOOD	0.66	0.594	0.066	0.0012	0.297	5,701
MISC INCLUDING TEXTILES	0.35	0.315	0.035	0.0145	0.1733	2,410
B. <u>FOOD WASTES</u>						
GARBAGE	1.40	0.392	1.008	0.0129	0.176	3,326
FATS	0.28	0.28	-----	-----	0.215	4,676
C. <u>YARD WASTES</u>						
GRASS	0.467	0.163	0.304	0.0036	0.0706	1,254
BRUSH	0.175	0.105	0.070	0.0021	0.0446	830
GREENS	0.175	0.067	0.108	0.0013	0.0270	474
LEAVES	0.583	0.292	0.291	0.0006	0.1183	2,072
D. <u>SEWAGE</u>						
FECES	1.32	0.45	0.87	0.027	0.225	3,450
URINE	9.15	0.40	8.75	0.068	0.056	-----
E. <u>WATER FOR PULPING</u>	4.09	----	4.09	-----	-----	-----
TOTALS	22.74	6.73	16.01	0.142	2.993	52,005

C/N RATIO - 21.1:1

A combined mixture of solid waste with a 1.2 to 1 liquid to solids ratio is combined with sewage waste having a liquid to solids ratio of 8:1 in the approximate proportion of 6:1 solid waste materials and sewage materials. This provides a ratio of approximately 2 to 1 liquids to solids, well within the tolerance or present practice and fully compatible with the nominal range of solid to sewage waste generation rates for residences.

A minimal amount of water is required for pulping the paper which is estimated at 4.09 pounds. Moisture in the system in addition to its effect on the composting also impacts energy recovery because all excess water must be evaporated with the consequent loss of useful recoverable heat.

The gross energy potential available in the waste materials, as shown in Table VII-7, is 52,005 Btu/day. The conversion efficiency of composting to heat is estimated at between 75% and 95% based on work previously done in the area of the thermodynamics of cellular oxidation. (9, 10). While classical thermodynamics deals with systems in equilibrium, living organism are rarely in equilibrium with its surroundings, except possibly in death (11). Estimating the heat output of a biomass under oxidation by bacteria, at any given instant, is difficult. For example, the oxidation of one mole of glucose to carbon dioxide and water releases 2512 Btu (633 kcal) of energy as measured by a calorimeter. Yet when this process occurs by bacterial oxidation only 60% of this energy is released; the other 40% goes back into the biological system in the form of high energy bonds in metabolically important molecules (12).

One thing is certain; the First Law of Thermodynamics (i.e. Conservation of Energy) will be followed. Therefore, when the biological oxidation is completed the total amount of heat released will be the total available less the amount remaining in any residual material.

9. J. Prigogine, "Introduction to Thermodynamics of Irreversible Processes", 2nd Ed. Wiley Interscience, New York, 1962.
10. A. Katchalsky and P. F. Curran, "Non-equilibrium Thermodynamics in Biophysics", Harvard University Press, Cambridge, Mass. 1965.
11. Arthur C. Geise, "Cell Physiology", W. B. Saunders Pub, 1973, Chapter 1, Application of the Laws of Thermodynamics to the Cell.
12. A. L. Lehninger, "Bioenergetics", 2nd Ed., W. A. Benjamin, Menlo Park, Ca. 1971.

The reduction of material by biological/bacterial processes ranges from 75% to 99% (13, 14, 15). If a value of 95% reduction of solids is used, then a 100 lb mass of refuse will yield 5 lbs of residue at the end of the oxidation. Using 7×10^3 Btu/lb as an average heat value, 100 lbs of waste contains 7×10^5 Btu of available energy (by oxidation). If we assume that the 5 lbs of residue is largely composed of cellulosic material, at an average of 7.5×10^3 Btu/lb, then it is possible to calculate the percent of available energy released.

$$\% \text{ released} = \frac{\text{Total Avail} - \text{Remaining}}{\text{Total Avail}} \times 100$$

$$\% \text{ released} = \frac{7 \times 10^5 \text{ Btu} - .375 \times 10^5 \text{ Btu}}{7 \times 10^5 \text{ Btu}} \times 100 = 94.6\%$$

The gross energy must be decreased by the conversion efficiency, by the energy required for moisture evaporation, by the energy picked up by the air flow and also by the energy lost in heating up the incoming charge.

The amount of moisture which must be evaporated is 7.59 pounds per day, which requires 1050 Btu per pound, for a total energy input of 7,970 Btu/day.

The air flow requirement will vary depending upon the final temperature to which the air is heated in passing through the compost pile. The most favorable air flow is 15 CFM, while the unfavorable case is that of a 29 CFM air flow. See the Appendix for air flow calculations. The 15 CFM air flow constitutes a heat loss of 11,600 Btu/day, while the 29 CFM represents a loss of 15,000 Btu/day.

The incoming charge per day is 22.74 pounds. Subtracting off the 7.59 pounds of water whose energy requirements have already been accounted for, the amount which must be heated to the pile temperature is 15.15 pounds per day. Assuming a pile temperature of 140°F and an incoming charge temperature of 75°F , the energy requirement is 985 Btu/day.

13. J. F. Smith, K. W. Young and R. B. Den, "Biological Oxidation and Disinfection of Sludge", *Water Research* 9(1), 17 January 1975.
14. S. J. Dea, "Aerobic Digestion and Evapotranspiration in Home Disposal Systems", *Water and Sewage Works*, February 1975, R-76, Ref #1975.
15. Data Supplied by Cromaglass Corp., Williamsport, Pa., Table A, "Operational Data of Various Activated Sludge Processes".

Using these values, the net energy available may be estimated for the two extremes as shown in Table VII-8.

F. SYSTEM ECONOMICS

Principal characteristics affecting comparative system economics are shown in Table VII-10. Initial cost was developed from manufacturers catalogs and quotations. Septic systems, where applicable, were estimated at from \$3,000 for a full scale system down to \$1,000 for a system for grey water only. These are conservative, mid-range estimates which have some degree of variation with ASA function of location, soil conditions and other influencing factors. Water and energy consumption have been taken directly from manufacturers information. The General Electric system electricity use is shown as a credit due to the contribution of the system to hot water heating.

Total system monthly costs are summarized in Table VII-11. Amortization assumes a 25 year, 9% mortgage by a homeowner in a 25 percent marginal tax bracket. The value shown is the increase in monthly mortgage cost incurred by adding the subject system to the house. This is evaluated on an after-tax basis to reflect the tax deductibility of interest. The effective interest rate (r) is reduced then to 6.75 percent ($.09(1-.25)$). Maintenance, water, sewer rent and trash pickup costs are assumed to escalate at a general inflation rate of 5 percent over the 25 year design lifetime. The values shown are levelized monthly costs. Levelizing accounts for cost escalation as well as the time value of money to establish a true life cycle cost indicator. The values may be viewed as the amount of money which, if deposited each month in an account earning interest rate r (6.75 percent in our case) would permit cash withdrawals to pay all lifetime costs. Note that although sewer rent and trash pickup costs have been nominally estimated at \$10 per month today (1977), escalation results in a levelized cost of \$17 per month over the system life. Electricity cost was treated similarly except a 6% escalation rate was assumed on a baseline value of 5¢/KWH. The 6% escalation rate, about 1% above general inflation, is well in line with current energy price projections.

Table VII-8 Compost Energy

	<u>Low Range</u>	<u>High Range</u>
Gross Energy of Solids	52,005	52,005
Solids Conversion	39,003 (75%)	49,405 (95%)
Moisture	- 7,970	- 7,970
Evaporating Air Flow	-15,000	-11,600
Heating Incoming Charge	- 985	- 985
Net Available	15,048	28,850

The amount of hot water required by the model home using the low water devices is shown below in Table VII-9.

Table VII-9 Hot Water Requirements

<u>Appliance</u>	<u>Usage</u>
Dishwasher	15 GPD
Kitchen	7
Utility	4
Lavatory	20
Bathing	33
Lavatory	<u>1</u>
	80 GPD

Assuming a temperature rise of 80°F, the energy required for hot water heating is:

$$80 \text{ GPD} \times 8.3 \frac{\text{lb.}}{\text{gal}} \times (1) \times 80^\circ\text{F} = 53,120 \text{ BTU/day}$$

$$\frac{28,850 \text{ BTU/DAY}}{53,120 \text{ BTU/DAY}} = 54.3\%$$

Thus, the integrated system can supply over 50% of the energy required for hot water heating.

Table VII-10. System Characteristics
1977 Baseline

		INITIAL COST	MONTHLY O&M	WATER USE	ELECTRICITY USE
SEWER	CONVENTIONAL	\$ 160	\$ 1	6 GALS/FLUSH	---
	LOW WATER	240	1	3 GALS/FLUSH	---
	PRESSURE	800	5	2 QTS/FLUSH	.2 KWH/DAY
	VACUUM	3300	5	1 PT/FLUSH	.3 KWH/DAY
SEPTIC SYSTEM	CONVENTIONAL	3160	\$ 1	6 GALS/FLUSH	---
	LOW WATER	2740	1	3 GALS/FLUSH	---
	PRESSURE	2800	5	2 QTS/FLUSH	.2 KWH/DAY
	VACUUM	5300	5	1 PT/FLUSH	.3 KWH/DAY
	AEROBIC	4400	5	3 GALS/FLUSH	8.5 KWH/DAY
	INCINERATION	2500	2	0	20 KWH/DAY
STORED	CONVENTIONAL	2160	15	6 GALS/FLUSH	---
	LOW WATER	2240	10	3 GALS/FLUSH	---
	OIL	4750	10	0	.3 KWH/DAY
COMPOSTING	CLIVUS MULTRUM	2826	1	NEG.	NEG.
	ECOLET	2512	1	NEG.	3.8 KWH/DAY
COMBINED	CYCLE-LET	6200	30	0	6 KWH/DAY
	GENERAL ELECTRIC	5200	6	0	(5 KWH/DAY)

(CREDIT)

Table VII-11. Monthly System Costs

		AMORTIZATION	MAINTENANCE	WATER	ELECTRICITY	SEWER RENT	TRASH PICKUP	TOTAL
SEWER	CONVENTIONAL	\$ 1	2	6	----	17	17	\$43
	LOW WATER	\$ 2	2	3	----	17	17	\$41
	PRESSURE	\$ 6	8	1	1	17	17	\$50
	VACUUM	23	8	1	1	17	17	\$67
SEPTIC SYSTEM	CONVENTIONAL	22	2	6	----		17	47
	LOW WATER	19	2	3	----		17	41
	PRESSURE	19	8	1	1		17	46
	VACUUM	37	8	1	1		17	64
	AEROBIC	30	8	3	24		17	82
STORED	CONVENTIONAL	15	25	6	----		17	63
	LOW WATER	15	17	3	----		17	52
	OIL	33	17	-	1		17	67
COMPOSTING	CLIVUS MULTRUM	20	2	-	----		17	39
	ECOLET	17	2	-	11		17	47
COMBINED	CYCLE-LET	43	50	-	17		17	127
	INCINERATION	17	3	-	57		17	94
	GENERAL ELECTRIC	36	10	-	(14)*			32

MAINTENANCE, WATER, SEWER RENT AND TRASH PICK

ESCALATED AT 5% ANNUALLY AND LEVELIZED OVER 25 Years

ELECTRICITY ESCALATED AT 6% ANNUALLY AND LEVELIZED

*CREDIT FOR RECOVERED ENERGY EQUIVALENT

The monthly total costs shown in Table VII-11 assume that the homeowner may utilize any of the options presented. This will not always be the case. For example, the homeowner may be required to tie into a sewer if one exists. If his land does not have proper soil conditions for a full septic system, the homeowner may require a stored, composting or combined system. Those limitations can be examined by bringing the cost of land into the analysis. Table VII-12 presents minimum system land requirements and assumed land costs. The latter are presented parametrically to account for wide differences in land prices. The high extreme at \$20,000 per acre corresponds roughly to Philadelphia suburban prices today. Variations to $\frac{1}{2}$ acre sewered lot and $\frac{1}{2}$ acre were developed from analysis of real estate agency land catalogs and discussions with agents. Moderate low and rural price ranges were taken as direct multiples of the high priced land. Sewers were assumed to be unavailable for rural land.

From the land costs of Table VII-12, land cost "penalties" were calculated. Shown in Table VII-13, these represent the increase in monthly mortgage costs incurred by buying land priced above the minimum lot cost. Thus for example, a homeowner in a high land price area would have to pay about \$8,000 more for a 1 acre septic approved lot than for the minimum $\frac{1}{2}$ acre lot. This would entail a \$55 increase in his monthly cost. Table VII-14, shows the monthly cost of each of the optimum systems from Table VII-11, with the land cost penalty added where applicable. Note that the septic and sewer systems become increasingly less economic as land price increases. This is shown graphically in Figure VII-6. As land price increases, it becomes increasingly more economic to purchase minimum cost land and employ a system such as the composting or General Electric combined system.

TABLE VII-12. SYSTEM LAND REQUIREMENTS

SYSTEM	
SEWER	1/2 ACRE WITH SEWER AVAILABLE
SEPTIC	1 ACRE SUITABLE FOR FULL SEPTIC
STORED, COMPOSTING AND COMBINED	1/2 ACRE SUITABLE FOR GREY WATER ONLY

LAND PRICE RANGE

	HIGH	MOD.	LOW	RURAL
1/2 ACRE W/SEWER	\$18,000	9000	4500	N.A
1 ACRE - SEPTIC	20,000	10,000	5000	2500
1/2 ACRE - LOW FLOW SEPTIC	12,000	6000	3000	1500

TABLE VII-13. LAND COST PENALTIES
\$/MONTH

	COST AREA			
	HIGH	MOD.	LOW	RURAL
1/2 ACRE W/SEWER	\$41	\$21	\$10	N.A
1 ACRE	\$55	\$28	\$14	\$7

PENALTY = INCREASE IN MONTHLY MORTGAGE COST (AFTER TAX) OVER THAT FOR
MINIMUM COST LAND (1/2 ACRE/NO SEWER)

ASSUMPTIONS = 9% 25 YEAR MORTGAGE

30% HOMEOWNER TAX BRACKET

TABLE VII-14. MONTHLY COST OF OPTIMUM SYSTEMS

	LAND COST AREA				
	WITHOUT LAND	HIGH	MOD.	LOW	RURAL
SEWER	\$41	\$82	\$62	\$51	--
SEPTIC	\$41	\$96	\$69	\$55	48
STORED	\$52				→
COMPOSTING	\$39				→
COMBINED (GE)	\$32				→

Figure VII-6. Effect of Land Cost on System Economics

VIII DEVELOPMENT PLAN & POLICY RECOMMENDATIONS

Household Energy Conservation Systems (HECS) placed in single family detached houses offer unique opportunities for reducing water consumption, eliminating trash and rubbish removal costs, and reducing homeowner costs for hot water heating. Single family residences constitute by far the largest category of dwelling types, accounting for almost 70 percent of the total residential housing inventory in 1970.¹ In the same year, new single family dwellings accounted for more than half of all residential housing starts.²

This numerical dominance by single family housing is expected to continue, although other types of dwellings will attract larger market shares than in the past. As indicated in Table VIII-1, single family dwellings are projected to decrease slightly in their share of new construction from 1970 to 1985, after which a small upturn is anticipated, due to the age structure of the population. As a percent of housing inventory, single family dwellings are estimated to decrease in share from 75 percent (1960) to approximately 62 percent (1990).

Single family dwellings are also anticipated to maintain their dominant share of residential energy consumption. In 1970, one-unit detached dwellings accounted for approximately 75 percent of residential energy demand. Project Independence projections show the share as 74 percent of residential consumption in 1990.³ HECS applied to single family dwellings thus offers an opportunity to introduce innovative energy and water conservation systems into the largest housing segment in the residential sector.

This section is divided into four parts. Part A presents the R&D needs. Part B discusses the market for HECS systems. Growth in single-family dwellings is projected; penetration rates for HECS are selected and translated

into the number of cumulative HECS units in 2000 A.D. Part C deals with the barriers facing the implementation of this technology and incentives which will increase the probability of attaining the penetration described in Part B as well as incentives which would make penetration even greater. Part D describes implementation recommendations and presents a development plan. Appendices A and B describe the various methodologies used in this section and present detailed sets of data.

Table VIII-1.
TRENDS IN RESIDENTIAL INVENTORY MIX
1970 - 1990 (4)

	Percent Distribution of New Construction by Housing Type			
	1960-1970	1970-1980	1980-1985	1985-1990
Mobile Home	13	18	16	15
Single-Family	55	48	48	52
Low-Density	5	18	19	18
Low-Rise	27	10	11	10
High-Rise				

	Percent Distribution of Inventory by Housing Type				
	1960	1970	1980	1985	1990
Mobile Home	1	3	7	8	8
Single-Family	75	66	63	62	62
Low-Density	14	16	16	16	16
Low-Rise	11	10	9	9	9
High-Rise		5	5	5	5

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A. R & D NEEDS

Composting processes commonly operate to reduce bulk of wastes and to produce a useful or salable end product with heat a lost by product. The extraction of heat energy from high temperature aerobic composting has not been attempted on a useful scale. Because of this, there is limited information on design parameters such as heat generation rates, conversion efficiencies and desirable microorganism types. While peripheral systems provide some data from which estimated performance can be derived, more definitive design information is required prior to system finalization.

A modest test program should be conducted utilizing a modified commercial composting toilet. With proper instrumentation and careful recording of inputs and outputs, the heat generation rates and conversion efficiencies may easily be obtained. This test bed could then be utilized to determine the sensitivity of the compost to various parameters, such as feed stocks contaminants or poisons, and microorganism pedigrees.

The hardware elements of the integrated system are well defined and in many cases readily available off-the-shelf. Consequently no R&D or development requirements are seen as being required in those areas.

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B. MARKET PENETRATION

HOUSING PROJECTIONS

Single family detached houses represent the most important potential market for Household Energy Conservation Systems (HECS) because of the energy contribution available from yard trash and the possibility of disposing of compost residue on-site. Therefore, the starting point for estimating the size of the HECS market is the projection of future demand for this housing type. Population and household size are assumed to be the determinants of the size of the housing inventory.* The population series used here to project single family residences is the Bureau of Census Series E.** The demand for new construction results from increasing numbers of resident households and from the demolition of existing housing. It should be noted that growth in new construction of single family detached residences is projected to be primarily caused by population growth. Demolition rates vary from region to region, but at the national average, 1.4 percent of single family detached housing is estimated to be removed each year from 1970 to 1980. The rate is projected to decrease over time to less than one percent per year for the last decade of the century.⁵

Based upon the assumptions stated above, the inventory of single family detached houses (Table VIII-2)* is expected to increase an average of 0.8 percent per year, thus reflecting the growth in the total number of households. The inventory of single family detached units is expected to grow to 53 million units in 2000 A.D. Of this stock, 48 percent will consist of houses built before 1970, with 52 percent representing residences constructed in the last three decades of the century. Table VIII-3 presents the projections for new construction of single family detached housing in the United States.*

* A detailed description of the projection methodology and detailed data are given in Appendix A.

** This projection assumes a 264 million population in 2000 A.D.

TABLE VIII-2.
PROJECTIONS OF THE NATIONAL INVENTORY OF
SINGLE FAMILY DETACHED HOUSES (Millions)

Year	1970	1980	1990	2000
Inventory	41.46	46.13	49.49	52.68
Annual Rate of Growth	--	1.1%	0.7%	0.6%

TABLE VIII-3.
PROJECTIONS OF NEW CONSTRUCTION OF
SINGLE FAMILY DETACHED HOUSES
(Millions of Units)

	1970-1980	1981-1990	1991-2000
New Construction	10.98	8.52	8.09

PENETRATION OF THE MARKET

The share of all single family detached houses equipped with HECS in the year 2000 depends upon the penetration of two markets: (1) new homes constructed after HECS commercialization (assumed here to be 1982), and (2) homes already standing.

New Construction

The number of homes originally equipped with HECS standing in 2000 A.D. depends upon the number of single family homes constructed between 1982 and 2000 A.D. and the rate at which HECS penetrates the market for new construction. As Table VIII-4 shows, 26 percent of the U.S. inventory of single family detached houses standing in 2000 will be built after the introduction of HECS and will be a market for HECS.

Not all new homes are candidates for HECS systems, given current costs and institutional barriers. The penetration scenario discussed here will describe a baseline in that most of the cost and institutional barriers will be accepted as given. A discussion of these barriers and suggested incentives and plans to overcome them will be given in C. In the event that these incentive plans are adopted or the relative cost situation changes, then a more optimistic scenario can be depicted.

It is assumed in the baseline scenario that those homes being built in areas serviced with public sewers will not be candidates for HECS. Under current municipal pricing systems, in many cases the homebuilder (and, therefore, the home buyer) is not paying the full costs of hooking into the sewer system. For example, in Boulder, Colorado, the cost of supplying sewer and water services to new homes is \$1,450 per home while the charge is only \$600.⁶ The difference is made up by tax revenues from established residents. The proportion of single family homes not serviced by public systems was 38 percent in 1970. The baseline assumes that this proportion will remain the same

* 19.5 million or 29 percent of all housing units in 1970 were not hooked to public sewers. Reference (1)

TABLE VIII-4.
SUMMARY OF HOUSING PROJECTIONS

	Inventory of Single-Family Detached Homes 2000	New Construction 1982-2000	Percent of Year 2000 Inventory Constructed After 1982
TOTAL U.S.	53 million	14 million	26%

through 2000 A.D. Under certain conditions such as increased costs or complexities of sewer or water service, or as a result of legislated safeguards, however, this could increase, thereby increasing the HECS market. For example, the population may move more to rural areas. Also, as water shortages become more common and waste increases, the existing public sewer systems may be found unsatisfactory.⁷ All of these possibilities are, of course, conjectural and difficult to quantify but they do imply a optimistic outlook for HECS growth.

Of all of those homes built in non-sewered areas, some should be excluded from the HECS market because (1) the soil is very suitable for traditional septic tanks, (2) water prices are low, and (3) water heating fuel prices are low. An estimate of the share of this category is 20 percent. Therefore, the HECS new construction market is defined as 80 percent of the single family detached houses built in areas not served by public sewers. This is approximately 8 percent of the inventory of single family detached houses standing in 2000 A.D.

The portion of this eight percent that can be HECS equipped in 2000 depends on the rate at which HECS penetrates the new housing market. For this analysis, it is assumed that HECS penetration of the new housing market is comparable to the experience projected for solar heating and cooling systems in the SHACOB Study.⁸ In SHACOB, it was assumed that the share of new housing captured by the solar thermal technology would initially increase slowly, followed by a period of accelerated growth. The growth rate would then decrease as the maximum market potential was approached.*

*For a complete description of the penetration methodology, see Appendix B.

The mathematical function used to project the growth of market share has two parameters: (1) the time required following introduction to achieve one percent of the maximum attainable market, and (2) the time required to achieve the market share from 10 to 90 percent. For this scenario, a takeover time of 15 years has been assumed. A 15-year period falls at the shorter end of the takeover times reported by Fisher and Pry (see Appendix B) for 17 different cases of completed diffusion.* One to two years is estimated as the time required to penetrate one percent of the market. This period is relatively short and assumes the HECS system is cost-competitive, and receives Government support. These values yield an estimated market share of 90 percent where the market is defined as 80 percent of single family detached houses constructed in the non-sewered areas in the year 2000.

The projections of HECS equipped single family detached houses result from applying the assumed penetration rate to the new construction projections described above. Assuming that the number of HECS homes destroyed but not replaced is negligible up to the year 2000, the total number of HECS units at the end of the century is the sum of new HECS homes constructed during the 18 years 1982-2000. Table VIII-5 presents the results of market penetration calculations.

In 2000, HECS represents four percent of the inventory of single family detached houses and the HECS additions in 2000 will be 25 percent of single family detached houses constructed in that year.

* The specific function used is: $P = \frac{e^{f(t)}}{1+e^{f(t)}}$, where $f(t) = \frac{2(2.2)}{\Delta t} (t-t_m)$;

Δt is the "takeover time," the period during which the penetration increases from 0.1 to 0.9; t_m is the midpoint of the takeover period; and t is the time variable.

TABLE VIII-5.
NATIONAL HECS PENETRATION PROJECTION
(thousands)

Year	Total Inventory	Annual HECS Additions	Cumulative HECS Units
1985	47,800	39	78
1990	49,490	104	468
1995	51,085	162	1,155
2000	52,680	225	2,155

The Retrofit Market

A second (and larger) market for HECS is all of the single-family detached houses already standing at the time of HECS commercialization and, in later years, those homes which were built after HECS commercialization, but did not have the system installed then. As was the case with the new construction market, only certain categories of these homes can be considered as likely candidates for HECS in the absence of significant government incentive or institutional change.

First of all, the initial HECS market will probably be limited to owner-occupied housing. Table VIII-6 shows the inventory of owner-occupied single-family detached houses in 1970, 1980, 1990, and 2000 A.D.* The advantage of HECS is lower operating (i.e., energy, water and waste disposal) costs. It is unlikely that a owner would make the initial investment if he could not take advantage of the lower operating costs and it is quite likely that he will not be able to raise rents sufficiently to recoup costs. Also, not only may the selling price of the house not fully reflect the investment, but there may be a penalty attached due to the "different" equipment. On the other hand, the tenant of a house is not likely to invest in a property over which he has no property rights.

Homes connected to public sewers will be excluded from the market in this scenario for the same reasons that public sewerred areas were excluded from the new construction HECS market and the share of units not hooked to public sewers is assumed to remain at 38 percent.**

Once a house reaches a certain age, some of its components must be replaced. Retrofit of a house with HECS is considered more likely if the components which it replaces have reached the end of their useful life. The components most relevant to this study are the hot water heater and the sewage disposal system. The useful life of the hot water heater is estimated

* These estimates assume that owner-occupied single family detached houses maintain a 77 percent share.

** The same caveats apply to this assumption as in the new construction case.

TABLE VIII-6.
INVENTORY OF OWNER-OCCUPIED SINGLE
FAMILY DETACHED HOUSES
(Millions)

<u>1970</u>	<u>1980</u>	<u>1990</u>	<u>2000</u>
31.92	35.52	38.11	40.58

at twenty years.⁴ Much shorter lived, however, is the septic tank system. The FHA reports that the historic failure rate of septic tanks was 30 percent in two to three years. Failure was characterized by the clogging of the soil and the consequent appearance of wastewater on the surface of the ground.⁹

For the purpose of defining a reasonable retrofit market, it is assumed that those houses over 10 years old will be more likely to replace the relevant components and, therefore, more likely to consider HECS. In 1970, 74 percent of single family detached houses were over 10 years old. It is assumed that their share will remain constant through 2000 A.D. In order to avoid double counting, the houses which are HECS equipped as new construction from 1982-1990 must be excluded from the 10+ category as they enter it in the latter part of the period of interest.

It is assumed that annually 10 percent of the houses older than 10 years must make a decision to use HECS or to go with another system. A limit of 50 percent is set as the maximum penetration of HECS into this category of homes. Therefore, the maximum attainable market is approximately 19 percent of the inventory of single family detached houses standing in 2000.

The penetration of the retrofit market is also assumed to have a 15 year takeover time and a relatively short time to one percent penetration. These assumptions yield an estimated HECS market share of 90 percent of the market as described above.

When this penetration scenario is combined with the inventory projections, projections of the number of HECS-retrofit residences can be made. If it is assumed that the number of HECS retrofit homes destroyed but not replaced is negligible up to the year 2000, the total number of HECS retrofit homes at the end of the century is the sum of homes retrofitted from 1982-2000. Table VIII-7 presents the results of the market penetration calculation. In 2000, HECS retrofit represents eight percent of the inventory of single family detached houses or twice the number of homes projected to be HECS equipped at the time of their construction.

* Project Independence.

** Polluted Groundwater: Some Causes, Effects, Controls, and Monitoring,
U.S. Environmental Protection Agency, July 1973.

TABLE VIII-7.
NATIONAL HECS RETROFIT PENETRATION PROJECTIONS
(Thousands)

<u>Year</u>	<u>Total Inventory</u>	<u>HEC Annual Retrofit</u>	<u>HECS Cumulative Retrofit</u>
1985	47,800	75	150
1990	49,490	216	916
1995	51,085	340	2,369
2000	52,680	500	4,509

Combined New Construction and Retrofit

It is interesting to look at the penetration of both of these markets. Table VIII-8 shows the summed penetration calculations for new construction and retrofit. Cumulative HECS units in 2000 A.D. are projected to total over six million or 12 percent of the inventory of single family detached houses. Figure VIII-1 shows plots of the HECS units through time.

TABLE VIII-8

NATIONAL HECS RETROFIT AND NEW CONSTRUCTION
PENETRATION PROJECTIONS
(Thousands)

<u>Year</u>	<u>Total Inventory</u>	<u>HECS Annual Addition</u>	<u>HECS Cumulative</u>
1985	47,800	114	228
1990	49,490	320	1,384
2000	51,085	502	3,524
2000	52,680	725	6,664

100,000,000

10,000,000

1,000,000

100,000

10,000

Figure VIII-1
NATIONAL HECS PENETRATION

C. BARRIERS AND INCENTIVES

This section discusses barriers to the rapid penetration of HECS and the incentives designed to overcome them. ERDA has defined "barrier" as "any factor, relationship, or characteristic that has the potential to retard or limit the introduction and widespread utilization of... energy systems." "Incentive" is defined as "any action that can be taken by the government to encourage and/or accelerate the commercialization of...energy systems."*(10) Incentives and barriers are being studied intensively by ERDA with special emphasis upon those associated with solar heating and cooling. This work will be drawn upon when applicable to the HEC system.

BARRIERS

Three categories of barriers will be looked at here: (1) Economic and Financial, (2) Public Acceptance, and (3) Building Codes.

Economic and Financial

HECS is characterized by relatively high initial costs and low operating costs which when costed over its life cycle make it very competitive with other hot water heating and sewage disposal systems. There are factors, however, which serve to obscure the relative competitiveness of HECS.

SUBSIDIZED CONVENTIONAL SYSTEMS. First of all, in many cases the users of conventional water and sewage systems are not made to bear

the full costs of the service. Therefore, under these circumstances the relative advantages of HECS are not apparent to the user. The subsidy going to users of the conventional systems may take two forms. First, the new customer may not be charged the full hook-up (initial) cost. As was mentioned earlier in the report; in Boulder, Colorado, the cost of supplying water and sewer services to new homes is \$1,450 while the charge is only \$600. A second method of subsidy is in the unit charge for water and sewer use. Some areas do not even meter the water consumed by the users. As long as water and sewage treatment are relatively cheap commodities, there will be little incentive to conserve in their use.

One solution to this problem is to charge full costs for conventional sewage systems and for water. A second solution is to offer equivalent financial incentives for HECS, thereby making it competitive. No prediction can be made here as to the likelihood of the former occurring. The latter will be discussed below.

SHORT-SIGHTED CONSUMERS. Given its relatively high initial cost, HECS must be viewed over its operating life to see its financial attractiveness. This may be a barrier to many potential users given the frequency with which home owners move. The U.S. League of Savings Associations estimates that the average owner-occupied home mortgage runs six or seven years. Some believe that unusual home systems will not be accepted until payback periods are shorter than a mortgage's life. Another problem with this life-cycle approach is the uncertainty of events over the next 25 years.* (11) For example, uncertainties exist with respect to prices, costs of alternative systems, and the durability of HECS. Once again, there may be certain financial incentives which may increase the short-term attractiveness of HECS and promote penetration until that time when uncertainty will be minimized.

FINANCING DIFFICULTIES. Persons desiring to finance a HECS home may not be able to get as large a loan as they need because of: (1) lender's hesitancy to finance a HECS home, and (2) secondary market constraints.

Lender Acceptance. Since HECS has not actually reached the market, it is difficult to predict with certainty how lenders will respond to the new concept. However, inferences can be drawn from past experience with solar technologies. Figure VIII-2 shows those factors most important in the lender's decision. A recent survey of lenders found only 43 percent viewing a solar system as adding to the value of a home, while 16 percent thought it would reduce the home's value. It was also found that most lenders would exclude some or all of the costs of a solar system when appraising a house. Finally, when ruling on the home buyer's ability to pay, the higher capital costs of the system are not viewed in the light of lower long-term operating costs. (12)

On the encouraging side, however, it appears that more and more groups are advocating life-cycle costing in investment decisions. In fact, the survey of lenders found a good number concerned with information on life-cycle costing and payback periods.

Secondary Market Constraints. Many lending institutions plan to sell their mortgages to the secondary market which consists of private and public buyers such as FHLMC and FNMA. FHLMC and FNMA are very conservative with respect to unproven technologies. For example, their position on solar equipment is that its cost should not be mortgageable until there is more market acceptance. (13)

FIGURE VIII-2

ISSUES OF CONCERN TO LENDERS IN MAKING LOANS (14)

PERCENTAGE OF LENDERS IDENTIFYING
SELECTED ASPECTS OF SOLAR ENERGY
HEATING SYSTEMS AS PRIMARY OR
SUBSTANTIAL CONCERNS IN FUTURE LENDING DECISIONS

The Retrofit Market. The Home Owners' Loan Act of 1933 allows federally chartered savings and loans to give only first mortgages in residential markets. This restriction is also usually included in state charters. These requirements definitely will impact the HECS retrofit market in that home owners will, in many cases, be unable to finance HECS at the relatively low interest rates available with second mortgages. Instead, the consumer may be required to finance either with high interest personal installment loans or home improvement loans. Other alternatives will include refinancing the entire home probably at a higher interest rate and a "wrap-around mortgage" where a new loan is wrapped around an existing loan.

Public Acceptance

The rapid penetration of HECS may be stymied somewhat by the reluctance of the public to accept a new technology irrespective of its cost advantage over conventional systems. The reasons can be categorized as (1) user reluctance to change, (2) aesthetic qualities, and (3) inconvenience.

Consumers are usually conservative and it has been found that new techniques and products are accepted more rapidly when they are serving a new demand rather than attempting to capture part of the market served by an established product.* Even if this bias against "new" is not present, certain aesthetic barriers can retard public willingness to accept the product. In the case of HECS, individuals may object initially to the mineral oil used to flush the toilet and food wastes and to the idea of its reuse for this purpose even though filtered. Finally, users may consider the minimal maintenance as too bothersome. HECS users will be required to empty the residue compartment twice a year and to change the fluid filter yearly. The residue will be placed in a special bag (as in a trash compacter) so that no handling of the residue will be required. However, the bag will require disposal. In addition, a daily requirement of the system will be the separation of glass, plastics and metal from household and yard wastes.

Although these requirements for user intervention seem trivial, it has been found that residents are often lazy in maintaining certain products. For example, in the case of solar energy, the experience of architects and mechanical engineers was that even when exterior movable louvers were necessary to control the amount of sun on exterior wall glazing, regular movement did not take place.(16) On the other hand, there are certain legislative and environmental movements which would require some of the trash separation regardless of the household disposal system selected. Many states are considering legislation which would ban or put a tax on no-return bottles or place a deposit on bottles. Environmentalists and industry have also advocated the recycling of aluminum. (17) These efforts would increase separation of trash in the absence of HECS and therefore trash separation would not be such a barrier to consumer acceptance.

Building Codes

A third barrier to the rapid penetration of HECS is the presence of building codes. A building code is a set of regulations concerning standards for materials and equipment and their use. The code also provides for permits and enforcement.

A permit must be obtained before any construction is performed. This is routine when the materials, equipment, and methods are specifically called for in code specification standards. However, new materials or systems such as HECS are required to receive special approval, a procedure that is more costly in time and money than the routine approval. Also, approval is not guaranteed but its likelihood might vary across jurisdictions. Therefore, producers might be forced to market several systems to satisfy the different codes or to market only one expensive system designed to meet the strictest requirements. The probability of approval is increased,

however, when manufacturing, marketing, and installation channels are the same as for existing technologies and this places HECS in a relatively good position given that it is made of off-the-shelf components.

INCENTIVES

Incentives are means whereby some or all of the barriers described above may be overcome. The incentives discussed here may be categorized as either economic, relating to the dissemination of information or of a legislative nature.

Economic Incentives

The primary financial incentives are grants and subsidies, income tax credits and deductions, federal compensation for state and local property and sales taxes, and low cost and guaranteed loans.

GRANTS AND SUBSIDIES. The government could reduce the initial high cost of HECS with a one-time direct grant to consumers. It is the opinion of ERDA that such a program would involve high costs (both direct and administrative) relative to the benefits expected from the program.(18)

INCOME TAX CREDITS AND DEDUCTIONS. An income tax credit would involve the reduction of the purchaser's total tax liability by a specified amount. This method is advantageous in that relief is felt in the initial stages of system operation and the benefits are felt equally across all tax brackets. The disadvantages of the tax credit are its rigidity once it becomes part of the tax code and the lag between time of purchase and time of credit receipt.

An income tax deduction would allow a user to deduct part of the system costs from his adjusted gross income. The main argument to this idea is that the actual subsidy would vary with tax brackets. The objections given against credits would also apply.

FEDERAL COMPENSATION FOR STATE AND LOCAL PROPERTY AND SALES TAXES. Because HECS has value, the purchaser may have to pay sales taxes and increased property taxes. In those states which do not offer tax reductions for these systems, the federal government could give a compensating federal tax deduction. A serious flaw of this type of incentive is that local assessors may overvalue the new systems since the government will be paying any increased taxes.

LOW COST AND GUARANTEED LOANS. Since the cost and availability of financing is a critical factor in the successful implementation of HECS, a promising incentive is the provision of low interest loans. This is preferable to tax credits since the aid is given immediately rather than at the end of the tax year. Working out the administration of the program, however, may prove difficult so alternatives such as bank sponsorship will have to be looked into.

Guaranteed loans may be a method whereby the federal government could alleviate lenders' concerns about the risk of borrower default on mortgages for HECS equipped homes. The Federal Housing Administration and the Veterans Administration have created precedents for this type of incentive.

SUMMARY. ERDA looked into each of these financial incentives to see where in the case of solar heating and cooling the benefits per dollar of cost were the greatest. (19) Although success with HECS does not necessarily correspond with success in solar heating and cooling, their findings are interesting. The ranking is as follows: Guaranteed loan, tax credit, tax deduction, 2.4% property tax exemption, 2% loan, sales tax exemption.

Information Dissemination

Included in the category of information dissemination are public information programs and demonstration projects. The media could be used to develop public awareness of the many aspects of HECS including its economics and environmental aspects. Public feedback concerning bad attitudes toward HECS can then be used to shape future education programs.

Demonstration projects can be used to encourage private institutions to support HECS. It is important that energy, water, and waste disposal cost savings as well as the appearance of the system be demonstrated to the public.

Legislation

The government can induce people to select HECS by passing certain legislation. First of all, building codes may be specified in such a way that HECS will not be at a disadvantage to established sewage and hot water systems. A suggested solution would be the development of a set of national standards and testing procedures and national recognized accreditation organizations.

A more coercive means would be to require that individuals install HECS or suffer some penalty. For example, a municipality facing overloaded sewers may state that no new homes may hook into the sewer system unless they utilize all or part of HECS. Although such a rule would interfere with the property rights of the home owner or builder, there are many existing municipal requirements concerning equipment on a house. In fact, it was found that there are no legal barriers to requiring installation of specified equipment on houses not yet built. With respect to retrofit, it was concluded that an ordinance would be upheld if it provided for differences in suitability among houses.(20)

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D. IMPLEMENTATION

The Household Energy Conservation System (HECS) study has focused on the reclamation of energy from single family residential household waste products. A system concept has been synthesized from new combinations of existing technology and commercially available type hardware products. Data from similar operational and experimental processes have been combined with the specified performance parameters of available hardware. The analyses of the system concept indicate that it is technically feasible, and requires only empirical validation and product design. Current costs of the hardware elements based upon catalog data, and estimated system lifetime operational costs have been assigned suitable time valuation. Analysis of this cost data indicates economic life cycle viability for the system concept when compared only to the direct consumer costs of existing techniques.

The systems concept for reclaiming the energy content of household waste products will provide a major portion of the thermal energy requirements for residential hot water energy demand. Since there is an approximate correlation between the hot water usage, number of household members, and the volume of waste products; the portion of thermal energy requirements supplied by the residential waste products will stay approximately constant, i.e.: the more you need, the more you have. In the process of making a direct energy contribution, other auxillary benefits will accrue with widespread application of the system concept. These include a reduction in residential requirements for either individually or community supplied.

- Potable Water
- Sewer System
- Trash Disposal

These reductions in service demands will create a concomitant amelioration of:

- Energy demands related to water, sewer and trash services
- Environmental pollution due to residential waste disposal
- and Scarcity of residential land

This latter factor is based upon the serviceability of land for residential purposes with reduced water, sewage, and trash service requirements. Land that is now marginal or unusable due to service inadequacies will become available for reduced service requirements. If it can be assumed that this marginal land is lower in cost then its availability will assist the reduction of housing costs, and enlarge the base of potential homeowners.

The recommended system concept directly meets both technically and economically the ERDA mission requirement for the reduction of conventional fossil fuel consumption now used for residential hot water energy needs. The associated benefits in addition, directly meet mission requirements of other federal and state agencies. In particular, the Environmental Protection Agency and the Department of Housing and Urban development are directly concerned with pollution, sewers and residential housing. The widespread potential for direct and indirect benefits resulting from system concept applications warrants further program efforts to develop, and apply the concept. These recommended efforts have been grouped into three broad categories to span the range of activities from the current study and analysis activity to future market application and commercialization of the system concept.

These are:

- Concept Test and Evaluation Phase
- Demonstration Planning Phase
- Demonstration Program

The Concept Test and Evaluation Phase provides for the logical next step in the concept development. As currently planned, this phase consists of four major task elements to provide empirical process validation and an initial product design and test evaluation. These tasks are:

- Evaluation of Process Parameters
- Heat Extraction Design Techniques
- Prototype Assembly and Evaluation
- Residential Model Design Requirements

The work content planned for these tasks define the essential elements for the development of the concept. This work has been incorporated into a planned 18 month program. The first task provides for an experimental validation of the analytically predicted process results, and evaluation of parameter ranges to establish control modes. This will require experimental investigation of such things as mixture ratios, flow rates, temperature ranges, time varying use patterns and residue analysis. A parallel effort on the second task will be implemented to establish the specific design requirements for the composter tank. This will include the tank itself, the heat exchanger, insulation, turntable, and associated hardware. Once the specific design requirements for the extraction of heat energy from the aerobically processed compost of waste products are established, the prototype system can be assembled and evaluated. The prototype will be assembled from commercially available hardware

elements to the maximum extent possible. It is anticipated that the experimental investigations of process parameters and heat extraction techniques will be completed during the first half of the program, and that the testing and evaluation of an operating prototype will be conducted during the second half of the program. During the last quarter, the preliminary design and detail requirements for a residential model of the system will be prepared. The results of this Concept Evaluation phase will provide the baseline and guidelines for the Demonstration Planning phase.

The Demonstration Planning and Demonstration programs have not been planned in detail at this time. These phases are intended to define the necessary activities required for field demonstration, proof of concept and market development. Detail planning and definition of these activities is contingent upon the analytical concept feasibility to be demonstrated in the test and evaluation phase described above, and the magnitude and scope (future decisions on benefits gained and development resource allocation) of the future development effort.

A brief description of typical types of activities required for full development is given below:

Residential Model Design, Assembly and Test - Design and evaluation of residential unit based upon requirements established during prototype testing. Commercial elements modified to provide a balanced hardware set for residential use.

Multiple Dwelling Unit Application Study - Examination of the feasibility for broader applications of the system concept to apartments, condominiums, and small housing clusters.

Demonstration Requirements - Synthesis of detail requirements for demonstration planning including objectives, constraints, and criteria precedence.

Demonstration Design - Analysis and specification of differing demonstration types from fully instrumented technical information and evaluation units to larger scale final use type of units to achieve objectives.

Demonstration Selection - Analysis and specification of criteria to be used on selection of demonstrations.

Demonstration Implementation Plan - Detail management, resource allocation and schedule plan for carrying out demonstration program.

Barrier Analysis - Detail examination of the social, economic, and political barriers to widespread application with recommended techniques to be used in overcoming problems of implementation.

Mar Act Analysis - Detail examination of the specific range of applicability and techniques for achieving significant penetrations.

Demonstrations - The actual implementation of sponsored field units to establish field operational data and market acceptability, (including collection and reduction of data).

Information Program - Data evaluation and dissemination activities to meet goals of widespread application.

Considerable overlap and interaction among these development activities are possible and desirable. By appropriate scheduling and overlap of tasks, several demonstration units should be in the field in a 2 to 3 year time period. A schedule reflecting the approach discussed is shown in Figure VIII-3.

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Figure VIII-3 Development Schedule

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APPENDIX A

HOUSING PROJECTIONS

The projections of inventories and new construction of single family detached houses are based upon projections done by General Electric for a market assessment of Solar Heating and Cooling of Buildings (SHACOB).^{*} Two adjustments of the SHACOB data were made for the HECS Market Study. First, the data were converted from one and two-family housing inventory projections (as presented in SHACOB) to single-family housing inventory projections (as required of this study). Second, the demolition rates used for the new construction estimates were for single-family detached housing rather than for all building types (as were used in SHACOB).

SHACOB Methodology

The SHACOB inventory projections were predicated upon the assumption that housing inventory in any year is a function of population, the occupancy rate and average household size. The 1970 baseline housing data were taken from the 1970 Census of Housing^{**} and the population projections used are the Series E projections of the Bureau of the Census.^{***} The E Series assumes 2.1 children per woman and a national population of 264 million by 2000 A.D.

Other assumptions made in the SHACOB study are listed below:

(1) Persons per household unit have declined and will continue to decline. Table A-1 shows values for 1970 to 2000.

Table A-1

<u>1970</u>	<u>1980</u>	<u>1990</u>	<u>2000</u>
3.2539	2.9473	2.8068	2.6138

(2) The housing share of one and two family dwellings will decline by a third from 1970 to 2000.

* General Electric, Solar Heating and Cooling of Buildings, Phase O, Feasibility and Planning Study, Final Report, May 1974.

**Bureau of the Census, Department of Commerce, Detailed Housing Characteristics-1970.

***1972 OBERS Projections, Vol. 1, Concepts, Methodology, and Summary Data, U.S. Water Resources Council, pp. 97-8, 108-14.

(3) Mobile homes will double their share by 2000.

(4) The share lost by one and two family homes will be picked up by mobile homes or apartments.

(5) The mix for 1970 is set by the Census of Housing data.

The SHACOB projections are disaggregated by climatic areas which are groups of BEA's.

Table A-2 shows the inventory projections for one and two family housing units for each of the climatic areas and for the United States.

Conversion to single-family housing inventories was made assuming that the ratio of single-family detached houses to single and two family detached houses will remain constant from 1970 through 2000. The 1970 ratio for the United States is 0.89. The SHACOB one and two-family housing inventory figures have been adjusted by these ratios to give single family detached housing inventories through the year 2000. (Table A-3).

These projected inventories of single-family detached homes are then used to derive estimates of new construction for 1970-2000, using the formula:

$$\begin{array}{lcl} \text{New Construction} & \text{Region} & \\ & \text{T to T+10} & \\ & = & \text{inventory of single family detached housing in T+10} \\ & & - \text{inventory of single family detached housing in T} \\ & & + \text{Replacement} \end{array}$$

or

$$\begin{array}{lcl} \text{New Construction} & \text{Region} & \\ & \text{T to T+10} & \\ & = & (1 + \frac{d}{2}) \text{ inventory of single family detached housing in T+10} \\ & & - (1 - \frac{d}{2}) \text{ inventory of single family detached housing in T} \end{array}$$

where d is the removal rate or demolition rate for the decade for single family detached homes in that area. These new construction estimates are given in Table A-4.

Table A-2

BASE PROJECTION OF THE INVENTORY OF
ONE AND TWO FAMILY DETACHED HOUSES

(Millions)

Climatic Region	1970	1980	1990	2000
Madison	4.18	4.74	5.12	5.48
Boston (Cleveland)	11.94	13.32	14.21	15.02
D.C.	5.77	6.53	7.00	7.43
Charleston	4.42	5.13	5.43	5.75
Nashville	5.50	6.01	6.35	6.72
Miami	1.04	1.07	1.22	1.36
Bismarck	2.20	2.41	2.50	2.60
Omaha	2.20	2.29	2.40	2.52
Ft. Worth	2.82	3.02	3.20	3.40
Phoenix	0.60	0.74	0.83	0.90
Seattle	1.16	1.25	1.36	1.45
L.A.	4.58	5.08	5.72	6.28
Alaska	0.04	0.06	0.06	0.07
Hawaii	0.14	0.18	0.20	0.21
U.S.	46.59	51.83	55.61	59.19

Source: G.E., Solar Heating and Cooling of Buildings, Phase 0, Vol. 3, Bk. 2, Feasibility and Planning Study, Final Report, May 1974.

TABLE A-3
 BASE PROJECTION OF THE INVENTORY OF
 SINGLE FAMILY DETACHED HOUSING
 (Millions)

Climatic Region	1970	1980	1990	2000
Madison	3.68	4.17	4.50	4.82
Boston (Cleveland)	9.31	10.39	11.08	11.72
D.C.	4.50	5.09	5.46	5.80
Charleston	4.11	4.77	5.05	5.35
Nashville	5.17	5.65	5.97	6.32
Miami	0.97	0.00	1.13	1.26
Bismarck	2.02	2.22	2.30	2.39
Omaha	2.02	2.11	2.21	2.32
Ft. Worth	2.65	2.84	3.01	3.20
Phoenix	0.56	0.70	0.78	.85
Seattle	1.09	1.18	1.28	1.36
L.A.	4.30	4.78	5.38	5.90
Alaska	0.03	0.05	0.05	0.06
Hawaii	0.13	0.16	0.18	0.19
U.S.	41.46	46.13	49.49	52.68

TABLE A-4
NEW CONSTRUCTION-SINGLE FAMILY DETACHED HOUSES

CLIMATIC REGION	1970-80	1980-90	1990-2000
Madison	0.98	0.76	0.79
Boston (Cleveland)	1.91	1.59	1.60
D.C.	0.99	0.81	0.81
Charleston	1.33	0.82	0.82
Nashville	1.30	0.96	0.96
Miami	0.18	0.25	0.25
Bismarck	0.46	0.31	0.32
Omaha	0.35	0.32	0.34
Ft. Worth	0.61	0.49	0.50
Phoenix	0.27	0.18	0.15
Seattle	0.33	0.27	0.21
L.A.	1.43	1.31	1.08
Alaska	0.03	0.01	0.02
Hawaii	0.06	0.04	0.03
U.S.	10.98	8.52	8.09

The demolition rates which are used in this study are based on those in the A. D. Little report for Project Independence.* These rates (presented in Table A-5) differ greatly from those reported in the SHACOB text since the SHACOB study used an average rate for all buildings while A.D. Little used different estimated rates for each type of building. The estimated rate for single family detached homes varies over region but converges to approximately one percent per year for all regions in the year 2000.

* Project Independence Residential and Commercial Energy Use Patterns 1970-1990, p. 53.

TABLE A-5
DEMOLITION RATES^a

CLIMATIC REGION	1970-80	1980-90	1990-2000
Madison	0.124	0.100	0.100
Boston (Cleveland)	0.084	0.084	0.084
D.C.	0.084	0.084	0.084
Charleston	0.155	0.110	0.100
Nashville	0.155	0.110	0.100
Miami	0.155	0.110	0.100
Bismarck	0.124	0.100	0.100
Omaha	0.124	0.100	0.100
Ft. Worth	0.155	0.110	0.100
Phoenix	0.210	0.140	0.100
Seattle	0.210	0.140	0.100
L.A.	0.210	0.140	0.100
Alaska	0.210	0.140	0.100
Hawaii	0.210	0.140	0.100
U.S.	0.143	0.109	0.096

^a Source: Project Independence, Residential and Commercial Energy Use Patterns 1970-1990, p. 53; and G.E. TEMPO.

APPENDIX B

PENETRATION ANALYSIS METHODOLOGY

Some indication of what is credible as a penetration scenario can be derived from history. Fisher and Pry (1971) collected data from available sources on 17 innovations over the past century. In each case the innovation was the substitution of a new product or process for an existing one, which proceeded nearly to completion. In each case the fractional penetration into the combined market for the old and the new was approximately a symmetric S-shaped curve as shown in Figure B-1. The cases could be characterized by the year representing the mid-point, or 50 percent penetration, and by the steepness, expressed as the time difference between the 10 and 90 percent penetration. When each innovation was normalized to a best-fit pair of these parameters, the scatter diagram of all of them superimposed shows a remarkably consistent shape.

The terminology used is that ΔT , between the 10 and 90 percent penetration points, is the "takeover time." At low penetration levels, the growth is exponential and at levels near market saturation the shape is inverted. An analytic expression that fits these conditions is:

$$f = \frac{e^{at}}{1 + e^{at}} = \frac{1}{1 + e^{-at}}$$

where f is the fractional penetration, a is $(4.4/\Delta T)$ for the takeover time as defined, and t is $(Y - Y_{50})$, i.e., the difference between the year of interest and the year for 50 percent penetration. The symmetry of this expression is such that the time between one percent penetration, the takeoff point, and 50 percent is the same as that between the 50 percent and the 99 percent, or saturation point. Each of these times is only a few percent greater than the takeover time, so twice the takeover time covers the period from takeoff to saturation.

FIGURE B-1. Penetration Curve and Data Points.
(Fisher-Pry, 1974)

Fisher and Pry (1971) found that half the innovations had takeover times from 40 to 60 years and only three had ΔT less than 15 years: Basic Oxygen Furnace/Open Hearth Steels (10.5 years) and detergents/soaps (8.5 years) in both the U.S. and Japan. Some of the longer takeovers were synthetics for natural rubber (58), for natural fibers (58), for natural leather (57), and margarine/butter (56). (See Table B-1)

Clearly, the rate of substitution depends on some of the characteristics of the old products or processes and the new ones replacing them. Cost and performance are two of these characteristics. If the new is considerably better and cheaper than the old, takeover can be quite rapid. Solid-state pocket calculators are clearly in this class as added features and price reductions at roughly 40 percent per year speeded their penetration. Factors associated with public acceptance also play a role. With time the risks and uncertainties of reliability, life, and safety may be dissipated, the media may promote familiarity, and new modes of use of the innovation may alter the total size of the market. Where the innovation proves disappointing, as with the maintenance problems of heat pumps in the 1960's, penetration may falter or fail.

Attention therefore must be given to the characteristics of the market, and to defining submarkets where the price or performance advantage of the innovation may appear earlier and/or be larger than in other submarkets. New demands are more promising than replacement of existing equipment or products with remaining useful life; the economics of the latter must consider the sunk costs. For example, adding solar or wind energy systems to new residences is a market more easily penetrated than the retrofit of old residences; penetration into net additions to capacity of a utility is easier than obsoleting and replacing existing capacity. However, the inventory of existing equipment is much larger than the annual purchases in most cases. Including the replacement/retrofit market will make penetration considerably slower, with a takeover time related to the useful life of the current equipment, but the saturation level will be higher.

TABLE B-1
TAKEOVER TIMES

Substitution	ΔT (years)
Synthetic/Natural Rubber	58
Synthetic/Natural Fibers	58
Plastic/Natural Leather	57
Margarine/Butter	56
Electric Arc/Open Hearth Specialty Steels	47
Water Based/Oil-Based Paint Remover	43
Open Hearth/Bessemer Steel	42
Sulfate/Tree-Tapped Turpentine	42
Plastic/Hardwood Residence Floors	25
Plastic/Other - Pleasure Boat Hulls	20
Organic/Inorganic Insecticides	19
Synthetic/Natural Tire Fibers	17.50
Plastics/Metal - Cars	16
BOF/Open Hearth - Steels	10.50
Detergent/Natural Soap (U.S.)	8.75
Detergent/Natural Soap (Japan)	8.25

There are examples, such as detergents for soap in the cleaning and washing markets, where the product is consumed rapidly and the inventory turnover is rapid. This in part explains the short takeover time for this innovation. Yet, another submarket, cosmetic use of soap, has not been penetrated rapidly by detergents because of public resistance. Margarine for butter, similarly a consumable rapid turnover product, had a long takeover time in part because of the legal and institutional barriers constructed by the competition. Existing manufacturing capacity and plant lifetimes may significantly slow the penetration of innovations where the total market is not growing rapidly. The replacement of natural rubber, fibers, and leather by synthetics (all ~57 years) may be explained this way. Yet examples exist where the technological and economic superiority of the new process over the old makes obsolescent the existing plant within a decade or two (e.g., the float glass process for plate glass) and currently the replacement of open hearth steels by the BOF.

Some energy related substitutions can also be derived from historical statistics and forecasts. The substitution of mineral fuels for wood as the principal energy source of the U.S. had a takeover time of over 60 years (GPO, Historical Statistics of the U.S.). The 1, 10, 50 and 90 percent years were 1825, 1850, 1885, and 1913, respectively. Similarly, within mineral fuels a major substitution of oil and gas for coal occurred. From statistics to date, it appears that the saturation level is about 70 percent substitution; 30 percent of the market continues to be served by coal. For this saturation level the 10, 50, and 90 percent years were 1900, 1936, and 1952: about a 50-year takeover time.

More recent and relevant energy examples are the additions of gas turbines and nuclear power plants to electric utility generating capacity. Data for both recent history and forecasts by the industry to 1995 are found in the "26th Annual Electric Industry Forecast" (Electrical World, September 15, 1975). It is interesting to note that the penetration of each of these can be found either as a fraction that the annual additions of each constitute of the total annual additions, or as a fraction that the cumulative total of each in service comprise of the total installed capacity. The former gives shorter penetration times, but has erratic data as the additions made or planned vary randomly from year to year. The cumulative fraction of capacity gives smoother data illustrating long-term trends.

For gas turbines, a rapid rise in additions to capacity began in the early 1960's and peaked in the early 1970's at 22 percent of new capacity additions. The takeover time, as defined previously, was five years. Interestingly, the period 1970-1975 and the forecasts to 1985 show a decline in additions to new capacity to as low as 5 percent, and then an increase in the 1990's to over 10 percent again. This can be better understood by studying the cumulative total of GT capacity vs total capacity. It takes longer for a given percentage of new additions to reach a given percentage of total capacity. Gas turbines rose to between 9 and 10 percent of total capacity by 1974 and leveled off. Actual and forecast additions keep the fraction of total capacity constant between 8.5 and 10 percent to 1995. It appears that it was found that the 10 percent rather than the 20 percent level was optimum for a saturation level. An overshoot to 20 percent of new additions brought the level to saturation sooner. On the cumulative basis, the takeover time was slightly under eight years rather than the 15 years it would have been if the fraction of new additions had been limited to 10 percent.

There are interesting parallels in the case of nuclear additions. By 1974, nuclear steam plants were 25 percent of new additions but cumulatively only 7 percent of total capacity. The forecast shows new additions going to over 65 percent of new capacity then falling to 55-60 percent in the 1990's. This gives a cumulative fraction of total capacity by 1995 of 30 percent. The takeover time for 55-65 percent of new capacity as a saturation level is 10 years. The takeover time for fraction of total capacity is 20 years if the saturation level is 30 percent of total capacity, or 40 years if the saturation level is 50 percent of total capacity. Again, overshoot in share of annual additions speeds up total capacity takeover time, and cumulative takeover time (i.e., share of total energy produced) is considerably longer than the takeover time in annual additions.

APPENDIX C

HEAT EXCHANGER AND GRAVITY FLOW CALCULATIONS

The maximum energy from the compost pile is approximately 28,850 Btu/day as calculated in Table VII-8, Page VII-26. From Table VII-9, the hot water required per day is 80 gallons. The average flow rate shall be calculated on a 16 hour period to account for usage patterns.

$$\frac{80 \text{ GPD} \times 8.3 \text{ LB/GAL}}{16 \text{ HR}} = 41.5 \text{ LB/HR or } 0.692 \text{ LB/MIN}$$

$$Q = 28,850 \frac{\text{BTU}}{\text{DAY}} \times \frac{\text{DAY}}{16 \text{ HR}} \times \frac{\text{HR}}{60 \text{ MIN}} = 30 \text{ BTU/MIN}$$

The maximum temperature gain is:

$$\Delta t = \frac{Q}{mC_p} = \frac{30}{(0.692)(1)} = 43.4^\circ\text{F}$$

A stratified heating tank is assumed, with the upper temperature at 123°F and the lower at 80°F. Note that this is not the temperature of entering fresh water (65°F or 40°F depending upon source) but slightly above that temperature since the entering water will be tempered by the hotter water already in the stratified tank. The heat exchanger receives water at 90°F, and discharges it at 123°F. The area for this exchanger is then calculated as follows:

From Eckert & Drake, "Heat and Mass Transfer", Second Edition, Page 194, for constant heat flow rate:

$$N_U = \frac{hd}{k} = 4.36 \quad \begin{array}{l} \text{where } h = \text{film heat transfer coefficient} \\ d = \text{diameter} \\ k = \text{thermal conductivity of water} \end{array}$$

Solving for h, when d is 1/2 inch and k is 0.359 Btu-ft/hr-ft²-°F

$$h = 37.56 \frac{\text{Btu}}{\text{hr-ft}^2 - ^\circ\text{F}}$$

The overall heat transfer coefficient is calculated by:

$$\frac{1}{U} = \frac{1}{h_o} + \frac{x}{k} + \frac{1}{h_i} \quad \text{where } h_o = \text{outside film coefficient}$$

x = metal thickness

k = thermal conductivity of metal

h_i = inside film coefficient

$$= 37.56 \text{ Btu/hr-ft}^2\text{-}^\circ\text{F}$$

From Marks, "Handbook for Mechanical Engineers", 7th edition, page 4-98;

$h_o = 130$ for scale deposit of Chicago Sanitary
Canal Water

$$k = 9.4$$

$$x = .035 \text{ inches}$$

$$U = 28.9 \frac{\text{Btu}}{\text{hr-ft}^2} - ^\circ\text{F}$$

The log mean temperature difference is calculated assuming a constant pile temperature of 140°F and water temperatures of 123°F exiting and 80°F entering.

$$(\Delta t)_{ln} = \frac{\Delta t_{\text{max}} - \Delta t_{\text{min}}}{\ln \frac{\Delta t_{\text{max}}}{\Delta t_{\text{min}}}} = \frac{60-17}{\ln \frac{60}{17}} = 34.1^\circ$$

$$\text{Required Area } A = \frac{Q}{U(\Delta t)_{ln}} = \frac{1803}{(28.9)(34.1)} = 1.83 \text{ ft.}^2$$

The outside surface of a 1/2" O.D. tube is 0.1309 ft.²/ft.

The required length then is: $\frac{1.83}{0.1309} = 13.98$ or 14 feet

The flow velocity, pressure drop, and velocity head will now be determined. The total head will then be compared against that developed on the gravity circulation concept to determine if such is feasible.

Velocity at 0.692 LB/minute:

$$\text{Tube flow area} = \frac{\pi (.5)^2}{4} \times \frac{1}{144} = 0.00136 \text{ ft.}^2$$

$$0.692 \frac{\text{lb}}{\text{min.}} \times \frac{\text{ft.}^3}{62.4 \text{ lb.}} \times \frac{\text{min}}{60 \text{ sec}} = 0.000185 \text{ ft.}^3/\text{sec.}$$

$$\text{Velocity} = \frac{0.000185 \text{ ft.}^3/\text{sec.}}{0.00136 \text{ ft.}^2} = 0.136 \text{ ft./sec. or } 1.6 \text{ inches/sec.}$$

$$\text{Reynolds number } R_e = \frac{VD}{V} \quad \text{Where } V = \text{Velocity} - 0.136 \text{ ft./sec.}$$

$$D = \text{Diameter} - 0.04167 \text{ feet}$$

$$V = \text{Viscosity} - 7.44 \times 10^{-6} \text{ ft.}^2/\text{sec.}$$

$$R_e = 761.7 \text{ (Laminar Flow)}$$

$$f = \frac{64}{R_e} = 0.084$$

$$\text{Frictional Pressure } \Delta P = f \frac{L}{D} \frac{V^2}{2g}$$

f = friction factor
L = Length of tubing
D = Diameter of Tubing
V = Velocity
g = Gravitational constant

$$\Delta P = 0.084 \left(\frac{18}{0.04167} \right) \frac{(0.136^2)}{64.4}$$

$$\Delta P = 0.0104 \text{ feet of head or } 0.125" \text{ water}$$

Therefore the total head required is:

$$\text{Friction} - 0.0104$$

$$\text{Velocity} - \underline{0.0003}$$

$$\text{TOTAL} - 0.0107 \text{ feet of head}$$

The available head due to the gravity flow will now be calculated and compared against that required.

From Marker, "Handbook for Mechanical Engineer", Fifth Edition, Page 1610, the total head may be calculated by:

$$H = 2h \frac{(\rho_2 - \rho_1)}{\rho_2 + \rho_1}$$

where

h = height difference (assumed at 2 feet)

ρ_1 = density of hot water (61.7 lb./ft.³ @ 120°F)

ρ_2 = density of cold water (62.2 lb./ft.³ @ 80°F)

$$H = (2)(2) \frac{(62.2 - 61.7)}{(62.2 + 61.7)} = 0.01614 \text{ feet of head.}$$

Therefore, the available head is greater than the required head and the system will flow slightly faster than the minimum velocity required. The system is also self compensating as the faster flow will increase slightly the pressure drop. A warmer return will reduce the head provided, which of course will reduce the flow velocity. This is fine, as the required energy is also less since the incoming water to the heat exchanger has also increased.

APPENDIX D

VENT STACK CALCULATIONS

Air is required in the compost pile to provide a drying effect and to aerate the pile in order to maintain aerobic conditions. The temperature the air will be heated to and the degree of saturation obtained is currently unknown and may most easily be obtained by test. Several assumptions, however, will approximate the situation for initial vent sizing.

Case 1:

Assumption: incoming air is at 70°F and 40% RH. The external pile temperature is at 120°F and the air

is warmed to 90°F. Note that while a 140°F or more pile temperatures were referenced in Figure IV-6, page IV-11, those temperatures were internal to the pile. The surface temperature may expected to be slightly lower than the 140°F. Also 120°F is utilized for conservative design; Moisture is added to arrive at a final temperature of 80°F with a RH of 40%.

$$\begin{aligned} \text{Amount of Air Required} &= \frac{7.59\# \text{ Water Vapor} \times 7000 \text{ grains/\#}}{61 - 44} \\ &= 3125.3 \text{ lb air/day or } 29 \text{ cfm} \end{aligned}$$

Energy lost to air:

$$3125.3 \frac{\#}{\text{Day}} \times (28.8 - 24) \text{ BTU/\#} = 15,000 \text{ BTU/day}$$

Case 2:

Assumption: incoming air is heated to 100°F prior to moisture addition which leaves the air at a 50% RH and 80°F dry bulb temperature.

$$\text{Amount of Air required} = \frac{7.59 \times 7000}{76-44} = 1660\#/ \text{day}$$

or 15 cfm

Energy lost to air:

$$1660\#/\text{Day} \times (31-24) \text{ Btu}/\# = 11,600 \text{ Btu}/\text{day}$$

The vent diameter for each case will now be investigated. From "Steam, Air, and Gas Power", by Severns, Degler and Miles, Page 204, the gas velocity in a chimney stack is:

$$V = 8.02 \sqrt{h \frac{T_g}{T_a}} \quad \text{where } h = \text{stack height}$$

T_g = stack gas temp

T_a = Atmospheric temp

Assuming that the composteur is in the basement of a two story house, h is estimated at 22 feet

$$T_g = 80^\circ\text{F} + 460 = 540^\circ\text{F}$$

$$T_a = 70^\circ\text{F} + 460 = 530^\circ\text{F}$$

$$V = 8.02 \cdot 22 \frac{(540 - 1)}{530} = 5.167 \text{ feet per second.}$$

The required stack cross sectional area is calculated by:

$$A = \frac{Q}{KV} \quad \text{where } Q = \text{volume of gas, CFS}$$

$K = \text{coefficient of velocity}$

$V = \text{Theoretical gas velocity FPS}$

For Case 1:

$$A = \frac{(29/60)}{(0.8)(5.167)} = 0.1169 \text{ ft.}^2 = 16.8 \text{ in}^2$$

$$\text{Diameter} = 4.6''$$

For Case 2:

$$A = \frac{(15/60)}{(0.8)(5.167)} = 0.0605 \text{ ft.}^2 = 8.7 \text{ in}^2$$

$$\text{Diameter} = 3.3''$$

If the air can be heated to 100°F in the pile, the stack may be smaller and also the heat loss created by the air flow is less. Since this is dependent on testing, a 4.0" stack will be assumed for further component definition.

APPENDIX E

COMPOST TANK EVAPORATION AREA

A surface area is required to ensure evaporation of the 7.59 lb. of water vapor per day in order to maintain the proper humidity level in the compost material.

From "Fan Engineering" by Buffalo Forge Co., Page 95, the pickup of moisture by air flowing over a liquid surface may be defined by:

$$W = \frac{95 + .425V}{r} (\rho_w - \rho_a)$$

where

W = pounds of water vapor per sq. ft. per hour

V = air velocity, ft./minute

r = water latent heat, Btu/lb.

ρ_w = vapor pressure corresponding to water temperature

ρ_a = vapor pressure of moisture in air, in Hg

Approximately 15 cfm flows thru an area of 4.5 ft. dia.

$$\text{Velocity} = \frac{15 \text{ ft.}^3}{15.9 \text{ ft.}^2 \text{ min.}} = 0.94 \text{ ft./min.}$$

$$r = 1040 \text{ Btu/\#}$$

$$\rho_w = 3.4458" \text{ Hg @ } 120^\circ\text{F}$$

$$\rho_a = 0.3004" \text{ Hg @ } 70^\circ\text{F and 40\% RH}$$

$$W = \frac{95 + .425(0.94)}{1040} (3.4458 - 0.3004)$$

$$= 0.2885 \text{ lb./ft.}^2 \text{ HR}$$

$$\text{Evaporation Potential} = 0.2885 \frac{\text{lb}}{\text{ft}^2 \text{HR}} \times 24 \text{ HR} \times 15.9 \text{ ft.}^2 = 110.1 \text{ ft.}^2$$

Therefore the provided area is more than adequate.

APPENDIX F

**SUMMARY OF SALIENT INFORMATION OBTAINED FROM PROJECT STUDIES/
INVESTIGATIONS REPORTED IN THE JOINT USEPA-TVA COMPOSTING PROJECT**

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FROM J. A. Geating, Supervisor-Biomedical
Programs Lab, Room #U-4447, VFSC X-6014

TO E. F. Rockefeller, Program Manager
Advanced Energy Systems, Room #M-4214, VFSC

DATE SENT

6-2-77

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PROJECT AND REQ. NO.

REFERENCE DIR. NO.

SUBJECT

Summary of Salient Information Obtained From Project Studies/Investigations
Reported in the Joint USEPA-TVA Composting Project*

INFORMATION REQUESTED/RELEASED

1.0 BACKGROUND

Treatment of trash and sewage sludge through aerobic windrow composting is regarded as a possible alternative for the disposition of typical household wastes. Much of the information presented in a joint USEPA-TVA project report* has significant bearing and potential on the design and operation of a unit-sized, household application. The following tables, figures and discussion present relevant summaries and overviews of the information presented in the studies and investigations carried out during this joint project.

The term windrow as used in the USEPA project report is defined as a long (several hundred feet), low (1.5 feet) and narrow (5-6 feet) pile of moist municipal trash, with or without sewage sludge, which is left to decompose by aerobic microbiological activity at temperatures up to 140°F. The aerobic conditions are maintained by periodic mechanical turning of the refuse pile. Total time required averages six weeks or longer.

*Composting at Johnson City, Final Report on Joint USEPA-TVA Composting Project, with Operational Data 1967-1971, Vol. I & II U. S. Environmental Protection Agency, 1975.

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2.0 STUDIES AND INVESTIGATIONS

2.1 Basic Windrow Characteristics

The range of typical temperature patterns of the windrows are depicted in Figure 2-1. As shown, the most dramatic temperature variations occur within the first five days, with the highest temperatures occurring between day 8 to 15. The inner mass of the windrow reached 140°F (60°C) for significant time periods, i.e. > 7 days, regardless of the ambient temperatures. After turning, the windrows quickly return to the temperature existing before turning. The upward convection currents originating within the windrow aid in the aeration of the compost.

The definition of what constituted the "best" decomposition is not given except in terms of highest overall temperature attained and the highest time-temperature span. These conditions appear to have been met when the windrow was turned, i.e. aerated, twice a week over the entire length of the composting period.

It can be inferred from the text of the report that higher Nitrogen content also increases the value of the compost. This value is generally expressed as the Carbon/Nitrogen Ratio (C/N), where the lower the number, i.e. higher percentages of N, is more desirable.

2.2 Effects of Various Additions to Windrows

Table 2-1 summarizes the effects of adding a variety of material to the normal municipal waste windrows to increase either the rate of decomposition and/or the value of the compost which results. As shown in the table, the addition

FIGURE 2-1 RANGE OF NORMAL WINDROW TEMPERATURE PROFILES DURING COMPOSTING

Table 2-1
Effects Of Addition Of Other Material To Normal Windrow Compost Piles¹

Experimental Results

Material Added	Percent (Dry Wt.) Of Material Added	Max. Temp. °F ²		pH Range - Units		C/N Ratio At End ³		Percent N ⁴		Remarks
		Test	Control	Test	Control	Test	Control	Test	Control	
1. Sewage Sludge	2	160	164	4.4-8.1	4.3-8	ND	ND			With addition of sewage at these ratios there is no appreciable advantage as gauged by N content or on composting process.
	3-5	158	162	5.5-7.8	5-8.2	31.9	33			
	9	158	165	5.2-8	4.4-8.1	ND	ND			
	12	Normal	158	ND	ND	25.4	ND	1.02	0.97	Texture and appearance of compost improved. No improvement over 12% trial as above.
	34			9-6-8.8	6-8	ND	ND	1.58	0.88	
	50			6-7.5	5.2-8	ND	ND			
2. Urea-Ammonium Nitrate (~27% N)	(3.5% N at start Vs. 0.94% N Control)	150	165	8.2-6-8.2	6.6-7.9	22.4	ND	2.75	1.14	Overall Conclusion Sludge can be composted with municipal waste with no appreciable effect on rate of decomposition; in high ratios some improvement on N content may be experienced.
	(2.5% N at start Vs. 0.93% N Control)	155	163	8.1-5.3-8.4	6.2-4.6-7			1.52	~1.0	
3. Buffering Agent (Limestone)	21.2% as Stone, Plus 3-5% Sludge	158	163	7.5-6-8.4	6-5-8.6			0.57	1.02	Conclusion Temperature rise was accelerated, but significant loss of N resulting in poorer compost.
	9% as Dust	160	160	6.2-8.5	5.5-8			0.65	0.96	
	16% as Dust	163	160	6.3-8.7	5.5-8			0.49	0.96	
4. Cow Manure	15.4	155 (a Week Lag from Control)	155	7.2-9.4	5.2-9.4			1.14	0.93	Overall Conclusion Demonstration that these types of waste can be composted with the typical municipal waste with no serious effect on rate of decomposition. Quality of finished product is relatively unchanged except where the N content is significantly increased.
5. Paunch Manure	14.9 (2.48% N)	160 (Identical Curves)	160	ND	ND	28.5	ND	1.26	1.04	
6. Chicken Manure (Aged)	21.2 (2.4% N) + 2-5% Sludge Solids	165 (Faster Temp. Rise)	158	ND	ND	24.0	ND	1.25	1.05	
Chicken Manure (Fresh)	20.1	155	155	7.8-6-8.6	6.2-5.4-8.4			1.32	0.99	
7. Beef Blood	Est. <1% - Plus ~3% Sludge Solids	160 (2 Week Lag)	160			22.5	ND	1.25	1.05	
8. Canning Wastes (Pimento Pepper)	14(2.82% N)	155	155	ND	ND	26.5	ND	1.13	1.01	
	6.3(2.68% N)	158	158	5.7-8.4	5.9-8			1.1	1.01	

¹ - Normal compost from municipal waste allowed to decompose in windrows for 42-54 days.

² - Maximum temperature recorded at base of windrow during compost decomposition.

³ - C/N Ratio is the total % inorganic Carbon divided by the total % inorganic Nitrogen.

⁴ - Total % inorganic N to dry weight of solids.

ND = Not Determined

of raw sewage solids, various animal manures, and limestone, or Nitrogen in the form of Urea-Ammonium Nitrate allows the waste mixture to decompose at the high temperatures ($> 140^{\circ}\text{F}$) usually attained by the municipal waste alone. Alterations in the form of temperature lags or changes in the pH cycle may result in temporary deviations from the normal, but degradation is accomplished in about 6 weeks. Chicken manure results in a significant increase in the % Nitrogen available in the final product.

Covering the windrow piles with plastic or old compost material in cold weather was not beneficial in the long run. The results demonstrated an adverse effect on the core temperature with no significant advantage being gained with the surface temperatures, i.e. no decrease in degradation time.

2.3 Microbiological and Fly Population Studies

2.3.1 Survival of *Mycobacterium phlei*

M. phlei is a non-pathogenic close relative of the species which includes the strain of virulent tuberculosis (TB). It was employed as a simulant for TB. The recovery of viable samples of their cultures, which were placed at various levels within the windrow, was entirely time-temperature dependent. A summary of the results is presented in Table 2-2. As shown, a few cultures were recovered from sites within the higher temperatures, but the conditions were artificial due to experimental necessity. It was concluded, however, that temperatures over 128°F for longer than 7 days would be sufficient to kill the tuberculi bacilli.

2.3.2 Microbiological Isolation Studies

An attempt, utilizing 602 separate samples taken from 30 different windrows, was made to isolate any of 9 pathogenic micro-organisms commonly associated with human disease. Table 2-3 summarizes those data.

Table 2-2

Recovery Of Mycobacterium pflei From Windrows At Various Depths

<u>Placement</u>	<u>Sample Conditions</u>		<u>Recovery</u>
	<u>Temp. °F</u>	<u>Time (Days)</u>	
2 in. Depth	92	49*	Yes
2 in. Depth	118	21	No
2 in. Depth	128	14	No
Mid-Depth	138	7	Yes
Mid-Depth	138	>7	No

*One Case Only

Table 2-3

Recovery Of Selected Pathogenic Micro-organisms From Various Windrows

<u>Organisms Included</u>	<u>Time Of Isolation</u>			
	<u>0</u>	<u>1 Week</u>	<u>2 Weeks</u>	<u>6 Weeks</u>
Coliforms	+	+	+	+
Fecal Coliforms	+	+	+	+
Fecal Streptococci	+	+	+	+
Coagulase Positive Staphylococci	+	0	0	0
Salmonella Species	+	0	0	0
Shigella Species	+			
Enteroviruses (Polio)	0	0	0	0
Pathogenic "Fungi"	+	(Inconclusive Beyond 0 Day)		
Parasites (Protozoa Cestodes, Nematodes)	+	+	+	+

Table 2-3

Recovery Of Selected pathogens Inserted Within
Windrows And Withdrawn After Intervals

<u>Micro-organism Inserted</u>	<u>7 Days</u>	<u>Recovery After 14 Days</u>	<u>25-28 Days</u>
Bacteria:			
<u>E. coli</u>			
<u>Salmonella typhimurium</u>	+	+	+
<u>Shigella sonnei</u>	+	0	0
<u>Staphylococcus aureus</u>	+	0	0
Parasites:			
<u>Endamoeba histolytica</u>	0		
<u>Ascaris lumbricoides</u>	+	+	+
<u>Endolimax nana</u>	0		
<u>Necatur americanus</u>	0		
Fungus:			
<u>Histoplasma capsulatum</u>	+	+	+
<u>Blastomyces dermatitidis</u>	0	0	0
<u>Aspergillus fumigatus</u>	+	+	+
<u>Geotrichum candidum</u>	+	+	+
Virus:			
<u>Polio-Type II</u>	+	+ ¹	0
Spirochoetes:			
<u>Leptospira philadelphia</u>	0	0	

+ = Viable Organisms Recovered

0 = No Viable Organisms Recovered

¹ = Possibility of Re-contamination of Polio Samples After Recovery

Coliforms tend to be most hardy, sometimes growing back to high concentration when the temperatures decreased during latter stages of the composting. Fecal coli especially were able to maintain high concentrations even with temperatures of 130-140°F.

2.3.3 Microbiological Insertion Studies

A total of 1,137 samples of bacteria, fungi, parasites and viruses was inserted in 24 windrows at various sites and then withdrawn at intervals for viability testing. These samples were inserted in ampules and not directly into the refuse itself. The results are summarized in Table 2-3.

As shown, the results suggest higher survivability of these pathogens than might be expected if the organisms were deposited directly on the compost pile. The unsuccessful attempts at isolating many of these same micro-organisms (Section 2.3.2) suggest that under the natural conditions, they could not survive.

NOTE: Public Health officers apparently draw a distinction between the levels or numbers of pathogenic micro-organisms present and the potential risk to humans under the philosophy that in low numbers ($\sim 10^3/\text{gm.}$) the average healthy human can overcome the potential effect of these organisms. The line between acceptable risk and possible danger is difficult to draw and is dependent on the organisms in question, the virulence of the strain, the age of the individual, and the overall health.

2.3.4 Cellulolytic Activity

The rate at which the cellulose wastes will be reduced within the windrows is dependent upon the temperature, the pH and the quality of the natural

thermophilic micro-organisms which are present. A species of thermophilic actinomycetes was isolated which appeared to have high potential as a cellulose reducer.

2.3.4 Fly Population Counts

Fly population studies performed in the late summer/early fall showed that most flies arrived with the fresh waste and on new windrows just being formed. The stored compost appeared to have no attractiveness for flies under the conditions which prevailed.

2.3.5 Carbon/Nitrogen Analyses (C/N)

A measure of value of the finished compost is contained in the C/N ratios which exist. Figure 2-2 depicts the rate at which the C/N ratios fall (more desirable) with windrows containing sewage solids (sludge) and those without. As shown, composts which contain sludge show an earlier decrease in the C/N ratio, but which arrive at approximately the same value by the end of the storage time.

FIG 2-2 COMPARISON OF CARBON/NITROGEN RATIOS WITH TIME
FROM WINDROWS WITH AND WITHOUT SLUDGE

APPENDIX G
REGULATIONS AND STANDARDS FOR INDIVIDUAL ON-SITE WASTE WATER
TREATMENT DISCHARGE AND HOME INCINERATOR/FURNACE EMISSIONS

APPENDIX G

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FROM L. Walker, Medical Scientist, Biomedical
Programs, Room #U-4435, VFSC X-5654TO J. D. Schelkopf, Engineer
Environmental Engineering

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6/22/77

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PROJECT AND REQ. NO.

REFERENCE DIR. NO.

SUBJECT Regulations and Standards for Individual On-Site Waste Water Treatment Discharge and
Home Incinerator/Furnace Emissions

INFORMATION REQUESTED/RELEASED

1.0 INTRODUCTION

Since air emission standards and wastewater effluent requirements either proposed or adopted on a large scale may impact the design of domestic waste treatment systems, an investigation was made of primarily federal, but also state and local laws applicable to such systems. General trends in usage and output of incinerators and wastewater treatment systems were also noted.

2.0 AIR EMISSION STANDARDS

2.1 Background

While backyard burning is still widely used for disposal of domestic waste in rural areas, the smoke, odor and appearance of the outdoor incinerators have forced their abandonment in metropolitan and suburban areas. Some have been replaced with household incinerators. Table 2.0-1 compares emissions from prototype domestic incinerators developed through the American Gas Association, with those of manufactured domestic units, municipal incinerators, and furnaces. As design, materials, and manufacturing methods improve, greater reliability should be expected with the smokeless-odorless units.²

Particulate matter, sulfur dioxide, carbon monoxide, hydrocarbons and nitrogen dioxide are the elements of concern in air emissions. Domestic means of handling waste other

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☐ 720 MOS.	☐ 732 MOS.
☐ 732 MOS.	☐ 744 MOS.
☐ 744 MOS.	☐ 756 MOS.
☐ 756 MOS.	☐ 768 MOS.
☐ 768 MOS.	☐ 780 MOS.
☐ 780 MOS.	☐ 792 MOS.
☐ 792 MOS.	☐ 804 MOS.
☐ 804 MOS.	☐ 816 MOS.
☐ 816 MOS.	☐ 828 MOS.
☐ 828 MOS.	☐ 840 MOS.
☐ 840 MOS.	☐ 852 MOS.
☐ 852 MOS.	☐ 864 MOS.
☐ 864 MOS.	☐ 876 MOS.
☐ 876 MOS.	☐ 888 MOS.
☐ 888 MOS.	☐ 900 MOS.
☐ 900 MOS.	☐ 912 MOS.
☐ 912 MOS.	☐ 924 MOS.
☐ 924 MOS.	☐ 936 MOS.
☐ 936 MOS.	☐ 948 MOS.
☐ 948 MOS.	☐ 960 MOS.
☐ 960 MOS.	☐ 972 MOS.
☐ 972 MOS.	☐ 984 MOS.
☐ 984 MOS.	☐ 996 MOS.
☐ 996 MOS.	☐ 1008 MOS.
☐ 1008 MOS.	☐ 1020 MOS.
☐ 1020 MOS.	☐ 1032 MOS.
☐ 1032 MOS.	☐ 1044 MOS.
☐ 1044 MOS.	☐ 1056 MOS.
☐ 1056 MOS.	☐ 1068 MOS.
☐ 1068 MOS.	☐ 1080 MOS.
☐ 1080 MOS.	☐ 1092 MOS.
☐ 1092 MOS.	☐ 1104 MOS.
☐ 1104 MOS.	☐ 1116 MOS.
☐ 1116 MOS.	☐ 1128 MOS.
☐ 1128 MOS.	☐ 1140 MOS.
☐ 1140 MOS.	☐ 1152 MOS.
☐ 1152 MOS.	☐ 1164 MOS.
☐ 1164 MOS.	☐ 1176 MOS.
☐ 1176 MOS.	☐ 1188 MOS.
☐ 1188 MOS.	☐ 1200 MOS.
☐ 1200 MOS.	☐ 1212 MOS.
☐ 1212 MOS.	☐ 1224 MOS.
☐ 1224 MOS.	☐ 1236 MOS.
☐ 1236 MOS.	☐ 1248 MOS.
☐ 1248 MOS.	☐ 1260 MOS.
☐ 1260 MOS.	☐ 1272 MOS.
☐ 1272 MOS.	☐ 1284 MOS.
☐ 1284 MOS.	☐ 1296 MOS.
☐ 1296 MOS.	☐ 1308 MOS.
☐ 1308 MOS.	☐ 1320 MOS.
☐ 1320 MOS.	☐ 1332 MOS.
☐ 1332 MOS.	☐ 1344 MOS.
☐ 1344 MOS.	☐ 1356 MOS.
☐ 1356 MOS.	☐ 1368 MOS.
☐ 1368 MOS.	☐ 1380 MOS.
☐ 1380 MOS.	☐ 1392 MOS.
☐ 1392 MOS.	☐ 1404 MOS.
☐ 1404 MOS.	☐ 1416 MOS.
☐ 1416 MOS.	☐ 1428 MOS.
☐ 1428 MOS.	☐ 1440 MOS.
☐ 1440 MOS.	☐ 1452 MOS.
☐ 1452 MOS.	☐ 1464 MOS.
☐ 1464 MOS.	☐ 1476 MOS.
☐ 1476 MOS.	☐ 1488 MOS.
☐ 1488 MOS.	☐ 1500 MOS.
☐ 1500 MOS.	☐ 1512 MOS.
☐ 1512 MOS.	☐ 1524 MOS.
☐ 1524 MOS.	☐ 1536 MOS.
☐ 1536 MOS.	☐ 1548 MOS.
☐ 1548 MOS.	☐ 1560 MOS.
☐ 1560 MOS.	☐ 1572 MOS.
☐ 1572 MOS.	☐ 1584 MOS.
☐ 1584 MOS.	☐ 1596 MOS.
☐ 1596 MOS.	☐ 1608 MOS.
☐ 1608 MOS.	☐ 1620 MOS.
☐ 1620 MOS.	☐ 1632 MOS.
☐ 1632 MOS.	☐ 1644 MOS.
☐ 1644 MOS.	☐ 1656 MOS.
☐ 1656 MOS.	☐ 1668 MOS.
☐ 1668 MOS.	☐ 1680 MOS.
☐ 1680 MOS.	☐ 1692 MOS.
☐ 1692 MOS.	☐ 1704 MOS.
☐ 1704 MOS.	☐ 1716 MOS.
☐ 1716 MOS.	☐ 1728 MOS.
☐ 1728 MOS.	☐ 1740 MOS.
☐ 1740 MOS.	☐ 1752 MOS.
☐ 1752 MOS.	☐ 1764 MOS.
☐ 1764 MOS.	☐ 1776 MOS.
☐ 1776 MOS.	☐ 1788 MOS.
☐ 1788 MOS.	☐ 1800 MOS.
☐ 1800 MOS.	☐ 1812 MOS.
☐ 1812 MOS.	☐ 1824 MOS.
☐ 1824 MOS.	☐ 1836 MOS.
☐ 1836 MOS.	☐ 1848 MOS.
☐ 1848 MOS.	☐ 1860 MOS.
☐ 1860 MOS.	☐ 1872 MOS.
☐ 1872 MOS.	☐ 1884 MOS.
☐ 1884 MOS.	☐ 1896 MOS.
☐ 1896 MOS.	☐ 1908 MOS.
☐ 1908 MOS.	☐ 1920 MOS.
☐ 1920 MOS.	☐ 1932 MOS.
☐ 1932 MOS.	☐ 1944 MOS.
☐ 1944 MOS.	☐ 1956 MOS.
☐ 1956 MOS.	☐ 1968 MOS.
☐ 1968 MOS.	☐ 1980 MOS.
☐ 1980 MOS.	☐ 1992 MOS.
☐ 1992 MOS.	☐ 2004 MOS.
☐ 2004 MOS.	☐ 2016 MOS.
☐ 2016 MOS.	☐ 2028 MOS.
☐ 2028 MOS.	☐ 2040 MOS.
☐ 2040 MOS.	☐ 2052 MOS.
☐ 2052 MOS.	☐ 2064 MOS.
☐ 2064 MOS.	☐ 2076 MOS.
☐ 2076 MOS.	☐ 2088 MOS.
☐ 2088 MOS.	☐ 2100 MOS.
☐ 2100 MOS.	☐ 2112 MOS.
☐ 2112 MOS.	☐ 2124 MOS.
☐ 2124 MOS.	☐ 2136 MOS.
☐ 2136 MOS.	☐ 2148 MOS.
☐ 2148 MOS.	☐ 2160 MOS.
☐ 2160 MOS.	☐ 2172 MOS.
☐ 2172 MOS.	☐ 2184 MOS.
☐ 2184 MOS.	☐ 2196 MOS.
☐ 2196 MOS.	☐ 2208 MOS.
☐ 2208 MOS.	☐ 2220 MOS.
☐ 2220 MOS.	☐ 2232 MOS.
☐ 2232 MOS.	☐ 2244 MOS.
☐ 2244 MOS.	☐ 2256 MOS.
☐ 2256 MOS.	☐ 2268 MOS.
☐ 2268 MOS.	☐ 2280 MOS.
☐ 2280 MOS.	☐ 2292 MOS.
☐ 2292 MOS.	☐ 2304 MOS.
☐ 2304 MOS.	☐ 2316 MOS.
☐ 2316 MOS.	☐ 2328 MOS.
☐ 2328 MOS.	☐ 2340 MOS.
☐ 2340 MOS.	☐ 2352 MOS.
☐ 2352 MOS.	☐ 2364 MOS.
☐ 2364 MOS.	☐ 2376 MOS.
☐ 2376 MOS.	☐ 2388 MOS.
☐ 2388 MOS.	☐ 2400 MOS.
☐ 2400 MOS.	☐ 2412 MOS.
☐ 2412 MOS.	☐ 2424 MOS.
☐ 2424 MOS.	☐ 2436 MOS.
☐ 2436 MOS.	☐ 2448 MOS.
☐ 2448 MOS.	☐ 2460 MOS.
☐ 2460 MOS.	☐ 2472 MOS.
☐ 2472 MOS.	☐ 2484 MOS.
☐ 2484 MOS.	☐ 2496 MOS.
☐ 2496 MOS.	☐ 2508 MOS.
☐ 2508 MOS.	☐ 2520 MOS.
☐ 2520 MOS.	☐ 2532 MOS.
☐ 2532 MOS.	☐ 2544 MOS.
☐ 2544 MOS.	☐ 2556 MOS.
☐ 2556 MOS.	☐ 2568 MOS.
☐ 2568 MOS.	☐ 2580 MOS.
☐ 2580 MOS.	☐ 2592 MOS.
☐ 2592 MOS.	☐ 2604 MOS.
☐ 2604 MOS.	☐ 2616 MOS.
☐ 2616 MOS.	☐ 2628 MOS.
☐ 2628 MOS.	☐ 2640 MOS.
☐ 2640 MOS.	☐ 2652 MOS.
☐ 2652 MOS.	☐ 2664 MOS.
☐ 2664 MOS.	☐ 2676 MOS.
☐ 2676 MOS.	☐ 2688 MOS.
☐ 2688 MOS.	☐ 2700 MOS.
☐ 2700 MOS.	☐ 2712 MOS.
☐ 2712 MOS.	☐ 2724 MOS.
☐ 2724 MOS.	☐ 2736 MOS.
☐ 2736 MOS.	☐ 2748 MOS.
☐ 2748 MOS.	☐ 2760 MOS.
☐ 2760 MOS.	☐ 2772 MOS.
☐ 2772 MOS.	☐ 2784 MOS.
☐ 2784 MOS.	☐ 2796 MOS.
☐ 2796 MOS.	☐ 2808 MOS.
☐ 2808 MOS.	☐ 2820 MOS.
☐ 2820 MOS.	☐ 2832 MOS.
☐ 2832 MOS.	☐ 2844 MOS.
☐ 2844 MOS.	☐ 2856 MOS.
☐ 2856 MOS.	☐ 2868 MOS.
☐ 2868 MOS.	☐ 2880 MOS.
☐ 2880 MOS.	☐ 2892 MOS.
☐ 2892 MOS.	☐ 2904 MOS.
☐ 2904 MOS.	☐ 2916 MOS.
☐ 2916 MOS.	☐ 2928 MOS.
☐ 2928 MOS.	☐ 2940 MOS.
☐ 2940 MOS.	☐ 2952 MOS.
☐ 2952 MOS.	☐ 2964 MOS.
☐ 2964 MOS.	☐ 2976 MOS.
☐ 2976 MOS.	☐ 2988 MOS.
☐ 2988 MOS.	☐ 3000 MOS.
☐ 3000 MOS.	☐ 3012 MOS.
☐ 3012 MOS.	☐ 3024 MOS.
☐ 3024 MOS.	☐ 3036 MOS.
☐ 3036 MOS.	☐ 3048 MOS.
☐ 3048 MOS.	☐ 3060 MOS.
☐ 3060 MOS.	☐ 3072 MOS.
☐ 3072 MOS.	☐ 3084 MOS.
☐ 3084 MOS.	☐ 3096 MOS.
☐ 3096 MOS.	☐ 3108 MOS.
☐ 3108 MOS.	☐ 3120 MOS.
☐ 3120 MOS.	☐ 3132 MOS.
☐ 3132 MOS.	☐ 3144 MOS.
☐ 3144 MOS.	☐ 3156 MOS.
☐ 3156 MOS.	☐ 3168 MOS.
☐ 3168 MOS.	☐ 3180 MOS.
☐ 3180 MOS.	☐ 3192 MOS.
☐ 3192 MOS.	☐ 3204 MOS.
☐ 3204 MOS.	☐ 3216 MOS.
☐ 3216 MOS.	☐ 3228 MOS.
☐ 3228 MOS.	☐ 3240 MOS.
☐ 3240 MOS.	

Table 2.0-1 Trace Effluents in Stack Emissions from Domestic Gas-Fired, Municipal, and Commercial Incinerators, and Backyard Trash Burners, Compared with Gas- and Oil-Fired Heating Units and Automobile Exhausts^a

Source															Particulate Matter ^a (gr/ft ³)		Smoke Compliance with ASA Requirements
	Aldehydes ^b		Nitrogen Oxides ^c		Organic Acids ^d		Ammonia		Hydrocarbons ^e		Sulfur Oxides ^f		Carbon Monoxide (ppm)	At Standard Temperature and Pressure ^g	At 500°F ⁱ		
	ppm	lb/ton	ppm	lb/ton	ppm	lb/ton	ppm	lb/ton	ppm	lb/ton	ppm	lb/ton					
Domestic gas-fired incinerators:																	
AGA prototype:																	
Shredded paper	8-21	0.9-2.3	8-13	1.0-2.2	—	—	<5	—	—	—	—	—	100	0.017-0.019	0.023-0.028	Yes	
ASA domestic wastes	8	0.8	15	2.1	7	1.9	<5	—	0.7	0.3	2	—	200-400	0.005-0.018	0.006-0.028	Yes	
New manufacturers' units:																	
Shredded paper	4-67	0.7-13.9	2-7	0.3-2.6	—	—	<5	—	—	—	—	—	200-400	0.013-0.095	0.033-0.222	Yes	
ASA domestic wastes	25-40	—	2-3	—	—	—	<5	—	—	—	—	—	200-1000	0.006-0.012	0.011-0.028	Yes	
Other units:																	
Shredded paper	24-48	0.3-0.4	5	0.6-0.9	—	—	5	—	—	—	—	—	—	0.039-0.132	0.084-0.252	No	
ASA domestic wastes	5-30	5-6	1-3	0.6-2	17	6.6	5	—	4.7	2.5	—	—	—	0.019-0.097	0.122-0.528	No	
Municipal incinerators:																	
Glendale, Calif.:																	
With scrubber	1-9	—	24-58	—	—	—	—	—	—	None	—	—	<1000	0.035-0.060	0.12-0.15	—	
Without scrubber	1-22	—	38-92	—	—	—	—	—	—	None	—	—	<1000-3000	0.128-0.347	0.14-0.068	—	
Other units:																	
Single chamber	—	0.03-2.7	—	3.9-4.6	—	2.0-3.9	—	0.23-0.5	—	None	—	1.4-2.3	—	0.73	—	—	
Backyard:																	
Paper and trimmings	760	20	<1.5	<0.1	—	—	65	1.8	—	—	—	—	5500-27,000	—	—	—	
6-ft ³ paper	40	2.1	7	0.5	18	1.5	4	0.1	—	—	34	1.2	—	—	—	—	
Industrial heating units:																	
Large, gas fired	49	2	215	14	30	2.5	0.6	—	—	—	4	0.3	—	—	—	—	
Large, oil fired	61	2.4	390	26	363	30	0.6	—	—	—	750	60	—	—	—	—	
Automobile exhaust:																	
Accelerating	1369	41	4190	190	—	—	—	—	410	30	—	—	<100	—	—	—	
Cruising	264	8	1668	75	—	—	—	—	354	28	—	—	4000	—	—	—	

- Data from Hein, G. M. and R. B. Engdehl, "A Study of Effluents from Domestic Gas-Fired Incinerators, AGA, NY, 1959.
- As formaldehyde.
- As nitrogen oxide.
- As acetic acid.
- As hexane.
- As sulfur dioxide.
- Including tarry organic materials.
- Actual.
- 50 percent excess air.
- Battelle.

than burning have apparently not had an impact on air quality sufficient to generate any widespread legislation.

2.2 Federal Laws

There are at present no federal regulations governing emissions from single-family units for incinerating, composting or producing heat.

The Clean Air Act, as amended in June 1974, sets forth the federal position on air quality. It includes the Clean Air Act of 1963 and amendments made by the Motor Vehicle Air Pollution Control Act, the Clean Air Act Amendments of 1966, the Air Quality Act of 1967, the Clean Air Amendments of 1970, the Comprehensive Health Manpower Training Act of 1971 and the Energy Supply and Environmental Coordination Act of 1974.

The act gives each state the responsibility for assuring that national primary and secondary standards, i.e. those requisite to protect the public health and welfare, respectively, are achieved and maintained within each air quality control region in the state.

Table 2.2-1 shows those pollutants included in the national primary and secondary standards.

Regional plans have been developed within and between states to meet these ambient air quality standards.

2.3 State Laws

Pennsylvania, because of its areas of high population density and industrialization, has stringent air standards⁴ which can be used to illustrate the

Table 2.2-1 National Primary and Secondary
Ambient Air Quality Standards

Pollutant	Primary Standard	Secondary Standard
Sulfur Oxides	80 ug/cu meter - annual arithmetic mean 365 ug/cu meter - max. 24 hour conc. not to be exceeded more than once a year	1,300 ug/cu meter max. 3 hour conc. not to be exceeded more than once a year
Particulates	75 ug/cu meter - annual geometric mean 260 ug/cu meter max. 24 hour conc. not to be exceeded more than once a year	60 ug/cu meter - annual geometric mean 150 ug/cu meter - max. 24 hour conc. not to be exceeded more than once a year.
Carbon Monoxide	10 mg/cu meter - max. 8 hour conc. not to be exceeded more than once a year 40 mg/cu meter - max. 1 hour conc. not to be exceeded more than once a year	Same as primary
Photochemical Oxidants	160 ug/cu meter - max. 1 hour conc. not to be exceeded more than once a year	Same as primary
Hydrocarbons	160 ug/cu meter max. 3 hour conc (6-9 a.m.) not to be exceeded more than once a year	
Nitrogen Dioxide	100 ug/cu meter - annual arithmetic mean	

state level position on air emissions. Pennsylvania's Air Pollution Control Act of October, 1972 provides for six air pollution control regions. Within a region, emissions limitations for each category of sources (power plants, industrial sources etc.) are established in order to meet ambient air quality standards. Pennsylvania has adopted national standards and in addition set standards for settled particulate, lead, beryllium, sulfates, fluorides and hydrogen sulfide. Only a few states have adopted more stringent standards than the National Ambient Air Quality Standards. Under Title 25, Part 1, Subpart C, Chapter 127, air contamination sources used in residential premises designed to house four or less families are exempt from the requirement to obtain approval and a permit to operate from the Department of Environmental Resources and there have been no emission limitations established for this source category.

2.4 Local Laws

In general, municipal air pollution control legislation also does not regulate emissions from sources as small as a single family dwelling. Incineration, which on an apartment or municipal scale is being phased out, is controlled by legislation. In Philadelphia, the following requirements have been established for new incinerators.

1. A burning rate of >10,000 lbs per hour for type 0, 1 and 2 wastes.
2. Multiple chambers, an auxiliary heat source and suitable controls.
3. Particulate emission of <0.08 grains per standard cu. ft. of flue gas on a dry basis adjusted to 12% carbon dioxide.
4. No visible fly ash emission.
5. No visible emission except uncombined water for a period of more than 30 consecutive seconds in any one hour or an aggregate of more than 3 minutes in any day which is equal to or greater than 20

percent opacity, or for any period which is equal to or greater than 60 percent opacity.

6. No odor emission. (Gases from primary combustion chamber must be maintained for not less than 0.5 seconds at not less than 1400 degrees F).⁵ Open fires, with the exception of backyard cooking, are prohibited.

Townships may depend on state air pollution codes or adopt regulations to deal with local situations. Local zoning laws may also affect the use of certain domestic disposal systems since restrictions are sometimes placed on the location of facilities which produce odors, smoke, toxic gases and dust or are accompanied by fire or explosion hazards.

2.5 Outlook

The contribution of single family homes to air pollution in most areas is at present considered by government to be insignificant. State and federal requirements would not impact the design of a domestic composting unit. Local ordinances based on unknown criteria might affect acceptance in some areas.

3.0 EFFLUENT DISCHARGE FROM DOMESTIC WASTEWATER TREATMENT.

3.1 Wastewater Treatment-General

Because of growing concern for water and energy conservation, there is a movement back to smaller systems for treatment of household wastewater.⁶ Experience with methods of treatment and the need to assure the quality of underground water supplies and of rivers and streams have given rise to regulation of the siting and design of systems used for treatment and surface or subsurface discharge of wastewater. On-site operation and maintenance

of septic systems is not well regulated but more extensive requirements have been established for use of innovative systems. It is likely that the units of government currently responsible for conventional systems will in the future be called upon to regulate new systems as they develop and are proven acceptable.⁷

3.2 Federal Laws Affecting Effluent Discharge

The Federal Water Pollution Control Act in general gives the states the prerogative in controlling discharge to streams. Each surface discharge system is required to have a pollution discharge permit (NPDES) and meet federally set discharge standards (currently secondary treatment requirements). Monitoring and reporting minimums have been established under PL 92-500.

3.3 State Laws Affecting Effluent Discharge

3.3.1 Regulation of Disposal Systems

Regulation of on-site disposal systems by the states varies from no control to almost total control. A permit for on-site systems and site inspection by the state agency are required in many states including:

Alabama	New Hampshire
Colorado	New Mexico
Delaware	North Carolina
Hawaii	Oklahoma
Maryland	Pennsylvania
Massachusetts	Rhode Island
Missouri	South Dakota
Nevada	West Virginia

This scheme is considered to be the most effective. A few states have no requirements either at the state or local level. Some of these merely supply information to the public and others will take regulatory action only in the case of proven water pollution.⁸

Mississippi and Louisiana have particularly stringent regulations. The former will not approve individual residential sewage disposal systems of

any type in new subdivisions unless the establishment of a community system is not economically feasible. Louisiana, because of its experience with failure of individual facilities in built-up areas, discourages the use of other than temporary individual facilities in land developments.⁹ In states such as:

Arizona	New York
Georgia	Ohio
Illinois	South Carolina
Indiana	Tennessee
Iowa	Texas
Nebraska	Utah

Local health authorities have all of the permit and inspection responsibilities. Some of these states have adopted minimum standards.

Other states like Wisconsin divide the responsibilities giving local authorities control of on-site systems serving isolated homes and state authorities control of subdivisions and commercial installations.¹⁰

3.3.2 On-Site System Standards and Specifications

Equally divergent are the on-site system standards and specifications used by the 50 states. Two publications on which many of the states have relied for standards are the Manual of Septic Tank Practice, publication no. PHSP526, 1957 and National Sanitation Foundation Standard No. 40 Relating to Individual Aerobic Wastewater Treatment Plants, 1970. Standards must be adopted to meet individual state problems.

3.3.2.1 Subsurface Disposal

3.3.2.1.1 Soil Absorption System

Soil is considered suitable for absorption of septic tank effluent if it has a percolation time within the range specified in Table 3.3.2.1.1-1 and the maximum seasonal elevation of the ground water table and/or impervious strata are at least 4 ft. below the bottom of the trench or seepage pit.

The absorption area required is determined as in Table 3.3.2.1.1-1, and the

Table 3.3.2.1.1-1 Absorption-Area Requirements
for Individual Residences (a)

[Provides for Garbage Grinder and Automatic Clothes Washing Machines]

Percolation rate (time required for water to fall one inch, in minutes)	Required absorption area, in sq. ft. per bedroom (b), standard trench (c), seepage beds (c), and seepage pits (d)	Percolation rate (time required for water to fall one inch, in minutes)	Required absorption area in sq. ft. per bedroom (b), standard trench (c), and seepage beds (c), and seepage pits (d)
1 or less.....	70	10.....	165
2.....	85	15.....	190
3.....	100	30 (e).....	250
4.....	115	45 (e).....	300
5.....	125	60 (e), (f).....	330

(a) It is desirable to provide sufficient land area for entire new absorption system if needed in future.¹

(b) In every case sufficient land area should be provided for the number of bedrooms (minimum of 2) that can be reasonably anticipated, including the unfinished space available for conversion as additional bedrooms.

(c) Absorption area is figured as trench-bottom area and includes a statistical allowance for vertical side wall area.

(d) Absorption area for seepage pits is figured as effective side wall area beneath the inlet.

(e) Unsuitable for seepage pits if over thirty.

(f) Unsuitable for absorption systems if over sixty.

¹ Section 5.1(b) (2) (A) Page 20 of *Recommended State Legislation and Regulations: Urban Water Supply and Sewerage Systems Act and Regulations, Water Well Construction and Pump Installation Act and Regulations, Individual Sewerage Disposal Systems Act and Regulations*. U.S.D.H.E.W., Public Health Service, July 1963

system is chosen to suit the location.¹¹ Since disposal systems are required to be constructed in direct proportion to waste water flows, an output which is considerably lower in flow and sewage strength, i.e. grey water only, is of great value in reducing the cost of on-site disposal by reducing the size of the system required or greatly extending its life. The state of Maine allows a 35-40% reduction in the size of a system if used with a composting, incinerating, or recirculating toilet, due to the reduced hydraulic load.¹² Cutting down on the size of drainage fields can allow construction on previously unsuitable property, since restrictions are often placed on location in relation to property boundaries, etc. In Pennsylvania, minimum isolation distances between the features named and subsurface absorption area are:

1. Individual water supply or water supply system suction line - 100 ft.
2. Streams, lakes or other surface water - 50 ft.
3. Occupied buildings - 10 ft.
4. Property lines or right-of-way - 10 ft.
5. Water supply line under pressure - 25 ft.¹³

Reduction in size of drainage fields also can eliminate the need for a dosing tank. In Pennsylvania these are required when the total area of the laterals exceeds 2,500 sq. ft. and in the case of a sand filter when the total area is >1,800 sq. ft.¹⁴

Another advantage to the output of only grey water lies in the reduction in impurities which must be absorbed, precipitated, filtered out or biologically degraded in the soil. "Since grey water contains little, if any, nitrogenous materials, the traditional problem of an increase in nitrate level in ground water fed comigled sewage is greatly reduced."¹⁵ Organic matter is also lower in grey water. Using BOD as a measure, it was found, in addition, that black water from toilets decomposes more slowly than grey water.¹⁶

3.3.2.1.2 Elevated Sand Mound and Evapotranspiration

Requirements for health and pollution hazard reduction still hold when elevated sand mounds or evapotranspiration are used for disposal of wastewater where trenches and seepage beds cannot be used. The advantages of disposing of grey water only in these systems are the same as in the absorption systems.

3.3.2.2 Surface Discharge

Effluent of any system discharging to streams must not only meet federal standards but, in some cases, rather stringent state standards. In Illinois, for instance, sewage effluent entering an intermittent stream must have a BOD ≤ 4 mg/l, suspended solids ≤ 5 mg/l and fecal coliform levels $\leq 400/100$ ml. Quality of water in receiving stream must be maintained within the following limits:

1. DO > 5 mg/l and not < 6 mg/l for any 16 hour period of the day.
2. Ammonia ≤ 1.5 mg/l.
3. Fecal coliforms $< 200/100$ ml as a geometric mean.
4. Phosphorus < 0.05 mg/l in any river at the point at which it joins a reservoir.

An exception is available to small sewage disposal systems to allow high BOD and suspended solids in some instances.¹⁷

Many oxidation lagoon and sand filter systems can meet a reasonable effluent quality standard, but few, if any, can meet the very stringent standards which are now in existence. None of the systems are able to provide effluent with nutrient standards acceptable for streams in many areas.¹⁸ In these cases compliance might be attained through the use of a segregated system in which grey water alone was treated for surface disposal.

In Pennsylvania each basin has its own requirements. In addition to 85% organics and suspended solid removal, some basins require aeration for removal of ammonia. A segregated system, disposing of grey water only, would be expected to meet the requirement without treatment for ammonia removal.

3.5 Outlook

Figure 3.5-1 shows a matrix of anticipated possible treatment and disposal combinations of on-site sewerage systems.¹⁹ Innovative systems for disposing of wastewater are in general subject to more regulation than standard systems. This is necessary, in the installation, maintenance and failing phases in the life of an on-site system. A system which utilizes standard wastewater treatment/disposal techniques but prior to treatment/disposal diverts the black water from the system will probably meet with less difficulty in gaining acceptance among units of government regulating wastewater disposal than those combining innovative treatment and disposal.

Segregation of wastes will be beneficial in systems designed to discharge treated wastewater to surface waters, since a high quality effluent is needed. The U. S. Environmental Protection Agency has set maximums of 30 mg/l BOD₅ and 30 mg/l suspended solids for municipal plants discharging to water courses. "Lower maximum might be set for scattered individual systems, discharging to small intermittent streams." It could be expected that maximums for total and fecal coliforms of 1000/100 ml and 200/100 ml, respectively, might be established for individual systems discharging to recreational waters.²⁰

		Disposal				
Treatment		No (Containment)	Conventional (Subsurface Soil)		Innovative	
				Soil	Surface Water Discharge	E-T
	No	1. Holding tanks 2. Recycle toilets (non-water carriage) 3. Self-contained toilets	1. Cesspool	Unlikely	Unlawful	Unlikely
Conventional (Septic Tank)	Unlikely	1. Septic tank- soil absorp- tion field	1. Mound systems 2. Fill systems	Probably unlawful	1. E-T beds	
Innovative	1. Composting toilets	1. Mechanical aeration-soil absorption field	1. Mechanical aeration- mound system	1. Sand filters 2. Physical- chemical 3. Lagoons 4. Mechanical aeration 5. Others	1. Not known at this time	

Figure 3.5-1 Matrix of Anticipated Possible Treatment and Disposal Combinations of On-Site Sewage Systems

Sand Filtered septic tank effluents and aerobic unit effluents appear to meet current EPA standards for BOD and total suspended solids, but would require further treatment for coliforms.²¹ Chlorination is called for in some states under these conditions. Input of only grey water could significantly reduce the coliform count in effluents from such systems.

A reduction in strength and quantity of wastewater, provided by segregated wastes, appears to be equally beneficial for standard soil absorption systems. Regulations currently applicable to these systems are concerned with the capacity of the soil for absorption and renovation.

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APPENDIX H
WASTE WATER TREATMENT AND DISPOSAL SYSTEMS - EFFECTS OF STRENGTH
AND QUANTITY OF WASTE WATER

APPENDIX H

GENERAL ELECTRIC

SPACE DIVISION
PHILADELPHIA

CLASS. LTR.	OPERATION	PROGRAM	SEQUENCE NO.	REV. LTR.
U	1R60	77	150	
PIR NO.				

PROGRAM INFORMATION REQUEST/RELEASE

*USE "C" FOR CLASSIFIED AND "U" FOR UNCLASSIFIED

FROM L. A. Walker, Medical Scientist - Life Sciences, Room #U-4435, VFSC X-5654 TO J. D. Schelkopf, Engineer - Environmental Engineering, M4214

DATE SENT 7/5/77	DATE INFO. REQUIRED	PROJECT AND REQ. NO.	REFERENCE DIR. NO.
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SUBJECT Wastewater Treatment and Disposal Systems - Effects of Strength and Quantity of Wastewater.

INFORMATION REQUESTED/RELEASED

1.0 Tank Treatment

Soils clog quickly with untreated household grey water. The treatment tank removes solids by reducing the flow to allow settling and flotation, and decomposes solids and liquids using anaerobic bacteria. Because of the relatively wider fluctuations of flow in small tanks than in larger units, minimum liquid capacities have been established for household grey water tanks. These are lower than needed for combined black and grey water tanks. A 4 bedroom house would require a tank having a 600 gal. capacity for the grey water (1) and 1000 gal. capacity for combined wastes. (2) These minimums are designed to provide for use of garbage grinders which would not contribute to the proposed system's grey water.

2.0 Drainage Fields

While the soil mantle, by virtue of its immense volume and purification potential, functions well as a natural treatment system, it can be made to fail by overloading or inclusion of toxic substances in the waste.

In laboratory studies clogging in some soil types was found to be a function of the sum of the suspended solids and BOD₅ concentrations in the effluent (3). BOD₅ is not significantly reduced by septic tank treatment.

The volume and concentration of wastes are substantially reduced in a system free of toilet waste, as illustrated in Table 2.0-1 (4), making clogging less likely.

cc: S. R. Hunt, Ph.D.
E. F. Rockefeller

PAGE NO.

1 OF 4

RETENTION REQUIREMENTS

COPIES FOR

MASTERS FOR

☐ 1 MO.☐ 3 MOS.☐ 3 MOS.☐ 6 MOS.☐ 6 MOS.☐ 12 MOS.☐ MOS.☐ MOS.☐☐ DO NOT DESTROY

Table 2.0-1 Effect of toilet waste segregation on household wastewater

Parameter*	% Reduction
Flow	22-31%
BOD ₅	22-49
Suspended solids	36-67
Total Phosphorus, P	14-42
Total Kjeldahl Nitrogen, N	68-99

*Although not shown, there would also be substantial reductions in the quantities of pathogenic organisms.

2.1 Purification

2.1.1 Nitrogen

Total removal of nitrogen from normal septic tank/disposal field systems is estimated at 40-72% and from chlorinated sewage sprayed on crop and forest cover, 68-82%. (5) Since input from garbage grinders and toilet is considered to be responsible for most of the nitrogen content in wastewater, grey water disposed of from a household in which a composting system is used should contribute a negligible amount of nitrogen.

2.1.2 Organics

Some of the solid organic matter in grey water is converted in the septic tank to liquid/soluble material which diffuses into the soil for further stabilization or breakdown. Grey water contains less organic matter than black water and does not pose a serious problem. Relatively less degradable materials like

oil and grease which may hinder removal are accumulated at the top of a treatment tank and removed during cleaning. (6)

2.2 Soil Factors Affecting Clogging

2.2.1 Physical Factors

Compaction, sedimentation and entrapment of fines on the downstream side of larger particles occur even with clear water. Reduced volume is expected to lengthen the period of time required to reach clogging. (7)

2.2.2 Chemical Factors

Ion exchange and other chemical reactions may produce clogging. The best example of this is deflocculation of soils by high concentrations of sodium (8). Waste brines from water softener units may cause a slight shortening of life of a disposal field in a structured clay type soil (9).

2.2.3 Biological Factors

Reduction of surface pore space by bacteria growing on entrapped or dissolved solids may lead to clogging.

Since substrate and water volume are reduced in grey water systems, this type of clogging should be minimized.

Pore spaces may reopen as a result of aerobic bacterial decomposition of entrapped organic matter or the decline of anaerobic bacterial growth during drying periods or periods of inadequate substrate. Aerobic conditions favor reopening of clogged pores. (10).

If there is constant soaking, anaerobic bacteria are encouraged. These sometimes produce gelatinous materials or reduce sulfates to sulfides which bind up trace elements to form heavy black deposits. (11) Lower volumes would be expected to allow drying time.

3.0 Summary/Conclusions

Reduced strength and quantity of wastewater resulting from segregation of garbage grinder and toilet wastes from grey water are beneficial in preventing some of the problems associated with standard septic tank/drainage field systems. With these reductions, tank capacity and absorption area can be lowered. Clogging of soil is less likely because of slower compaction and sedimentation, lower substrate for anaerobic bacterial growth and periodic drying which encourages growth of aerobic bacteria to assimilate trapped organic particles. The capacity of the soil for renovation is not taxed as heavily as under normal circumstances because of the lower quantities of organics, phosphorus and particularly nitrogen released in the effluent.

References 2

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WASTEWATER DISPOSAL
EVAPORATION TECHNIQUES

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EVAPORATOR PARAMETERS

The rate of evaporation of moisture from a liquid surface is influenced by the air flow past the surface, the latent heat of vaporization, and the degree of saturation of the receiving air. Assuming a latent heat of vaporization of 1050 Btu/lb of moisture, the potential for moisture transfer can be estimated from the following equations:

$$\frac{W_v}{S} (e_w - e_a) = \frac{95 + .425V}{1050} \quad \text{for parallel flow}^1$$

$$\frac{W_v}{S} (e_w - e_a) = \frac{201 + .88V}{1050} \quad \text{for transverse flow}$$

Where: W_v = Pounds of water evaporated per hour
 S = Liquid surface area in square feet
 e_w = Vapor pressure corresponding to water temperature, in Hg
 e_a = Vapor pressure of moisture in air, in Hg
 V = Air velocity, feet per minute

These two equations are plotted in Figure 1 for various wind speeds. It can be seen that for any given wind speed, the mass transfer potential of transverse flow is over twice that of parallel flow.

Using the parallel flow equation, the evaporation rate potential was calculated for the data examples given with the EPA mechanical evaporation unit. These comparisons are shown in Figures 2 and 3.

In the Figure 2 comparison, the disks were receiving direct sun with a mean wind speed of 2.2 mph. Information as to sun exposure was not included for the test data shown in Figure 3. However, the disks were parallel with the wind. The isolated data point on Figure 3 was transposed from Figure 2 data for comparison.

While complete data on the University of Colorado tests was not available,

1. "Fan Engineering", Buffalo Forge Company, Buffalo, New York, 1970, Page 51.

FIGURE 1

FIGURE 3

several observations might be made in referring to the two Figures. At low wind speeds, with adequate amounts of radiant energy, the efficiency of the unit is good. There is room for improvement, however, particularly at the higher humidity deficiency values (Figure 2), where possibly the rate of radiant energy received by the disks is not sufficient to provide the 1050 Btu/pound required for evaporation.

Comparison of test data versus the theoretical rate for Figure 3 shows a greater inefficiency. Again, specific reasons for this are not readily attainable without more data, but comparison of the isolated data point from Figure 2 against the test data for a 1.0" disk spacing would seem to show that the unit was not receiving adequate amounts of solar energy for the desired evaporation rate.

Several areas of improvement might be:

1. Utilize transverse flow, if possible
2. Add energy to the system by
 - a. Heating the water
 - b. Heating the Air
 - c. Heating both air and water
3. Augment wind by forced circulation during calm periods

The addition of energy to the system provides the latent heat of vaporization and increases the vapor pressure differential, thereby improving performance. In a spray chamber, for example, the temperature of the recirculating water approaches the wet bulb temperature of the entering air. With no heat the process potential is shown on the following page.

If the water is heated, or if the air is heated and the water recirculated, then the potential increases:

This heating of the air or water might be provided by solar heat or by waste heat sources such as the energy given up by an air conditioning evaporator.

DESIGN CONCEPTS

Several concepts which incorporate or have the potential for incorporation of improvements are presented on the following pages.

Figure 4 and 5 show a modified version of the EPA developed mechanical evaporation unit.

Basically the modification consists of the disks being opened in the centers and fixed to a hollow drive shaft. The hollow shaft permits air to be blown transversely thru the disk material which could be a Scott foam or a perforated metal which would allow water pickup, but also pass air. The

MECHANICAL EVAPORATION DEVICE MODIFIED FOR FORCED AIR FLOW

FIGURE 4

EVAPORATION WHEEL USING TRANSVERSE AIR FLOW

FIGURE 5

intimate mixing of air with the water provides a greater potential for moisture pickup.

The air duct provides a ready made coupling with solar heat sources and/or waste heat sources. A solar air system would be preferred over a water collector in order to eliminate problems such as corrosion, solids buildup, etc., which would be of concern with wastewaters. Data on an air collector showed that on a non-optimum day, the energy collected was in excess of 100,000 Btu for 180 CFM with a nominal $50^{\circ} \Delta T$. This is the energy required for approximately 12 gallons of water. This 8' X 12' panel utilizes a 1/12 HP blower. The amount of collected energy available for this wastewater application would be greater than 100,000 Btu as lower ΔT values could be utilized, thus extending the usable sun time as well as improving the collector efficiency since it operates at a lower temperature differential.

A built-in advantage for this system is that it may operate in many different modes with only intake modification. Some of these modes are:

- a. As the standard EPA designed system
- b. With transverse air flow (blower on-ambient air)
- c. Transverse flow augmented with solar heating
- d. Transverse flow augmented with waste heat

As previously noted, transverse flow improves the evaporation rate potential by a factor of 2 over that for parallel flow. Assuming that test data shows the same efficiencies as noted for the EPA mechanical evaporation unit, then the required surface area could be reduced to 1/2 that required for parallel flow. Solar augmentation will reduce the required area approximately 8% or greater for each 8' X 12' panel utilized.

Figure 6 shows a concept which is designed to improve evaporation efficiency by directly heating the wastewaters. This "Christmas tree" configuration allows trickling wastewaters to flow over sun facing panels where the water is heated and exposed to the available wind for evaporation. The water is returned on the top side of a shaded panel. This shaded panel is perforated to allow the water to wet the outside surface to aid in evaporation. This concept is not direction sensitive as an equal amount of surface area is exposed regardless of wind direction.

This concept may also utilize forced convection. The flow pattern will be primarily parallel to the panels as air is directed via the collecting troughs to flow over the panels. Some secondary transverse flow will occur as air is forced through the perforations of the shaded panels. This concept may also accommodate augmentation by solar air panels and waste heat sources.

A third concept is shown in Figure 7. Natural wind currents provide both parallel and transverse flows. Parallel flows are located at the tangent points to the radius, while transverse flow is encountered as the wind flows through the foam housing. A pipework grid provides both the liquid distribution system and the structure. Scott foam or metal mesh is attached to this gridwork to provide the wetted surface for moisture pickup. As air may flow through the media, this concept may be utilized for natural winds and also the interior may be pressurized by a top mounted fan to provide forced circulation during periods of calm. A roof is provided to eliminate rainfall loading of the wastewater tank.

Augmentation of this concept by solar or waste heat sources required re-location of the blower or ducting of the inlet in order to provide an interface for connection.

EVAPORATION/TRICKLING COLLECTOR CONCEPT

NON-DIRECTIONAL EVAPORATION CONCEPT

FIGURE 7

SOLAR AUGMENTATION

Augmentation of the mechanical evaporation unit by solar energy is particularly attractive. Since the evaporation unit does not require high temperatures for operation, but only a temperature in excess of the ambient, the solar collector may operate at a substantially decreased fluid temperature from that normally required for space heating or domestic hot water heating. The collector curves shown below point out the advantage incurred when operating at lower fluid temperatures. While the curves shown are for liquid collectors, air collectors also follow a similar trend.

For use with the mechanical evaporation unit, the fluid (air) temperature need only exceed ambient to provide an energy input to the system. For a fluid temperature of 100°F for example, the flat plate collector efficiency is approximately 50-60% and the evacuated tube collector efficiency is approximately 60-65%. If the collectors were used for domestic hot water heating, for example, the efficiency would degrade as the required fluid temperature is increased to approximately 140°F. While the efficiency of the evacuated tube collector remains near 55%, the flat plate collector efficiency drops to nearly 40%. This illustration points out that since lower grade energy is utilized by the mechanical evaporation unit, it

presents a near ideal application of solar energy.

An additional gain realized by utilization of the lower temperature energy is the increased solar operating period possible by using otherwise marginal energy collecting periods. While under certain environmental conditions a collector may not be able to provide substantial amounts of energy at the temperature required for hot water heating, it could fulfill the lower temperature requirements of the mechanical evaporation unit.

MATERIALS CONSIDERATION

As previously noted, the evaporation potential for transverse air flow is approximately twice that of parallel flow. In order to effectively utilize this capability with forced flow the material used should exhibit a large surface area while offering a low pressure drop to the flow of air. Other considerations include openings large enough to pass any entrained solids, but small enough to effectively retain a large amount of exposed air flow surface over a small face or footprint area.

One candidate material is the polyurethane foam produced by the Foam Division of Scott Paper Company. This is an "open-pore" material utilized in diverse applications as air cleaning, humidification, water separation, and is produced in a range of pore sizes from 10 PPI (pores per linear inch) to 100 PPI.

If a material thickness of 1/2 inch is assumed for this application, then the exposed surface for air flow divided by the face or footprint area may be calculated. This is shown in Figure 8 for various pore size foams. In order to keep the pressure drop low and to prevent solids retention, a

20 PPI foam would probably be recommended. The surface area is approximately 14 square feet per square foot of frontal area for this grade foam. This example illustrates the tremendous surface area available thru the use of such a material. This material allows a large intimate contact area between the water and air which serves to increase the overall evaporator efficiency. The maximum evaporation rate is still governed by the theoretical curve, but the use of such material greatly improves the potential for obtaining performances closer to this theoretical for a mechanical evaporation device.

FIGURE 8