FINAL REPORT

LIFE CYCLE INVENTORY OF SINGLE-TRIP AND MULTI-TRIP STEEL DRUM SYSTEMS IN THE U.S., EUROPE, AND JAPAN

Submitted to:

The International Confederation of Container Reconditioners

January 1999

SCIENCE • STRATEGY • TECHNOLOGY • SOLUTIONS

McLaren/Hart, Inc.

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LIFE CYCLE INVENTORY OF SINGLE-TRIP AND MULTI-TRIP STEEL DRUM SYSTEMS IN THE U.S., EUROPE, AND JAPAN

Prepared for

THE INTERNATIONAL CONFEDERATION OF CONTAINER RECONDITIONERS

by

FRANKLIN ASSOCIATES
A Service of McLaren/Hart
Prairie Village, Kansas

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PREFACE

This study was conducted for the International Confederation of Container Reconditioners (ICCR), under the direction of Paul Rankin, President of the Reusable Industrial Packaging Association (RIPA; formerly the Association of Container Reconditioners). The report was made possible through the cooperation of ICCR members and staff, particularly Dana Worcester of RIPA, who provided much valuable assistance. Much of the analysis is based on data provided by steel drum manufacturers and reconditioners in the U.S., Europe, and Japan in response to a survey conducted specifically for this study.

The study was performed at Franklin Associates, a Service of McLaren/Hart under the direction of Beverly Sauer, Project Manager and Principal Analyst. Significant contributions were made by Melissa Huff. William E. Franklin served as Principal in Charge. Robert G. Hunt provided technical guidance.

This study was conducted for ICCR by Franklin Associates as an independent contractor. The findings and conclusions presented in this report are strictly those of Franklin Associates. Franklin Associates makes no statements nor supports any conclusions other than those presented in this report.

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INTRODUCTION

A life cycle inventory (LCI) quantifies the energy consumption and environmental emissions for a given product based upon the study boundaries established. The unique feature of this type of analysis is its focus on the entire life cycle of a product, from raw material acquisition to final disposition, rather than on a single manufacturing step or environmental emission.

The resource and environmental profile analyses presented in this study quantify the total energy requirements, energy sources, atmospheric pollutants, waterborne pollutants, and solid wastes resulting from the production, reconditioning, recycling and disposal of 55-gallon steel drums, including transportation. (In these analyses, all steel drums are assumed to be recycled after they are retired from service; thus "disposal" refers to the disposal of products made with steel from recycled drums.) Open- and tight-head steel drums of four different thicknesses are evaluated.

In addition, comparative economic data are presented. These data were derived solely by Franklin Associates based on energy costs, raw steel costs, scrap prices, and material costs from public sources including authoritative industry publications.

Purpose of the Study

This study was prepared for the International Confederation of Container Reconditioners (ICCR). The purpose of this study is to provide an LCI that quantifies the energy use and environmental emissions associated with the production, reconditioning, and recycling of steel drums, as well as disposal of products made with steel from recycled drums. The systems analyzed comprise a variety of drum configurations, reuse rates, reconditioning processes, and geographic locations. A general flow diagram illustrating life cycle processes for steel drums is shown in Figure ES-1.

Systems Studied

Data in this study are based on an extensive survey of drum manufacturers and reconditioners in the U.S., Japan, and Europe. Survey data, where available, were used to develop data on drum weights, trip rates, and transportation, as well as data for new drum manufacturing and drum reconditioning processes, including chemical use.

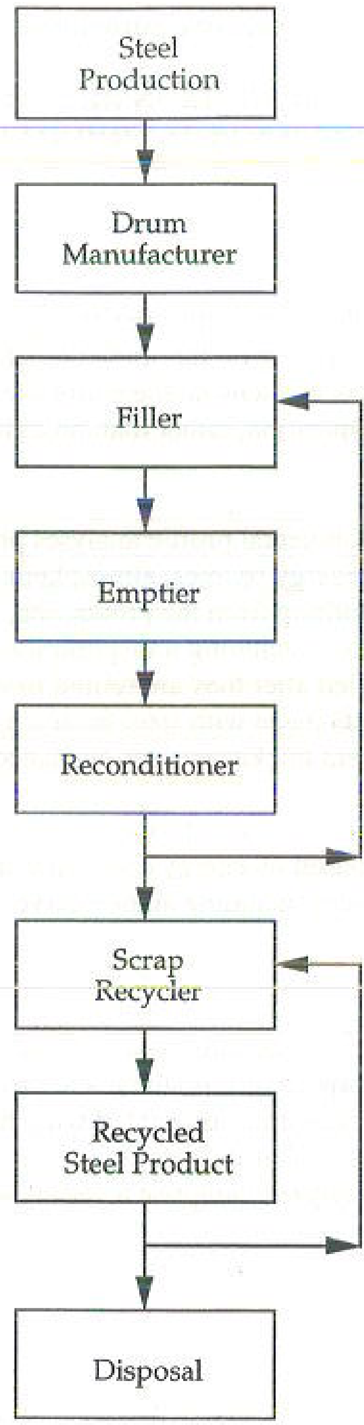


Figure ES-1. General flow diagram for the life cycle of steel drums.

Note: "Steel Production" box represents all process steps from raw material extraction through production of steel.

The data provided by survey participants did not cover all processes and geographic locations, so it was necessary to make several assumptions in conducting the analysis. Assumptions are listed in Chapter 1.

Weights and trip rates for each drum system analyzed in the study are presented in Table ES-1. Weights are reported on the basis of 55,000 gallons of product delivered, or 1,000 drum trips. The number of drums required depends on the trip rate.

It is not accurate to say that any 55-gallon steel drum of any thickness is always used one time and then recycled. Therefore, for the purposes of this study, ICCR chose a drum known to have a much lower trip rate than its heavier counterparts (0.8 mm for the U.S. and Japan, and 0.8/0.7/0.8 mm for Europe) to represent single-trip steel drums.

In the U.S., many 0.8 mm steel drums are scrapped after a single use because the Department of Transportation prohibits the reuse of 0.8 mm drums for the shipment of hazardous materials. In Japan and Europe there are not minimum thickness requirements for reuse; however, after the initial use, these containers often do not meet the needs of the customers for safety or cosmetic reasons. For these reasons, in this analysis 0.8 mm drums and 0.8/0.7/0.8 mm drums are represented as single-trip drums, although some surveys did indicate low reuse rates for these drums.

Scope and Boundaries

The analysis includes the following steps for each steel drum system:

- Raw materials acquisition
- Production of intermediate materials for the manufacture of steel drums
- Fabrication of steel drums
- Reconditioning of steel drums, including the production of chemicals used in reconditioning processes
- Transportation
- Recycling of steel drums
- Disposal of products made with steel from recycled drums.

The analysis did not include filling and use steps for drums, nor the manufacture or application of paints and protective drum linings. These steps are expected to represent a very small percentage of the total energy and wastes. Because a fresh coat of paint or liner must be applied every time a drum is used, whether it is a new or reconditioned drum, paint and liner usage are expected to be very similar for all drum systems, whether single-trip or multi-trip.

Drum manufacturers and reconditioners provided data on all drum transportation except for transportation from drum fillers to emptiers. As a result, transportation energy is somewhat understated in the results; however, since 1,000 drum trips means 1,000 trips from fillers to emptiers, regardless of trip rate, this omission is the same magnitude for all systems and does not affect comparisons between systems.

Table ES-1

STEEL DRUM WEIGHTS AND TRIP RATES

U.S.	Drum Weight (pounds)	Lid Wt (pounds)	Average No. of Trips/Cleanings (1)	Steel per 1,000 Trips (2) (pounds)
1.2 mm multi-trip				
Tight head	41.5		7.9	5,253
Open head	44.8	6.5	7	8,740
1.0 mm multi-trip				
Tight head	37.7		6.4	5,891
Open head	41.0	5.5	5.4	9,475
1.2/0.9/1.2 mm multi-trip				
Tight head	36.0		6.3	5,714
Open head	40.2	6.5	5.2	9,936
0.8 mm single-trip				
Tight head	30.8		1	30,800
Open head	34.1	5	1	34,100
EUROPE				
1.2 mm multi-trip				
Tight head	41.5 (3)		8.1	5,123
Open head	44.8 (3)	6.5	8.7	6,875
1.0 mm multi-trip				
Tight head	37.7 (3)		5.9	6,390
Open head	41.0 (3)	5.5	6.3	7,896
1.0/0.9/1.0 mm multi-trip				
Tight head	35.7		3.6	9,912
Open head	41.0 (3)	5.5	4.3	10,801
0.8/0.7/0.8 mm single-trip				
Tight head	29.5		1	29,515
Open head	34.1 (3)	5	1	34,100
JAPAN				
1.2 mm multi-trip				
Tight head	47.0		5	9,400
Open head	50.2	7.0	4.6	11,023
1.0 mm multi-trip				
Tight head	39.2		2.3	17,043
Open head	40.5	5.9	2.3	17,676
1.2/0.9/1.2 mm multi-trip				
Tight head	41.9		2.6	16,115
Open head	45.8	7.0	2.8	16,448
0.8 mm single-trip				
Tight head	30.8 (3)		1	30,800
Open head	34.1 (3)	5.1	1	34,100

(1) Average number of trips based on survey of steel drum reconditioners.
Number of trips = number of reconditionings + initial use.
All drums are cleaned before recycling.
(2) Replacement rate for open-head lids: 42% for U.S., 2% for Japan, 30% for Europe.
(3) No survey data; used weight for corresponding US drum.

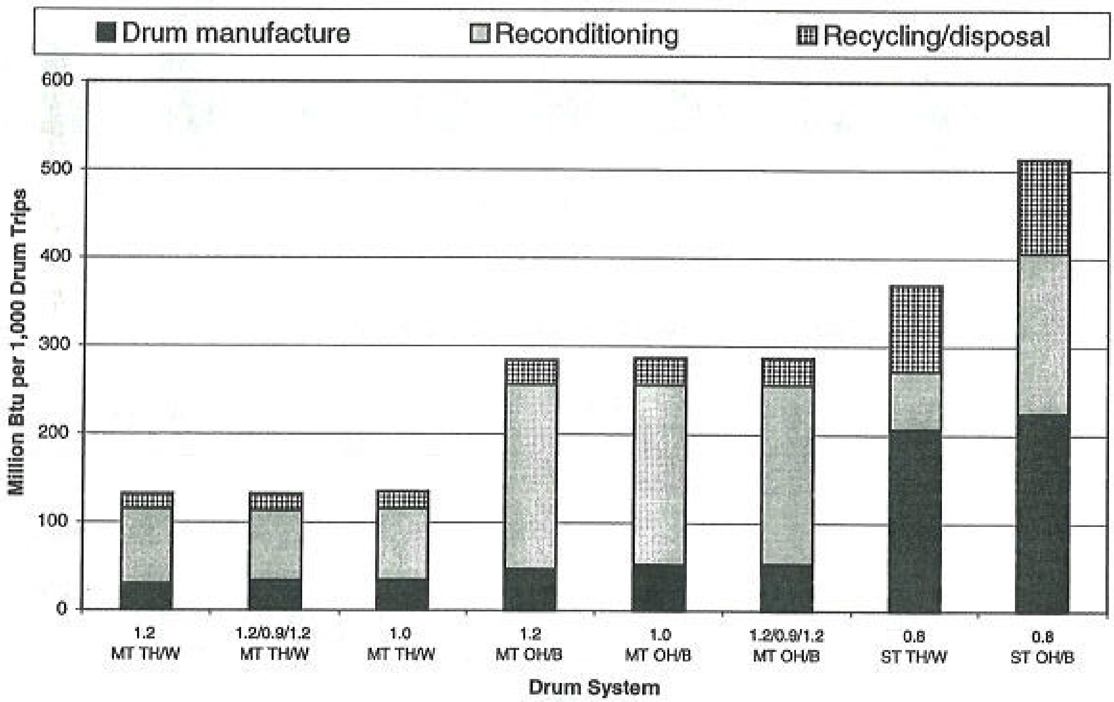
Source: Franklin Associates

RESULTS

Energy

Energy results for drum systems are shown in Figures ES-2-US, -E, and -J for the U.S., Europe, and Japan, respectively[1]. Results are shown in order from lowest to highest. The burn reconditioning process requires over twice as much energy as the wash process. Transportation of drums accounts for a significant portion of total energy. (Drum transportation energy is not shown separately in Figure ES-2, but is shown in Table 2-2 in Chapter 2.) Energy requirements for multi-trip drums are lower than for corresponding single-trip systems. For example, Figure ES-2-US shows that total energy for multi-trip tight-head drum systems is about 130 million Btu per 1,000 drum trips, while total energy for the single-trip tight-head drum system is 370 million Btu per 1,000 drum trips.

Figure ES-2-US. Total Energy for U.S. Drum Systems



1 Abbreviations used in the figures represent the following:
MT = multi-trip
ST = single-trip
TH/W = tight-head drum/wash reconditioning
OH/B = open-head drum/burn reconditioning

Figure ES-2-E. Total Energy for European Drum Systems

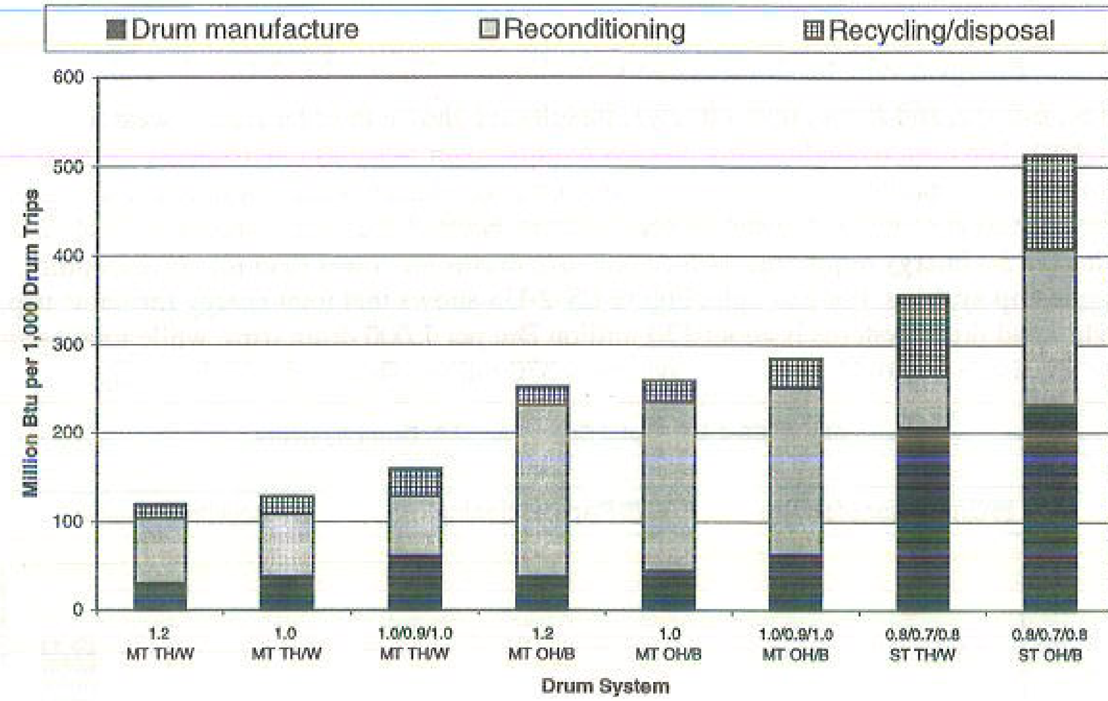
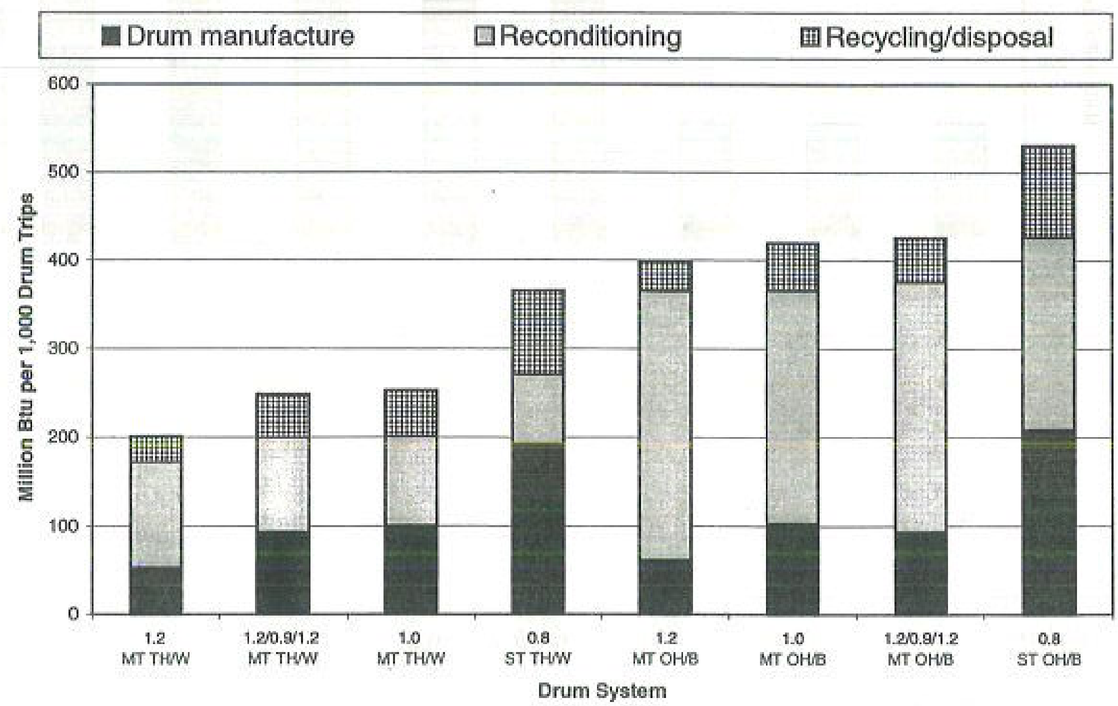


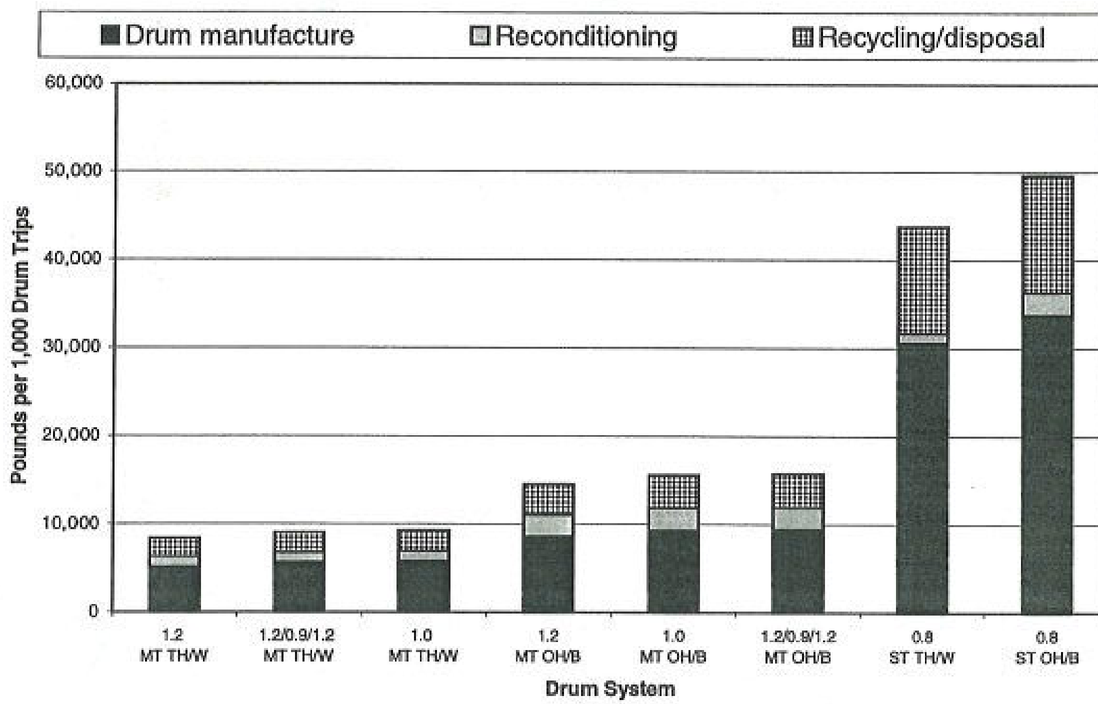
Figure ES-2-J. Total Energy for Japanese Drum Systems



Solid Wastes

Solid waste results (by weight) are shown in Figures ES-3-US, -E, and –J for the U.S., Europe, and Japan[2]. Results are shown in order from lowest weight of solid waste to highest. Solid wastes reported for the burn reconditioning process are considerably higher than those reported for the wash reconditioning process. Over half of total solid wastes are associated with steel production; thus, the systems with the highest steel usage (i.e., single-trip drums) have the highest solid wastes. For example, in Figure ES-3-US, total solid waste for the single-trip tight-head drum system is nearly 44,000 pounds per 1,000 drum trips, with over 30,000 pounds from drum manufacture. This is more than 4 times the weight of solid waste for multi-trip tight-head drum systems, which generate less than 10,000 pounds of solid waste per 1,000 drum trips, just over half from drum manufacture.

Figure ES-3-US. Total Weight of Solid Waste for U.S. Drum Systems



2 Abbreviations used in the figures represent the following:
MT = multi-trip
ST = single-trip
TH/W = tight-head drum/wash reconditioning
OH/B = open-head drum/burn reconditioning

Figure ES-3-E. Total Weight of Solid Waste for European Drum Systems

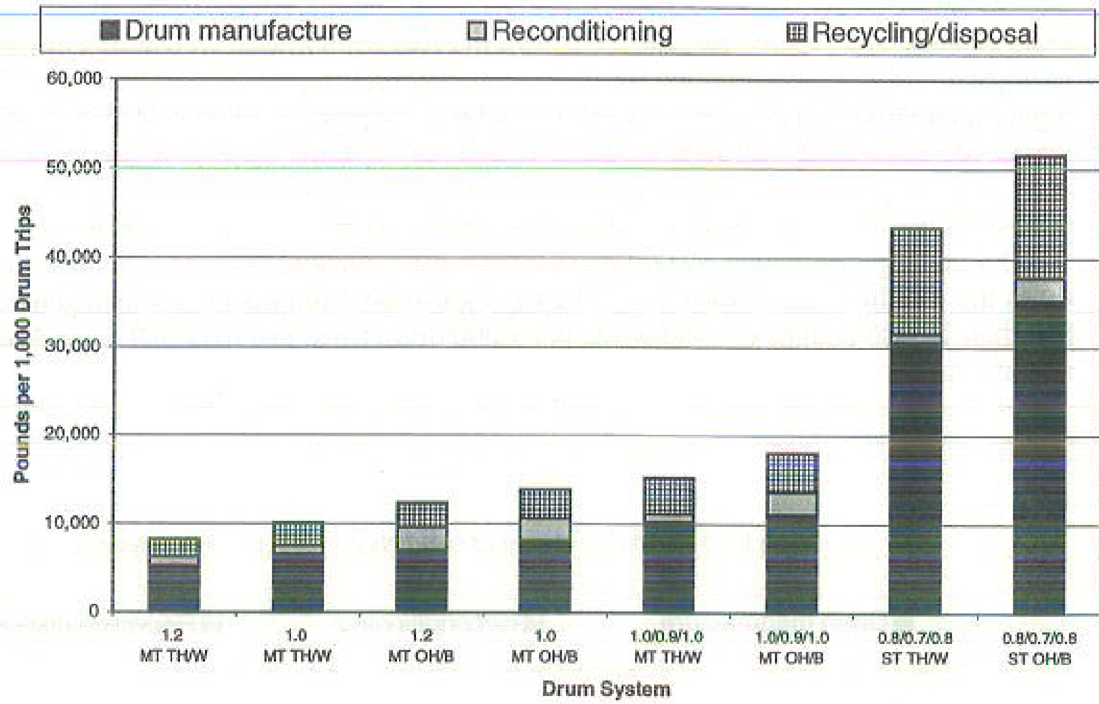
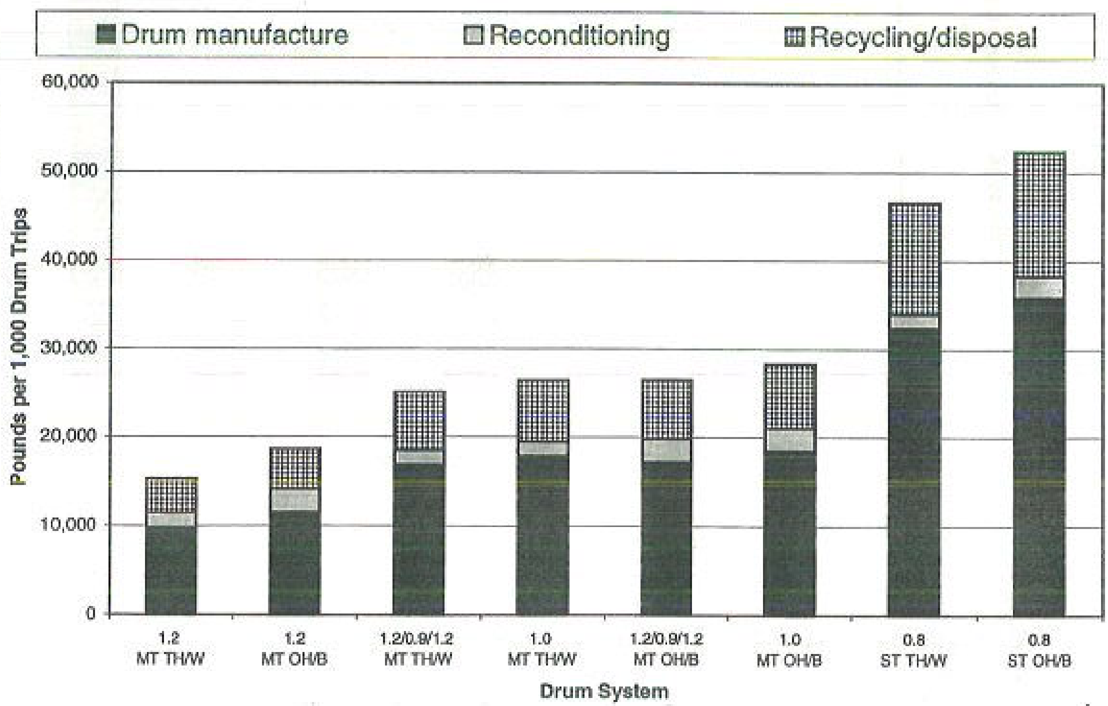


Figure ES-3-J. Total Weight of Solid Waste for Japanese Drum Systems



Atmospheric and Waterborne Emissions

Weights of selected atmospheric and waterborne emissions for each drum system are shown in Tables ES-2-US, -E, and –J for the U.S., Europe, and Japan, respectively. Wash reconditioning generally produces less emissions than burn reconditioning, with a few exceptions. Atmospheric emissions of hydrogen chloride (HCl) and hazardous air pollutants (HAPs) are higher for wash reconditioning in the U.S. and Japan, and waterborne biochemical oxygen demand (BOD) and chemical oxygen demand (COD) are higher for wash reconditioning in all countries. Emissions for single-trip systems are generally higher than for multi-trip systems.

Emissions for drum manufacturing and reconditioning processes are shown in the report appendix tables. The majority of remaining emissions are associated with the production and combustion of fuels used for process energy and transportation.

Costs for Selected Life Cycle Steps

Costs for selected life cycle steps were estimated for each system based on the cost of materials and fuels (both process fuels and fuels for transportation) for steel drum manufacturing and reconditioning, as well as the scrap value of drums and lids retired at end of life. Fuel and material requirements were derived from surveys of drum manufacturers and reconditioners in the U.S., Europe, and Japan, while material and energy prices and scrap prices were obtained from public sources including industry publications.

Estimated costs are shown in Tables ES-3-US, -E, and –J for the U.S., Europe, and Japan. New steel prices and steel scrap prices were higher for the U.S. compared to Europe and Japan, while U.S. fuel prices were lower. Initial costs, which depend largely on costs for steel, dominate results. Initial costs for single-trip drums are highest because 1,000 drums are required.

Table ES-2-US

SELECTED ATMOSPHERIC AND WATERBORNE WASTES FOR SINGLE- AND MULTI-TRIP STEEL DRUMS IN THE U.S.
(pounds per 1,000 drum trips)

	1.2 mm multi-trip		1.0 mm multi-trip		1.2/0.9/1.2 mm multi-trip		0.8 mm single-trip	
	Tight-head Wash	Open-head Burn	Tight-head Wash	Open-head Burn	Tight-head Wash	Open-head Burn	Tight-head Wash	Open-head Burn
Atmospheric Emissions (1)								
Particulates	32.7	119	34.4	121	33.5	121	129	214
Nitrogen Oxides	105	227	105	225	102	225	280	392
Hydrocarbons	194	303	197	306	196	307	346	449
Sulfur Oxides	133	356	138	362	137	363	372	589
Carbon Monoxide	111	195	113	197	109	197	390	464
Methane	30.2	74.9	31.9	76.9	31.5	77.3	97.4	141
HCl	4.79	1.69	4.82	1.71	4.81	1.72	5.68	2.56
Carbon Dioxide (fossil sources)	19,151	38,720	19,564	39,089	19,125	39,121	56,531	74,823
HAPs	44.5	12.4	44.5	12.4	44.5	12.4	44.5	12.4
Other organics	27.1	40.0	24.9	36.8	23.8	36.1	40.8	49.2
Waterborne Emissions (1,2)								
Acid	17.3	28.9	19.4	31.3	18.9	31.7	102	113
Metal Ion-unspecified	0.047	0.070	0.044	0.065	0.042	0.064	0.086	0.10
Dissolved Solids	134	442	139	449	138	450	345	649
Suspended Solids	54.3	18.1	55.1	18.9	54.9	19.1	82.7	46.2
BOD	67.8	0.52	67.8	0.54	67.8	0.55	68.4	1.06
COD	69.1	6.37	69.2	6.48	69.2	6.50	72.7	9.85
Oil	3.15	8.73	3.31	8.93	3.27	8.96	9.52	15.0
Iron	0.39	0.57	0.42	0.60	0.41	0.60	1.53	1.70
Sulfates	33.5	63.3	37.2	67.5	36.2	68.2	179	208

(1) Includes process emissions and fuel-related emissions.
(2) For tight-head wash systems, emissions from the reconditioning process represent at least 85% of the total waterborne emissions of BOD, COD, and suspended solids. Reconditioning process emissions are based on responses from the survey of drum reconditioners; however, less than half of the reconditioners surveyed provided data on waterborne emissions, and the reported values varied widely. Therefore, the reader is cautioned against drawing conclusions about tight-head wash systems in the categories of BOD, COD, and suspended solids.

Source: Franklin Associates.

Table ES-2-E

SELECTED ATMOSPHERIC AND WATERBORNE WASTES FOR SINGLE- AND MULTI-TRIP STEEL DRUMS IN EUROPE
(pounds per 1,000 drum trips)

	1.2 mm multi-trip		1.0 mm multi-trip		1.0/0.9/1.0 mm multi-trip		0.8/0.7/0.8 mm single-trip	
	Tight-head Wash	Open-head Burn	Tight-head Wash	Open-head Burn	Tight-head Wash	Open-head Burn	Tight-head Wash	Open-head Burn
Atmospheric Emissions (1)								
Particulates	27.8	110	32.1	113	45.2	124	122	215
Nitrogen Oxides	87.5	192	92.3	194	113	212	260	382
Hydrocarbons	139	287	146	292	164	306	292	447
Sulfur Oxides	109	335	120	344	151	370	344	591
Carbon Monoxide	98.7	155	109	162	146	193	378	466
Methane	24.9	70.4	28.2	73.2	37.4	80.6	90.9	143
HCl	0.32	1.62	0.37	1.66	0.49	1.76	1.17	2.56
Carbon Dioxide (fossil sources)	17,830	33,737	19,286	34,792	24,137	38,852	55,071	74,790
HAPs	0	12.4	0	12.4	0	12.4	0	12.4
Other organics	21.6	26.9	20.3	25.1	20.5	26.0	37.5	44.3
Waterborne Emissions (1,2)								
Acid	16.5	22.2	20.6	25.5	32.0	34.9	95.3	110
Metal Ion-unspecified	0.098	0.048	0.097	0.046	0.10	0.050	0.14	0.095
Dissolved Solids	105	428	115	436	142	458	314	651
Suspended Solids	7.97	16.0	9.35	17.1	13.2	20.2	34.9	45.8
BOD	2.43	0.49	2.45	0.51	2.52	0.56	2.98	1.06
COD	16.2	6.11	16.4	6.25	16.9	6.60	19.8	9.86
Oil	2.88	8.25	3.19	8.51	4.03	9.18	9.06	15.0
Iron	0.34	0.49	0.40	0.53	0.56	0.67	1.45	1.73
Sulfates	31.1	51.9	38.1	57.6	57.8	73.8	167	204

(1) Includes process emissions and fuel-related emissions.
(2) For tight-head wash systems, emissions from the reconditioning process represent at least 85% of the total waterborne emissions of BOD, COD, and suspended solids. Reconditioning process emissions are based on responses from the survey of drum reconditioners; however, less than half of the reconditioners surveyed provided data on waterborne emissions, and the reported values varied widely. Therefore, the reader is cautioned against drawing conclusions about tight-head wash systems in the categories of BOD, COD, and suspended solids.

Source: Franklin Associates.

Table ES-2-J

SELECTED ATMOSPHERIC AND WATERBORNE WASTES FOR SINGLE- AND MULTI-TRIP STEEL DRUMS IN JAPAN
(pounds per 1,000 drum trips)

	1.2 mm multi-trip		1.0 mm multi-trip		1.2/0.9/1.2 mm multi-trip		0.8 mm single-trip	
	Tight-head Wash	Open-head Burn	Tight-head Wash	Open-head Burn	Tight-head Wash	Open-head Burn	Tight-head Wash	Open-head Burn
Atmospheric Emissions (1)								
Particulates	74.6	183	96.4	191	94.9	194	141	236
Nitrogen Oxides	224	462	238	423	242	452	289	445
Hydrocarbons	233	380	260	389	257	391	331	451
Sulfur Oxides	146	408	202	447	195	442	312	567
Carbon Monoxide	245	431	295	426	294	448	406	523
Methane	33.8	82.9	52.4	98.5	50.0	95.6	87.6	139
HCl	4.97	1.82	5.27	2.08	5.23	2.03	5.84	2.74
Carbon Dioxide (fossil sources)	31,470	57,379	39,923	60,782	39,223	61,701	57,872	78,721
HAPs	44.5	12.4	44.5	12.4	44.5	12.4	44.5	12.4
Other organics	88.4	173	70.7	127	76.1	149	51.9	83.9
Waterborne Emissions (1,2)								
Acid	30.1	35.3	54.6	56.7	51.7	52.7	98.7	109
Metal Ion-unspecified	0.12	0.18	0.11	0.15	0.12	0.16	0.12	0.13
Dissolved Solids	103	466	143	496	138	492	223	583
Suspended Solids	13.0	21.0	21.4	28.2	20.3	26.8	36.9	46.3
BOD	14.1	0.68	14.3	0.82	14.2	0.78	14.7	1.22
COD	12.3	7.03	13.0	7.53	12.9	7.45	14.6	9.14
Oil	3.49	9.51	4.96	10.7	4.78	10.5	7.80	13.9
Iron	0.61	0.72	0.99	1.05	0.94	0.98	1.69	1.87
Sulfates	53.4	74.8	95.1	111	90.0	104	170	201

(1) Includes process emissions and fuel-related emissions.
(2) For tight-head wash systems, emissions from the reconditioning process represent at least 85% of the total waterborne emissions of BOD, COD, and suspended solids. Reconditioning process emissions are based on responses from the survey of drum reconditioners; however, less than half of the reconditioners surveyed provided data on waterborne emissions, and the reported values varied widely. Therefore, the reader is cautioned against drawing conclusions about tight-head wash systems in the categories of BOD, COD, and suspended solids.

Source: Franklin Associates.

Table ES-3-US

LIFE CYCLE COSTS FOR U.S.STEEL DRUMS (1)
(basis: US$ per 1,000 drum trips)

U.S.	Initial Cost (2)	Transportation Costs (3)	Use Costs (4)	Scrap Value (5)	Net Cost (6)
1.2 mm multi-trip					
Tight head	1,631	227	220	210	1,868
Open head	2,705	328	508	350	3,192
1.0 mm multi-trip					
Tight head	1,831	205	220	236	2,021
Open head	2,937	297	508	379	3,362
1.2/0.9/1.2 mm multi-trip					
Tight head	1,777	196	220	229	1,964
Open head	3,079	290	508	397	3,480
0.8 mm single-trip					
Tight head	9,598	266	220	1,232	8,852
Open head	10,613	328	508	1,364	10,084

(1) All costs expressed in U.S. dollars, based on public data on prices of fuels and materials. No cost data were collected in surveys of drum manufacturers and reconditioners.
(2) Cost of steel and energy for producing the weight of steel drums and lids required for 1,000 trips, based on average trip rate.
(3) Cost of fuel for transportation to and from reconditioners for 1,000 drum trips. Includes initial transportation of new drums to user.
(4) Cost of fuels and chemicals used in reconditioning process (wash process for tight-head drums, burn process for open-head drums).
(5) Value of steel scrap from drums required for 1,000 trips.
(6) Net cost = initial cost + transportation costs + use costs - scrap value.

Source: Franklin Associates.

Table ES-3-E

LIFE CYCLE COSTS FOR EUROPEAN STEEL DRUMS (1)
(basis: US$ per 1,000 drum trips)

EUROPE	Initial Cost (2)	Transportation Costs (3)	Use Costs (4)	Scrap Value (5)	Net Cost (6)
1.2 mm multi-trip					
Tight head	1,007	491	308	205	1,602
Open head	1,344	605	619	275	2,293
1.0 mm multi-trip					
Tight head	1,259	446	308	256	1,757
Open head	1,548	551	619	316	2,402
1.0/0.9/1.0 mm multi-trip					
Tight head	1,956	420	308	397	2,287
Open head	2,120	546	619	432	2,853
0.8/0.7/0.8 mm single-trip					
Tight head	5,844	667	308	1,180	5,638
Open head	6,731	793	619	1,364	6,779

(1) All costs expressed in U.S. dollars, based on public data on prices of fuels and materials. No cost data were collected in surveys of drum manufacturers and reconditioners.
(2) Cost of steel and energy for producing the weight of steel drums and lids required for 1,000 trips, based on average trip rate.
(3) Cost of fuel for transportation to and from reconditioners for 1,000 drum trips. Includes initial transportation of new drums to user.
(4) Cost of fuels and chemicals used in reconditioning process (wash process for tight-head drums, burn process for open-head drums).
(5) Value of steel scrap from drums required for 1,000 trips.
(6) Net cost = initial cost + transportation costs + use costs - scrap value.

Source: Franklin Associates.

Table ES-3-J

LIFE CYCLE COSTS FOR JAPANESE STEEL DRUMS (1)
(basis: US$ per 1,000 drum trips)

JAPAN	Initial Cost (2)	Transportation Costs (3)	Use Costs (4)	Scrap Value (5)	Net Cost (6)
1.2 mm multi-trip					
Tight head	2,124	1,128	578	47	3,783
Open head	2,483	2,235	1,617	55	6,279
1.0 mm multi-trip					
Tight head	3,885	862	578	85	5,240
Open head	4,021	1,611	1,617	88	7,160
1.2/0.9/1.2 mm multi-trip					
Tight head	3,661	938	578	81	5,096
Open head	3,720	1,897	1,617	82	7,151
0.8 mm single-trip					
Tight head	7,121	575	578	154	8,120
Open head	7,833	985	1,617	171	10,265

(1) All costs expressed in U.S. dollars, based on public data on prices of fuels and materials. No cost data were collected in surveys of drum manufacturers and reconditioners.
(2) Cost of steel and energy for producing the weight of steel drums and lids required for 1,000 trips, based on average trip rate.
(3) Cost of fuel for transportation to and from reconditioners for 1,000 drum trips. Includes initial transportation of new drums to user.
(4) Cost of fuels and chemicals used in reconditioning process (wash process for tight-head drums, burn process for open-head drums).
(5) Value of steel scrap from drums required for 1,000 trips.
(6) Net cost = initial cost + transportation costs + use costs - scrap value.

Source: Franklin Associates.

CONCLUSIONS

The following conclusions can be drawn about the steel drum systems analyzed in this life cycle inventory:

- **Energy Comparison for Single-trip and Multi-trip Drums:** Total energy requirements for single-trip drums are higher than for corresponding multi-trip drums. For the purposes of this study, all drums are assumed to be cleaned after each use, whether they are to be used again or retired for recycling. Therefore, 1,000 drum trips = 1,000 cleanings, so energy differences between MT and ST drums reflect differences in energy requirements for drum manufacture and transportation. Energy for single-trip drum systems is higher because more drums (i.e., more steel and thus more manufacturing and transportation energy) are required.

- **Drum Transportation Energy:** The energy for transportation of drums accounts for a significant portion of total energy, ranging from 10-36% of total energy for MT systems, and 8-12% for ST systems. (This percentage is for transportation of manufactured and reconditioned drums. Transportation of raw materials, steel, etc. is included in the total energy, but only transportation of *finished drums* is reported separately in results tables.)

- **Solid Waste Comparison for Single-trip and Multi-trip Drums:** The majority of total solid waste for all systems is process waste from steel production processes. Because more drums (i.e., more steel) are required for single-trip systems, solid wastes from these systems are much higher than for corresponding multi-trip drum systems.

- **Emissions Comparison for Single-trip and Multi-trip Drums:** Atmospheric and waterborne emissions for single-trip drums are generally higher than for corresponding multi-trip drums.

- **Cost Comparisons:** Net costs were highest for single-use drums. Initial costs, which depend largely on steel costs, generally dominate results. The initial cost for single-trip drums is highest because 1,000 drums are required. For multi-trip drums, initial costs are higher for open-head drums than for corresponding tight-head drums because more steel is required (drums are heavier and a percentage of open-head lids are replaced after reconditioning).

Chapter 1

STUDY APPROACH AND METHODOLOGY

OVERVIEW

The resource and environmental profile analysis presented in this study quantifies the total energy requirements, energy sources, atmospheric pollutants, waterborne pollutants, and solid waste resulting from the production, reconditioning, and recycling of 55-gallon steel drums, as well as disposal of products made with steel from recycled drums. Transportation is also included. The methodology used for this inventory is consistent with the methodology for Life Cycle Inventory (LCI)[3] as described by the Society of Environmental Toxicology and Chemistry (SETAC) and in the ISO 14040 Standard documents.

This analysis is not an impact assessment. It does not attempt to determine the fate of emissions, or the relative risk to humans or to the environment due to emissions from the systems. In addition, no judgments are made as to the merit of obtaining natural resources from various sources.

A life cycle inventory (LCI) quantifies the energy consumption and environmental emissions (i.e., atmospheric emissions, waterborne wastes, and solid wastes) for a given product based upon the study boundaries established. The unique feature of this type of analysis is its focus on the entire life cycle of a product, from raw material acquisition to final disposition, rather than on a single manufacturing step or environmental emission. Figure 1-1 illustrates the general approach used in an LCI analysis.

The information from this type of analysis can be used as the basis for further study of the potential improvement of resource use and environmental emissions associated with a given product. It can also pinpoint areas in the life cycle of a product or process where changes would be most beneficial in terms of reduced energy use or environmental emissions.

Purpose of the Study

The purpose of this study is to provide an LCI that quantifies the energy use and environmental emissions associated with the production, reconditioning, and recycling of steel drums, including disposal of products made with the steel from recycled drums. The systems analyzed comprise a variety of drum configurations, reuse rates, reconditioning processes, and geographic locations.

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3 SETAC. 1991. **A Technical Framework for Life-Cycle Assessment.** Workshop report from the Smugglers Notch, Vermont, USA, workshop held August 18-23, 1990.

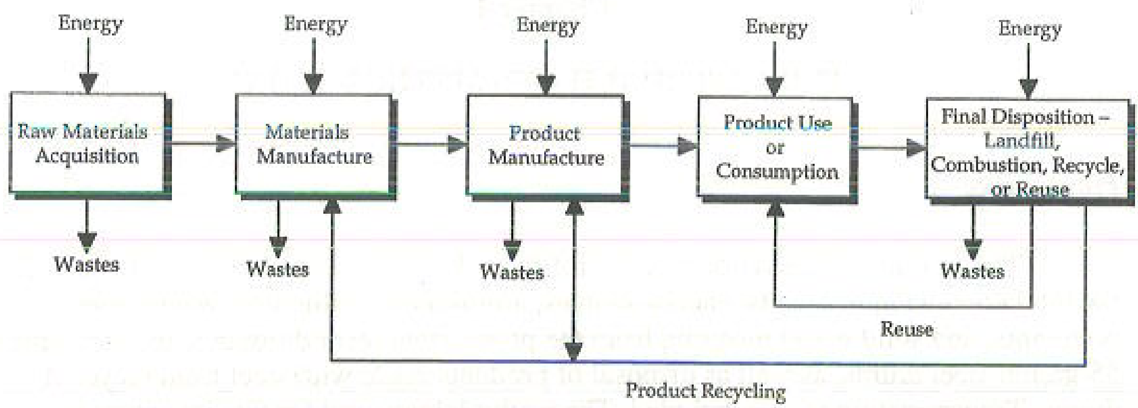

Figure 1-1. General materials flow for "cradle-to-grave" analysis of a product system.

System Scope and Boundaries

An LCI encompasses the entire life cycle of a product, from raw material acquisition to final disposition, rather than a single manufacturing step or environmental emission. Accordingly, the study boundaries of this LCI of steel drums include the following elements:

- Raw materials acquisition
- Production of intermediate materials for the manufacture of steel drums
- Fabrication of steel drums
- Reconditioning of steel drums, including the production of chemicals used in reconditioning processes
- Transportation
- Recycling of steel drums
- Disposal of products made with steel from recycled drums.

Descriptions of manufacturing and reconditioning processes for steel drum systems can be found in the report appendix.

Data for drum reuse rates and for new drum manufacturing and drum reconditioning processes (both wash and burn processes), including chemical use, were developed based on surveys of drum manufacturers and reconditioners in the U.S., Japan, and Europe. The data provided by survey participants did not cover all processes and geographic locations, so it was necessary to make several assumptions in conducting the analysis. The following assumptions were made in this report:

- **System Weights and Trip Rates**

  Where possible, container weights were based on data provided by steel drum manufacturers in the geographic area indicated. Weights of some Japanese and European drums were not provided, so weights of corresponding U.S. drums were used to represent the missing drum weights.

  Trip rates for each drum were developed from data provided by steel drum reconditioners. Because steel drums manufactured from thinner steel have much lower reuse rates than thicker and heavier steel drums, 0.8 mm and 0.8/0.7/0.8 mm steel drums were chosen in this analysis to represent single-trip drums. In the U.S., the Department of Transportation prohibits the reuse of 0.8 mm drums for the shipment of hazardous materials. In Japan and Europe, there are not minimum thicknesses for reuse; however, after the initial use, these containers often do not meet the needs of the customers for safety or cosmetic reasons. For these reasons, in this analysis 0.8 mm drums and 0.8/0.7/0.8 mm drums are represented as single-trip drums, although some surveys did indicate low reuse rates for these drums.

- **Drum Manufacture**

  No European new drum manufacturers responded to the survey; therefore, U.S. drum manufacturing data were used to represent Europe.

- **Reconditioning**

  In this study it is assumed that each drum is cleaned (e.g., reconditioned) after each use, whether or not it will be reused. Drums used for hazardous materials must be cleaned after use before they can be sold for scrap[4]. Multi-trip drums are cleaned and reused multiple times before a final cleaning before scrapping. Therefore, in this study it was assumed that 1,000 drum trips = 1,000 drum cleanings for all systems analyzed. It was also assumed that the energy and materials for cleaning a drum does not depend on the drum weight or trip rate, i.e., washing a 1.2 mm multi-trip tight-head drum is the same as washing a 0.8 mm single-trip tight-head drum. Thus, the energy for 1,000 drum washings is the same for all washed drums, and the energy for 1,000 drum burnings is the same for all burned drums. In this study, all tight-head drums were assumed to be reconditioned by washing and all open-head drums by burning.

  Many reconditioning facilities that responded to the survey used both wash and burn processes. It was not possible to separate data for the individual processes, so data for individual reconditioning processes were developed based on surveys from facilities using a single reconditioning process. No European burn-only facilities responded to the survey; therefore U.S. process data (along with European transportation data) were used to represent the European burn process. Only one Japanese burn-only facility provided data. The data were quite similar to U.S. process data; therefore, in order to protect the confidentiality of the Japanese data, U.S. process data (along with Japanese transportation data) were used to represent the Japanese burn process.

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4 See copy of ACR/ISRI agreement in report appendix.

Japanese new drum and drum reconditioning facilities reported atmospheric emissions on a volume basis. Data for converting to a weight basis were not available; therefore, U.S. emissions data were used to represent Japanese process emissions.

- **Recycling and Disposal**

  In this analysis it is assumed that all drums are sold for scrap and recycled when they are retired from use. U.S. process and transportation data for steel recycling are used to represent steel recycling for Europe and Japan.

  Because all drums are assumed to be recycled at end of life, disposal in this analysis refers to the disposal of products made from the steel from recycled drums. U.S. disposal practices are used to represent all systems.

- **Transportation**

  Data sets were developed for each process in the life cycle of steel drums from raw material extraction through disposal. Each data set includes the energy for transportation of the material or product to the next process step. For this study, drum manufacturers provided data on transport to fillers. Reconditioners provided data on transport from emptiers to reconditioners and from reconditioners to fillers and recyclers. No data were provided on transportation from fillers to emptiers. All other transportation is included in the analysis. As a result, transportation energy is somewhat understated in the results; however, since 1,000 drum trips means 1,000 trips from fillers to emptiers, regardless of trip rate, this omission is the same magnitude for all systems and does not affect comparisons between systems.

- **Data**

  Country-specific data for the following processes were developed based on surveys:
  - Steel drum manufacture
  - Drum transportation distances
  - Drum reconditioning processes (including chemical use)

  Life cycle data from Franklin Associates' U.S. database are used to represent all other processes, materials, and fuels in the analysis. For example, U.S. steel production data are used to represent production of steel for Japanese and European drums.

Basis for Comparison

The results of this analysis are presented on the basis of 55,000 gallons of product delivered, or 1,000 drum trips. The number of drums required and weight of steel required varies depending on the drum configuration and number of reconditionings.

LIFE CYCLE INVENTORY METHODOLOGY

Key elements of the LCI methodology include the study boundaries, resource inventory (raw materials and energy), emissions inventory (atmospheric, waterborne, and solid waste), and recycling and disposal practices. Additional discussion on the basic methodology used to calculate product life cycle resource and environmental emissions is presented in the following section of this chapter. The LCI study boundaries for steel drum systems were discussed in the previous section of this chapter.

Franklin Associates has developed a methodology for performing resource and environmental profile analyses (REPA), commonly called life cycle inventories (LCI). This methodology has been documented for the U.S. Environmental Protection Agency and is incorporated in the EPA report **Product Life-Cycle Assessment Inventory Guidelines and Principles.** The methodology is also consistent with the life cycle inventory methodology described in two workshop reports produced by the Society of Environmental Toxicology and Chemistry (SETAC): **A Technical Framework for Life-cycle Assessment, January 1991** and **Guidelines for Life-Cycle Assessment: 'A Code of Practice', 1993,** as well as the ISO 14040 standards. The data presented in this report were developed using this methodology, which has been in use for over 20 years.

Figure 1-2 illustrates the basic approach to data development for each major process in an LCI analysis. This approach provides the essential building blocks of data used to construct a complete resource and environmental emissions inventory profile for the entire life cycle of a product. Using this approach, each individual process included in the study is examined as a closed system, or "black box", by fully accounting for all resource inputs and process outputs associated with that particular process. Resource inputs accounted for in the LCI include raw materials and energy use, while process outputs accounted for include products manufactured and environmental emissions to land, air, and water.

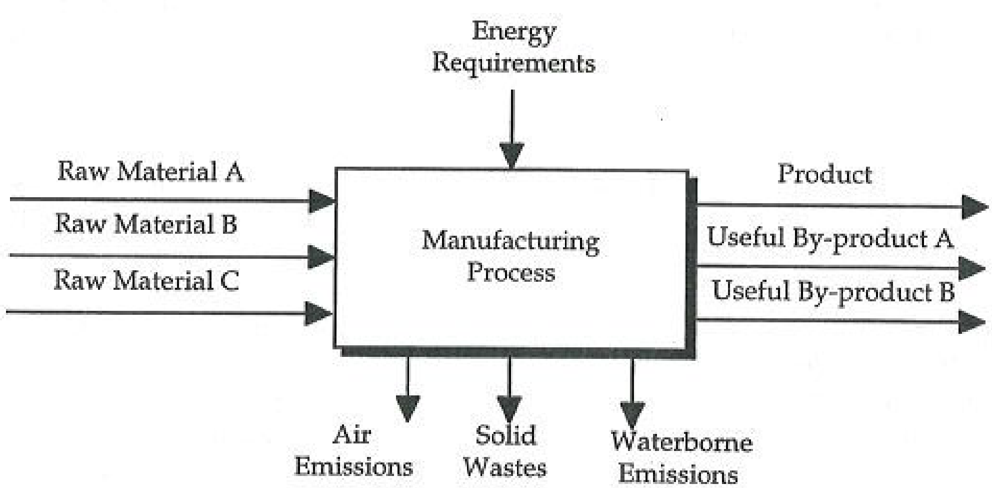


Figure 1-2. Basic input/output concept for developing LCI data.

For each process included in the study, resource requirements and environmental emissions are determined and expressed in terms of a standard unit of output. A standard unit of output is used as the basis for determining the total life cycle resource requirements and environmental emissions of a product.

Material Requirements

Once the LCI study boundaries have been defined and the individual processes identified, a material balance is performed for each individual process. This analysis identifies and quantifies the input raw materials required per standard unit of output, such as 1,000 pounds, for each individual process included in the LCI. The purpose of the material balance is to determine the appropriate weighting factors used in calculating the total energy requirements and environmental emissions associated with the steel drum systems. Energy requirements and environmental emissions are determined for each process and expressed in terms of the standard unit of output.

Once the detailed material balance has been established for a standard unit of output for each process included in the LCI, a comprehensive material balance for the entire life cycle of each steel drum system is constructed. This analysis determines the quantity of materials required from each process to produce and dispose of the required quantity of each steel drum system component and is typically illustrated as a flow chart. Data must be gathered for each process shown in the flow diagram, and the weight relationships of inputs and outputs for the various processes must be developed.

Energy Requirements

The average energy requirements for each process identified in the LCI are first quantified in terms of fuel or electricity units, such as cubic feet of natural gas, gallons of diesel fuel, or kilowatt-hours (kWh) of electricity. The fuels used to transport materials to each process are included as a part of the LCI energy requirements. Transportation energy requirements for each step in the life cycle are developed in the conventional units of ton-miles by each transport mode (e.g. truck, rail, barge, etc.). Government statistical data for the average efficiency of each transportation mode are used to convert from ton-miles to fuel consumption.

Once the fuel consumption for each industrial process and transportation step is quantified, the fuel units are converted from their original units to an equivalent Btu value based on standard conversion factors.

The conversion factors have been developed to account for the energy required to extract, transport, and process the fuels and to account for the energy content of the fuels. The energy to extract, transport, and process fuels into a usable form is called precombustion energy. For electricity, precombustion energy calculations include adjustments for the average efficiency of conversion of fuel to electricity and for transmission losses in power lines based on national averages.

The Btu values for fuels and electricity consumed in each industrial process are summed and categorized into an energy profile according to the six basic energy sources listed below:

- Natural gas
- Petroleum
- Coal
- Nuclear
- Hydropower
- Other

The "other" category includes nonconventional sources, such as solar, biomass and geothermal energy. Also included in the LCI energy profile are the Btu values for all transportation and all fossil fuel-derived raw materials. Energy requirements for each steel drum system examined in this LCI are presented in Chapter 2.

Environmental Emissions

Environmental emissions are categorized as atmospheric emissions, waterborne wastes, and solid wastes and represent discharges into the environment after the effluents pass through existing emission control devices. Similar to energy, environmental emissions associated with processing fuels into usable forms are also included in the inventory. When efforts to obtain actual industry emissions data fail, published emissions standards are used as the basis for determining environmental emissions.

The different categories of atmospheric and waterborne emissions are not totaled in this LCI because it is widely recognized that various substances emitted to the air and water differ greatly in their effect on the environment. Individual environmental emissions for each steel drum system are presented in Chapter 2.

Atmospheric Emissions. These emissions include substances classified by regulatory agencies as pollutants, as well as selected nonregulated emissions such as carbon dioxide. Atmospheric emissions associated with the combustion of fuel for process or transportation energy, as well as process emissions, are included in this LCI. Emissions are reported as pounds of pollutant per unit of product output. The amounts reported represent actual discharges into the atmosphere after the effluents pass through existing emission control devices. Some of the more commonly reported atmospheric emissions are carbon dioxide, carbon monoxide, hydrocarbons, nitrogen oxides, particulates, and sulfur oxides.

Waterborne Wastes. As with atmospheric emissions, waterborne wastes include all substances classified as pollutants. Waterborne wastes are reported as pounds of pollutant per unit of product output. The values reported are the average quantity of pollutants still present in the wastewater stream after wastewater treatment and represent discharges into receiving waters. This includes both process-related and fuel-related waterborne wastes. Some of the most commonly reported waterborne wastes are acid, ammonia, biochemical oxygen demand (BOD), chemical oxygen demand (COD), chromium, dissolved solids, iron, and suspended solids.

Solid Wastes. This category includes solid wastes generated from all sources that are landfilled or disposed of in some other way. It does not include materials that are recovered for reuse or recycling.

When performing an LCI, typically both postconsumer and industrial wastes are considered. Postconsumer solid waste in this study is the steel that is discarded after recycling. Examples of industrial solid wastes are wastewater treatment sludge, solids collected in air pollution control devices, trim or waste materials from manufacturing operations that are not recycled, and fuel combustion residues such as the ash generated by burning coal or wood.

DATA

Data necessary for conducting this analysis are separated into two categories: process-related data and fuel-related data.

Process Data

Data Collection and Sources. A flow diagram is constructed illustrating each life cycle process within the system boundaries. Each process and material is identified and traced back to raw materials and energy sources. Data are then collected for each material and process in the flow diagram.

Surveys of steel drum manufacturers and reconditioners were a vital part of this study. Surveys were sent to drum manufacturers and reconditioners in the U.S., Japan, and Europe. Survey respondents provided data on material usage, energy, emissions, and solid wastes for the manufacture of steel drums and for the wash and burn reconditioning processes, as well as data on steel drum weights, reuse rates, and transportation distances and loads. Franklin Associates' staff reviewed the survey data, entered it into spreadsheets, converted data to a common basis of 1,000 drums, then aggregated and averaged the data for each reconditioning process and geographic region.

Franklin Associates' life cycle database was used for data for the production of steel and reconditioning chemicals, from raw materials through production, and for steel recycling. This database has been developed over a period of years through research for many LCI projects. The database has been extensively reviewed, and data sets are continually updated each time an LCI featuring that material or process is conducted.

Confidentiality. The survey data are considered proprietary by the survey respondents. In order to protect the confidentiality of the data, only aggregated average data are presented in report tables, so that individual company data cannot be calculated or identified.

Fuel Data

Fuel-related data are developed for fuels that are burned directly in industrial furnaces, boilers, and transport vehicles. Fuel-related data are also developed for the production of electricity. These data are assembled into a database from which the energy requirements and environmental emissions for the production and combustion of process fuels are calculated.

Energy data are developed in the form of measured units of each primary fuel required per measured unit of each fuel type. For electricity production, U.S. government and utility association statistical records provided data for the amount of fuel required to produce electricity from each fuel source, and the total amount of electricity generated from petroleum, natural gas, coal, nuclear, hydropower, and other (solar, geothermal, etc.). Literature sources and U.S. government statistical records provided data for the emissions resulting from the combustion of fuels in utility boilers, industrial boilers, stationary equipment such as pumps and compressors, and transportation equipment. Because electricity is required to produce primary fuels, which are in turn used to generate electricity, a circular loop is created. Iteration techniques are utilized to resolve this loop.

Franklin Associates' U.S. database on the production and consumption of fuels is used for all steel drum systems in this analysis.

METHODOLOGY ISSUES

The following sections address how key methodology issues are handled in this analysis.

Precombustion Energy and Emissions

The energy content of fuels has been adjusted to include the energy requirements for extracting, processing, and transporting fuels, in addition to the primary energy of a fuel resulting from its combustion. In this study, this additional energy is called precombustion energy. Precombustion energy refers to all the energy that must be expended to prepare and deliver the primary fuel. Adjustments for losses during transmission, spills, leaks, exploration, and drilling/mining operations are incorporated into the calculation of precombustion energy.

Precombustion environmental emissions (air, waterborne, and solid waste) are also associated with the acquisition, processing, and transportation of the primary fuel. These precombustion emissions are added to the emissions resulting from the burning of the fuels.

Electricity Fuel Profile

In general, detailed data do not exist on the fuels used to generate the electricity consumed by each industry. Electricity production and distribution systems in the United

States are interlinked and are not easily separated. Users of electricity, in general, cannot specify the fuels used to produce their share of the electric power grid. Therefore, the national average fuel consumption by electrical utilities is assumed.

Electricity generated on-site at a manufacturing facility is represented in the process data by the fuels used to produce it. A portion of on-site generated electricity is sold to the electricity grid. This portion is accounted for in the calculations for the fuel mix in the grid.

Coproduct Credit

In some cases, more than one useful product is produced by a process. Material and energy requirements and environmental releases must be allocated among the useful products. An example of this is the production of steel scrap in the fabrication of steel drums. In this analysis, process inputs and outputs are allocated among coproducts on a mass basis, as shown in Figure 1-3.

Recycling

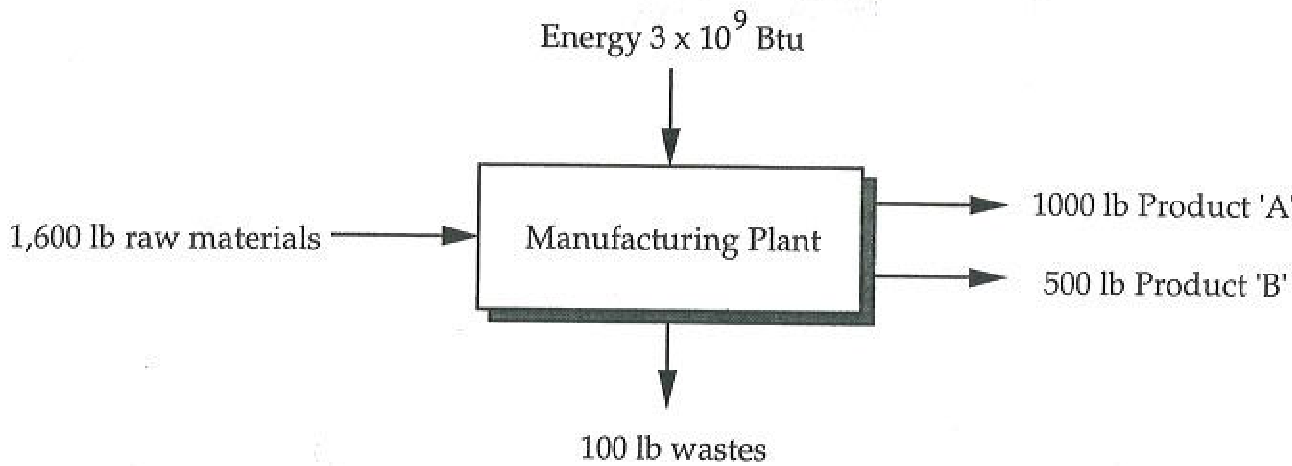
Both closed-loop and open-loop recycling are evaluated as means to divert products from the municipal solid waste stream. In this study, it was assumed that all steel drums were recycled at end of life. Some steel goes into products that are repeatedly recycled, while some goes into products that are disposed.

In a closed-loop system, illustrated in Figure 1-4, material is diverted from disposal by its unlimited recycling or reuse. For example, steel may be recycled into steel drums, food cans, or automobile parts that are recovered and recycled. Since recycling of the same material can occur over and over, it may be permanently diverted from disposal. Figure 1-4 shows that, at the ideal 100 percent recycling rate, the energy requirements and environmental emissions from the virgin raw material acquisition/processing and disposal become negligible.

In an open-loop system, a product made from virgin material is manufactured, recovered for recycling, and manufactured into a new product which is generally not recycled. This extends the life of the initial material, but only for a limited time. Figure 1-5 illustrates how the processes in an open-loop recycling system are analyzed.

The significant difference between open-loop and closed-loop systems is the way recycling benefits are incorporated or credited to the product system underexamination. In a closed-loop system, since the material is recycled many times, the energy and emissions of the initial virgin material manufacture are divided between the first product and all subsequent products made from that original material. Consequently, these initial impacts become insignificant. The only significant energy and emissions associated with closed-loop recycled material are those which result from the recycling process and any processes that follow, such as fabrication. Likewise, ultimate disposal of the recycled material becomes insignificant within the context of the numerous recycling loops that have occurred.

Actual process flow diagram.



Using coproduct allocation, the flow diagram utilized in the LCI for product 'A', which accounts for 2/3 of the output, would be as shown below.

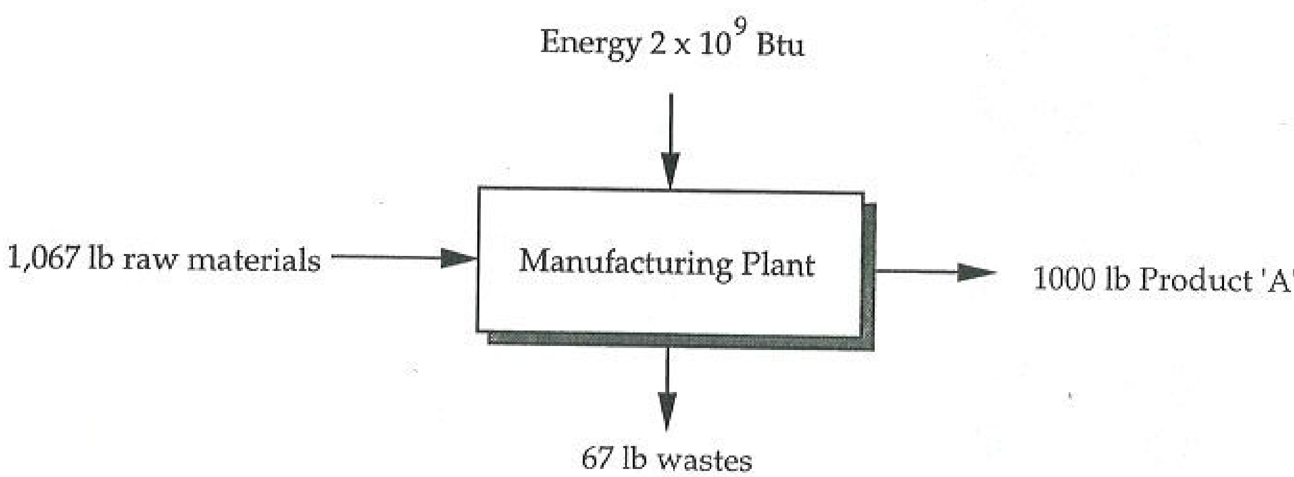


Figure 1-3. Flow diagrams illustrating coproduct allocation for product 'A'.

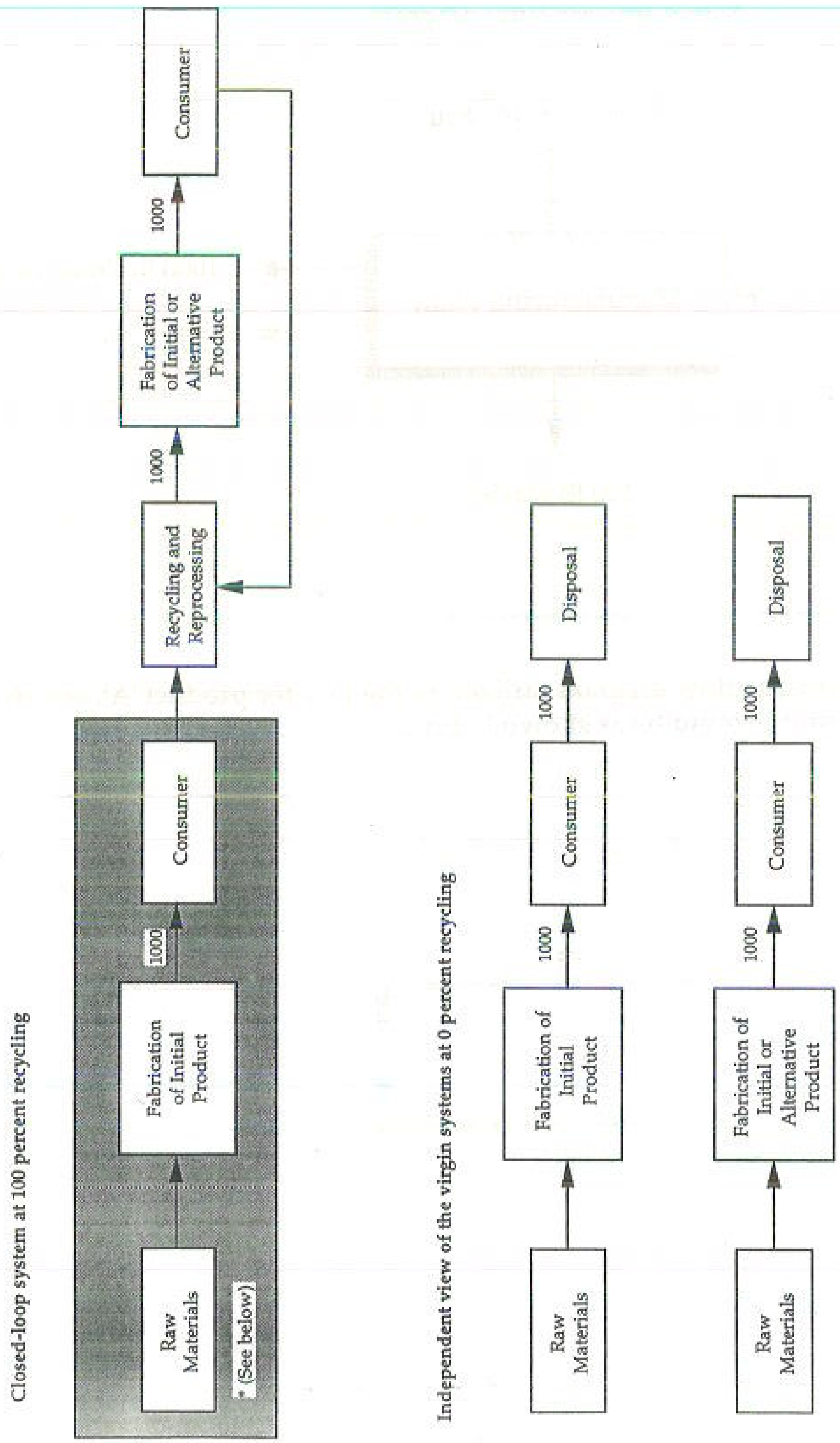


Figure 1-4. Illustration of closed-loop recycling system in comparison to each system independently.

* Note: In a closed-loop system, since the material is recycled many times, the impacts of the initial virgin system manufacturing steps are divided between all of the many products made from that original material. Consequently, these initial impacts become negligible, and the only impacts associated with closed-loop recycled material are those which result from the recycling process and any subsequent processes such as fabrication.

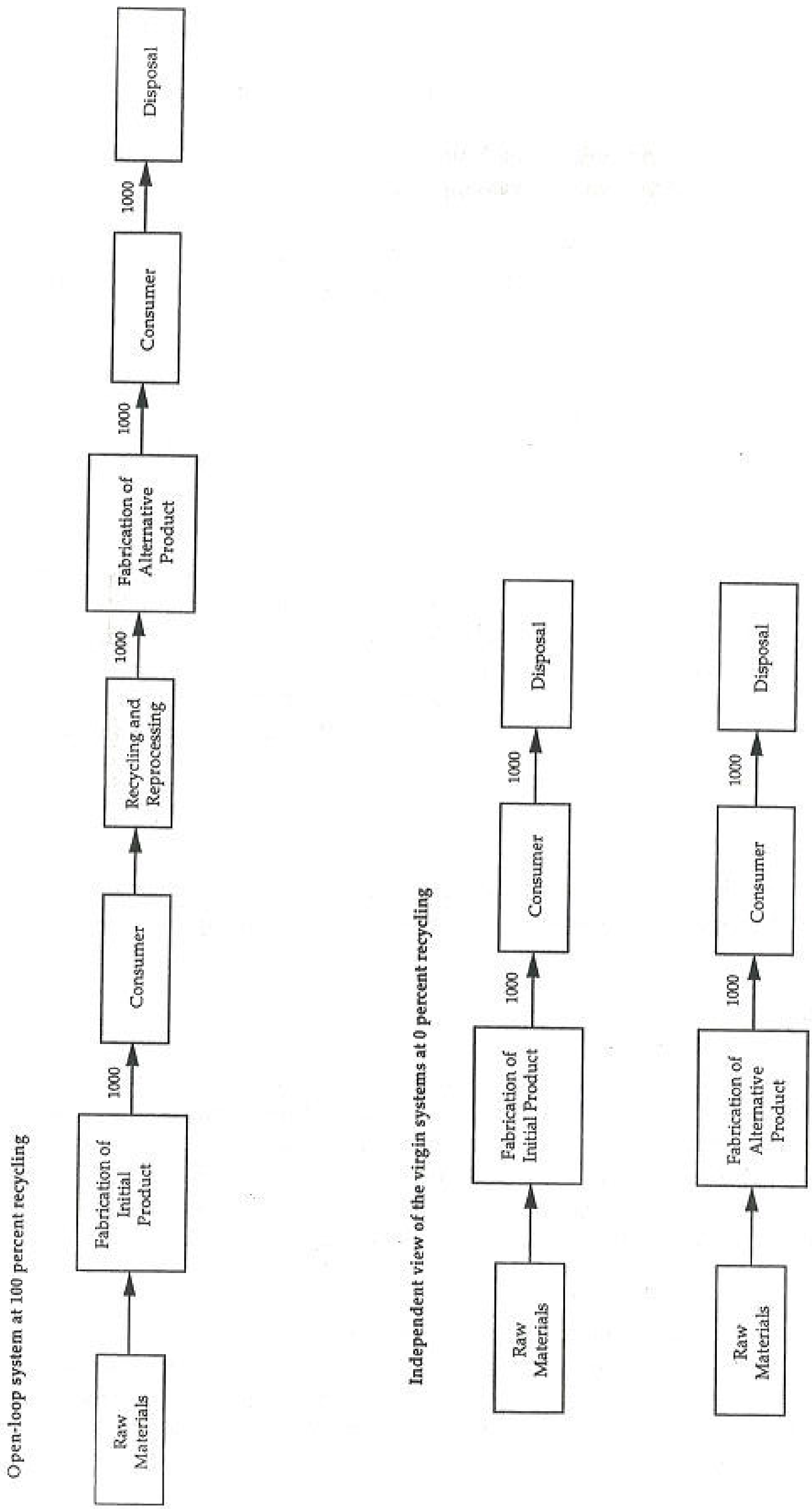


Figure 1-5. Illustration of open-loop recycling system in comparison to each system independently.

Material in an open-loop system is typically used to make two products. Initially, virgin material is used to make a product which is recycled into a second product that is not recycled. Thus, for open-loop recycling, the energy and emissions of virgin material manufacture, recycling, and eventual disposal of the recycled material are divided evenly between the first and second product. This analysis inherently assumes that the recycled material replaces virgin material when producing the second product.

Steel scrap is used in the production of new steel in basic oxygen furnaces (BOF) and recycled steel in electric arc furnaces (EAF). In this analysis, it is assumed that 100% of steel drums are recycled. Statistics from the Steel Recycling Institute on the postconsumer steel scrap content of BOF and EAF steel and the relative amounts of steel produced in BOF and EAF furnaces were used to estimate the percentages of open-loop and closed-loop recycling for U.S. steel drums. Open- and closed-loop recycling for Japan and Europe were estimated based on Japanese and European BOF and EAF steel production quantities.

Drum Transportation

Fuel requirements for drum transportation is an important part of this analysis. Fuel requirements for transportation are based on trucks carrying a full weight load; however, the number of drums in a truckload is limited by volume, not by weight. The LCI model was adjusted to calculate fuel requirements based on the number of truckloads required for 1,000 drum trips. Because the drums are transported to and from reconditioners several times over their useful life, transportation is a significant factor in the analysis results.

LIMITATIONS

Some general decisions are always necessary to limit a study such as this to a reasonable scope. It is important to understand these decisions. The key assumptions and limitations for this study are discussed in the following sections.

Geographic Scope

As stated earlier in this chapter, each geographic region in the analysis is represented by data obtained from surveys of drum manufacturers and reconditioners in that region. U.S. data were used to represent data for which survey data were missing or could not be used due to confidentiality issues, including some drum weights, European drum manufacturing data, and European and Japanese burn data. For this analysis, U.S. data for production of raw materials, production and consumption of fuels, and recycling were used for Europe and Japan.

For the U.S., data for production of oil overseas were not available. The energy requirements and emissions for production of oil in foreign countries were assumed to be the same as for U.S. production. Since foreign standards and regulations vary from those of the United States, it is acknowledged that this assumption may introduce some error. Fuel usage for transportation of materials from overseas locations is included in the study.

System Components Not Included

The following components of each system are not included in this LCI study:

Capital Equipment. The energy and wastes associated with the manufacture of capital equipment are not included. This includes equipment to manufacture buildings, motor vehicles, and industrial machinery. The energy and emissions associated with such capital equipment generally, for 1,000 pounds of materials, become negligible when averaged over the millions of pounds of product which the capital equipment manufactures.

Space Conditioning. The fuels and power consumed to heat, cool, and light manufacturing establishments are omitted from the calculations in most cases. For most industries, space conditioning energy is quite low compared to process energy. Energy consumed for space conditioning is usually less than one percent of the total energy consumption for the manufacturing process.

Support Personnel Requirements. The energy and wastes associated with research and development, sales, and administrative personnel or related activities have not been included in this study. Similar to space conditioning, energy requirements and related emissions are assumed to be quite small for support personnel activities.

Sodium Nitrite Production. The analysis includes data for the production of chemicals used in the production of steel drums and in the reconditioning of steel drums, with the exception of one process step. Sodium nitrite is a rust inhibitor used in small quantities in some reconditioning plants. A literature search was conducted to identify the materials from which sodium nitrite is produced. Data for production of these materials were taken from Franklin Associates' database and included in the system model. Data were not available for the process step by which sodium nitrite is produced; therefore, energy and emissions for reconditioning include all steps in the production of sodium nitrite except for the final production step. Because sodium nitrite is used in such small quantities and only one process step is omitted from the data, the effect on results is negligible.

Miscellaneous Materials and Additives. Selected materials such as catalysts, pigments, or other additives which total less than one percent by weight of the net process inputs are not included in the assessment. Omitting miscellaneous materials and additives helps keep the scope of the study focused and manageable within budget and time constraints.

Chapter 2

ENERGY AND ENVIRONMENTAL RESULTS FOR SINGLE-TRIP AND MULTI-TRIP STEEL DRUM SYSTEMS

INTRODUCTION

A life cycle inventory (LCI) quantifies the energy consumption and environmental emissions for a given product based upon the study boundaries established. The unique feature of this type of analysis is its focus on the entire life cycle of a product, from raw material acquisition to final disposition, rather than on a single manufacturing step or environmental emission.

The resource and environmental profile analysis presented in this study quantifies the total energy requirements, energy sources, atmospheric pollutants, waterborne pollutants, and solid wastes resulting from the production, reconditioning, recycling and disposal of 55-gallon steel drums, including transportation. (In this analysis, all steel drums are assumed to be recycled after they are retired from service; thus "disposal" refers to the disposal of products made with steel from recycled drums.) Open- and tight-head steel drums of four different thicknesses are evaluated.

In addition, comparative economic data are presented. These data were derived by Franklin Associates based on energy costs, raw steel costs, scrap prices, and material costs from public sources including authoritative industry publications.

Purpose of the Study

This study was prepared for the International Confederation of Container Reconditioners (ICCR). The purpose of this study is to provide an LCI that quantifies the energy use and environmental emissions associated with the production, reconditioning, and recycling of steel drums, as well as disposal of products made with steel from recycled drums. The systems analyzed comprise a variety of drum configurations, reuse rates, reconditioning processes, and geographic locations. A general flow diagram illustrating life cycle processes for steel drums is shown in Figure 2-1.

Systems Studied

The following 55-gallon drum systems and reconditioning processes are analyzed in this study:

- **U.S. Drum Systems**
  1.2 mm multi-trip drum—tight-head/wash process
  1.2 mm multi-trip drum—open-head/burn process
  1.0 mm multi-trip drum—tight-head/wash process
  1.0 mm multi-trip drum—open-head/burn process

0.8 mm single-trip drum—tight-head/wash process
0.8 mm single-trip drum—open-head/burn process
1.2/0.9/1.2 mm multi-trip drum—tight-head/wash process
1.2/0.9/1.2 mm multi-trip drum—open-head/burn process

- **Japanese Drum Systems**
  1.2 mm multi-trip drum—tight-head/wash process
  1.2 mm multi-trip drum—open-head/burn process
  1.0 mm multi-trip drum—tight-head/wash process
  1.0 mm multi-trip drum—open-head/burn process
  0.8 mm single-trip drum—tight-head/wash process
  0.8 mm single-trip drum—open-head/burn process
  1.2/0.9/1.2 mm multi-trip drum—tight-head/wash process
  1.2/0.9/1.2 mm multi-trip drum—open-head/burn process
- **European Drum Systems**
  1.2 mm multi-trip drum—tight-head/wash process
  1.2 mm multi-trip drum—open-head/burn process
  1.0 mm multi-trip drum—tight-head/wash process
  1.0 mm multi-trip drum—open-head/burn process
  0.8/0.7/0.8 mm single-trip drum—tight-head/wash process
  0.8/0.7/0.8 mm single-trip drum—open-head/burn process
  1.0/0.9/1.0 mm multi-trip drum—tight-head/wash process
  1.0/0.9/1.0 mm multi-trip drum—open-head/burn process

For this study, an extensive survey was conducted of drum manufacturers and reconditioners in the U.S., Japan, and Europe. Survey data, where available, were used to develop data on drum weights, trip rates, and transportation, as well as data for new drum manufacturing and drum reconditioning processes, including chemical use. The data provided by survey participants did not cover all processes and geographic locations, so it was necessary to make several assumptions in conducting the analysis. Assumptions are listed in Chapter 1.

Weights and trip rates for each drum system are presented in Table 2-1. Weights are reported on the basis of 55,000 gallons of product delivered, or 1,000 drum trips. The number of drums required depends on the trip rate.

It is not accurate to say that any 55-gallon steel drum of any thickness is always used one time and then recycled. Therefore, for the purposes of this study, ICCR chose a drum known to have a much lower trip rate than its heavier counterparts (0.8 mm for the U.S. and Japan, and 0.8/0.7/0.8 mm for Europe) to represent single-trip steel drums.

In the U.S., many 0.8 mm steel drums are scrapped after a single use because the Department of Transportation prohibits the reuse of 0.8 mm drums for the shipment of hazardous materials. In Japan and Europe there are not minimum thickness requirements for reuse; however, after the initial use, these containers often do not meet the needs of the customers for safety or cosmetic reasons. For these reasons, in this analysis 0.8 mm drums and 0.8/0.7/0.8 mm drums are represented as single-trip drums, although some surveys did indicate low reuse rates for these drums.

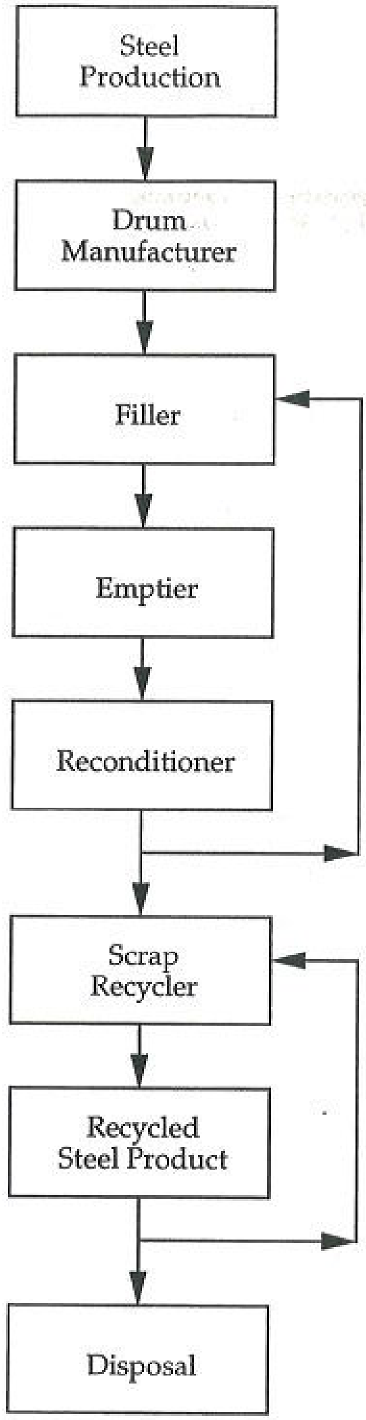


Figure 2-1. General flow diagram for the life cycle of steel drums.

Note: "Steel Production" box represents all process steps from raw material extraction through production of steel.

Table 2-1

STEEL DRUM WEIGHTS AND TRIP RATES

U.S.	Drum Weight (pounds)	Lid Wt (pounds)	Average No. of Trips/Cleanings (1)	Steel per 1,000 Trips (2) (pounds)
1.2 mm multi-trip				
Tight head	41.5		7.9	5,253
Open head	44.8	6.5	7	8,740
1.0 mm multi-trip				
Tight head	37.7		6.4	5,891
Open head	41.0	5.5	5.4	9,475
1.2/0.9/1.2 mm multi-trip				
Tight head	36.0		6.3	5,714
Open head	40.2	6.5	5.2	9,936
0.8 mm single-trip				
Tight head	30.8		1	30,800
Open head	34.1	5	1	34,100
EUROPE				
1.2 mm multi-trip				
Tight head	41.5 (3)		8.1	5,123
Open head	44.8 (3)	6.5	8.7	6,875
1.0 mm multi-trip				
Tight head	37.7 (3)		5.9	6,390
Open head	41.0 (3)	5.5	6.3	7,896
1.0/0.9/1.0 mm multi-trip				
Tight head	35.7		3.6	9,912
Open head	41.0 (3)	5.5	4.3	10,801
0.8/0.7/0.8 mm single-trip				
Tight head	29.5		1	29,515
Open head	34.1 (3)	5	1	34,100
JAPAN				
1.2 mm multi-trip				
Tight head	47.0		5	9,400
Open head	50.2	7.0	4.6	11,023
1.0 mm multi-trip				
Tight head	39.2		2.3	17,043
Open head	40.5	5.9	2.3	17,676
1.2/0.9/1.2 mm multi-trip				
Tight head	41.9		2.6	16,115
Open head	45.8	7.0	2.8	16,448
0.8 mm single-trip				
Tight head	30.8 (3)		1	30,800
Open head	34.1 (3)	5.1	1	34,100

(1) Average number of trips based on survey of steel drum reconditioners.
Number of trips = number of reconditionings + initial use.
All drums are cleaned before recycling.

(2) Replacement rate for open-head lids: 42% for U.S., 2% for Japan, 30% for Europe.

(3) No survey data; used weight for corresponding US drum.

Source: Franklin Associates

Scope and Boundaries

The analysis includes the following steps for each steel drum system:

- Raw materials acquisition
- Production of intermediate materials for the manufacture of steel drums
- Fabrication of steel drums
- Reconditioning of steel drums, including the production of chemicals used in reconditioning processes
- Transportation
- Recycling of steel drums
- Disposal of products made with steel from recycled drums.

The analysis did not include filling and use steps for drums. These steps will vary depending on the contents of the drum and the application for which they are used. Also, energy requirements and wastes associated with these processes are expected to be negligible in comparison to other life cycle steps such as drum manufacture or reconditioning.

Paints and protective drum linings are also not included, for several reasons. First, these materials account for a very small percentage of the total drum weight. Drum paint and linings are removed in the reconditioning process, so single-trip and multi-trip drums alike receive 1,000 coats of paint for 1,000 trips. Protective linings are applied to the drum interior only for certain use applications; however, when lining is used it must be applied for each drum use. Thus, there is no distinction between paint and lining applications for single-use and multi-use drums.

Drum transportation data for this study were provided by drum manufacturers and reconditioners. These sources were able to provide data on all drum transportation except transportation from drum fillers to emptiers. As a result, transportation energy is somewhat understated in the results; however, since 1,000 drum trips means 1,000 trips from fillers to emptiers, regardless of trip rate, this omission is the same magnitude for all systems and does not affect comparisons between systems.

RESULTS

Results are presented in this chapter for 8 drum scenarios in the U.S., Japan, and Europe, for a total of 24 scenarios as listed above. For each scenario, data are presented on total energy use, solid waste, and atmospheric and waterborne emissions. In addition, life cycle costs are estimated for each system based on the cost of materials used, the costs of fuels used for processes and transportation, and the scrap value of the drums at end of life.

Energy

Total Energy. The total energy requirements for each system are shown in Tables 2-2-US, -E, and -J and Figures 2-2-US, -E, and –J for the United States, Europe, and Japan, respectively[5]. Total energy requirements include process energy and transportation energy. Process energy includes energy used for extraction of raw materials, processing them into usable form, manufacturing and reconditioning of steel drums, and recycling and disposal at end of life. Transportation energy includes the energy for the production and consumption of fuels used to transport raw materials and drums between process steps.

Energy requirements for drum transportation represent a significant part of the total energy for each system. Drums are transported several times over their useful life: from the manufacturer to the filler, from the filler to the emptier (end user), from the emptier to the reconditioner, and from the reconditioner to either the recycler or the filler. Multi-trip drums are transported back and forth between fillers, emptiers, and reconditioners several times before they are recycled. In addition, the number of drums in a truckload is limited by volume, not by weight, so multiple truckloads are generally required to transport the drums required for 1,000 drum trips, resulting in higher fuel requirements. Because transportation is a significant factor, the energy tables provide additional detail on drum transportation.

Total energy requirements shown in Table 2-2 and Figure 2-2 are broken out into 3 categories: drum manufacture, reconditioning, and recycling/disposal. For drum manufacture and reconditioning, the energy for transporting drums is also shown separately in the table, by quantity (million Btu) and as a percentage of the total energy for that step.

For a given reconditioning process, it is assumed that it takes the same amount of energy to clean one drum, regardless of the steel thickness or trip rate; i.e., the energy for washing one 1.2 mm tight-head drum with a trip rate of 7.9 is assumed to be the same as the energy required to wash a 0.8 mm single-trip tight-head drum. For the purposes of this study it is assumed that drums are cleaned after each use, whether they are to be reused or retired for recycling, so there are 1,000 reconditionings for 1,000 drum trips, regardless of steel thickness and trip rate. Thus, reconditioning process energy is the same for all tight-head/wash drums or for all open-head/burn drum systems. For a given drum type (open-head or tight-head), variations in reconditioning energy shown in Table 2-2 reflect differences in transportation requirements for the different drum weights and trip rates.

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5 Abbreviations used in the figures represent the following:
MT = multi-trip
ST = single-trip
TH/W = tight-head drum/wash reconditioning
OH/B = open-head drum/burn reconditioning

Table 2-2-US

TOTAL ENERGY REQUIREMENTS FOR
SINGLE- AND MULTI-TRIP STEEL DRUMS IN THE U.S.
(basis: 1,000 drum trips)

	Total Energy (million Btu)	Percent of Total Energy	Drum Transportation (million Btu)	Drum Transportation % of category
1.2 mm multi-trip				
Tight head, wash process				
Drum mfr (1)	30.3	23%	1.4	4%
Reconditioning (2)	84.5	64%	33.1	39%
Recycling/disposal (3)	16.5	13%		
Total	131		34.5	26%
Open head, burn process				
Drum mfr (1)	46.8	17%	1.7	4%
Reconditioning (2)	209	74%	48.1	23%
Recycling/disposal (3)	27.5	10%		
Total	283		49.8	18%
1.0 mm multi-trip				
Tight head, wash process				
Drum mfr (1)	34.5	26%	1.5	4%
Reconditioning (2)	81.0	60%	29.6	37%
Recycling/disposal (3)	18.5	14%		
Total	134		31.2	23%
Open head, burn process				
Drum mfr (1)	52.2	18%	2.0	4%
Reconditioning (2)	204	71%	43.1	21%
Recycling/disposal (3)	29.8	10%		
Total	286		45.0	16%
1.2/0.9/1.2 mm multi-trip				
Tight head, wash process				
Drum mfr (1)	33.8	26%	1.5	4%
Reconditioning (2)	79.6	61%	28.2	35%
Recycling/disposal (3)	18.0	14%		
Total	131		29.7	23%
Open head, burn process				
Drum mfr (1)	53.1	19%	2.0	4%
Reconditioning (2)	203	71%	42.1	21%
Recycling/disposal (3)	30.2	11%		
Total	286		44.1	15%
0.8 mm single-trip				
Tight head, wash process				
Drum mfr (1)	207	56%	26.7	13%
Reconditioning (2)	65.0	18%	13.7	21%
Recycling/disposal (3)	96.9	26%		
Total	369		40.4	11%
Open head, burn process				
Drum mfr (1)	225	44%	29.5	13%
Reconditioning (2)	181	35%	20.2	11%
Recycling/disposal (3)	107.3	21%		
Total	513		49.7	10%

(1) Includes all steps from raw material extraction through steel drum manufacture and transport to user.
(2) Includes reconditioning process, production of chemicals used in reconditioning, and transport from user to reconditioner and back to user.
(3) Includes transport to steel mill, processing, and disposal of a percentage of products made from recycled drum steel.

Source: Franklin Associates.

Table 2-2-E

TOTAL ENERGY REQUIREMENTS FOR
SINGLE- AND MULTI-TRIP STEEL DRUMS IN EUROPE
(basis: 1,000 drum trips)

	Total Energy (million Btu)	Percent of Total Energy	Drum Transportation (million Btu)	% of category
1.2 mm multi-trip				
Tight head, wash process				
Drum mfr (1)	30.7	26%	1.3	4%
Reconditioning (2)	72.8	61%	25.4	35%
Recycling/disposal (3)	15.8	13%		
Total	119		26.8	22%
Open head, burn process				
Drum mfr (1)	38.5	15%	1.3	3%
Reconditioning (2)	193	76%	31.6	16%
Recycling/disposal (3)	21.2	8%		
Total	252		33.0	13%
1.0 mm multi-trip				
Tight head, wash process				
Drum mfr (1)	38.9	30%	1.7	4%
Reconditioning (2)	70.0	54%	22.6	32%
Recycling/disposal (3)	19.7	15%		
Total	129		24.3	19%
Open head, burn process				
Drum mfr (1)	45.6	18%	1.7	4%
Reconditioning (2)	189	73%	28.3	15%
Recycling/disposal (3)	24.3	9%		
Total	259		30.0	12%
1.0/0.9/1.0 mm multi-trip				
Tight head, wash process				
Drum mfr (1)	61.1	38%	2.6	4%
Reconditioning (2)	67.7	42%	20.3	30%
Recycling/disposal (3)	30.6	19%		
Total	159		22.9	14%
Open head, burn process				
Drum mfr (1)	63.2	22%	2.5	4%
Reconditioning (2)	188	66%	27.3	14%
Recycling/disposal (3)	33.3	12%		
Total	285		29.8	10%
0.8/0.7/0.8 mm single-trip				
Tight head, wash process				
Drum mfr (1)	207	58%	25.6	12%
Reconditioning (2)	58.1	16%	10.8	18%
Recycling/disposal (3)	90.9	26%		
Total	356		36.3	10%
Open head, burn process				
Drum mfr (1)	233	45%	29.5	13%
Reconditioning (2)	175	34%	13.7	8%
Recycling/disposal (3)	105.1	21%		
Total	512		43.2	8%

(1) Includes all steps from raw material extraction through steel drum manufacture and transport to use.
(2) Includes reconditioning process, production of chemicals used in reconditioning, and transport from user to reconditioner and back to user.
(3) Includes transport to steel mill, processing, and disposal of a percentage of products made from recycled drum steel.

Source: Franklin Associates.

Table 2-2-J

TOTAL ENERGY REQUIREMENTS FOR
SINGLE- AND MULTI-TRIP STEEL DRUMS IN JAPAN
(basis: 1,000 drum trips)

	Total Energy (million Btu)	Percent of Total Energy	Drum Transportation (million Btu)	Drum Transportation % of category
1.2 mm multi-trip				
Tight head, wash process				
Drum mfr (1)	53.3	27%	0.5	1%
Reconditioning (2)	118.7	59%	71.6	60%
Recycling/disposal (3)	28.8	14%		
Total	201		72.1	36%
Open head, burn process				
Drum mfr (1)	61.8	15%	0.6	1%
Reconditioning (2)	303	76%	142.3	47%
Recycling/disposal (3)	33.7	8%		
Total	399		142.9	36%
1.0 mm multi-trip				
Tight head, wash process				
Drum mfr (1)	100.0	40%	1.4	1%
Reconditioning (2)	100.9	40%	53.7	53%
Recycling/disposal (3)	52.1	21%		
Total	253		55.1	22%
Open head, burn process				
Drum mfr (1)	103.1	25%	1.5	1%
Reconditioning (2)	263	63%	101.6	39%
Recycling/disposal (3)	54.1	13%		
Total	420		103.0	25%
1.2/0.9/1.2 mm multi-trip				
Tight head, wash process				
Drum mfr (1)	93.3	38%	1.2	1%
Reconditioning (2)	105.9	43%	58.8	55%
Recycling/disposal (3)	49.3	20%		
Total	249		60.0	24%
Open head, burn process				
Drum mfr (1)	93.7	22%	1.1	1%
Reconditioning (2)	281	66%	120.2	43%
Recycling/disposal (3)	50.3	12%		
Total	425		121.3	29%
0.8 mm single-trip				
Tight head, wash process				
Drum mfr (1)	193	53%	5.9	3%
Reconditioning (2)	78.0	21%	30.9	40%
Recycling/disposal (3)	94.2	26%		
Total	365		36.8	10%
Open head, burn process				
Drum mfr (1)	209	39%	6.5	3%
Reconditioning (2)	218	41%	56.5	26%
Recycling/disposal (3)	104.3	20%		
Total	531		63.0	12%

(1) Includes all steps from raw material extraction through steel drum manufacture and transport to use:
(2) Includes reconditioning process, production of chemicals used in reconditioning, and transport from user to reconditioner and back to user.
(3) Includes transport to steel mill, processing, and disposal of a percentage of products made from recycled drum steel.

Source: Franklin Associates.

Figure 2-2-US. Total Energy for U.S. Drum Systems

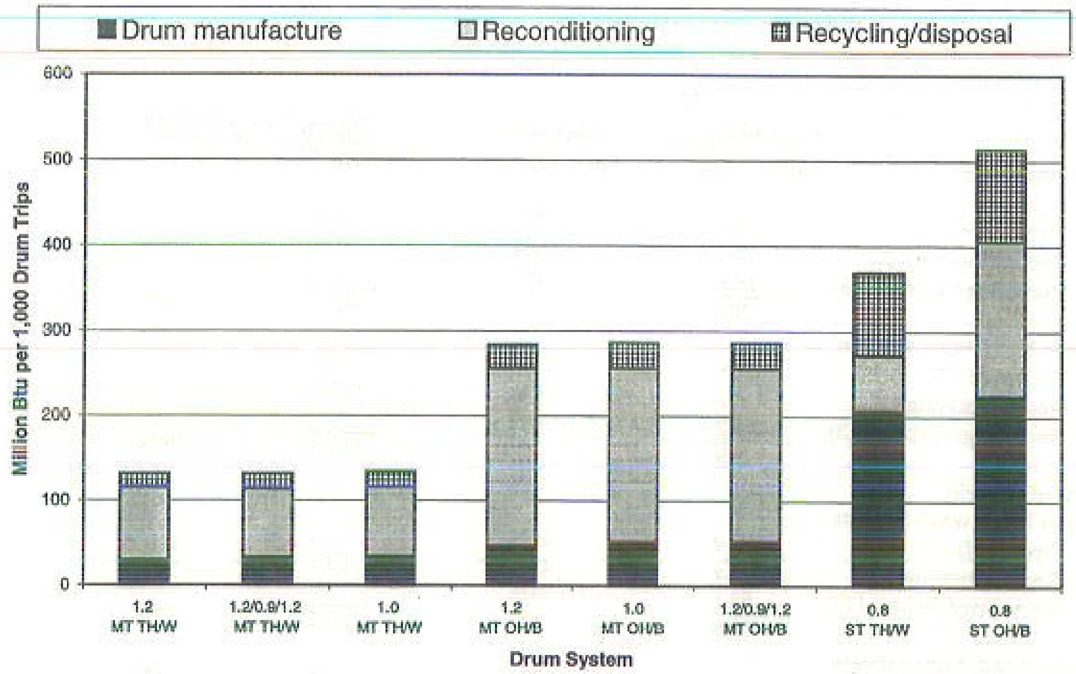


Figure 2-2-E. Total Energy for European Drum Systems

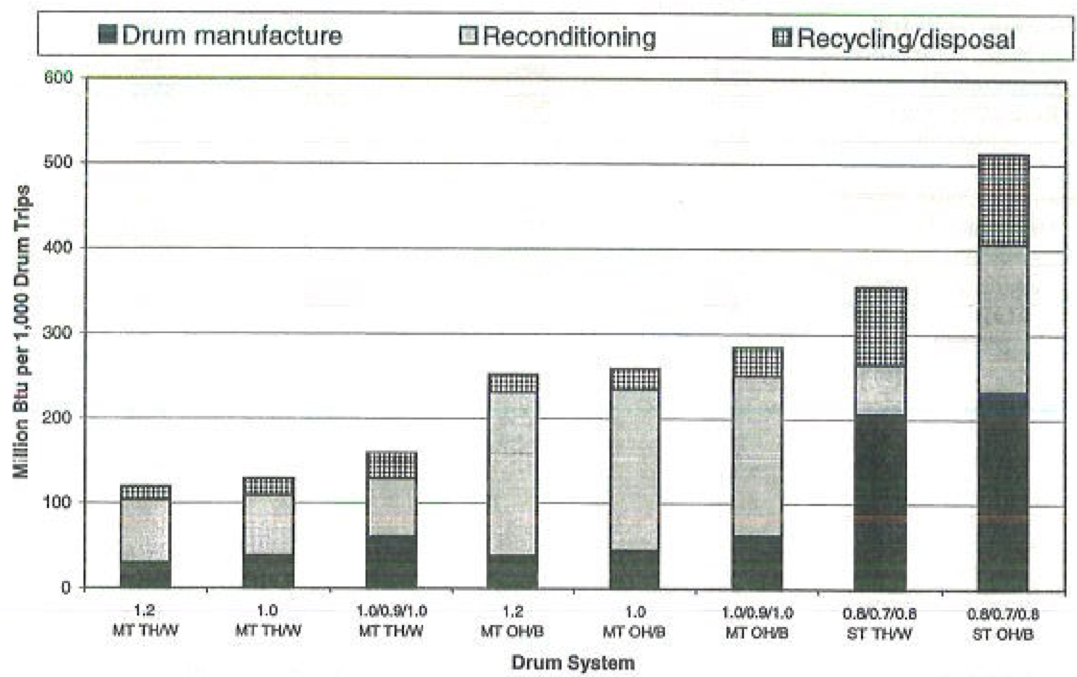
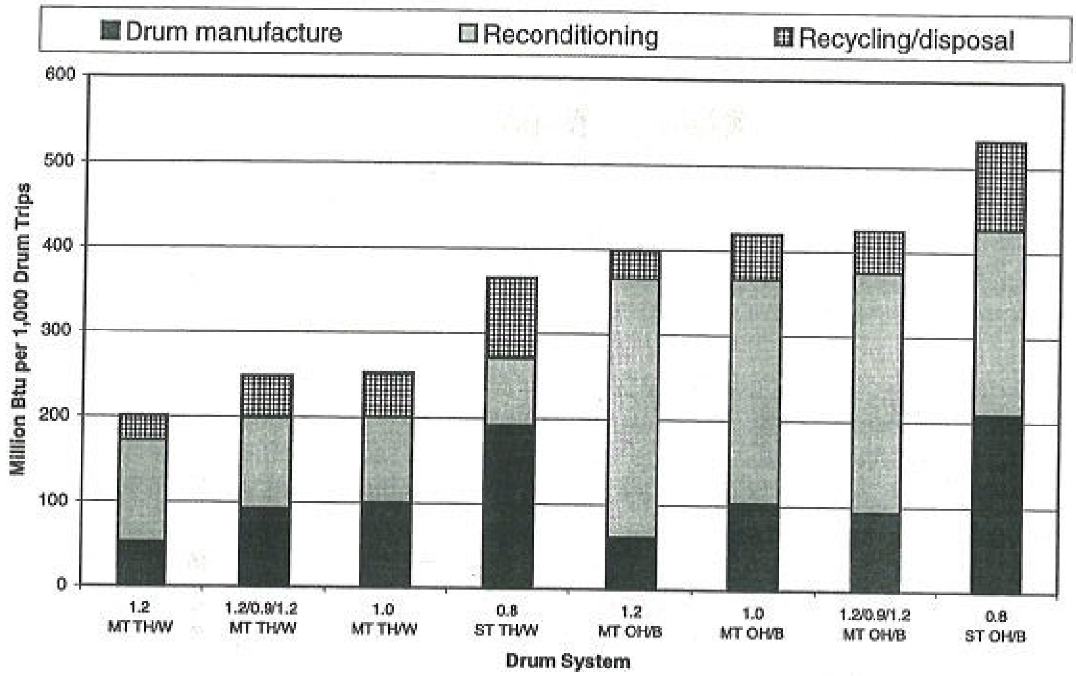


Figure 2-2-J. Total Energy for Japanese Drum Systems



Examination of results in Table 2-2 and Figure 2-2 shows that energy results are similar for corresponding U.S. and European drum systems. Energy results for Japanese single-trip systems are similar to U.S. and European single-trip systems. Japanese multi-trip drums are heavier and have lower trip rates than corresponding U.S. and European multi-trip drums; therefore energy results for Japanese multi-trip drums are higher.

Table 2-2 and Figure 2-2 show that energy results are generally similar within the following groupings of drums:

Multi-trip tight-head/wash (MT-TH/W)
Multi-trip open-head/burn (MT-OH/B)
Single-trip (ST)

Multi-trip Tight-head/Wash Drums. MT-TH/W drums have the lowest total energy requirements for each country.

U.S. Total energy for MT-TH/W drums ranges from 131-134 million Btu/1,000 drum trips for U.S. drum systems. Drum manufacturing energy ranges from 23-26% of total energy. New drum transportation energy is about 4% of the total energy for drum manufacturing. Reconditioning represents 60-64% of total energy, with drum transportation energy accounting for 35-39% of reconditioning energy. Recycling/disposal accounts for 13-14% of total energy.

Europe. Total energy for MT-TH/W drums ranges from 119-159 million Btu/1,000 drum trips for European drum systems. Drum manufacturing energy ranges from

26-38% of total energy. New drum transportation energy is about 4% of the total energy for drum manufacturing. Reconditioning represents 42-61% of total energy, with drum transportation energy accounting for 30-35% of reconditioning energy. Recycling/disposal accounts for 13-19% of total energy.

Japan. Total energy for MT-TH/W drums ranges from 201-253 million Btu/1,000 drum trips for Japanese drum systems. Drum manufacturing energy ranges from 27-40% of total energy. New drum transportation energy is only about 1% of the total energy for drum manufacturing. Reconditioning represents 40-59% of total energy, with drum transportation energy accounting for 53-60% of reconditioning energy. Recycling/disposal accounts for 14-21% of total energy.

Multi-trip Open-head/Burn Drums. The distribution of energy results for MT-OH/B drums is similar to MT-TH/W drums, but for most systems total energy requirements for MT-OH/B systems are about twice as high as for MT-TH/W. There are several reasons for the higher energy requirements. Open-head drums require more steel, because the drums are heavier and a percentage of lids are replaced when the drums are reconditioned; also, for U.S. drums, the trip rate for open-head drums is lower so more drums are required for 1,000 drum trips. Transporting more and/or heavier drums increases transportation energy. The burn reconditioning process used for OH drums is also much more energy-intensive than the wash process used for TH drums.

U.S. Total energy requirements for U.S. MT-OH/B drums range from 283-286 million Btu/1,000 drum trips. Compared to MT-TH/W drum systems, energy requirements for MT-OH/B drum systems are about 50% higher for drum manufacture, 150% higher for reconditioning, and 67% higher for recycling/disposal. Drum manufacture accounts for 17-19% of total energy (4% of this for drum transportation), reconditioning represents 71-74% of total energy (21-23% drum transportation), and recycling/disposal accounts for the remaining 10-11%.

Europe. Total energy requirements for European MT-OH/B drums range from 252-285 million Btu/1,000 drum trips. Compared to corresponding MT-TH/W drum systems, energy requirements for MT-OH/B drum systems are about 170% higher for reconditioning. Drum manufacture accounts for 15-22% of total energy (3-4% of this for drum transportation), reconditioning represents 66-76% of total energy (14-16% drum transportation), and recycling/disposal accounts for the remaining 8-12%.

Japan. Total energy requirements for Japanese MT-OH/B drums range from 399-425 million Btu/1,000 drum trips. Compared to corresponding MT-TH/W drum systems, energy requirements for MT-OH/B drum systems are similar for drum manufacture, 160% higher for reconditioning, and similar for recycling/disposal. Drum manufacture accounts for 15-25% of total energy (1% of this for drum transportation), reconditioning represents 63-76% of total energy (39-47% drum transportation), and recycling/disposal accounts for the remaining 8-13%.

Single-trip Drums. ST drums have the highest overall energy requirements compared to other drum systems with the same reconditioning process. Multi-trip systems require fewer drums, while 1,000 single-trip drums are required for 1,000 trips. The more drums that are required, the more energy that is required for drum manufacture and transport because of the greater weight of steel that must be produced, fabricated, and transported. Thus, the energy for new drum manufacture and transportation is much higher for ST systems than for MT systems because of the much greater number of drums required for the ST system.

Reconditioning transportation energy is lower for ST systems, because drums are not transported back and forth between the emptier, reconditioner, and filler. Recycling/disposal energy is much higher for ST systems because of the much greater weight of steel processed.

Solid Waste

Solid waste can be categorized into three main sources: 1) wastes generated by the various processes throughout the life cycle of the steel drum, 2) wastes associated with the production and consumption of fuels used for process energy and for transportation, and 3) wastes discarded by the end users of the product, i.e. the steel that is discarded from products made from the recycled drum steel.

Solid wastes for each system are presented by weight and by volume in Tables 2-3-US, -E, and –J, and in by weight in Figures 2-3-US, -E, and -J. Total solid waste includes process wastes and fuel-related wastes. For each life cycle process subcategory, the percentage of fuel-related solid waste is also shown in Table 2-3. Fuel-related wastes include the wastes associated not only with fuels used for drum transportation, but also with process fuels, such as the electricity and natural gas used in drum reconditioning processes.

Solid Waste by Weight

Drum Manufacturing Wastes. The majority of the process waste for drum manufacturing is from steel production processes, particularly for the mining of iron ore and coal. Wastes for single-trip systems are much higher than for corresponding multi-trip systems because more drums (i.e., more steel) must be manufactured and transported for 1,000 drum trips.

For all countries in the analysis, drum manufacturing accounts for 57-68% of the total solid waste for MT drum systems and 68-70% of the total for ST drum systems. Fuel-related wastes account for 4-5% of drum manufacturing wastes for all systems.

Table 2-3-US

SOLID WASTES FOR
SINGLE- AND MULTI-TRIP STEEL DRUMS IN THE U.S.
(basis: 1,000 drum trips)

	WEIGHT OF SOLID WASTE			VOLUME OF SOLID WASTE		
	Total Weight (pounds)	Percent of Total SW	Percent Fuel-related (4)	Total Volume (cu ft)	Percent of Total SW	Percent Fuel-related (4)
1.2 mm multi-trip						
Tight head, wash process						
Drum mfr (1)	5,175	62%	4%	104	48%	4%
Reconditioning (2)	1,114	13%	62%	22.3	10%	62%
Recycling/disposal (3)	2,059	25%	15%	88.3	41%	7%
Total	8,348		14%	214		11%
Open head, burn process						
Drum mfr (1)	8,556	59%	4%	171	46%	4%
Reconditioning (2)	2,517	17%	51%	50.3	14%	51%
Recycling/disposal (3)	3,426	24%	15%	147	40%	7%
Total	14,499		15%	368		11%
1.0 mm multi-trip						
Tight head, wash process						
Drum mfr (1)	5,815	63%	4%	116	49%	4%
Reconditioning (2)	1,111	12%	62%	22.2	9%	62%
Recycling/disposal (3)	2,309	25%	15%	99.0	42%	7%
Total	9,234		14%	238		11%
Open head, burn process						
Drum mfr (1)	9,299	60%	4%	186	47%	4%
Reconditioning (2)	2,513	16%	51%	50.3	13%	51%
Recycling/disposal (3)	3,714	24%	15%	159	40%	7%
Total	15,527		14%	396		11%
1.2/0.9/1.2 mm multi-trip						
Tight head, wash process						
Drum mfr (1)	5,646	63%	4%	113	49%	4%
Reconditioning (2)	1,110	12%	62%	22.2	10%	62%
Recycling/disposal (3)	2,240	25%	15%	96.1	42%	7%
Total	8,996		14%	231		11%
Open head, burn process						
Drum mfr (1)	9,423	60%	4%	188	47%	4%
Reconditioning (2)	2,512	16%	51%	50.2	13%	51%
Recycling/disposal (3)	3,762	24%	15%	161	40%	7%
Total	15,697		14%	400		11%
0.8 mm single-trip						
Tight head, wash process						
Drum mfr (1)	30,564	70%	4%	611	53%	4%
Reconditioning (2)	1,097	3%	61%	21.9	2%	61%
Recycling/disposal (3)	12,073	28%	15%	518	45%	7%
Total	43,735		9%	1,151		6%
Open head, burn process						
Drum mfr (1)	33,753	68%	4%	675	52%	4%
Reconditioning (2)	2,494	5%	50%	49.9	4%	50%
Recycling/disposal (3)	13,367	27%	15%	573	44%	7%
Total	49,614		9%	1,298		7%

(1) Includes all steps from raw material extraction through steel drum manufacture and transport to user.
(2) Includes reconditioning process, production of chemicals used in reconditioning, and transport from user to reconditioner and back to user.
(3) Includes transport to steel mill, processing, and disposal of a percentage of products made from recycled drum steel.
(4) Percentage of solid waste associated with the production and consumption of fuels for process energy and transportation.

Source: Franklin Associates.

Table 2-3-E

SOLID WASTES FOR
SINGLE- AND MULTI-TRIP STEEL DRUMS IN EUROPE
(basis: 1,000 drum trips)

	WEIGHT OF SOLID WASTE			VOLUME OF SOLID WASTE		
1.2 mm multi-trip	**Total Weight (pounds)**	**Percent of Total SW**	**Percent Fuel-related (4)**	**Total Volume (cu ft)**	**Percent of Total SW**	**Percent Fuel-related (4)**
Tight head, wash process						
Drum mfr (1)	5,283	64%	4%	106	50%	4%
Reconditioning (2)	892	11%	54%	17.8	8%	54%
Recycling/disposal (3)	2,077	25%	14%	89.7	42%	6%
Total	8,251		12%	213		9%
Open head, burn process						
Drum mfr (1)	7,049	57%	4%	141	45%	4%
Reconditioning (2)	2,504	20%	50%	50.1	16%	50%
Recycling/disposal (3)	2,787	23%	14%	120	39%	6%
Total	12,339		16%	311		12%
1.0 mm multi-trip						
Tight head, wash process						
Drum mfr (1)	6,601	65%	4%	132	50%	4%
Reconditioning (2)	889	9%	53%	17.8	7%	53%
Recycling/disposal (3)	2,590	26%	14%	111.8	43%	6%
Total	10,080		11%	262		8%
Open head, burn process						
Drum mfr (1)	8,117	59%	4%	162	46%	4%
Reconditioning (2)	2,501	18%	50%	50.0	14%	50%
Recycling/disposal (3)	3,200	23%	14%	138	39%	6%
Total	13,818		15%	351		12%
1.0/0.9/1.0 mm multi-trip						
Tight head, wash process						
Drum mfr (1)	10,256	68%	4%	205	52%	4%
Reconditioning (2)	887	6%	53%	17.7	4%	53%
Recycling/disposal (3)	4,019	27%	14%	173.6	44%	6%
Total	15,163		10%	396		7%
Open head, burn process						
Drum mfr (1)	11,115	62%	4%	222	48%	4%
Reconditioning (2)	2,500	14%	50%	50.0	11%	50%
Recycling/disposal (3)	4,378	24%	14%	189	41%	6%
Total	17,993		13%	461		10%
0.8/0.7/0.8 mm single-trip						
Tight head, wash process						
Drum mfr (1)	30,664	70%	4%	613	53%	4%
Reconditioning (2)	879	2%	53%	17.6	2%	53%
Recycling/disposal (3)	11,956	27%	14%	516	45%	6%
Total	43,500		8%	1,147		6%
Open head, burn process						
Drum mfr (1)	35,322	68%	4%	706	52%	4%
Reconditioning (2)	2,488	5%	50%	49.8	4%	50%
Recycling/disposal (3)	13,821	27%	14%	597	44%	6%
Total	51,631		9%	1,353		7%

(1) Includes all steps from raw material extraction through steel drum manufacture and transport to user.
(2) Includes reconditioning process, production of chemicals used in reconditioning, and transport from user to reconditioner and back to user.
(3) Includes transport to steel mill, processing, and disposal of a percentage of products made from recycled drum steel.
(4) Percentage of solid waste associated with the production and consumption of fuels for process energy and transportation.

Source: Franklin Associates.

Table 2-3-J

SOLID WASTES FOR
SINGLE- AND MULTI-TRIP STEEL DRUMS IN JAPAN
(basis: 1,000 drum trips)

	WEIGHT OF SOLID WASTE			VOLUME OF SOLID WASTE		
	Total Weight (pounds)	Percent of Total SW	Percent Fuel-related (4)	Total Volume (cu ft)	Percent of Total SW	Percent Fuel-related (4)
1.2 mm multi-trip						
Tight head, wash process						
Drum mfr (1)	9,812	64%	4%	196	50%	4%
Reconditioning (2)	1,588	10%	38%	31.8	8%	38%
Recycling/disposal (3)	3,852	25%	14%	166.7	42%	6%
Total	15,251		10%	395		8%
Open head, burn process						
Drum mfr (1)	11,492	62%	4%	230	48%	4%
Reconditioning (2)	2,596	14%	52%	51.9	11%	52%
Recycling/disposal (3)	4,516	24%	14%	195	41%	6%
Total	18,605		13%	477		10%
1.0 mm multi-trip						
Tight head, wash process						
Drum mfr (1)	17,847	68%	5%	357	52%	5%
Reconditioning (2)	1,573	6%	38%	31.5	5%	38%
Recycling/disposal (3)	6,983	26%	14%	302.2	44%	6%
Total	26,403		9%	691		7%
Open head, burn process						
Drum mfr (1)	18,496	65%	5%	370	50%	5%
Reconditioning (2)	2,562	9%	51%	51.2	7%	51%
Recycling/disposal (3)	7,242	26%	14%	313	43%	6%
Total	28,301		11%	735		9%
1.2/0.9/1.2 mm multi-trip						
Tight head, wash process						
Drum mfr (1)	16,854	67%	5%	337	52%	5%
Reconditioning (2)	1,577	6%	38%	31.5	5%	38%
Recycling/disposal (3)	6,603	26%	14%	285.8	44%	6%
Total	25,034		9%	654		7%
Open head, burn process						
Drum mfr (1)	17,173	65%	4%	343	50%	4%
Reconditioning (2)	2,578	10%	52%	51.6	8%	52%
Recycling/disposal (3)	6,739	25%	14%	292	42%	6%
Total	26,490		11%	687		9%
0.8 mm single-trip						
Tight head, wash process						
Drum mfr (1)	32,423	70%	5%	648	53%	5%
Reconditioning (2)	1,553	3%	37%	31.1	3%	37%
Recycling/disposal (3)	12,620	27%	14%	546	45%	6%
Total	46,597		8%	1,226		6%
Open head, burn process						
Drum mfr (1)	35,813	68%	5%	716	52%	5%
Reconditioning (2)	2,524	5%	51%	50.5	4%	51%
Recycling/disposal (3)	13,972	27%	14%	605	44%	6%
Total	52,309		9%	1,371		7%

(1) Includes all steps from raw material extraction through steel drum manufacture and transport to user.
(2) Includes reconditioning process, production of chemicals used in reconditioning, and transport from user to reconditioner and back to user.
(3) Includes transport to steel mill, processing, and disposal of a percentage of products made from recycled drum steel.
(4) Percentage of solid waste associated with the production and consumption of fuels for process energy and transportation.

Source: Franklin Associates.

Figure 2-3-US. Total Weight of Solid Waste for U.S. Drum Systems

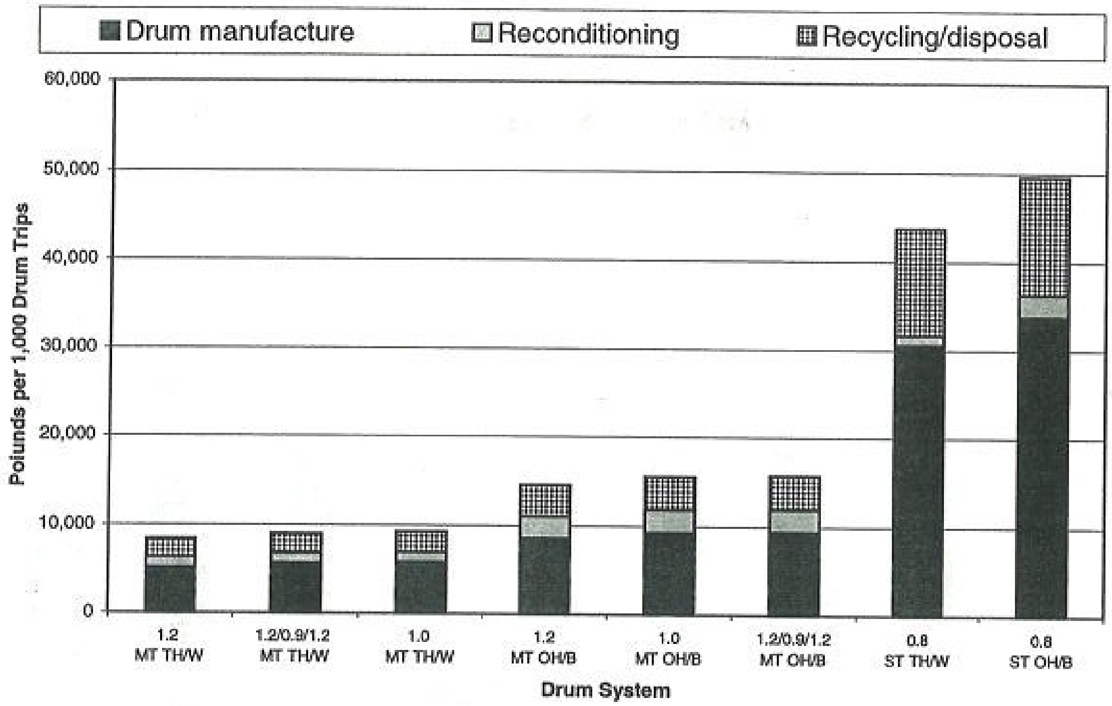


Figure 2-3-E. Total Weight of Solid Waste for European Drum Systems

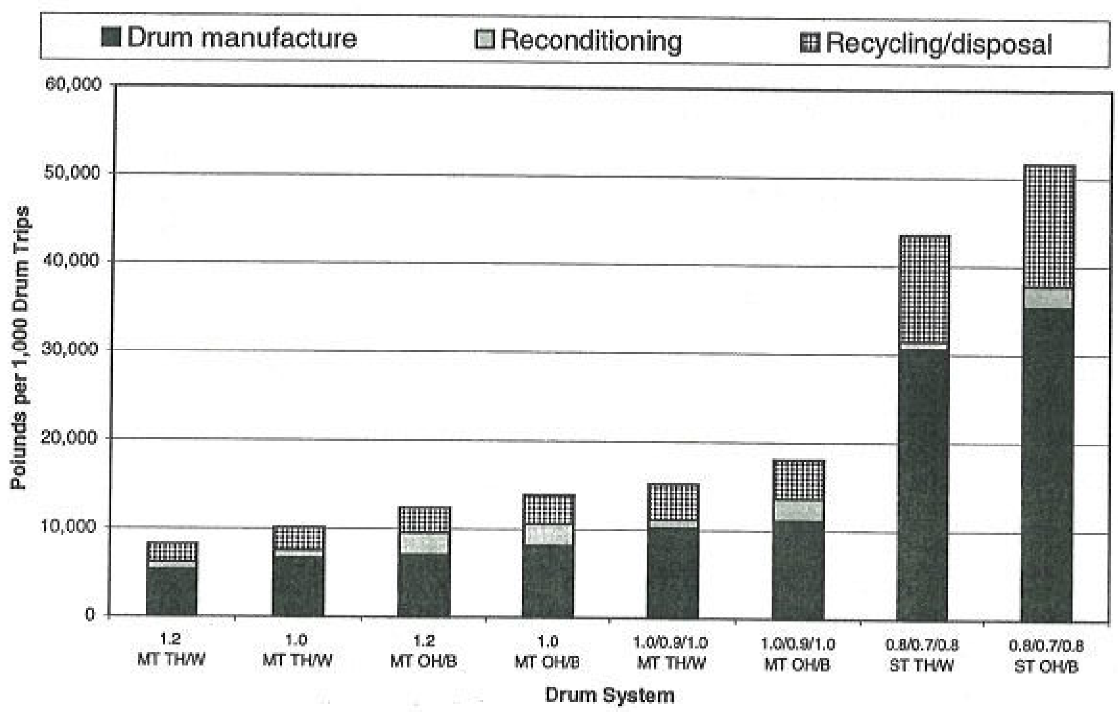
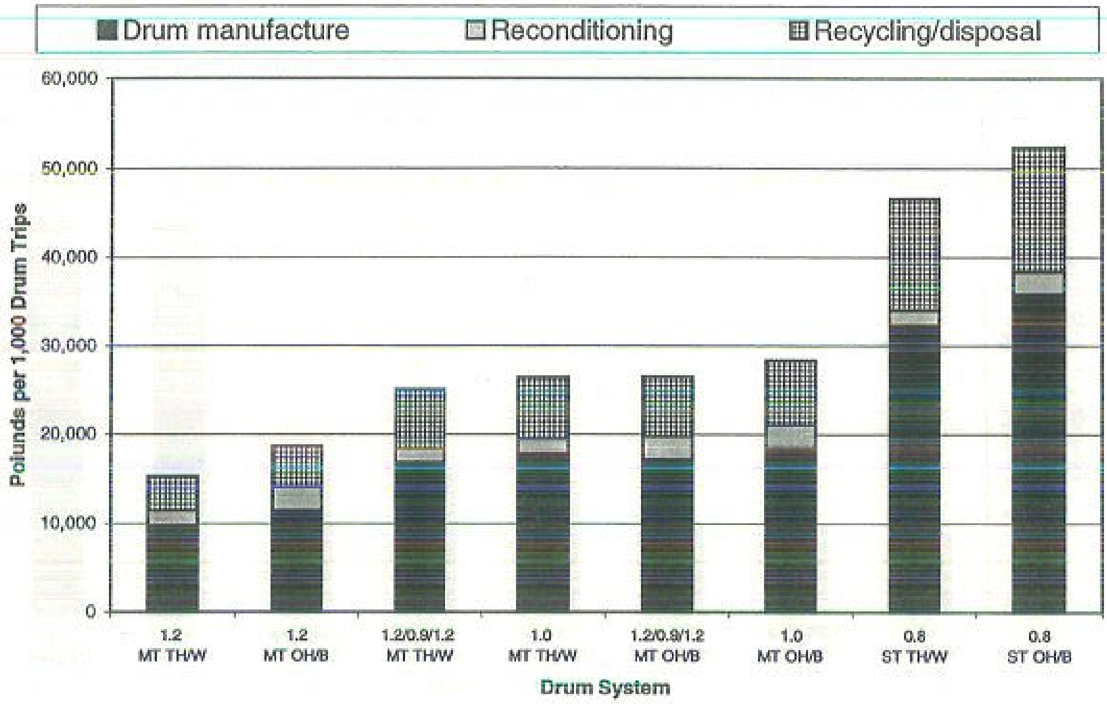


Figure 2-3-J. Total Weight of Solid Waste for Japanese Drum Systems



Reconditioning Wastes. Process wastes for reconditioning reported by U.S. and European wash facilities were about 400 pounds/1,000 drums, while Japanese wash facility wastes averaged 970 pounds/1,000 drums processed. Process solid wastes for burn facilities averaged 1,240 pounds/1,000 drums processed. These wastes do not include the wastes associated with the fuel used in the reconditioning process. Many survey responses did not provide information on the types of solid wastes; however, other surveys reported process solid waste as wastewater treatment sludge (from wash facilities), furnace ash sludge (from burn facilities), and shot blast waste. Process wastes for reconditioning are shown in Tables A-3 through A-8 in the Appendix document.

For a given reconditioning process, process wastes are the same for single-and multi-trip drums. For the purposes of this study, drums are assumed to be cleaned after each use, whether they are going to be reused or recycled; i.e., 1,000 drum trips = 1,000 cleanings. Transportation fuel wastes are higher for multi-trip drums because they are transported back and forth between emptier, reconditioner, and filler several times, while single-trip drums are only transported to the reconditioner once.

Fuel-related wastes account for about half of reconditioning wastes for most systems. This includes the wastes associated with the production and consumption of fuels used in the wash and burn processes and for transportation of drums from emptiers to reconditioners and back to fillers.

U.S. Total reconditioning wastes (process and fuel-related) for washed drums (ST and MT) are about 1,100 pounds/1,000 drum trips. This includes wastes generated at the reconditioning facility as well as wastes associated with the production and combustion of fuels for process energy and transportation. About 60% of wash reconditioning wastes are fuel-related. For burned drums, reconditioning wastes are about 2,500 pounds/1,000 drum trips. Fifty percent of burn reconditioning wastes are fuel-related. Reconditioning wastes represent about 12-17% of total solid wastes for MT systems, but only 3-5% of the total for ST (because total wastes for ST systems are so much higher).

Europe. Total reconditioning wastes for washed drums (ST and MT) are about 900 pounds/1,000 drum trips (53% fuel-related). For burned drums, reconditioning wastes are approximately 2,500 pounds/1,000 drum trips (50% fuel-related). Reconditioning wastes represent 6-20% of total solid waste for MT systems, and 2-5% of total solid waste for ST systems.

Japan. Process and fuel-related reconditioning wastes for washed drums (ST and MT) total about 1,570 pounds/1,000 drum trips (38% fuel-related). For burned drums, reconditioning wastes are approximately 2,550 pounds/1,000 drum trips (52% fuel-related). Reconditioning wastes represent 6-14% of total solid waste for MT systems, and 3-5% of total solid waste for ST systems.

Recycling/Disposal Wastes. The two main sources of waste for this category are fuel-related waste associated with steel recycling in the electric arc furnace, and postconsumer waste from disposal of a percentage of the products made from recycled drum steel. Recycling/disposal wastes for ST drums are much higher than for MT drums because 1,000 ST drums must be used for 1,000 drum trips. As a result, steel use is much higher than for MT systems with fewer drums.

Recycling/disposal wastes account for about 25% of total wastes for all drum systems in all countries. Approximately 15% of recycling/disposal wastes are fuel-related, primarily for the EAF furnace.

Solid Waste by Volume. Landfill density factors are used to convert weights of solid waste into volumes. Solid wastes from industrial processes and from the production and consumption of fuel are assumed to have a density of approximately 50 pounds/cubic foot. The weight of postconsumer steel products is based on actual measurements of landfilled steel products, with an average density of about 21 pounds/cubic foot. Solid waste volumes for each system are shown in Table 2-3.

Environmental Emissions

Atmospheric and waterborne emissions for each system include emissions from processes and emissions associated with the combustion of fuels. Tables 2-4-US, -E, and –J present a summary of the dominant emissions for drum systems in the U.S., Europe, and Japan, respectively.

It is important to realize that interpretation of these data requires great care. The effects of the various emissions on humans and on the environment are not fully known. It is not valid to simply add the weights of various pollutants together to arrive at a total effect. The degree of potential environmental disruption due to environmental releases is not related to the weight of the releases in a simple way. No valid impact assessment methodology currently exists for a life cycle study.

Atmospheric Emissions. All atmospheric emissions shown in Table 2-4 come from both process and fuel-related sources, with the exception of hazardous air pollutants (HAPS), which were reported only by U.S. and Japanese drum reconditioners.

For most atmospheric emissions categories, emissions for wash systems are significantly lower than for the corresponding burn system. Emissions of HCl are higher for U.S. and Japanese wash systems because hydrochloric acid is used in the wash process but not in the burn process. U.S. and Japanese wash reconditioners also reported higher emissions of HAPS than did burn reconditioners. European wash reconditioners did not report wash process emissions of HCl or HAPS.

Comparison of results for corresponding single-trip and multi-trip systems shows that most emissions for single-trip systems are higher than for corresponding multi-trip systems, with the exception of HAPS emissions. For each country, HAPS emissions are the same for all wash systems and for all burn systems because all reported HAPS emissions are from the reconditioning process, and there are 1,000 reconditionings for each system. For Japanese systems, the higher fuel requirements for transportation of multi-trip drums back and forth between emptiers, reconditioners, and fillers result in comparable atmospheric emissions of nitrogen oxides and higher emissions of other organics for some multi-trip systems.

Waterborne Emissions. All waterborne emissions shown in Table 2-4 come from both process and fuel-related sources. For all countries, BOD and COD were higher for wash systems than for corresponding burn systems.

U.S. Waterborne emissions of acid, metal ion, dissolved solids, oil, iron, and sulfates were higher for burn systems, while emissions of suspended solids, BOD, and COD were higher for corresponding wash systems. Emissions for single-trip drums are higher or not significantly different than emissions for multi-trip drums.

Europe. Waterborne emissions of acid, dissolved solids, suspended solids, oil, iron, and sulfates were higher for burn systems, while emissions of metal ion, BOD, and COD were higher for corresponding wash systems. Emissions for single-trip drums are higher or not significantly different than emissions for multi-trip drums.

Table 2-4-US

SELECTED ATMOSPHERIC AND WATERBORNE WASTES
FOR SINGLE- AND MULTI-TRIP STEEL DRUMS IN THE U.S.
(pounds per 1,000 drum trips)

	1.2 mm multi-trip		1.0 mm multi-trip		1.2/0.9/1.2 mm multi-trip		0.8 mm single-trip	
	Tight-head Wash	Open-head Burn	Tight-head Wash	Open-head Burn	Tight-head Wash	Open-head Burn	Tight-head Wash	Open-head Burn
Atmospheric Emissions (1)								
Particulates	32.7	119	34.4	121	33.5	121	129	214
Nitrogen Oxides	105	227	105	225	102	225	280	392
Hydrocarbons	194	303	197	306	196	307	346	449
Sulfur Oxides	133	356	138	362	137	363	372	589
Carbon Monoxide	111	195	113	197	109	197	390	464
Methane	30.2	74.9	31.9	76.9	31.5	77.3	97.4	141
HCl	4.79	1.69	4.82	1.71	4.81	1.72	5.68	2.56
Carbon Dioxide (fossil sources)	19,151	38,720	19,564	39,089	19,125	39,121	56,531	74,823
HAPs	44.5	12.4	44.5	12.4	44.5	12.4	44.5	12.4
Other organics	27.1	40.0	24.9	36.8	23.8	36.1	40.8	49.2
Waterborne Emissions (1,2)								
Acid	17.3	28.9	19.4	31.3	18.9	31.7	102	113
Metal Ion-unspecified	0.047	0.070	0.044	0.065	0.042	0.064	0.086	0.10
Dissolved Solids	134	442	139	449	138	450	345	649
Suspended Solids	54.3	18.1	55.1	18.9	54.9	19.1	82.7	46.2
BOD	67.8	0.52	67.8	0.54	67.8	0.55	68.4	1.06
COD	69.1	6.37	69.2	6.48	69.2	6.50	72.7	9.85
Oil	3.15	8.73	3.31	8.93	3.27	8.96	9.52	15.0
Iron	0.39	0.57	0.42	0.60	0.41	0.60	1.53	1.70
Sulfates	33.5	63.3	37.2	67.5	36.2	68.2	179	208

(1) Includes process emissions and fuel-related emissions.
(2) For tight-head wash systems, emissions from the reconditioning process represent at least 85% of the total waterborne emissions of BOD, COD, and suspended solids. Reconditioning process emissions are based on responses from the survey of drum reconditioners; however, less than half of the reconditioners surveyed provided data on waterborne emissions, and the reported values varied widely. Therefore, the reader is cautioned against drawing conclusions about tight-head wash systems in the categories of BOD, COD, and suspended solids.

Source: Franklin Associates.

Table 2-4-E

SELECTED ATMOSPHERIC AND WATERBORNE WASTES FOR SINGLE- AND MULTI-TRIP STEEL DRUMS IN EUROPE
(pounds per 1,000 drum trips)

	1.2 mm multi-trip		1.0 mm multi-trip		1.0/0.9/1.0 mm multi-trip		0.8/0.7/0.8 mm single-trip	
	Tight-head Wash	Open-head Burn	Tight-head Wash	Open-head Burn	Tight-head Wash	Open-head Burn	Tight-head Wash	Open-head Burn
Atmospheric Emissions (1)								
Particulates	27.8	110	32.1	113	45.2	124	122	215
Nitrogen Oxides	87.5	192	92.3	194	113	212	260	382
Hydrocarbons	139	287	146	292	164	306	292	447
Sulfur Oxides	109	335	120	344	151	370	344	591
Carbon Monoxide	98.7	155	109	162	146	193	378	466
Methane	24.9	70.4	28.2	73.2	37.4	80.6	90.9	143
HCl	0.32	1.62	0.37	1.66	0.49	1.76	1.17	2.56
Carbon Dioxide (fossil sources)	17,830	33,737	19,286	34,792	24,137	38,852	55,071	74,790
HAPs	0	12.4	0	12.4	0	12.4	0	12.4
Other organics	21.6	26.9	20.3	25.1	20.5	26.0	37.5	44.3
Waterborne Emissions (1,2)								
Acid	16.5	22.2	20.6	25.5	32.0	34.9	95.3	110
Metal Ion-unspecified	0.098	0.048	0.097	0.046	0.10	0.050	0.14	0.095
Dissolved Solids	105	428	115	436	142	458	314	651
Suspended Solids	7.97	16.0	9.35	17.1	13.2	20.2	34.9	45.8
BOD	2.43	0.49	2.45	0.51	2.52	0.56	2.98	1.06
COD	16.2	6.11	16.4	6.25	16.9	6.60	19.8	9.86
Oil	2.88	8.25	3.19	8.51	4.03	9.18	9.06	15.0
Iron	0.34	0.49	0.40	0.53	0.56	0.67	1.45	1.73
Sulfates	31.1	51.9	38.1	57.6	57.8	73.8	167	204

(1) Includes process emissions and fuel-related emissions.
(2) For tight-head wash systems, emissions from the reconditioning process represent at least 85% of the total waterborne emissions of BOD, COD, and suspended solids. Reconditioning process emissions are based on responses from the survey of drum reconditioners; however, less than half of the reconditioners surveyed provided data on waterborne emissions, and the reported values varied widely. Therefore, the reader is cautioned against drawing conclusions about tight-head wash systems in the categories of BOD, COD, and suspended solids.

Source: Franklin Associates.

Table 2-4-J

SELECTED ATMOSPHERIC AND WATERBORNE WASTES FOR SINGLE- AND MULTI-TRIP STEEL DRUMS IN JAPAN
(pounds per 1,000 drum trips)

	1.2 mm multi-trip		1.0 mm multi-trip		1.2/0.9/1.2 mm multi-trip		0.8 mm single-trip	
	Tight-head Wash	Open-head Burn	Tight-head Wash	Open-head Burn	Tight-head Wash	Open-head Burn	Tight-head Wash	Open-head Burn
Atmospheric Emissions (1)								
Particulates	74.6	183	96.4	191	94.9	194	141	236
Nitrogen Oxides	224	462	238	423	242	452	289	445
Hydrocarbons	233	380	260	389	257	391	331	451
Sulfur Oxides	146	408	202	447	195	442	312	567
Carbon Monoxide	245	431	295	426	294	448	406	523
Methane	33.8	82.9	52.4	98.5	50.0	95.6	87.6	139
HCl	4.97	1.82	5.27	2.08	5.23	2.03	5.84	2.74
Carbon Dioxide (fossil sources)	31,470	57,379	39,923	60,782	39,223	61,701	57,872	78,721
HAPs	44.5	12.4	44.5	12.4	44.5	12.4	44.5	12.4
Other organics	88.4	173	70.7	127	76.1	149	51.9	83.9
Waterborne Emissions (1,2)								
Acid	30.1	35.3	54.6	56.7	51.7	52.7	98.7	109
Metal Ion-unspecified	0.12	0.18	0.11	0.15	0.12	0.16	0.12	0.13
Dissolved Solids	103	466	143	496	138	492	223	583
Suspended Solids	13.0	21.0	21.4	28.2	20.3	26.8	36.9	46.3
BOD	14.1	0.68	14.3	0.82	14.2	0.78	14.7	1.22
COD	12.3	7.03	13.0	7.53	12.9	7.45	14.6	9.14
Oil	3.49	9.51	4.96	10.7	4.78	10.5	7.80	13.9
Iron	0.61	0.72	0.99	1.05	0.94	0.98	1.69	1.87
Sulfates	53.4	74.8	95.1	111	90.0	104	170	201

(1) Includes process emissions and fuel-related emissions.
(2) For tight-head wash systems, emissions from the reconditioning process represent at least 85% of the total waterborne emissions of BOD, COD, and suspended solids. Reconditioning process emissions are based on responses from the survey of drum reconditioners; however, less than half of the reconditioners surveyed provided data on waterborne emissions, and the reported values varied widely. Therefore, the reader is cautioned against drawing conclusions about tight-head wash systems in the categories of BOD, COD, and suspended solids.

Source: Franklin Associates.

Japan. Waterborne emissions of all substances except BOD and COD were higher for burn systems. Emissions for single-trip drums are higher than for corresponding multi-trip drums, with the exception of metal ion and BOD, which are not significantly different for MT and ST wash systems. Metal ion from ST burn is also slightly lower than from MT burn systems.

Costs for Selected Life Cycle Steps

Estimated costs for selected life cycle steps are shown in Tables 2-5-US, -E, and -J for the U.S., Europe, and Japan. These costs were estimated based on the costs of materials and energy used to manufacture and recondition drums, as well as the cost of fuels used for transportation of drums, and the scrap value of steel drums and lids when recycled at end of life. Fuel and material requirements were derived from surveys of drum manufacturers and reconditioners in the U.S., Europe, and Japan, while material and energy prices and scrap prices were obtained from public sources including industry publications. New steel prices and steel scrap prices were higher for the U.S. compared to Europe and Japan, while U.S. fuel prices were lower.

Initial costs dominate results, primarily costs for steel. Costs for single-trip drums are highest (1,000 drums required). Open-head (heavier drums and replacement of some lids after reconditioning) had higher initial costs than corresponding tight-head drums.

In the U.S. and Europe, transportation costs for single-trip drums were higher than for the corresponding multi-trip drum system. The fuel requirements for transporting 1,000 drums were higher than for transporting fewer drums back and forth to reconditioners. For Japan, transportation results were opposite. Drum trip rates were lower, requiring more multi-trip drums, and drums tended to be heavier and transported in smaller lots. As a result, transportation of multi-trip drums to and from reconditioners caused transportation costs for multi-trip drums in Japan to be higher than transportation costs for single-trip drums.

For each country, use costs were the same for all washed drums and all burned drums. For the purposes of this study it was assumed that each drum use results in one cleaning, and energy and chemical use for one drum cleaning were assumed to be the same for each drum regardless of weight or trip rate.

As with initial costs, scrap values were based on the amount of steel (number of drums and lids) required for each system; thus, scrap values were highest for single-use drums.

Net costs were highest for single-use drums. Cost results were dominated by the cost of steel to produce the drums and lids; therefore, the systems with the highest steel weights had the highest costs.

Table 2-5-US

LIFE CYCLE COSTS FOR U.S.STEEL DRUMS (1)
(basis: US$ per 1,000 drum trips)

U.S.	Initial Cost (2)	Transportation Costs (3)	Use Costs (4)	Scrap Value (5)	Net Cost (6)
1.2 mm multi-trip					
Tight head	1,631	227	220	210	1,868
Open head	2,705	328	508	350	3,192
1.0 mm multi-trip					
Tight head	1,831	205	220	236	2,021
Open head	2,937	297	508	379	3,362
1.2/0.9/1.2 mm multi-trip					
Tight head	1,777	196	220	229	1,964
Open head	3,079	290	508	397	3,480
0.8 mm single-trip					
Tight head	9,598	266	220	1,232	8,852
Open head	10,613	328	508	1,364	10,084

(1) All costs expressed in U.S. dollars, based on public data on prices of fuels and materials. No cost data were collected in surveys of drum manufacturers and reconditioners.
(2) Cost of steel and energy for producing the weight of steel drums and lids required for 1,000 trips, based on average trip rate.
(3) Cost of fuel for transportation to and from reconditioners for 1,000 drum trips. Includes initial transportation of new drums to user.
(4) Cost of fuels and chemicals used in reconditioning process (wash process for tight-head drums, burn process for open-head drums).
(5) Value of steel scrap from drums required for 1,000 trips.
(6) Net cost = initial cost + transportation costs + use costs - scrap value.

Source: Franklin Associates.

Table 2-5-E

LIFE CYCLE COSTS FOR EUROPEAN STEEL DRUMS (1)
(basis: US$ per 1,000 drum trips)

EUROPE	Initial Cost (2)	Transportation Costs (3)	Use Costs (4)	Scrap Value (5)	Net Cost (6)
1.2 mm multi-trip					
Tight head	1,007	491	308	205	1,602
Open head	1,344	605	619	275	2,293
1.0 mm multi-trip					
Tight head	1,259	446	308	256	1,757
Open head	1,548	551	619	316	2,402
1.0/0.9/1.0 mm multi-trip					
Tight head	1,956	420	308	397	2,287
Open head	2,120	546	619	432	2,853
0.8/0.7/0.8 mm single-trip					
Tight head	5,844	667	308	1,180	5,638
Open head	6,731	793	619	1,364	6,779

(1) All costs expressed in U.S. dollars, based on public data on prices of fuels and materials. No cost data were collected in surveys of drum manufacturers and reconditioners.
(2) Cost of steel and energy for producing the weight of steel drums and lids required for 1,000 trips, based on average trip rate.
(3) Cost of fuel for transportation to and from reconditioners for 1,000 drum trips. Includes initial transportation of new drums to user.
(4) Cost of fuels and chemicals used in reconditioning process (wash process for tight-head drums, burn process for open-head drums).
(5) Value of steel scrap from drums required for 1,000 trips.
(6) Net cost = initial cost + transportation costs + use costs - scrap value.

Source: Franklin Associates.

Table 2-5-J

LIFE CYCLE COSTS FOR JAPANESE STEEL DRUMS (1)
(basis: US$ per 1,000 drum trips)

JAPAN	Initial Cost (2)	Transportation Costs (3)	Use Costs (4)	Scrap Value (5)	Net Cost (6)
1.2 mm multi-trip					
Tight head	2,124	1,128	578	47	3,783
Open head	2,483	2,235	1,617	55	6,279
1.0 mm multi-trip					
Tight head	3,885	862	578	85	5,240
Open head	4,021	1,611	1,617	88	7,160
1.2/0.9/1.2 mm multi-trip					
Tight head	3,661	938	578	81	5,096
Open head	3,720	1,897	1,617	82	7,151
0.8 mm single-trip					
Tight head	7,121	575	578	154	8,120
Open head	7,833	985	1,617	171	10,265

(1) All costs expressed in U.S. dollars, based on public data on prices of fuels and materials. No cost data were collected in surveys of drum manufacturers and reconditioners.
(2) Cost of steel and energy for producing the weight of steel drums and lids required for 1,000 trips, based on average trip rate.
(3) Cost of fuel for transportation to and from reconditioners for 1,000 drum trips. Includes initial transportation of new drums to user.
(4) Cost of fuels and chemicals used in reconditioning process (wash process for tight-head drums, burn process for open-head drums).
(5) Value of steel scrap from drums required for 1,000 trips.
(6) Net cost = initial cost + transportation costs + use costs - scrap value.

Source: Franklin Associates.

CONCLUSIONS

The following conclusions can be drawn about the steel drum systems analyzed in this life cycle inventory:

- **Energy Comparison for Single-trip and Multi-trip Drums:** Total energy requirements for single-trip drums are higher than for corresponding multi-trip drums. For the purposes of this study, all drums are assumed to be cleaned after each use, whether they are to be used again or retired for recycling. Therefore, 1,000 drum trips = 1,000 cleanings, so energy differences between MT and ST drums reflect differences in energy requirements for drum manufacture and transportation. Energy for single-trip drum systems is higher because more drums (i.e., more steel and thus more manufacturing and transportation energy) are required.

- **Drum Transportation Energy:** The energy for transportation of drums accounts for a significant portion of total energy, ranging from 10-36% of total energy for MT systems, and 8-12% for ST systems. (This percentage is for transportation of manufactured and reconditioned drums. Transportation of raw materials, steel, etc. is included in the total energy, but only transportation of *finished drums* is reported separately in results tables.)

- **Solid Waste Comparison for Single-trip and Multi-trip Drums:** The majority of total solid waste for all systems is process waste from steel production processes. Because more drums (i.e., more steel) are required for single-trip systems, solid wastes from these systems are much higher than for corresponding multi-trip drum systems.

- **Emissions Comparison for Single-trip and Multi-trip Drums:** Atmospheric and waterborne emissions for single-trip drums are generally higher than for corresponding multi-trip drums.

- **Cost Comparisons:** Net costs were highest for single-use drums. Initial costs, which depend largely on steel costs, generally dominate results. The initial cost for single-trip drums is highest because 1,000 drums are required. For multi-trip drums, initial costs are higher for open-head drums than for corresponding tight-head drums because more steel is required (drums are heavier and a percentage of open-head lids are replaced after reconditioning).

Chapter 3

SENSITIVITY ANALYSIS

INTRODUCTION

As seen in Chapter 2, results for each drum system are strongly dependent on trip rate. The trip rate determines the number of drums required for 1,000 drum trips. The number of drums in turn affects the weight of steel required, which impacts manufacturing energy, transportation requirements, and recycling/disposal.

TRIP RATES

The trip rates used for each drum system in Chapter 2 are averages based on trip rates reported in a survey of drum reconditioners. The number of reconditionings reported by various respondents varied considerably. This chapter examines how energy and solid waste results and conclusions are affected by variations in trip rates.

Sensitivity of Energy Results to Trip Rate

For this sensitivity analysis, the multi-trip drum systems with the highest total energy requirements were selected. These are the results closest to single-trip drum results, and thus the most likely candidates for a change in conclusions regarding single-trip and multi-trip drums.

LCI results were recalculated using a trip rate of one-half the survey average (i.e., if the survey average was 6 trips, results were calculated based on 3 trips). Results for the lower trip rate are compared to results for the actual average trip rate and to results for the single-trip system. Results are shown in Tables 3-1-TH/W and –OH/B and in Figures 3-1-US, -E, and –J.

Decreasing the trip rate by one-half increased total energy requirements. Energy for drum manufacture (including new drum transportation) and recycling/disposal increased, while transportation energy for reconditioning decreased slightly. Total energy for the multi-trip drum systems was still lower than the single-trip systems. The conclusions of the analysis did not change.

Table 3-1-TH/W

SENSITIVITY OF ENERGY RESULTS TO TIGHT-HEAD DRUM TRIP RATE
(Million Btu per 1,000 drum trips)

US	1.0 MT TH/W		1.0 MT TH/W		0.8 ST TH/W	
	Total	Drum Transp	Total	Drum Transp	Total	Drum Transp
Times reconditioned	5.4		2.7		0	
Times used*	6.4		3.7		1	
Number of drums require	156		270		1,000	
Drum manufacture	34.6	1.5	59.9	2.6	207.8	26.7
Reconditioning	81.0	29.6	79.3	27.9	65.0	13.7
Recycling/disposal	18.5		32.1		96.9	
Total Energy	134.2	31.2	171.3	30.5	369.7	40.4

EUROPE	1.0/0.9/1.0 MT TH/W		1.0/0.9/1.0 MT TH/W		0.8/0.7/0.8 ST TH/W	
	Total	Drum Transp	Total	Drum Transp	Total	Drum Transp
Times reconditioned	2.6		1.3		0	
Times used*	3.6		2.3		1	
Number of drums require	278		435		1,000	
Drum manufacture	61.1	2.6	97.4	5.8	207.1	25.6
Reconditioning	67.7	20.3	66.1	18.7	58.1	10.8
Recycling/disposal	30.6		47.8		90.9	
Total Energy	159.3	22.9	211.3	24.6	356.1	36.3

JAPAN	1.0 MT TH/W		1.0 MT TH/W		0.8 ST TH/W	
	Total	Drum Transp	Total	Drum Transp	Total	Drum Transp
Times reconditioned	1.3		0.65		0	
Times used*	2.3		1.65		1	
Number of drums require	435		606		1,000	
Drum manufacture	100.0	1.4	140.2	2.7	192.7	5.9
Reconditioning	100.9	53.7	96.5	49.4	78.0	30.9
Recycling/disposal	52.1		72.7		94.2	
Total Energy	253.0	55.1	309.4	52.1	365.0	36.8

* Times used = times reconditioned + initial use.

Source: Franklin Associates.

Table 3-1-OH/B

SENSITIVITY OF ENERGY RESULTS TO OPEN-HEAD DRUM TRIP RATE
(Million Btu per 1,000 drum trips)

US	1.2/0.9/1.2 MT OH/B		1.2/0.9/1.2 MT OH/B		0.8 ST OH/B	
	Total	Drum Transp	Total	Drum Transp	Total	Drum Transp
Times reconditioned	4.2		2.1		0	
Times used*	5.2		3.1		1	
Number of drums require	192		323		1,000	
Drum manufacture	53.3	2.0	82.6	3.6	225.4	29.5
Reconditioning	203.1	42.1	200.1	39.1	181.2	20.2
Recycling/disposal	30.2		45.7		107.3	
Total Energy	286.5	44.1	328.5	42.7	513.9	49.7

EUROPE	1.0/0.9/1.0 MT OH/B		1.0/0.9/1.0 MT OH/B		0.8/0.7/0.8 ST OH/B	
	Total	Drum Transp	Total	Drum Transp	Total	Drum Transp
Times reconditioned	3.3		1.65		0	
Times used*	4.3		2.65		1	
Number of drums require	233		377		1,000	
Drum manufacture	63.2	2.5	98.7	5.1	232.6	29.5
Reconditioning	188.3	27.3	186.2	25.2	174.7	13.7
Recycling/disposal	33.3		50.8		105.1	
Total Energy	284.7	29.8	335.8	30.3	512.4	43.2

JAPAN	1.2/0.9/1.2 MT OH/B		1.2/0.9/1.2 MT OH/B		0.8 ST OH/B	
	Total	Drum Transp	Total	Drum Transp	Total	Drum Transp
Times reconditioned	1.8		0.9		0	
Times used*	2.8		1.9		1	
Number of drums require	357		526		1,000	
Drum manufacture	93.7	1.1	138.6	2.4	209.0	6.5
Reconditioning	281.2	120.2	269.5	108.5	217.5	56.5
Recycling/disposal	50.3		74.0		104.3	
Total Energy	425.3	121.3	482.1	111.0	530.9	63.0

* Times used = times reconditioned + initial use.

Source: Franklin Associates.

Figure 3-1-US. Sensitivity of Drum Energy to Trip Rate for U.S. Drum Systems

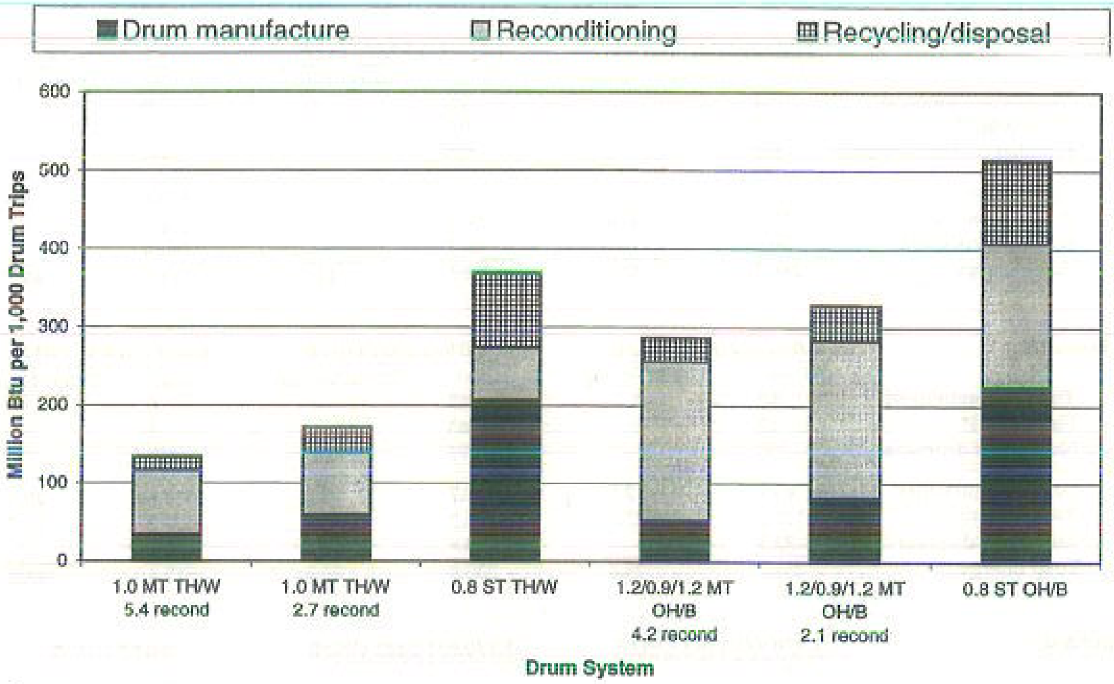


Figure 3-1-E. Sensitivity of Drum Energy to Trip Rate for European Drum Systems

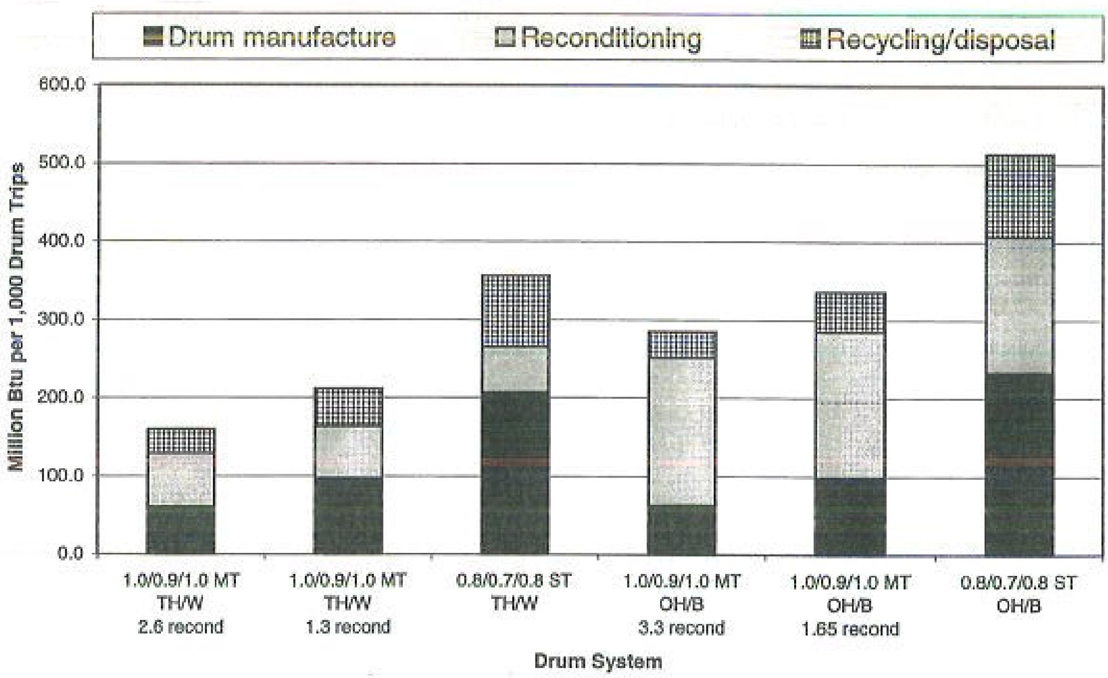
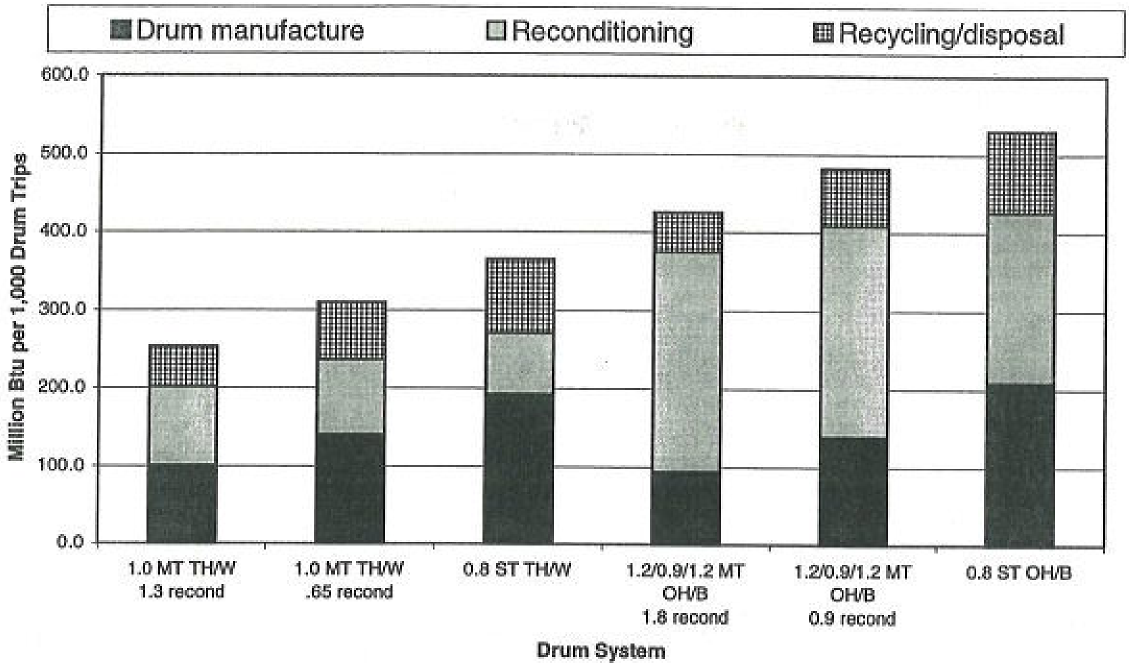


Figure 3-1-J. Sensitivity of Drum Energy to Trip Rate for Japanese Drum Systems



Sensitivity of Solid Waste Results to Trip Rate

As was done for the energy analysis, multi-trip drum systems with the highest solid waste were selected and results recalculated using a trip rate of one-half the survey average. Results for the lower trip rate are compared to results for the average trip rate and to single-trip drum system results. Results are shown in Tables 3-2-TH/W and –OH/B and in Figures 3-2-US, -E, and –J.

Decreasing the trip rate increased the total weight of solid waste. Solid wastes for drum manufacture and recycling/disposal increased, while there was a negligible decrease in fuel-related wastes for transportation to and from reconditioners. Even at half the average trip rate, multi-trip drum systems still produced less solid waste than the single-trip systems.

Table 3-2-TH/W

SENSITIVITY OF SOLID WASTE RESULTS TO TIGHT-HEAD DRUM TRIP RATE
(Pounds per 1,000 drum trips)

US	1.0 MT TH/W		1.0 MT TH/W		0.8 ST TH/W	
	Total	% Fuel-related	Total	% Fuel-related	Total	% Fuel-related
Times reconditioned	5.4		2.7		0	
Times used*	6.4		3.7		1	
Number of drums require	156		270		1,000	
Drum manufacture	5,815	4%	10,058	4%	30,564	4%
Reconditioning	1,111	62%	1,109	62%	1,097	61%
Recycling/disposal	2,309	15%	3,994	15%	12,073	15%
Total Solid Waste	9,234	14%	15,161	11%	43,735	9%

EUROPE	1.0/0.9/1.0 MT TH/W		1.0/0.9/1.0 MT TH/W		0.8/0.7/0.8 ST TH/W	
	Total	% Fuel-related	Total	% Fuel-related	Total	% Fuel-related
Times reconditioned	2.6		1.3		0	
Times used*	3.6		2.3		1	
Number of drums require	278		435		1,000	
Drum manufacture	10,256	4%	16,055	4%	30,664	4%
Reconditioning	887	53%	886	53%	879	53%
Recycling/disposal	4,019	14%	6,291	14%	11,956	14%
Total Solid Waste	15,163	10%	23,232	9%	43,500	8%

JAPAN	1.0 MT TH/W		1.0 MT TH/W		0.8 ST TH/W	
	Total	% Fuel-related	Total	% Fuel-related	Total	% Fuel-related
Times reconditioned	1.3		0.65		0	
Times used*	2.3		1.65		1	
Number of drums require	435		606		1,000	
Drum manufacture	17,847	5%	24,878	5%	32,423	5%
Reconditioning	1,573	38%	1,569	38%	1,553	37%
Recycling/disposal	6,983	14%	9,734	14%	12,620	14%
Total Solid Waste	26,403	9%	36,182	9%	46,597	8%

* Times used = times reconditioned + initial use.

Source: Franklin Associates.

Table 3-2-OH/B

SENSITIVITY OF SOLID WASTE RESULTS TO OPEN-HEADDRUM TRIP RATE
(Pounds per 1,000 drum trips)

US	1.2/0.9/1.2 MT OH/B		1.2/0.9/1.2 MT OH/B		0.8 ST OH/B	
	Total	% Fuel-related	Total	% Fuel-related	Total	% Fuel-related
Times reconditioned	4.2		2.1		0	
Times used*	5.2		3.1		1	
Number of drums require	192		323		1,000	
Drum manufacture	9,423	4%	14,295	4%	33,753	4%
Reconditioning	2,512	51%	2,510	50%	2,494	50%
Recycling/disposal	3,762	15%	5,697	15%	13,367	15%
Total Solid Waste	15,697	14%	22,501	12%	49,614	9%

EUROPE	1.0/0.9/1.0 MT OH/B		1.0/0.9/1.0 MT OH/B		0.8/0.7/0.8 ST OH/B	
	Total	% Fuel-related	Total	% Fuel-related	Total	% Fuel-related
Times reconditioned	3.3		1.65		0	
Times used*	4.3		2.65		1	
Number of drums require	233		377		1,000	
Drum manufacture	11,115	4%	16,998	4%	35,322	4%
Reconditioning	2,500	50%	2,498	50%	2,488	50%
Recycling/disposal	4,378	14%	6,687	14%	13,821	14%
Total Solid Waste	17,993	13%	26,183	11%	51,631	9%

JAPAN	1.0 MT OH/B		1.0 MT OH/B		0.8 ST OH/B	
	Total	% Fuel-related	Total	% Fuel-related	Total	% Fuel-related
Times reconditioned	1.3		0.65		0	
Times used*	2.3		1.65		1	
Number of drums require	435		606		1,000	
Drum manufacture	18,496	5%	25,735	5%	35,813	5%
Reconditioning	2,562	51%	2,554	51%	2,524	51%
Recycling/disposal	7,242	14%	10,076	14%	13,972	14%
Total Solid Waste	28,301	11%	38,365	10%	52,309	9%

* Times used = times reconditioned + initial use.

Source: Franklin Associates.

Figure 3-2-US. Sensitivity of Solid Waste to Trip Rate for U.S. Drum Systems

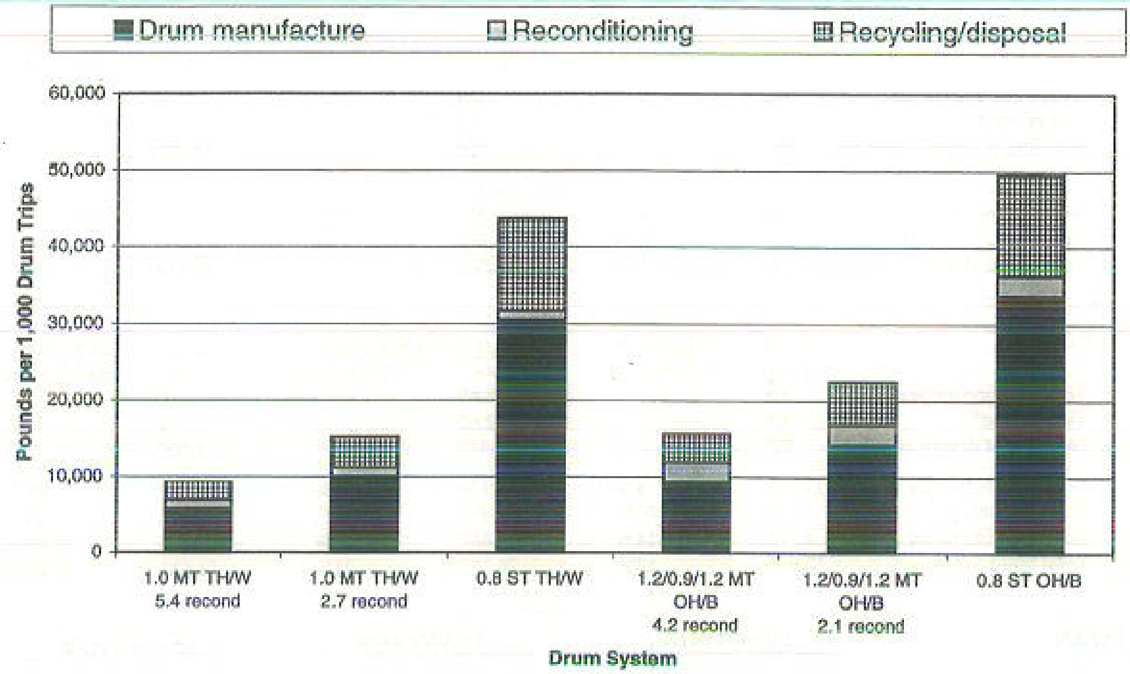


Figure 3-2-E. Sensitivity of Solid Waste to Trip Rate for European Drum Systems

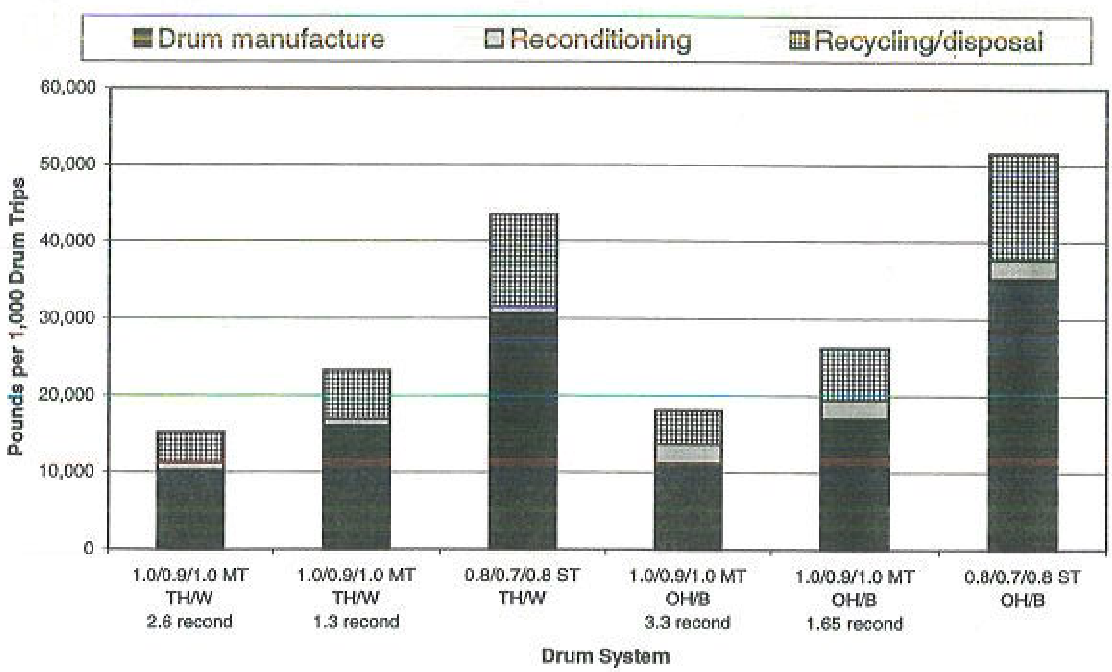
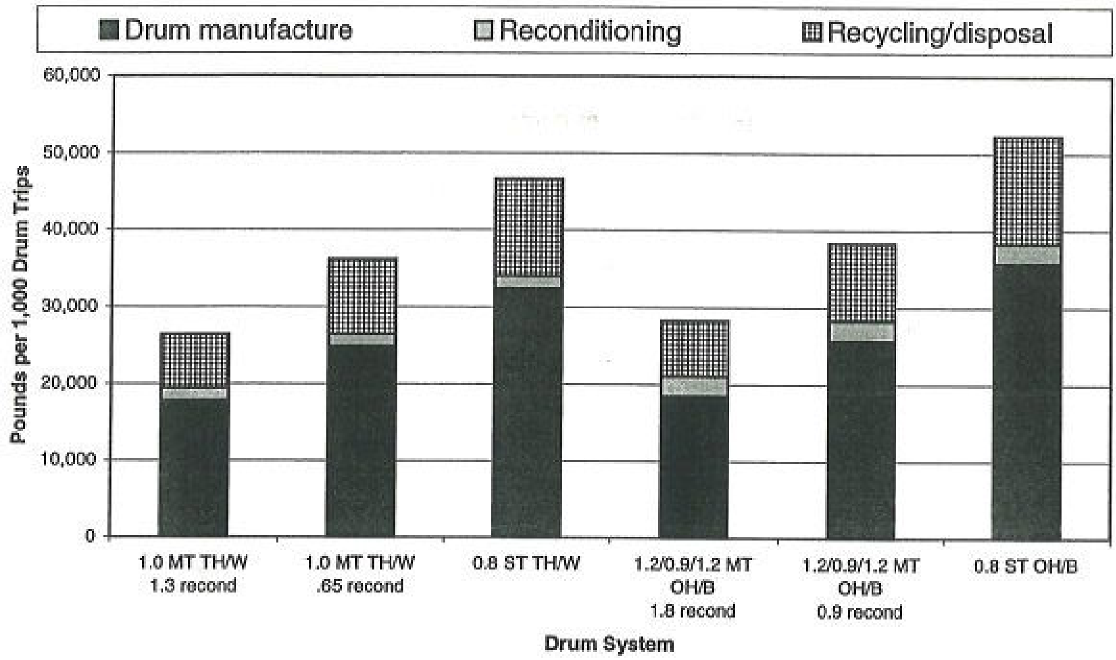


Figure 3-2-J. Sensitivity of Solid Waste to Trip Rate for Japanese Drum Systems



Appendix

STEEL DRUM MANUFACTURE AND RECONDITIONING

INTRODUCTION

Much of the data used in the analysis of steel drum systems was taken from Franklin Associates' life cycle database, which contains data for many materials and processes. These data sets are continuously being reviewed and updated as new studies are conducted. Data sets for several key processes in this analysis were developed from an extensive survey of drum manufacturers and reconditioners in the U.S., Europe, and Japan.

This appendix describes steel drum reconditioning processes and presents data tables for drum manufacture and reconditioning in each country. These tables were developed specifically for this analysis from survey responses and include raw material requirements, energy requirements, and environmental emissions for each process. Process descriptions are based on information provided by the Reusable Industrial Packaging Association (formerly the Association of Container Reconditioners) and on conversations with drum reconditioners.

STEEL DRUM MANUFACTURE

Steel drums are manufactured from cold rolled carbon steel coils. The coils are generally the proper height for manufacturing drums; however, the circular heads must be stamped out of a flat steel sheet. The coil is cut to the proper length, formed into a cylinder, and welded. For tight head drums, both the bottom and top heads are attached to the body by a mechanical seaming process. Linings are applied prior to the top head being attached. For open head drums, only the bottom head is attached by seaming. The top head is removable and is commonly attached to the body with a ring and bolt.

Data for process steps from raw material extraction through steel strip production were taken from Franklin Associates' life cycle database. Data for the manufacture of steel drums were derived from surveys of steel drum manufacturers in the U.S. and Japan. No European drum manufacturers responded to the survey; therefore, U.S. drum manufacturing data are used to represent Europe. Data for the production of 1,000 steel drums in the U.S. and Japan are presented in Tables A-1 and A-2, respectively.

Table A-1

DATA FOR THE PRODUCTION OF 1,000 NEW STEEL DRUMS IN THE U.S. AND EUROPE*

Raw Materials			
Steel	46,373	lb	
Phosphate treatment	9.8	gal	
Energy Usage			**Total Energy Thousand Btu**
Process Energy			
Electricity	100	kwh	1,118
Natural gas	35,743	cu ft	41,462
Distillate oil	0.066	gal	10.4
Total Process			42,590
Transportation			
Drums per load	300		
Distance			
Combination truck	350	miles	
Environmental Emissions			
Atmospheric Emissions			
Hydrocarbons	87.9	lb	
Nitrogen Oxides	2.93	lb	
Particulates	1.56	lb	
Sulfur Oxides	0.37	lb	
Aldehydes	0.37	lb	
Solid Wastes	553	lb	
Waterborne Wastes			
BOD	0.37	lb	
COD	0.62	lb	
Suspended solids	0.12	lb	
Dissolved solids	0.083	lb	
Oil	0.028	lb	
Nickel	0.0014	lb	
Cyanide	0.0011	lb	
Zinc	0.0024	lb	
Other Organics	3.5E-04	lb	

* No European new steel drum facilities elected to participate in the surveys for this study.

Reference: 1998 survey of new drum manufacturers.

Source: Franklin Associates

Table A-2

DATA FOR THE PRODUCTION OF 1,000 NEW STEEL DRUMS IN JAPAN

			Total Energy Thousand Btu
Raw Materials			
Steel	44,994	lb	
Phosphate treatment	9.8	gal	
Energy Usage			
Process Energy			
Electricity	1,747	kwh	19,434
Natural gas	8,409	cu ft	9,754
Distillate oil	63.0	gal	9,973
Total Process			39,161
Transportation			
Drums per load	300		
Distance			
Combination truck	77	miles	
Environmental Emissions			
Atmospheric Emissions*			
Hydrocarbons	83.9	lb	
Nitrogen Oxides	2.80	lb	
Particulates	1.49	lb	
Sulfur Oxides	0.35	lb	
Aldehydes	0.35	lb	
Solid Wastes	251	lb	
Waterborne Wastes			
BOD	0.58	lb	
COD	0.77	lb	
Suspended solids	0.55	lb	
Dissolved solids	0.062	lb	
Oil	0.13	lb	
Metal ions	9.4E-04	lb	

* U.S. atmospheric emissions were used in place of Japanese emissions.

Reference: 1998 survey of new drum manufacturers.

Source: Franklin Associates

STEEL DRUM RECONDITIONING

For the purposes of this study, it was assumed that drums are cleaned after each use, whether they are to be reused or retired for recycling. This assumption is based upon common industry practice. Facilities receiving drums containing hazardous materials residue must manage that residue in an environmentally sound manner. Scrap recycling facilities do not have the equipment or the desire to handle the residue. This mutual interest was recognized in an agreement between the Reusable Industrial Packaging Association (RIPA; formerly the Association of Container Reconditioners, or ACR) and the Institute of Scrap Recycling Industries (ISRI), pledging that containers will be cleaned prior to recycling[6]. Also, internationally accepted definitions of reconditioning require the cleaning of drums to the original material of construction (U.N. Transport of Dangerous Goods—Model Regulations).

Washing and burning are the two predominant cleaning methods used in steel drum reconditioning. Tight-head drums are cleaned using a wash process, while open-head drums are reconditioned using a burn process. For this analysis, reconditioning of "open-head" drums includes drums received as open-head as well as drums received as tight-head and converted to open-head for reconditioning by the burn process.

Because reconditioning destroys the painted finish on a drum, the final steps in drum reconditioning include application of a fresh coat of paint. Sometimes a phenolic-epoxy liner layer is sprayed inside the drum, depending on the application for which the barrel will be used. Paints and sprayed-on linings were excluded from the analysis for several reasons. First, these materials account for a very small percentage of the total drum weight. Also, because drum paint and linings are removed in the reconditioning process, drums are repainted before each use, so single-trip and multi-trip drums alike receive 1,000 coats of paint for 1,000 trips. Spray linings are not applied to every drum for every use; however, as with paint, when lining is required, it must be applied for each use. Thus, there is no distinction between paint and lining applications for single-use and multi-use drums.

Wash Process for Reconditioning Tight-head Drums

The tops of tight-head drums are not removed for the reconditioning process; washing and rinsing takes place through the bung hole on the top of the lid.

Washing. The wash process used to clean tight head steel drums consists of several steps, including preflush, caustic wash, rinse, acid wash, water reclamation and discharge, and drying.

Preflushing consists of small caustic wash units for cleaning drums containing viscous or sticky residues. These are generally used only when reconditioning drums that contain these types of stubborn residues.

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6 See copy of ACR/ISRI agreement at the end of this appendix.

Next, the inside of the drum is sprayed with a caustic wash followed by a neutral pH rinse. The exterior of the drum is also washed using the same or similar hot caustic solution. A buffing machine may be used to remove remaining paint and labels. A 15 to 20 percent sodium hydroxide solution is commonly used for the caustic wash. Caustic wash units are typically not emptied or drained; rather, fresh caustic (or caustic residue from incoming drums) is added as necessary to keep the proper pH level. Several of the reconditioners surveyed reported the use of a hydrochloric acid solution to supplement the caustic wash process and remove rust and stubborn residues from drum interiors.

Rinsing and Drying. After washing, drums are sent through a rinse unit. Any dirty rinse water not pumped into the wash units is discharged to the wastewater treatment system. Typically wash plants have a tank or sump for storage and treatment of wastewater. It is discharged to the sanitary sewer either continuously or in batches under local discharge permits.

Drums are then vacuumed or oven dried to remove excess rinse water. Some reconditioners also reported the use of sodium nitrite. This is a rust inhibitor used to protect the cleaned surface of barrels exposed to environments that may cause oxidation.

Drum Finishing. The final step is drum finishing. Typically drums are reworked (i.e., rechimed and dedented) as necessary, visually inspected, tested for leaks, painted (sometimes also sprayed inside with a protective coating), and refitted with bung plugs and lids.

Data for reconditioning 1,000 55-gallon tight-head steel drums using the wash process are summarized in Tables A-3, A-4, and A-5 for the U.S., Europe, and Japan, respectively. These data are based on survey responses from drum reconditioners. Less than half of the survey respondents provided requested data on emissions, and reported values varied widely. Therefore, the averaged emission values shown in the reconditioning tables are considered to have a high degree of uncertainty.

Table A-3

DATA FOR THE RECONDITIONING OF 1,000 STEEL DRUMS AT WASHING FACILITIES IN THE U.S.

			Total Energy Thousand Btu
Raw Materials			
Hydrochloric acid	45.6	lb	
Sodium hydroxide	194	lb	
Sodium nitrite	17.7	lb	
Energy Usage			
Process Energy			
Electricity	1,803	kwh	20,056
Natural gas	24,694	cu ft	28,645
Total Process			48,701
Transportation (1)			
Drums per load	212	(2)	
Distance to reconditioner			
Combination truck	124	miles	
Rail	73	miles	
Distance back to user			
Combination truck	115	miles	
Environmental Emissions (3)			
Atmospheric Emissions			
Hydrocarbons	134	lb	
Nitrogen Oxides	1.63	lb	
Particulates	2.50	lb	
Sulfur Oxides	0.33	lb	
Hydrochloric acid	4.40	lb	
HAPS	44.5	lb	
Solid Wastes	417	lb	
Waterborne Wastes			
BOD	67.6	lb	
COD	67.1	lb	
Suspended solids	45.2	lb	
Oil	0.22	lb	
Lead	0.0089	lb	
Zinc	0.089	lb	

(1) Transportation energy varies based on drum weight and number of reconditionings. Number of drums/load is limited by volume, not by weight; fuel usage adjusted to reflect this.

(2) The number of drums per load returning to customers is assumed to be equal to the number of drums per load sent to the reconditioner.

(3) Less than half of survey respondents provided data on emissions, and reported values varied widely. Therefore, the averaged emission values shown here are considered to have a high degree of uncertainty.

Reference: 1998 survey of U.S. drum reconditioners.

Source: Franklin Associates

Table A-4

DATA FOR THE RECONDITIONING OF 1,000 STEEL DRUMS AT WASHING FACILITIES IN EUROPE

			Total Energy Thousand Btu
Raw Materials			
Hydrochloric acid	22.6	lb	
Sodium hydroxide	90	lb	
Sodium nitrite	9.6	lb	
Energy Usage			
Process Energy			
Electricity	1,247	kwh	13,876
Natural gas	16,479	cu ft	19,115
Distillate oil	82.4	gal	13,038
Total Process			46,029
Transportation (1)			
Drums per load	222	(2)	
Distance to reconditioner			
Combination truck	109	miles	
Distance back to user			
Combination truck	84.5	miles	
Rail	4.35	miles	
Environmental Emissions (3)			
Atmospheric Emissions			
Hydrocarbons	85.4	lb	
Nitrogen Oxides	0.75	lb	
Particulates	0.43	lb	
Carbon Monoxide	0.19	lb	
Solid Wastes	410	lb	
Waterborne Wastes			
BOD	2.25	lb	
COD	14.6	lb	
Suspended solids	0.077	lb	
Oil	0.48	lb	
Metal ion	0.046	lb	
Chromium	0.019	lb	
Copper	1.58	lb	
Lead	0.048	lb	
Nickel	0.42	lb	
Zinc	2.11	lb	

(1) Transportation energy varies based on drum weight and number of reconditionings. Number of drums/load is limited by volume, not by weight; fuel usage adjusted to reflect this.

(2) The number of drums per load returning to customers is assumed to be equal to the number of drums per load sent to the reconditioner.

(3) Less than half of survey respondents provided data on emissions, and reported values varied widely. Therefore, the averaged emission values shown here are considered to have a high degree of uncertainty.

Reference: 1998 survey of European drum reconditioners.

Source: Franklin Associates

Table A-5

DATA FOR THE RECONDITIONING OF 1,000 STEEL DRUMS AT WASHING FACILITIES IN JAPAN

			Total Energy Thousand Btu
Raw Materials			
Hydrochloric acid	50.9	lb	
Sodium hydroxide	165	lb	
Sodium nitrite	2.09	lb	
Energy Usage			
Process Energy			
Electricity	1,734	kwh	19,285
Natural gas	6,485	cu ft	7,522
Distillate oil	102	gal	16,119
Residual oil	11.1	gal	1,897
Total Process			44,824
Transportation (1)			
Drums per load	119	(2)	
Distance to reconditioner			
Single unit truck	57	miles	
Distance back to user			
Single unit truck	37	miles	
Environmental Emissions (3)			
Atmospheric Emissions (4)			
Hydrocarbons	134	lb	
Nitrogen Oxides	1.63	lb	
Particulates	2.50	lb	
Sulfur Oxides	0.33	lb	
Hydrochloric acid	4.40	lb	
HAPS	44.5	lb	
Solid Wastes	973	lb	
Waterborne Wastes			
BOD	13.8	lb	
COD	10.5	lb	
Dissolved solids	0.75	lb	
Suspended solids	0.30	lb	
Oil	0.62	lb	
Metal	0.0027	lb	
Lead	5.8E-04	lb	

(1) Transportation energy varies based on drum weight and number of reconditionings. Number of drums/load is limited by volume, not by weight; fuel usage adjusted to reflect this.

(2) The number of drums per load returning to customers is assumed to be equal to the number of drums per load sent to the reconditioner.

(3) Less than half of survey respondents provided data on emissions, and reported values varied widely. Therefore, the averaged emission values shown here are considered to have a high degree of uncertainty.

(4) U.S. atmospheric emissions were used in place of Japanese emissions.

Reference: 1998 survey of Japanese drum reconditioners.

Source: Franklin Associates

Burn Process for Reconditioning Open-head Drums

The first step in burning open-head steel drums is to remove the rings and lids. Tight-head drums can be converted to open-head for the burn process by cutting off the top, similar to opening a food can.

Most burn operations are continuous (versus batch), and process from 150 to over 1,500 drums per day. Drums are inverted on a conveyor belt and sent into the burn unit, a refractory-lined furnace, with lids placed on top. The inverted position allows the contents to melt and flow out of the drums as well as burn. In some plants the conveyor chain is cooled by water and drum residues in a trough.

Some burn units have a pre-heat zone where drums are heated before entering the combustion chamber. In the combustion chamber, flames from natural gas or fuel oil burners directly contact the drums, charring drum residues and paint coatings. The average size combustion chamber is approximately 1,000 cubic feet, with temperatures ranging from 850 to 1500 degrees Fahrenheit. Residence time inside the combustion chamber ranges from 30 seconds to 10 minutes and can include time spent in pre-heat and cooling zones. Temperature and residence time can also vary based on the type of drum residue.

Combustion chambers vent to afterburners to combust exhaust gases and serve as an emission control measure. The technical design, operation, and maintenance of the afterburners varies considerably in the drum reconditioning industry. The efficiency of the afterburner depends on its operating temperature, gas retention time, and mixing gases within the combustion chamber. Typical retention times range from 0.4 to 1.7 seconds, with temperatures at 800 to 1800 degrees Fahrenheit.

Wet burner ash is collected with drainage residues when it falls into the cooling trough. After burning, drums are conveyed to a shot blaster where the drums are blasted with steel shot to remove remaining residue and paint. Shot blast dust created is normally collected by a bag house. After shot blasting the drums are rechimed, dedented, tested and finished similar to the wash process.

Only one burn-only facility participated in the surveys in Japan. That facility's data were compared to U.S. average data and found to be closely representative; therefore, in order to protect the confidentiality of the Japanese burn-only facility data, U.S. process data and Japanese transportation data are used to represent the Japanese operation. No burn-only reconditioners participated in the European survey for steel drum reconditioners; therefore, average U.S. process data and European transportation data are used to represent the European burn operation. Data for reconditioning 1,000 55-gallon open-head steel drums using the burn process are summarized in Tables A-6, A-7, and A-8 for the U.S., Europe, and Japan, respectively.

Table A-6

DATA FOR THE RECONDITIONING OF 1,000 STEEL DRUMS AT BURNING FACILITIES IN THE U.S.

			Total Energy Thousand Btu
Raw Materials			
Sodium nitrite	1.69	lb	
Energy Usage			
Process Energy			
Electricity	2,062	kwh	22,937
Natural gas	118,522	cu ft	137,486
Total Process			160,422
Transportation (1)			
Drums per load	247	(2)	
Distance to reconditioner			
Combination truck	197	miles	
Distance back to user			
Combination truck	187	miles	
Environmental Emissions			
Atmospheric Emissions			
Hydrocarbons	175	lb	
Nitrogen Oxides	41.3	lb	
Particulates	72.1	lb	
Sulfur Oxides	0.81	lb	
Hydrochloric acid	1.15	lb	
HAPS	12.4	lb	
Lead	0.0062	lb	
Chromium	0.0027	lb	
Carbon Monoxide	0.78	lb	
Benzene	0.0025	lb	
Solid Wastes	1,243	lb	

(1) Transportation energy varies based on drum weight and number of reconditionings. Number of drums/load is limited by volume, not by weight; fuel usage adjusted to reflect this.

(2) The number of drums per load returning to customers is assumed to be equal to the number of drums per load sent to the reconditioner.

References: 1998 survey of U.S. drum reconditioners.

Source: Franklin Associates

Table A-7

DATA FOR THE RECONDITIONING OF 1,000 STEEL DRUMS AT BURNING FACILITIES IN EUROPE (1)

			Total Energy Thousand Btu
Raw Materials			
Sodium nitrite	1.69	lb	
Energy Usage			
Process Energy			
Electricity	2,062	kwh	22,937
Natural gas	118,522	cu ft	137,486
Total Process			160,422
Transportation (2)			
Drums per load	230	(3)	
Distance to reconditioner			
Combination truck	124	miles	
Distance back to user			
Combination truck	107	miles	
Environmental Emissions			
Atmospheric Emissions			
Hydrocarbons	175	lb	
Nitrogen Oxides	41.3	lb	
Particulates	72.1	lb	
Sulfur Oxides	0.81	lb	
Hydrochloric acid	1.15	lb	
HAPS	12.4	lb	
Lead	0.0062	lb	
Chromium	0.0027	lb	
Carbon Monoxide	0.78	lb	
Benzene	0.0025	lb	
Solid Wastes	1,243	lb	

(1) No European burn only facilities elected to participate in this study; therefore, U.S. data are used with European transportation data.
(2) Transportation energy varies based on drum weight and number of reconditionings. Number of drums/load is limited by volume, not by weight; fuel usage adjusted to reflect this.
(3) The number of drums per load returning to customers is assumed to be equal to the number of drums per load sent to the reconditioner.

Reference: 1998 survey of drum reconditioners.

Source: Franklin Associates

Table A-8

DATA FOR THE RECONDITIONING OF 1,000 STEEL DRUMS AT BURNING FACILITIES IN JAPAN (1)

			Total Energy Thousand Btu
Raw Materials			
Sodium nitrite	1.69	lb	
Energy Usage			
Process Energy			
Electricity	2,062	kwh	22,937
Natural gas	118,522	cu ft	137,486
Total Process			160,422
Transportation (2)			
Drums per load	96	(3)	
Distance to reconditioner			
Single-unit truck	76	miles	
Distance back to user			
Single-unit truck	69	miles	
Environmental Emissions			
Atmospheric Emissions			
Hydrocarbons	175	lb	
Nitrogen Oxides	41.3	lb	
Particulates	72.1	lb	
Sulfur Oxides	0.81	lb	
Hydrochloric acid	1.15	lb	
HAPS	12.4	lb	
Lead	0.0062	lb	
Chromium	0.0027	lb	
Carbon Monoxide	0.78	lb	
Benzene	0.0025	lb	
Solid Wastes	1,243	lb	

(1) Only one burn facility from Japan participated in the survey. In order to protect the confidentiality of the data, U.S. average burn data have been used as a surrogate because the data sets were quite similar. Japanese transportation data are used.

(2) Transportation energy varies based on drum weight and number of reconditionings. Number of drums/load is limited by volume, not by weight; fuel usage adjusted to reflect this.

(3) The number of drums per load returning to customers is assumed to be equal to the number of drums per load sent to the reconditioner.

Reference: 1998 survey of drum reconditioners.

Source: Franklin Associates

U.S. RIPA/ISRI SCRAP PREPARATION STANDARD

For several years in the U.S., the Institute of Scrap Recycling Industries (ISRI) has cooperated closely with RIPA (the Reusable Industrial Packaging Association; formerly ACR, the Association of Container Reconditioners) in effecting a jointly-prepared scrap preparation standard. This standard is incorporated in the RIPA Code of Operating Practice:

> Drums that have been rejected during the inspection processes and cannot be repaired for hazardous materials service are to be cleaned and directed to non-hazardous material service or prepared for scrap. When preparing drums for scrap, the drum interior and exterior must be cleaned using an effective cleaning agent or must be thermally neutralized in a drum reclamation furnace, thereby removing all foreign matter, prior residues, labels, and decorative coatings, and the drum must be mechanically or hydraulically crushed or shredded.