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

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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
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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.

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.

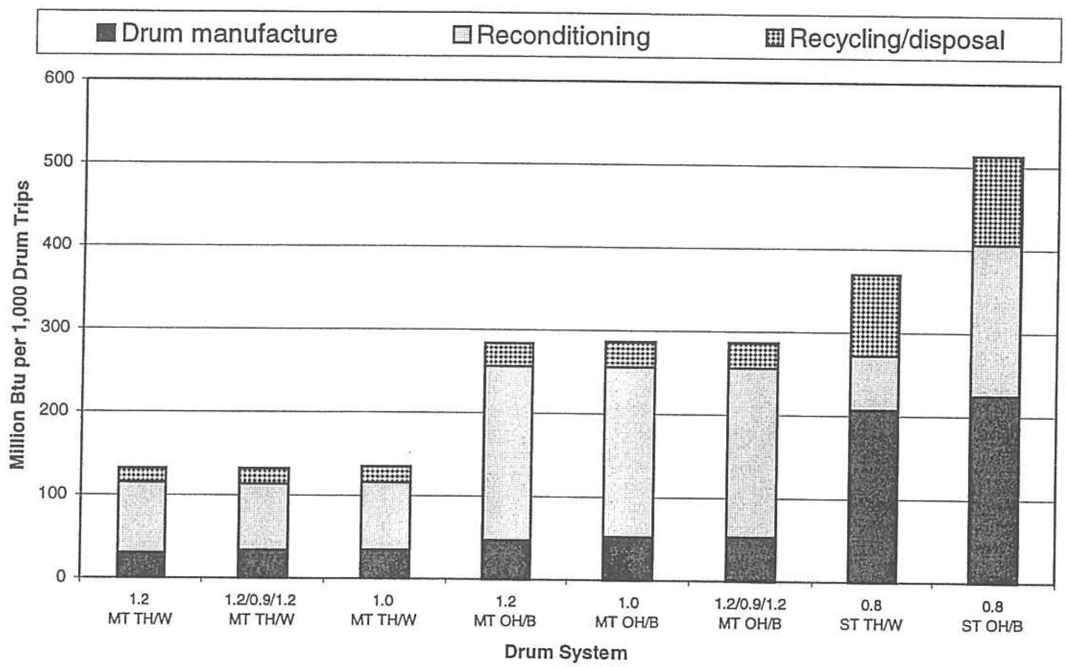
Drum manufacturers and reconditioners provided data on all drum transportation except for transportation from drum fillers to emptiers. As a result, transportation energy is somewhat understated in the results; however, since 1,000 drum trips means 1,000 trips from fillers to emptiers, regardless of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

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

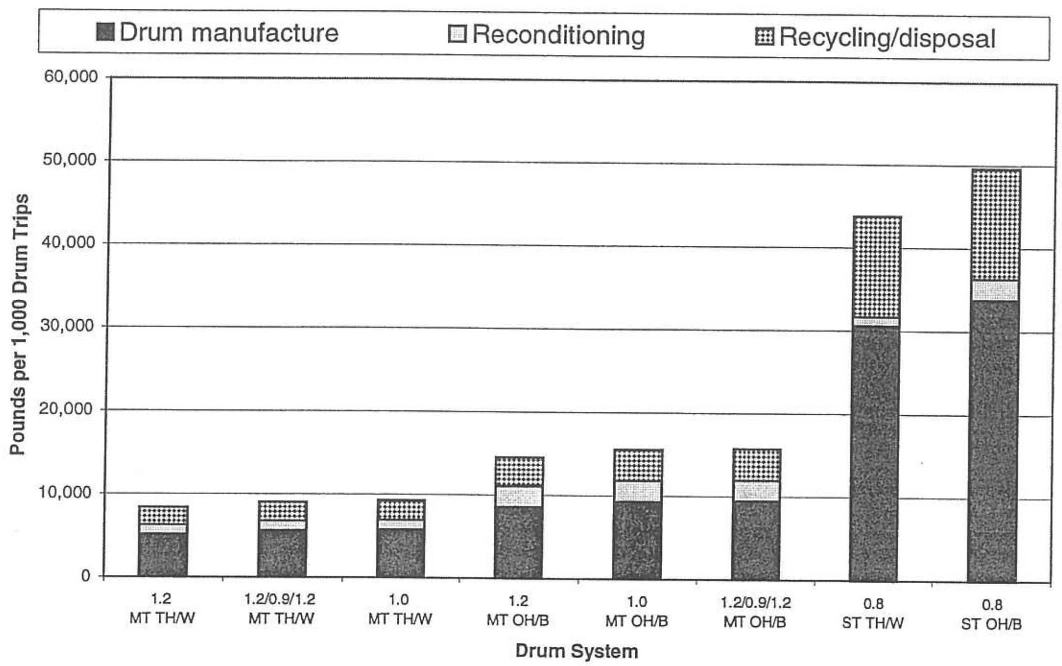


1 Abbreviations used in the figures represent the following:
MT = multi-trip
ST = single-trip
TH/W = tight-head drum/wash reconditioning
OH/B = open-head drum/burn reconditioning

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



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MT = multi-trip
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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-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-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-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.

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.

- **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.

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.

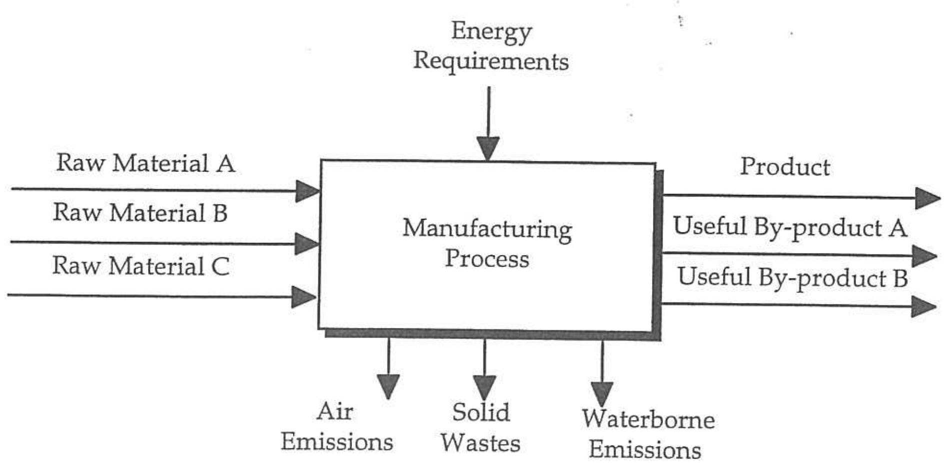


Figure 1-2. Basic input/output concept for developing LCI data.

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,

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

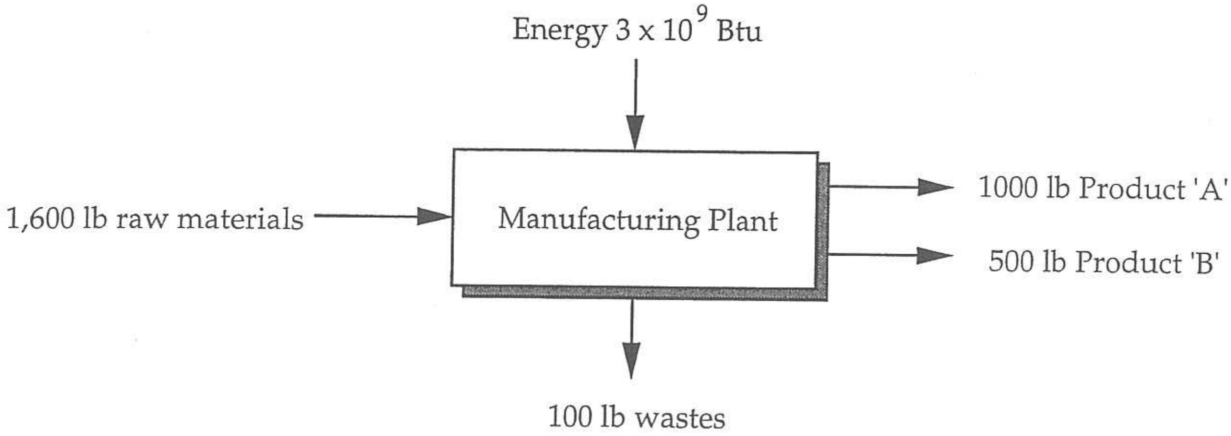
The energy content of fuels has been adjusted to include the energy requirements for extracting, processing, and transporting fuels, in addition to the primary energy of a fuel resulting from its combustion. In this study, this additional energy is called precombustion energy. Precombustion energy refers 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

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.

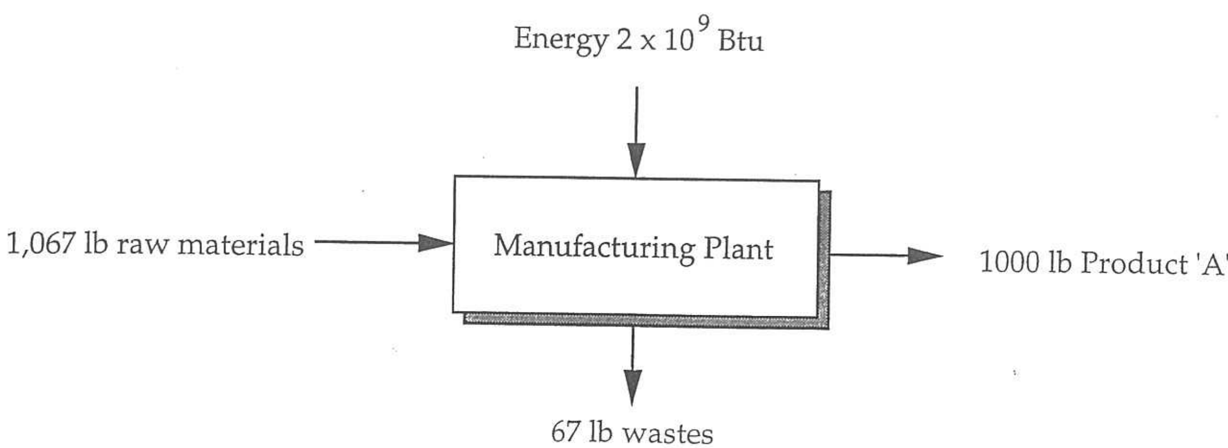


Figure 1-3. Flow diagrams illustrating coproduct allocation for product 'A'.

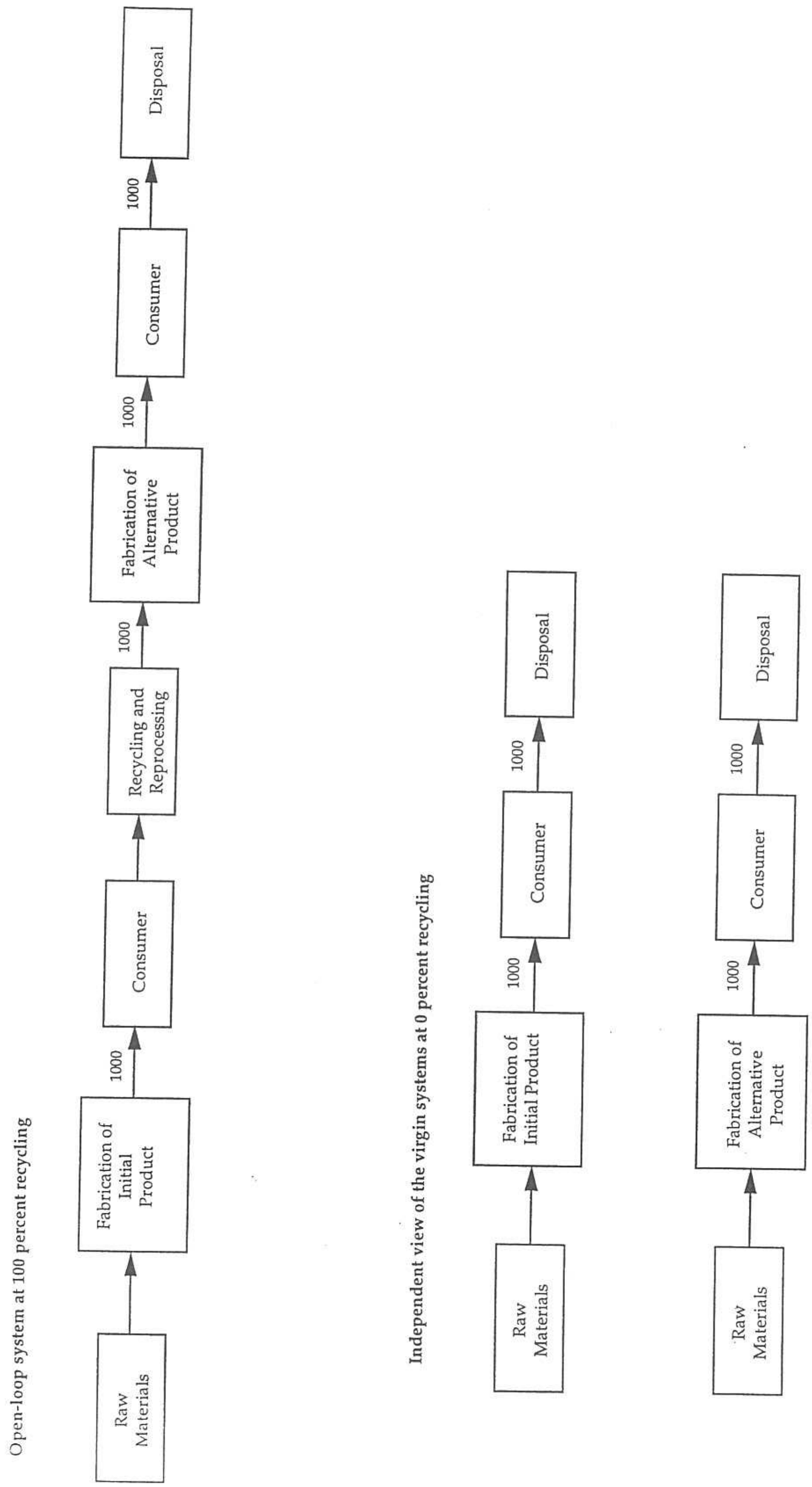


Figure 1-5. Illustration of open-loop recycling system in comparison to each system independently.

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

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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.

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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

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.

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)	% 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 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

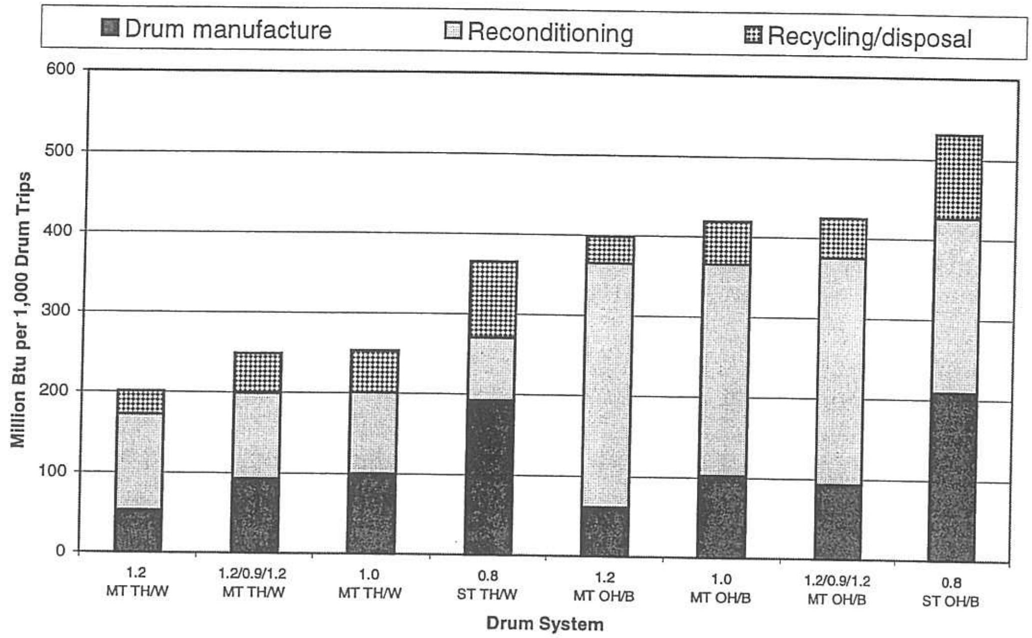
TOTAL ENERGY REQUIREMENTS FOR
SINGLE- AND MULTI-TRIP STEEL DRUMS IN JAPAN
(basis: 1,000 drum trips)

	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-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 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-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		
	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)	5,283	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.

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

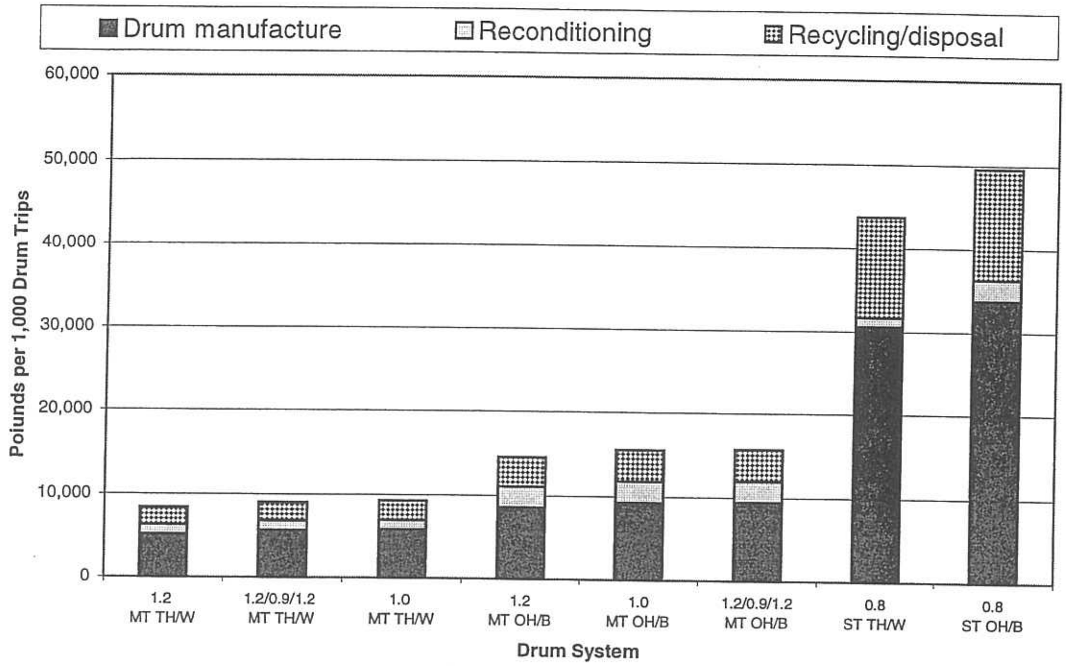
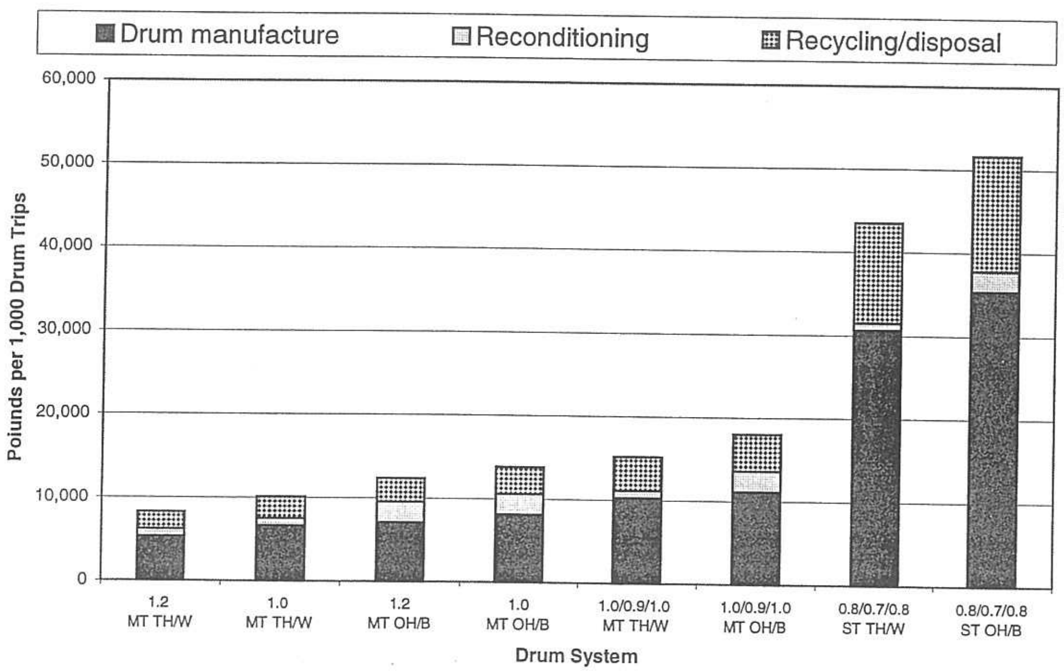


Figure 2-3-E. Total Weight of Solid Waste for European Drum Systems



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.

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-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 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-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

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-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

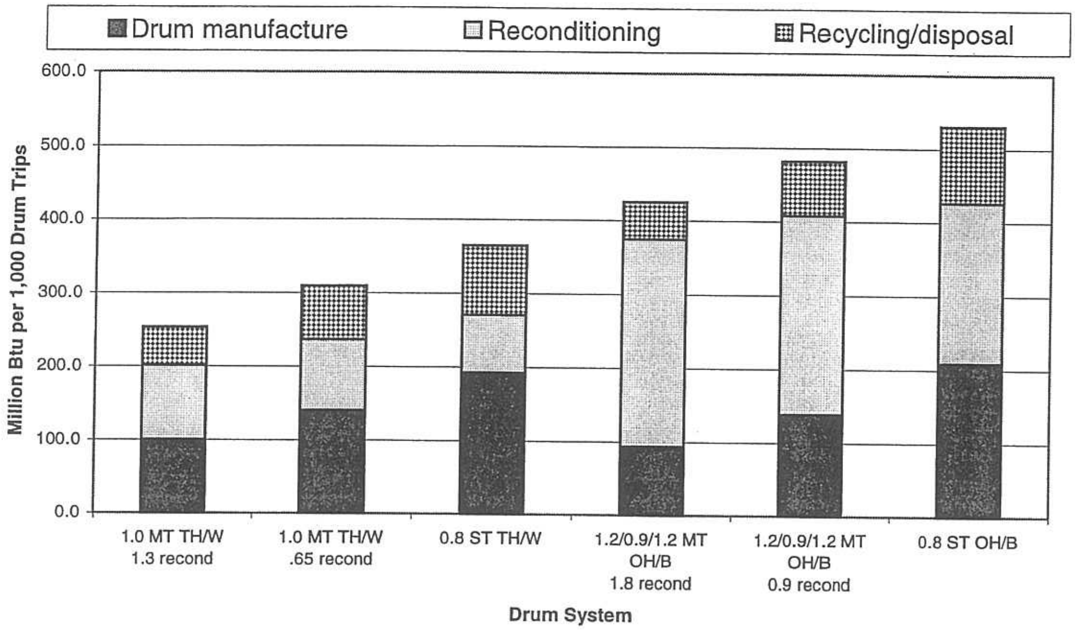
EUROPE	1.0/0.9/1.0 MT OH/B		1.0/0.9/1.0 MT OH/B		0.8/0.7/0.8 ST OH/B	
	Total	Drum Transp	Total	Drum Transp	Total	Drum Transp
Times reconditioned	3.3		1.65		0	
Times used*	4.3		2.65		1	
Number of drums require	233		377		1,000	
Drum manufacture	63.2	2.5	98.7	5.1	232.6	29.5
Reconditioning	188.3	27.3	186.2	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-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-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%

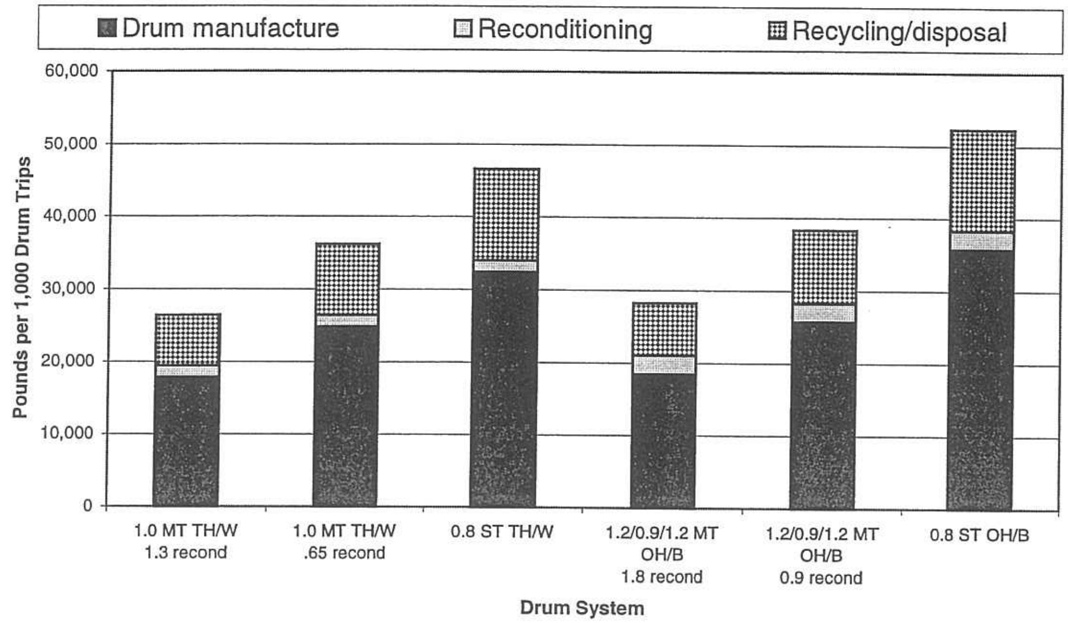
EUROPE	1.0/0.9/1.0 MT OH/B		1.0/0.9/1.0 MT OH/B		0.8/0.7/0.8 ST OH/B	
	Total	% Fuel-related	Total	% Fuel-related	Total	% Fuel-related
Times reconditioned	3.3		1.65		0	
Times used*	4.3		2.65		1	
Number of drums require	233		377		1,000	
Drum manufacture	11,115	4%	16,998	4%	35,322	4%
Reconditioning	2,500	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-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-2

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

Raw Materials			
Steel	44,994	lb	
Phosphate treatment	9.8	gal	
Energy Usage			**Total Energy Thousand Btu**
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

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-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

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-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

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.