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Total Cost of Ownership For Metalworking Fluids

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Abstract

Metalworking fluids have a greater financial impact on a company than the purchase price alone. This is often called the *Total Cost of Ownership* (*TCO),* and has two components – *hidden costs* and p*erformance leverage* - in addition to the fluid purchase price. Hidden costs arise from the fact that fluids must be managed, from purchasing and receiving, to plant floor clean-up, to waste treatment and disposal. Performance leverage results from fluids' effects on process performance, from machine tool life to product scrap and rework.

In this study, three plants using metalworking fluids were examined for fluid TCO. In all cases, annual fluid purchases were $100,000 or less. Results indicate that the ratio of annual hidden costs to fluid purchase costs ranged from a low of 1.5:1 to as high as 5.5:1 (this company spent approximately $5.50 managing fluids for every dollar of fluid purchased). The most significant components of TCO included chemical additives, electricity, spill management, and waste fluid treatment and disposal.

Performance leverage results indicated that a 20% improvement in fluid performance could produce a benefit-to-purchase cost ratio in excess of 5 (a 20% improvement in fluid performance resulted in a financial benefit more than five times larger than the purchase cost of the fluid). Most of the benefit was due to lower tooling costs from extended tool life.

These results suggest that management decisions based solely on the purchase price of metalworking fluids may be substantially different than those based on a more complete understanding of the total financial impact of fluids. In particular, opportunities to improve fluids and fluid management are currently undervalued. This results in excessive fluid waste and an unnecessary drain on company resources. The techniques used in this study provide a relatively quick and inexpensive method for companies to estimate the TCO and performance leverage for their own metalworking fluids.

Executive Summary

Metalworking fluids have a greater financial impact on a company than the purchase price alone. This is often called the *Total Cost of Ownership* (*TCO),* and has two components – *hidden costs* and p*erformance leverage* - in addition to the fluid purchase price. Hidden costs arise from the fact that fluids must be managed, from purchasing and receiving, to plant floor clean-up, to waste treatment and disposal. Performance leverage results from fluids' effects on process performance, from machine tool life to product scrap and rework.

Results from the three studies of smaller manufacturers suggest that the combined effect of hidden costs and performance leverage could range from 1-10 times the purchase cost of the fluids (see table below). These results are consistent with previous estimates for chemicals, which have suggested financial impacts of from one to seven times purchase costs. The greatest factors contributing to hidden costs include electricity, chemical additives, fluid clean-up, and waste treatment and disposal. The most significant sources of performance leverage were extended tool life and improved product quality (resulting in reduced scrap and rework).

However, results also suggest that the ratios, the major costs, and the major performance benefits, can vary significantly from plant to plant. The three plants in this study were all small to mid-size metalworking facilities in Illinois. Nevertheless, hidden cost ratios varied from 1.5:1 to 5.5:1 and performance leverage ratios varied from 0.3:1 to 5.2:1. For hidden costs, the major factors contributing to those costs were very different at each of the plants (Table 4-1). The reasons for variation in the hidden cost ratio suggest that a higher ratio does not, by itself, indicate higher costs for the plant. In fact, in some cases, as fluid management improves fluid purchases may decrease while the hidden cost ratio increases.

Summary of hidden costs and performance leverage for three case studies.

Hidden Costs: Ratio of Hidden Costs to Fluid Purchase Costs

PLANT	RATIO	GREATEST COSTS
Plant A	3.5:1	Electricity, chemical additives
Plant B	1.5:1	Waste disposal
Plant C	5.5:1	Fluid clean-up

Performance Leverage: Ratio of 20% Performance Benefits to Fluid Purchase Costs

PLANT	RATIO	GREATEST BENEFITS
Plant A	2:1 to 5:1	Tool purchases, scrap/rework, process cycle time[a]
Plant B	0.3:1	Tool rework
Plant C	5.2:1	Tool purchases, scrap

a – uncertain estimate
b – mostly labor savings

The TCO estimation method developed for this research appeared to work well, producing reasonably accurate results with a relatively small input of personnel time. The 8-step process was specifically designed to produce estimates in a relatively short period of time without extensive demands on personnel, yet produce results that are accurate enough to guide management decision-making. It is intended to be used by companies to produce results within two weeks under the direction of an experienced analyst.

The three case studies in this report found that both hidden costs and performance leverage estimates varied considerably between plants. More case studies are needed before the TCO for metalworking fluids can be accurately characterized. Moreover, very few TCO studies have been performed on chemicals other than metalworking fluids. Research is needed to characterize the range of total costs across a wide array of commonly used industrial chemicals. Such results are likely to lead to better management decision-making with regard to waste-minimization opportunities.

The TCO estimation method used in this study is similar to methods used by others and has proven to be practical. Greater businesses application of the TCO estimation method should improve environmental and economic performance. It may be possible to include TCO assessment as part of technical assistance programs currently offered to businesses by WMRC and similar agencies. It may also be possible to encourage businesses to undertake TCO assessment themselves through workshops or other venues at which the method can be demonstrated.

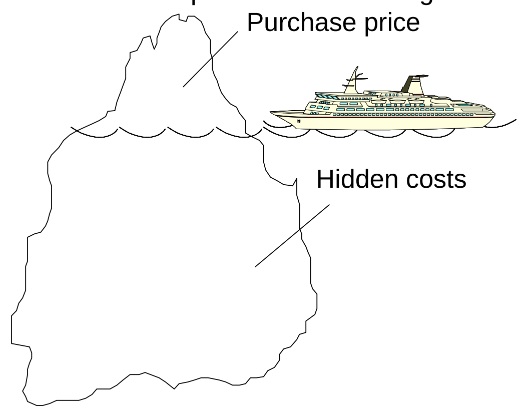
Chapter I

Introduction

What is Total Cost of Ownership and Why is it Important?

We learn early in life that the price of a product is often only a small part of the costs that we will experience over the life of the product. Electric toys require a steady stream of new batteries. Dolls require the latest in fashion accessories. Bicycles need new tires and brakes as well as regular maintenance. If we could sum these costs and add them to the original purchase price, we would reveal the product's Total Cost of Ownership (TCO). TCO represents the total of all costs related to a product, from purchase to usage to disposal (and beyond).

Figure 1-1. The hidden costs of materials are like the hidden portion of an iceberg.



One way to visualize TCO is an iceberg (Figure 1-1). The tip of the iceberg represents the product's purchase price. The bottom of the iceberg represents all the other costs that must be incurred in order to obtain, use, and dispose of the product.

Many business managers have come to recognize that the TCO for many of the products they buy are significantly greater than the purchase price. Probably no product has been more thoroughly studied from a TCO perspective than computers (Emigh 1999). For example, in some companies, the cost of managing the computer system can be as much as three times the cost of purchasing the computer hardware and software (Jacobs 1998a). Similar TCO studies have been performed on a diverse set of products, including photocopiers, office desks, and cars (Tibben-Lembke 1998). In general, it has been estimated that the price of materials purchased by manufacturers probably reflects only about 25%-35% of the total cost of those materials (Riggs and Robbins p77). [Total Cost of Ownership is often used synonymously with Life-cycle Cost. As we will use the term in this report, we refer to only that portion of the product life-cycle for which the manufacturing plant bears the costs.]

Table 1-1. Selected examples of the business benefits of TCO (adapted from Ellram, 1993).

- Provides critical data for product mix, target pricing, ABC, and other company initiatives.
- Drives plant and suppliers to focus on reducing total costs.
- Forces (and allows) purchasing to quantify tradeoffs with purchase price.
- Provides a framework to evaluate and compare suppliers.
- Provides a basis for supplier negotiations.
- Gets other personnel constructively involved in purchasing decisions.
- Improves communication about purchases both internally and with the supplier.
- Forces a firm to look at how their own requirements and procedures may actually increase costs.
- Measures results of improvement efforts.

In manufacturing, failing to account for the total cost of materials can lead to poor management decisions with significant implications for profitability. Environmentally, it can lead to excessive use and waste of materials. Specifically, lack of accurate TCO data can lead to at least two types of management errors. This first involves process improvement. As managers strive to continuously improve the efficiency of processes, they must rely on data about the cost of each operation in the manufacturing process. Underestimating the true cost of materials can make an operation appear to be far more efficient than it truly is. Efficiency improvement efforts and resources may be mistakenly directed elsewhere. Some of the business benefits of TCO are listed in Table 1-1.

The second type of management error involves product-mix decisions. Manufacturers that make a variety of products regularly assess the profitability of each product, promoting the more profitable products and changing or phasing-out the least profitable. Misallocating material costs will produce erroneous product cost estimates, distorting product profitability. This could lead to errors in determining which products to keep, change, or terminate (see box below).

Decision Errors in the Absence of TCO Data: An Example

A company makes two products, each of which requires one machining operation. Product A requires 10,000 gallons per year of metalworking fluid (MWF) costing $30/gallon for an annual buy of $300,000. Product B requires 50,000 gallons per year of a fluid costing $5/gallon, for an annual buy of $250,000. The fluid purchasing agent as well as the fluid supplier have been put under considerable pressure to reduce the price of fluid for Product A, since it is six-times the cost of fluid for Product B and has a larger annual buy.

Both fluids are mixed with water to a 5% solution, and all waste is taken by a private hauler at 30 cents per gallon. Assuming no loss of MWF, the plant generates 200,000 gal/yr of MWF waste from product A and 1,000,000 gal/yr from product B, for a total MWF waste disposal cost of $360,000/yr. The plant treats waste disposal costs as an overhead account and allocates this cost to Products A and B on the basis of employee headcount, which are equal. Thus, both are allocated a waste haulage cost of $180,000/yr. Annual costs are summarized below.

	Purchase	Allocated Haulage	Total Annual Cost
Product A	$300,000	$180,000	$480,000
Product B	$250,000	$180,000	$430,000
TOTAL	$550,000	$360,000	$910,000

Other costs for the two products are approximately equal, thus, management considered Product A to be a less profitable product. Attention was focused on the need to change or discontinue Product A. However, when waste costs are linked to the fluids that generate them, a very different profitability picture emerges.

	Purchase	Actual Haulage	Total Annual Cost
Product A	$300,000	$60,000	$360,000
Product B	$250,000	$300,000	$550,000
TOTAL	$550,000	$360,000	$910,000

In reality, Product A is considerably more profitable than Product B when the true hidden costs of metalworking fluids are identified. Moreover, management had missed an earlier opportunity to improve the profitability of Product B. The fluid supplier had previously suggested switching to a longer-lasting fluid for product B, but at a 50% price increase. This was rejected by the fluid purchaser, even though it would have reduced waste fluid by 75%. The 50% price increase would have increased the annual fluid buy to $375,000, higher than the annual buy for Product A. However, the savings in waste cost would have resulted in a net profit improvement of $100,000/yr.

	Purchase	Actual Haulage	Total Annual Cost
Product A	$300,000	$60,000	$360,000
Product B	$375,000	$75,000	$450,000
TOTAL	$675,000	$135,000	$810,000

Few studies have been performed on the TCO for chemicals used by manufacturers. Those results suggest that hidden chemical costs may range from less than one- to more than 10-times the purchase price for the chemicals (Mishra 1997, Votta et al 1998). No studies on the TCO for metalworking fluids (MWFs) have been found. Thus, manufacturers that use MWFs in the production process have little reliable data for estimating total costs. This leads to missed opportunities for improving process efficiency (reducing MWF waste) as well as over-production of high-cost products.

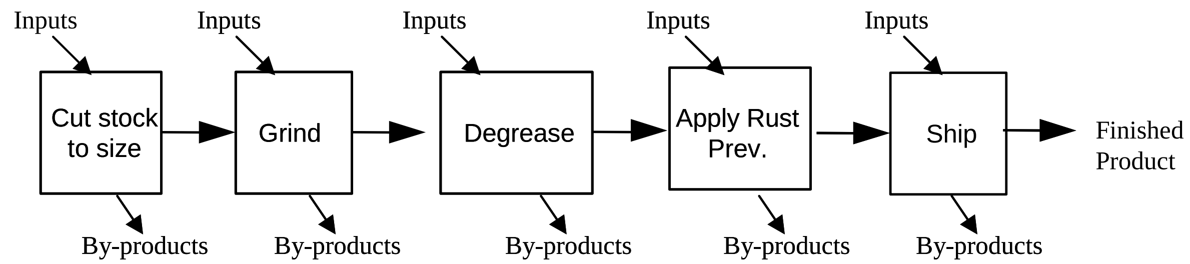
The purpose of this research is to evaluate the nature and magnitude of TCO for metalworking fluids at three manufacturing facilities. In addition to providing a better understanding of TCO, the research is intended to test the feasibility of a quick, efficient estimation process that could be used by manufacturers to estimate their own TCO for metalworking fluids.

Activities Create Costs

The best way to understand the Total Cost of Ownership and its impact on a business is to view the business as a collection of activities. Businesses exist to meet customer needs. These needs are met by performing a series of activities. For manufacturers, this involves not only manufacturing activities, but also all other activities that support manufacturing, from purchasing and maintenance to sales and waste disposal.

Take, for example, the simple manufacturing operation in Figure 1-2, composed of five basic manufacturing activities. Each activity requires certain inputs. For example, “grinding” requires inputs such as personnel, equipment, cutting fluid, and electricity. Each of these inputs represents a cost that should be allocated to that activity and added to the cost of the manufactured product. In addition, activities often result in by-products (waste) – unwanted materials or energy. These by-products may require resources for their management and disposal. Such costs should also be applied against the activity and added to the cost of the manufactured product.

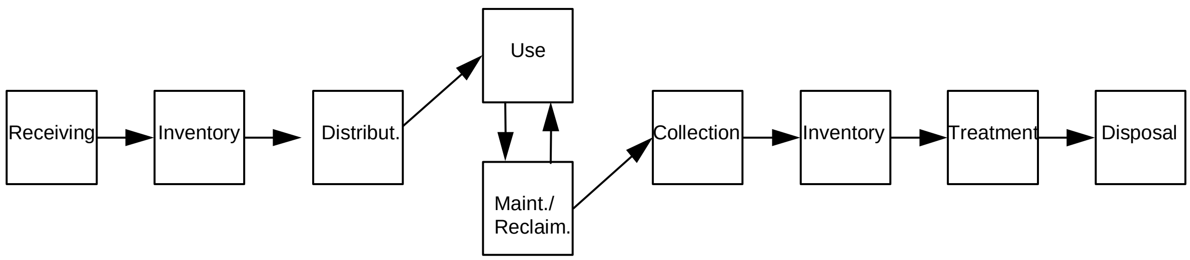
Figure 1-2. Simple manufacturing process, with inputs and by-products for each activity.



One of the inputs to the grinding operation is metalworking fluid. The total cost of the metalworking fluid should be applied to the cost of the grinding operation and the cost of the product being produced. To understand the TCO for MWF, we must identify the life-cycle of the

MWF in the plant. A typical life-cycle is pictured in Figure 1-3. Again, each activity in the life-cycle will require certain inputs and may produce certain by-products, which must be factored into the total fluid cost. Receiving includes all costs necessary to get the fluid in the plant, from vender negotiations and ordering, to receiving and vendor payment. Inventory includes costs related to storing the fluid. Distribution includes the cost of transporting fluids from storage to their point of usage. Use involves all costs associated with the actual use of the fluid, from equipment and utilities, to maintenance and employee training. Reclamation includes the cost of cleaning and/or reformulating the fluid in order to extend its useful life. It may be performed simultaneously with usage, or as a separate step. Collection includes the cost of transporting the spent fluid to treatment and/or disposal.

Figure 1-3. The typical in-plant life-cycle of a metalworking fluid (adapted from CSP1999).

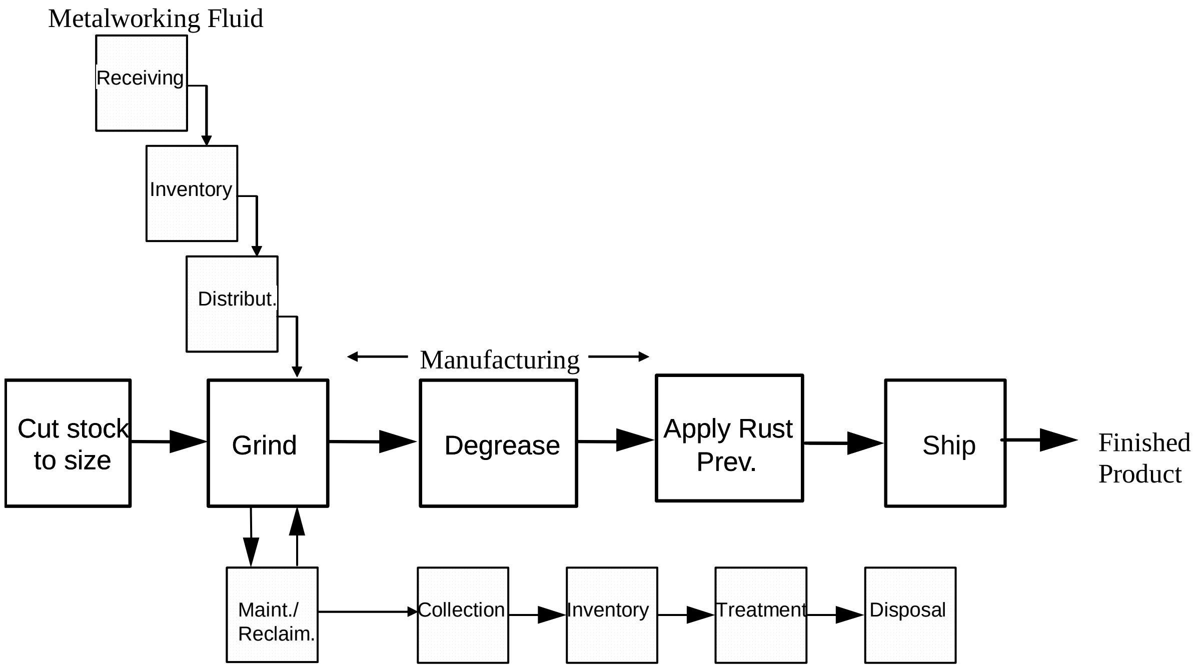


Figures 1-2 and 1-3 can be combined to illustrate how the life-cycle of the metalworking fluid intersects the production process (see Figure 1-4). Since, in this case, the grinding operation "drives" the need for metalworking fluid and its associated life-cycle costs, the grinding fluid TCO should be applied to the cost of grinding. Only then will management be able to make proper decisions about both opportunities to improve fluid management and also controlling overall costs of production.

Why "Hidden" Costs are Hidden

In most firms, the internal accounting system is used primarily to control budgets. Budgets are assigned to administrative departments, such as manufacturing, maintenance, purchasing, etc. However, manufacturing operations require activities that cut across administrative boundaries. As a result, internal accounting data usually provides little insight into the true cost of an activity. For example, if the cost of metalworking fluid is charged to the manufacturing department, maintenance may choose to deal with fluid rancidity by frequently dumping and refilling the fluid. This minimizes maintenance costs, but increases costs for manufacturing. It also increases treatment and disposal costs, which may be charged to EH&S. While each department may be held accountable for their budgets, the internal accounting system provides no overall picture of how costs are related to the activities that generate them.

Figure 1-4. The total cost of metalworking fluid is applied to the grinding operation and the cost of the manufactured product.



Moreover, many costs are allocated to "overhead" accounts – costs that are not directly related to production. These overhead costs are then allocated back to production units (and the products, themselves) in a manner that often does not reflect the true costs of production. For example, costs for treatment and disposal of MWFs may be allocated back to production units on the basis of direct labor hours in production, even though some production units may use little or no MWF (see Box, "Decision Errors in the Absence of TCO Data: An Example," above).

Together, these generally accepted accounting practices make it difficult to understand true productions costs from common internal accounting information. The result can be management errors in both production improvement and product-mix decisions.

TCO and ABC

The total cost of ownership is closely related to activity-based costing (ABC). ABC is an accounting technique to understand the true cost of processes, and thereby understand the true costs of products produced by that process. It is based upon the premise that product costs are accumulated at each step, or activity, in the production process. The cost of inputs used in each activity should be applied to the cost of the product, but it should be the *total cost* of each input, not just the purchase price. Thus, the total cost of ownership for each input is critical data for any ABC program. In this way, TCO can be viewed as one component of ABC. However, it is not necessary to be using an ABC accounting system to use and benefit from a TCO analysis.

TCO and Environmental Accounting

The past decade has seen considerable interest in the field of environmental accounting (EA – sometimes referred to as environmental management accounting). TCO has much in common with EA, but it also has some important differences with respect to the types of costs that are considered in the analyses.

Environmental accounting may include the five types of costs listed in Table 1-2, from conventional, internal costs, such as direct labor and materials, to societal costs associated with business activities or products, such as environmental damage or human health effects. TCO, on the other hand, typically includes only the first two types of costs. That is, TCO typically focuses on tangible, internal business costs that affect the "bottom line" of the firm. Contingent and intangible costs could be included in a TCO analysis, but most business managers consider such estimates speculative and less relevant for day-to-day management decision-making. Thus, TCO analysis in this report will follow the lead of previous TCO analyses by including only Type I and Type II costs.

Table 1-2: Costs typically included in Environmental Accounting (AIChE 1999, USEPA 1995).

Type I – Direct Costs – Direct cost of capital investment, labor, raw material and waste disposal (if allocated directly to the process)l. May include both recurring and non-recurring costs. Includes both capital and operations and maintenance (O&M) costs.

Type II – Potentially Hidden Costs – Indirect not allocated to the product or process. May include both recurring and non-recurring costs. May include both capital and operations and maintenance (O&M) costs. May include outsourced services.

Type III – Contingent Costs – Liability costs include fines and penalties caused by non-compliance, and future liabilities for forced clean-up, personal injury and property damage.

Type IV – Internal Intangible Costs – Costs that are paid by the company, but may be difficult to measure. Includes: customer acceptance, customer loyalty, worker morale, worker wellness, union relations, corporate image, community relations, and estimates of avoided costs – fines, capital, etc.

Type V – External Intangible Costs – Costs not paid directly by the company. Includes deterioration of the environment and health of the public.

TCO and EA also differ in the scope of the product life-cycle included in the analysis. Life-cycle addresses the flow of material through the business value chain, from raw material extraction and processing, to product fabrication, to the consumer, and to final disposal (AIChE, 99). EA can include this entire life-cycle range. TCO, on the other hand, is typically performed as a "gate to gate" analysis. That is, it examines the cost of a material from arrival at the loading dock, to its removal as a waste product.

Given these limitations on TCO, it is natural to ask why an environmental manager would choose to use TCO instead of EA. We believe that EA is an extremely valuable tool. However, for many companies, the move to EA from standard cost accounting and price-based purchasing is simply too large to make in one step. TCO offers a valuable first step on the road to EA. We believe that for many (perhaps most) businesses today, TCO is more likely than EA to lead to better environmental and business decision-making by management. This is based on three observations.

1. EA can require an enormous amount of data, typically well beyond the time and resources available to the environmental manager. While TCO can require a significant amount of data-gathering, it is typically much more feasible.

2. EA includes costs (Types III-V, such as possible future liabilities, worker morale, and environmental damage) that are extremely uncertain and are often not the basis on which managers are evaluated by superiors. As a result, estimates of such costs can become a justification for contesting or ignoring EA analyses if results conflict with decisions that would be in the manager's best short-term interests.

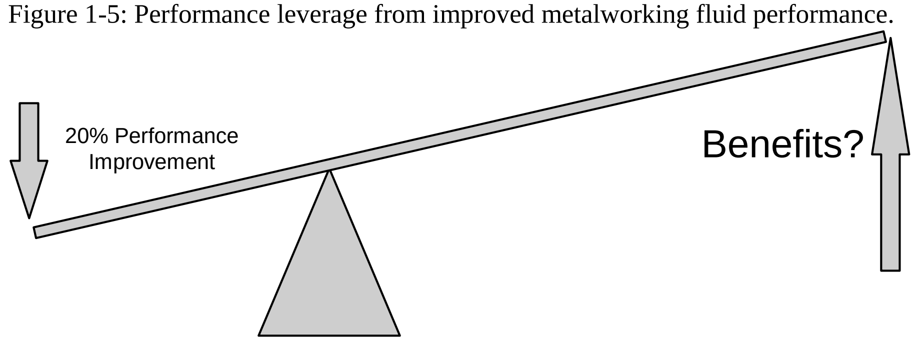
3. TCO analyses often provide sufficient evidence to move management in the direction of better environmental decisions.

Thus, in many circumstances, TCO is easier to implement, provides data that are more understandable and relevant to management, and moves management in the direction of environmentally-sound decision-making.

Performance Leverage

Metalworking fluids affect the financial health of a company not only in terms of what they cost to manage, but also in how they perform. Metalworking fluids affect such factors as machine tool life, equipment life, process downtime, scrap and rework. These can have a substantial financial impact on a company.

Figure 1-5: Performance leverage from improved metalworking fluid performance.



Thus, while fluid management costs can best be thought of as an iceberg, as in Figure 1-1, performance leverage can best be thought of as a lever (Figure 1-5). A given increase in the performance of the metalworking fluid, such as a 20% increase in tool life, produces a financial benefit for the company - the greater the benefit, the greater the performance leverage of the fluids (Bierma and Waterstraat, 2000).

It is unclear how other studies of chemical TCO have addressed the distinction between hidden management costs and performance leverage (Mishra 1997, Votta et al 1998). It is clear, however, that a rule-of-thumb ratio of 10:1 ($10 of hidden costs for every dollar of chemical purchased) that is often used by chemical suppliers includes performance leverage – tool costs, scrap, process downtime, etc.

Though it is often viewed as part of the total cost of ownership for metalworking fluids, performance leverage costs were kept separate from hidden fluid management costs in this study. This is for two reasons. First, the two types of costs address distinct questions. Hidden management costs address the question “What does it cost us to achieve the current level of metalworking fluid performance?” Performance leverage addresses the question “If we could get improved metalworking fluid performance, how significant would the benefit be for the company?” Second, estimating performance leverage as a hidden cost requires extensive process research. For example, to include machine tooling costs (a performance leverage issue) as a hidden cost, it is necessary to identify the extent to which tooling costs are increased by the current metalworking fluid over the tooling costs that would result from the best currently-available alternative fluid, taking into consideration price differences. This research is not only time and data intensive, but we believe that management is likely to be skeptical of the results since they are difficult to verify. Thus, for these reasons, we estimate hidden costs and performance leverage separately when examining the financial impact of metalworking fluids on the firm.

Chapter II

Methods

Types of Costs Included in TCO

TCO has been defined as "the sum of all expenses and costs associated with the purchase and use of equipment, materials, and services." (Monczka 1998). Riggs and Robbins (1998) suggest a formula for capturing total costs. The formula and its components are presented in Table 2-1.

Whereas TCO is typically applied to an asset (such as computers or photocopiers), chemicals are generally viewed as an expense. This requires several changes in the definition of TCO as applied to chemicals. Specifically, we estimate the TCO for metalworking fluids in three components:

1. Purchase Cost – the annual spend in metalworking fluids (MWFs)
2. Hidden Costs – costs related to the management and use of MWFs.
3. Performance Leverage – financial benefits expected from a 20% improvement in MWF performance.

Table 2-1-. Traditional cost components of the Total Cost of Ownership (TCO) (adapted from Riggs and Robbins 1998)

TCO = MC + A + T + M + O + E + H - S

MC = Material Cost
A = Acquisition Cost
T = Transport and storage (internal) costs
M = Maintenance costs
O = Operating costs
E = Environmental costs
H = Health and safety costs
S = Salvage value

In estimating hidden costs, we consider the following costs at each stage in the chemical life-cycle:

Direct Labor – personnel involved directly with the chemical, including purchasing, receiving, handling, monitoring, etc.)
Materials – additional materials required during any stage of the chemical life-cycle (water, fluid additives, etc.)
Equipment – depreciation costs for equipment needed to manage or use the chemical.
Energy – electricity or other energy needed to manage or use the chemical (heating fuel, electricity for pumps, etc.)
Auxiliary Operations – ongoing activities required to support chemical management or use (EH&S compliance, fluid clean-up, waste management, etc.)
Intermittent Operations – periodic activities required to support chemical management or use (equipment maintenance).

Examples of the above costs that might be experienced by a plant have been enumerated in many sources (AICHE 1999 p2-5, CSP 1999 p4.7; Pojacek 1997, Savage and White 1995 p9, WMRC 2003 p4). Readers are referred to these sources for more detail.

TCO Estimation Process

As discussed in the previous chapter, TCO can be viewed as a component of activity-based costing, or ABC. Thus, the basic steps in estimating TCO derive from ABC (Pojacek 1998). In general, the basic approach to estimating activity-based costs is:

1. Map the process – understand and diagram the activities that take place in the process being studied, including the flows of materials.
2. Account for resources – account for resources consumed by each activity, including equipment, materials, personnel, and utilities.
3. Cost the resources – estimate the cost of resources consumed by each activity.
4. Evaluate the costs – combine and analyze cost data to provide insights into nature and implications of the costs.

This basic approach has been adapted to TCO (Ostrenga 1992). Considerable work in applying TCO to chemicals had been performed by the Chemical Strategies Partnership of San Francisco (CSP 1999). Using their work as a foundation, we developed an the 8-step process outlined below, accommodating the separate evaluation of hidden costs and performance leverage. The 8-step process was specifically designed to produce estimates in a relatively short period of time without extensive demands on personnel, yet produce results that are accurate enough to guide management decision-making. It is intended to be used by companies to produce results within two weeks under the direction of an experienced analyst. Each case study in this report took considerably longer, however. This is because of the additional time needed to become familiar with the manufacturing process, identify and establish working relationships with appropriate information contacts within each plant, work-out the resource and cost estimation methods needed for each case, and build appropriate spreadsheet templates. However, our experience suggests that the entire process could be accomplished in under two weeks if conducted internally by plant personnel.

Ideally, each step is performed by a team representing the range of expertise needed to understand, document, and evaluate the process. However, this process can also be performed by a lead researcher who then meets individually with plant personnel familiar with different steps in the fluid life-cycle. Since it is difficult to coordinate schedules of many individuals, this one-on-one approach may be more practical. Our research was conducted using a mix of these two approaches.

Step 1 – Determine Scope of Study

Because a goal of this research was to demonstrate a TCO assessment method that could be applied by staff within a short time period, it was important to set the scope of the project accordingly. In a large, complex operation, this may mean limiting the study to a particular operation and a limited number of fluids. The case study for Plant A, for example, was limited to one type of grinding operation. Such studies can then be repeated for other operations or fluids in other parts of the plant as time and resources allow.

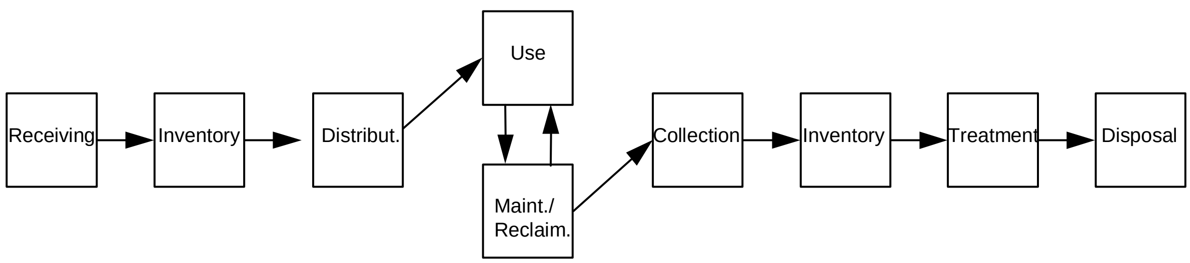
In smaller or less complex operations, most or all operations can be included in the study. A broader range of fluids can also be included. The case studies for Plants B and C, for example, were plant-wide and included all metal-working fluids.

Step 2 – Diagram the Fluid Life-cycle

From the plant's perspective, the metalworking fluid life-cycle begins with the need to purchase fluid and ends with disposal. Most life-cycles are variations on that pictured in Figure 2-1.

Each box in Figure 2-1 may be composed of many activities. For example, we typically include all purchasing-related activities in "Receiving" as well as activities related to unloading trucks and processing invoices.

Figure 2-1. The typical in-plant life-cycle of a metalworking fluid (adapted from CSP 1999).



Step 3 – Identify Inputs and Outputs at Each Step in the Life-cycle

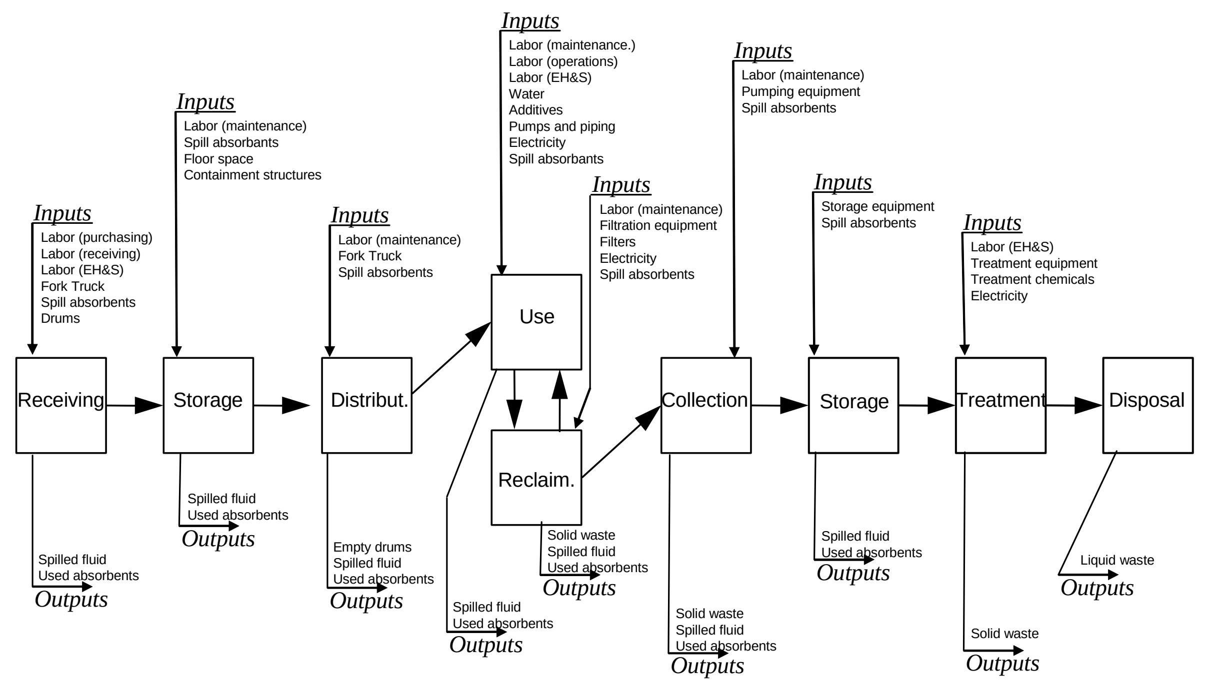
Most steps in the life-cycle of a metalworking fluid require certain inputs, such as labor, equipment, or energy, as they are performed. As we interview plant personnel, we usually begin by adding the inputs to a diagram of the fluid life-cycle (see Figure 2-2). The diagram provides a visual aid to the interviewee in explaining the activities involved in each step.

We also document process inputs and outputs in table form. Table 2-2 provides an example for the Receiving step. Note that Receiving is composed of five operations. In the first set of columns, personnel involved in each operation are identified by department. Materials, equipment, and energy inputs can be noted in the middle columns. Any outputs of the process can also be noted. In this case (Plant B case study) improved drum handling procedures had essentially eliminated spills, so there are no inputs or outputs related to fluid spills.

Step 4 – Identify Auxiliary and Intermittent Operations

Many activities are required to support the use of metalworking fluids, even though they are not directly related to fluid management or are not performed on an ongoing basis. These have been termed auxiliary (or ancillary) operations, and intermittent operations (Pojacek 1997). Auxiliary operations are activities performed on an ongoing basis, but are only indirectly related to fluid management. For example, environmental health & safety personnel may check drum labels, maintain chemical usage data, perform routine inspections, and complete regulatory paperwork. Maintenance personnel may clean floors and launder shop towels. Solid waste from fluid filtering operations must be disposed. Most outputs from the metalworking fluid life-cycle require some sort of auxiliary operation to manage them. Auxiliary operations are required by the use of metalworking fluids in the plant, but they do not involve the direct management of fluids.

Figure 2-2. Example inputs and outputs for the life-cycle of a metalworking fluid.



Intermittent operations are required only periodically. For example, equipment maintenance may be performed yearly. Dumping and refilling of central sumps for metalworking fluids may be performed every several months. Employees may need training and respiratory fit testing each year. Again, these are required by the use of metalworking fluids, but because they are not part of ongoing operations, they should be costed separately. All auxiliary and intermittent operations are noted in the same table as inputs and outputs (see Table 2-2 as an example).

Table 2-2. Example table for documenting inputs, outputs, auxiliary operations, and intermittent operations for a step in the fluid life-cycle.

	Personnel					Inputs			Outputs	Auxiliary Operations	Intermittent Operations
ACTIVITY	Operations	Maint.	Purchasing	Receiving	Accounting	Materials	Equipment	Energy			
1.1 Inventory check/ Paperwork	X	X									
1.2 Order			X								
1.3 Receive/log				X						EH&S	
1.4 Transport to storage /Return empty bins				X			Fork truck				
1.5 Payment					X						

Step 5 – Estimate Costs for Inputs, Auxiliary Operations, and Intermittent Operations.

Cost estimation is the most time-consuming and uncertain step in the analysis. However, it should be remembered that one goal of this project was to use cost estimation procedures that were relatively quick, yet provide sufficient accuracy to result in significantly better management decisions. We will first discuss cost estimation for inputs and then explain how auxiliary and intermittent operations are costed. All costs are expressed on an annual basis.

Costing Inputs

Cost estimation for inputs is done in two stages. First, the amount of each input consumed at each operation is estimated. Second, the cost of these resources is estimated. Quantifying the consumption of inputs is done by either a "top down" or "bottom up" approach. In a "top down" approach, the total consumption of an input is known, and the amount devoted to a specific operation is estimated. For example, it may be known that the plant has one staff member devoted to fluid management. This person estimates the proportion of his/her time devoted to the operation in question. Similarly, the total volume of deionized water produced for plant may be known. The proportion of this water used in the operation in question is subsequently estimated.

On the other hand, a "bottom up" approach begins with estimating consumption of the input each time the operation is performed. This is multiplied by the number of times the operation is performed in a year to get annual consumption. For example, unloading a truck of metalworking fluid may require two Receiving personnel for one hour. In a year of 20 deliveries, this would consume 40 staff-hours.

The choice of "top down" or "bottom up" cost estimation depends upon the quality of available data. Where "bottom up" data are readily available and reliable; this approach is usually preferable since it is calculated from a detailed understanding of the operation in question. However, "top down" data is often easier to obtain, and can provide estimates that are sufficiently accurate for our purposes. A mix of "top down" and "bottom up" estimation was used in this study.

Cost data for each input was also collected from participating plants. Personnel were costed at an hourly rate provided by management and included fringe benefits. Equipment costs were annualized by dividing the capital costs by the expected useful life of the equipment. No attempt was made to account for the cost of capital (except for inventory) or the time value of money (present value analysis). We found that management preferred simple and straightforward cost estimates, rather than those involving more complex accounting and financial analysis. It also simplified the estimation process.

Costing Auxiliary and Intermittent Operations

Auxiliary and intermittent operations were costed as independent activities and applied to the cost of fluid management. For example, clean-up of fluid that splashes from machines to the plant floor is an auxiliary operation and requires labor, materials (absorbent products), and contractual expenses for waste disposal. These are combined into an annualized cost an applied to the fluid management life-cycle. Similarly, maintenance and repair of a central fluid system is an intermittent operation that usually requires labor and equipment expenditures. These are combined, annualized and applied to the fluid life-cycle.

Step 6 – Identify Significant Costs and Improve Cost Estimates Where Warranted.

Once costs are estimated, the most significant costs can be identified. This is done both by cost type and by stage in the fluid life-cycle. The most significant costs can be re-examined to determine if more precise cost estimates are warranted. For example, in Plant A, electricity for central system pumps was identified as one of the most significant factors contributing to overall fluid costs. Based upon this, additional time was spent to gather more accurate data on the size of motors and pumps, and the periods of operation. Though the new data did not significantly change the estimated costs, management could be more confident in the accuracy of this cost. In some cases, the time and effort needed to develop more accurate cost estimates are significant and may exceed the value of the new data. This iterative approach to improved cost estimation helps avoid spending resources on improving costs that have relatively little impact on overall costs, or would require more resources than warranted by the data.

Step 7 – Evaluate Costs by Type, Stage in the Fluid Life-cycle, Variable/Fixed Nature, and TCO Ratio.

Hidden fluid costs can be evaluated in at least four ways:

1. TCO ratio – the ratio of total annual fluid management costs to annual fluid purchases.
2. Cost type - personnel, materials, energy, etc.
3. "Hard"/"Soft" nature – costs that can produce an immediate benefit to the bottom line (such as utilities or additive purchases) versus those that must be reallocated (personnel).
4. Variable/fixed nature - costs that tend to vary with fluid volume or other short-run factors as opposed to costs that are relatively fixed.

Each of these methods can provide insights to the causes of TCO costs and opportunities for improvement. Perhaps most important is the identification of those costs that are relatively variable with the volume of fluid and fluid waste. These are costs that could be reduced in the short-run given improvements in fluid management. Materials, energy, and waste haulage are often "hard," variable costs. For example, extending fluid life can immediately reduce the volume of fluid waste and, for companies paying to haul away their waste fluid, can immediately produce savings through reduced haulage costs.

On the other hand, costs such as personnel and equipment are relatively fixed. Small reductions in personnel time generally will not reduce costs, since the person's time is simply directed to other tasks. While productivity may increase, a benefit to the company, managers are generally reluctant to consider this a cost savings.

Step 8 – Estimate Fluid Performance Leverage.

As discussed previously, performance leverage is the potential benefit that could be realized by the plant from an improvement in the performance of metalworking fluids. A 20% performance improvement was used as a benchmark, since this was judged to be both large enough to make a significant financial impact yet small enough to be considered technically feasible in many cases.

The estimation process went as follows:

1. Plant personnel were asked to identify realistic benefits that could result from improved MWF performance – such as extended tool life, extended equipment life, reduced equipment downtime, improved product quality, etc. No attempt was made to second-guess plant judgment. For example, if plant personnel believed that product quality would not be improved, no estimate of quality improvement benefits was made, even if there was some evidence for linking product quality and MWF performance.

2. Plant personnel were asked to roughly estimate the financial impact of such benefits that could be justified. In many cases, this was relatively simple, such as assuming that a 20% extension in tool life would result in a 20% reduction in tool purchases. In other cases, plant personnel developed more involved estimates of impacts on personnel and other plant activities.

3. Where a quantitative estimate was not possible, plant personnel were asked to assess the benefits in qualitative terms.

Chapter III

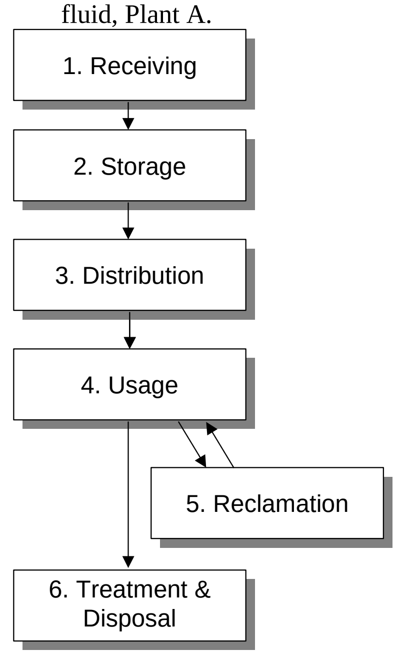
Results

Plant A - Grinding Operation

Plant and Process Background

The plant in this case study (designated "Plant A") manufactures metal components for the automotive, farm equipment, and heavy equipment industries. Many of the components require precision grinding. Over 50 grinding machines are used, drawing semi-synthetic grinding fluid from a 20,000-gallon central system. The fluid is 5% concentrate and 95% reverse-osmosis water. Approximately $96,000 in MWF is used each year by the grinding operation.

Figure 3-1. Life-cycle of grinding fluid, Plant A.



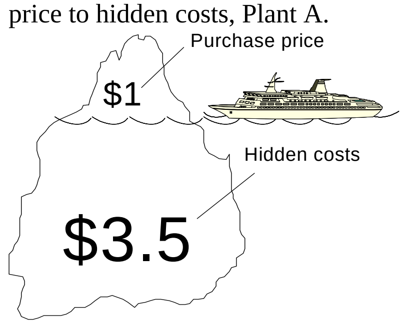
MWF Life-cycle

The plant life-cycle of the MWF (grinding fluid) can be described in six distinct stages: receiving (including purchasing), storage, transport, usage, reclamation, and treatment (see Figure 3-1). Reclamation involves pumping the fluid through a filter for one shift each working day. Each time the central system is dumped and refilled, spent MWF is sent to the plant wastewater treatment system. MWF from the grinding operations composes approximately 8% of total wastewater treated at the plant. Each of the life-cycle stages is composed of a number of smaller activities and is detailed in the appendix to this report.

Results

Results indicate that hidden costs for metalworking fluids are approximately 3.5 times greater than purchase costs for the grinding area of Plant A (Figure 3-2). That is, for every $1 spent on MWF, the plant incurred $3.50 in costs to manage and use the MWF. For Plant A, these additional costs amounted to approximately $350,000 per year. A detailed analysis of costs is provided in the appendix to this report.

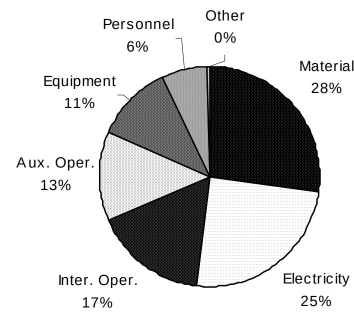
Figure 3-2. The ratio of purchase price to hidden costs, Plant A.



The breakout of these costs by cost-type is presented in Figure 3-3. Approximately one-half of the costs are due to additional materials and electricity. Material costs include all additions to the MWF concentrate. Though reverse-osmosis water is the greatest addition by volume, material costs are dominated by chemical additives. Electricity costs are driven by the energy required to pump the MWF. These two costs, materials and electricity, are both "hard" costs – any savings in these costs will contribute directly to plant profitability.

Intermittent and auxiliary operations account for about 30% of hidden costs. The largest cost in intermittent operations is the maintenance and rebuilding of motors, pumps, and other components of the central fluid system. Several significant costs are included in auxiliary operations, including wastewater treatment, swarf disposal, towel laundering, gloves, and EH&S.

Figure 3-3. Hidden cost of grinding fluid by cost-type, Plant A.



Personnel costs are a relatively small portion of overall hidden costs, although these reflect only "direct" personnel costs – individuals directly involved in managing MWFs. Personnel costs are also included in intermittent and auxiliary operations through such activities as maintenance and EH&S.

Performance leverage is the estimated benefit to the plant that would result from an improvement in metalworking fluid performance. Plant personnel indicated that extended grinding wheel life and reduced scrap and rework would be the most likely areas in which improved fluid performance would benefit the plant. They estimated that a 20% improvement in performance would result in a savings of $99,000 per year on grinding wheel purchases and $89,000 per year on scrap and rework (Table 3-1). Plant personnel also believed that improved performance could potentially reduce process downtime and increase production cycle time, though the feasibility of such improvements was unclear. They estimated that a 20% performance improvement in these areas could save the plant $296,000 per year as well as increasing production capacity. Much of these savings are from assumed reductions in labor costs. Thus, the overall benefits from a 20% improvement in fluid performance are from $188,000 - $484,000. Expressed as a ratio to current fluid purchase costs, the performance leverage for Plant A is 2:1 to 5:1 (Figure 3-4)

Table 3-1: Summary of performance leverage results, Plant A.

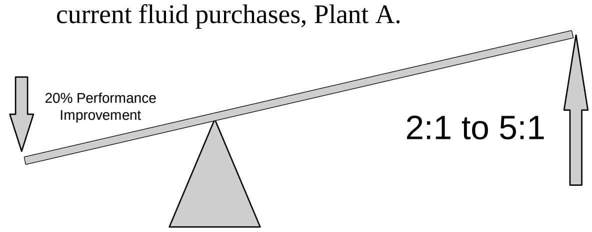
Performance Area	Annual benefit from 20% improvement
Tool purchases	$99,000
Product quality/scrap/rework	$89,000
Process cycle time/downtime	$296,000[a]
TOTAL ANNUAL BENEFIT	$188,000-$484,000[a]

a – very uncertain estimate

Implications

The financial impact of metalworking fluids at Plant A is significantly greater than the MWF purchase costs. Hidden life-cycle costs are about 3.5 times greater than purchase costs. Fluid performance improvements of 20% could produce savings of from 2 to 5 times purchase costs. Thus, there is significant potential to improve plant financial performance by improving MWFs and MWF management.

Figure 3-4. Performance leverage: ratio of benefits from 20% improved fluid performance to cost of current fluid purchases, Plant A.



The majority of hidden costs are “hard” costs – producing a direct effect on profitability. There may be numerous opportunities to reduce the need for chemical additives by finding a superior grinding fluid as well as an alternative means of controlling bacterial growth (such as pH control or membrane filtration). Electricity might be reduced by optimizing motors and pumps or using a grinding fluid that works at a lower flow rate.

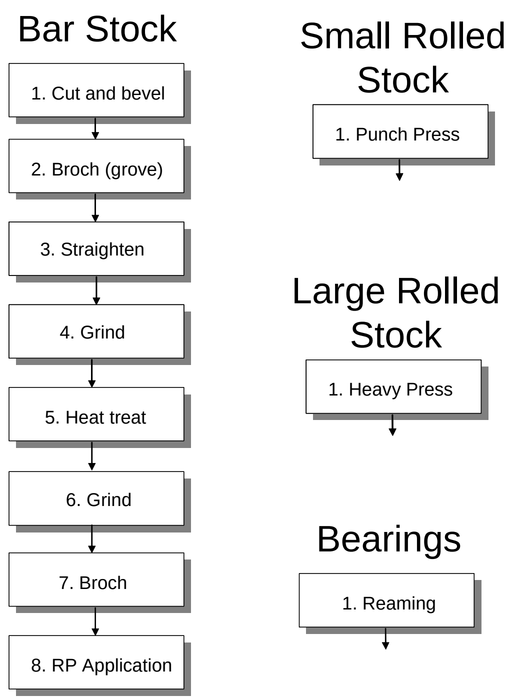
Improved fluid performance could extend tool life and reduce scrap and rework. Much of these savings involve “hard” costs, such as the purchase of grinding wheels and steel. Improved fluid performance could also potentially reduce process cycle time, though most of these savings would be in labor.

There may also be opportunities to reduce other costs. Improved filtration technology could extend not only the life of the grinding fluid, but also the life of pumps and other system components. This could reduce grinding fluid purchases, wastewater disposal costs and maintenance costs, although swarf disposal and energy costs could increase somewhat.

Plant B – Metal Products Fabricator

Plant and Process Background

Figure 3-5. Operations using metalworking fluids, Plant B.



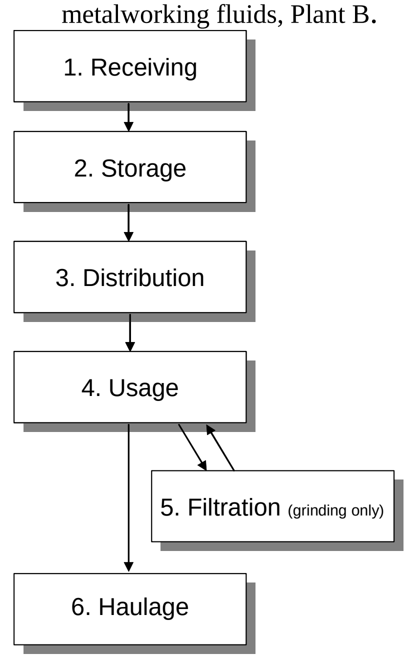
The plant in this case study (designated "Plant B") is a small-to-mid-sized metal products fabricator. Approximately 100 employees work on two shifts. The plant operated approximately 38 weeks during the year being studied.

Four processes in the plant use metalworking fluids: preparation of bar stock, small rolled stock, large rolled stock, and bearings. Important operations with regard to metalworking fluid in each of these processes are presented in Figure 3-5. Fluids include straight oils for cutting, water soluble oils for broaching and grinding, and water-based stamping fluids.

Most of the plant's metalworking equipment draws fluid from individual sumps. Several grinding machines, however, share a central sump. In addition, punch presses for small rolled stock use metalworking fluid on a one-pass basis. Approximately $65,000 in metalworking fluids are used each year.

MWF Life-cycle

Figure 3-6. Life-cycle of metalworking fluids, Plant B.



The plant's MWF life-cycle generally follows five stages: receiving (including purchasing), storage, transport, usage, and disposal (see Figure 3-6). Reclamation as a separate step occurs only for grinding operations, where the fluid is continuously pumped through a high-pressure filter. All waste fluid is hauled away by a private hauler. No wastewater treatment occurs as the plant.

Each of the life-cycle stages is composed of a number of smaller activities. Each stage and activity is presented in greater detail in the appendix to this report.

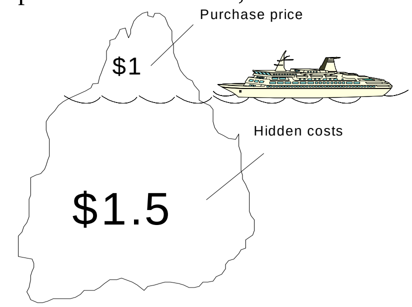
Results

Results indicate that hidden costs for metalworking fluids are approximately 1.5 times greater that purchase price (Figure 3-7). That is, for every $1 spent on MWF, the plant incurred

$1.50 in costs to manage and use the MWF. For Plant B, these additional costs amounted to approximately $97,000 per year. A detailed analysis of costs is provided in the appendix to this report.

The breakout of these costs by cost-type is presented in Figure 3-8. More than half the costs are auxiliary operations, primarily the disposal of waste metalworking fluid. Because there is no wastewater treatment at the plant, all liquid wastes are hauled off-site. For the plant, this is a "hard" cost directly related to the volume of metalworking fluid waste. Any reduction in waste generation will produce a reduction in waste hauling costs.

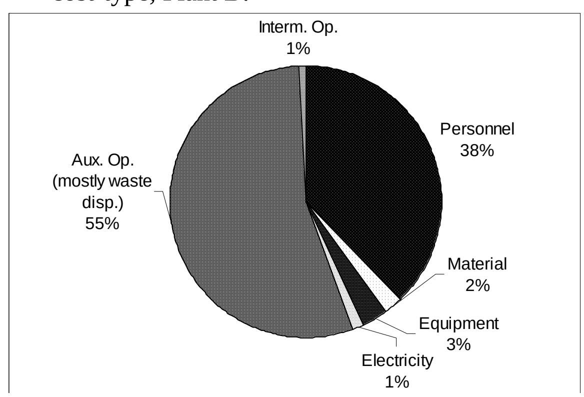
Figure 3-7 The ratio of purchase price to hidden costs, Plant B.



The other major cost is personnel, primarily involved in handling MWFs and waste MWFs. This cost is not easily reduced, since personnel time is generally redirected rather than eliminated. However, personnel time could be directed to other production related activities..

Performance leverage was assessed by the plant to be significant only for the reworking of machine tools. The plant reworks their machine tools in-house, and has relatively small annual purchases of new tools. The plant estimated that a 20% improvement in tool life would result in $16,320 less labor required for rework of tools (Table 3-2), producing an overall ratio of 0.3:1 (Figure 3-9). Since tools would be changed less often, 64 additional hours of production time (eight additional shifts) would be possible each year. Though the plant was not able to quantify this benefit monetarily, it represents an important increase in production capacity. No other area of performance leverage was considered significant and/or relevant by the plant personnel.

Figure 3-8. Hidden cost of metalworking fluid by cost-type, Plant B.



Implications

Estimates of hidden chemical costs suggest significant opportunities for cost savings. Most significant is waste disposal, which equals about 75% of annual chemical purchase costs. Since hauling costs are "hard" costs, any reduction in fluid waste will produce an immediate reduction in hauling costs. There are also a number of potential

Table 3-2: Summary of performance leverage results, Plant B.

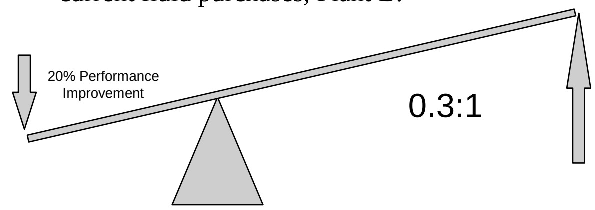
Performance Area	Annual benefit from 20% improvement
Tool rework	$16,320
Product quality/scrap/rework	a
Production downtime	b
Process cycle time	a
TOTAL ANNUAL BENEFIT	$16,320

a – not considered significant and/or relevant by plant
b – 8 additional shifts of production due to fewer tool changes

opportunities for reducing MWF fluid use and associated hidden costs. These range from cleaning and reusing stamping fluid to minimizing fluid leaks from machining equipment. Such improvements would not only reduce the cost of fluid purchases, but also reduce proportionately the cost of waste dispose.

Performance leverage results were also quite low, though not insignificant. A 20% improvement in fluid performance could result in more than a $16,000 savings. However, because this savings results from personnel reductions, it is not clear how much could actually be realized.

Figure 3-9. Performance leverage: ratio of benefits from improved fluid performance to cost of current fluid purchases, Plant B.



Estimates of both hidden chemical costs and performance leverage at Plant B were significantly lower that the other two plants studied. Possible reasons for this are discussed in the next chapter.

Plant C – Metal Products Fabricator

Plant and Process Background

The plant in this case study (designated "Plant C") is a small-to-mid-sized metal products fabricator with approximately 130 employees. The plant produces a number of products that are used as components in heavy equipment.

The plant uses two types of fluids, a straight oil for cutting and a water-soluble coolant for a variety of machining operations. Machining is done on both aluminum and steel, in separate areas of the plant. Each metalworking machine draws fluid from its own sump. Approximately $41,000 in metalworking fluids is used each year.

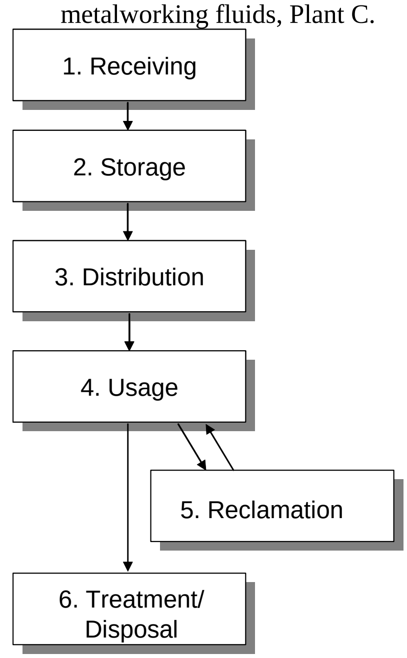


Figure 3-10. Life-cycle of metalworking fluids, Plant C.

MWF Life-cycle

The plant's MWF life-cycle generally follows five stages: receiving (including purchasing), storage, transport, usage, and disposal (see Figure 3-10). Reclamation as a separate step occurs only for the coolant from aluminum machining operations, though cutting oil is re-used until it becomes excessively contaminated with tramp oil. Coolant reclamation is accomplished through a batch operation, where used coolant is skimmed, filtered, and centrifuged. The reclaimed coolant is stored in a sump and pumped through re-supply lines back to each machine where operators use it to refill machine sumps.

During usage, a significant amount of fluid is lost through splashing or misting from the machines. This is particularly true for cutting oil, since it is applied to the cutting surface via a high pressure jet. To maintain a clean and safe work area, the plant spends considerable time and resources to collect and remove fluid lost from the machines. Dry absorbent products are used as well as gloves, uniforms, and "runners" to collect the fluid and protect workers. Each work area is also cleaned each shift.

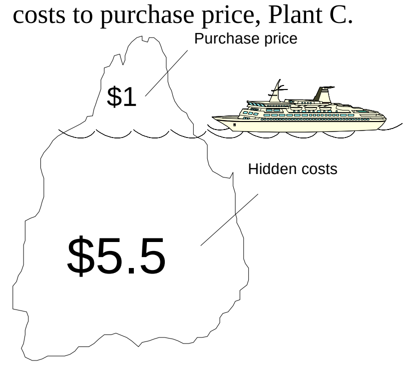


Figure 3-11. The ratio of hidden costs to purchase price, Plant C.

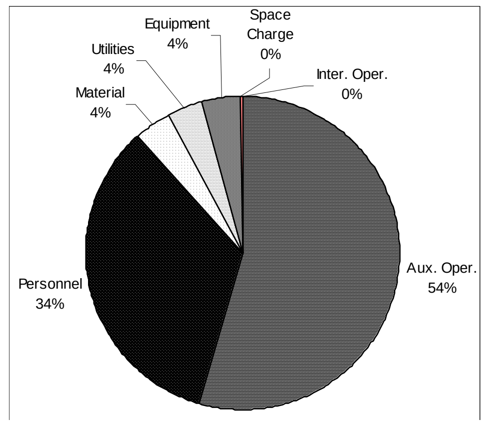
Waste oil is removed by a private hauler. Waste coolant and mop water, however, are processed in a pretreatment operation using a membrane filter to separate water from other wastes. Waste water is discharged to the local sanitary district at no additional charge. The filtered wastes are removed by a private hauler.

Results

Results indicate that hidden costs for metalworking fluids are approximately 5.5 times greater than the purchase price (Figure 3-11). That is, for every $1 spent on MWF, the plant incurred about $5.50 in costs to manage and use the MWF. For Plant C, these additional costs amounted to approximately $227,000 per year. A detailed analysis of costs is provided in the appendix to this report.

The breakdown of these costs by cost-type is presented in Figure 3-12. More than half the costs are auxiliary operations. The majority of these costs, approximately 83%, are due to oil and coolant clean-up operations at the end of each shift. Of the more than $100,000 per year spent on clean-up, only about 21% is labor. The remainder is spent on the purchase, laundering and disposal of items used to collect lost fluids.

Figure 3-12. Hidden cost of metalworking fluid by cost-type, Plant C.



About one-third of hidden costs are personnel primarily involved in handling MWFs and waste MWFs. Again, these costs are not easily translated into savings.

Performance leverage was assessed by the plant personnel to significant affect tool purchases and product quality (Table 3-3). An overall savings of $241,700 was estimated, for a ratio to purchase cost of 5.2:1 (Figure 3-13). In other words, a 20% improvement in metalworking fluid performance would result in financial benefits 5.2 times greater than it cost to buy the fluid.

Table 3-3: Summary of performance leverage results, Plant C.

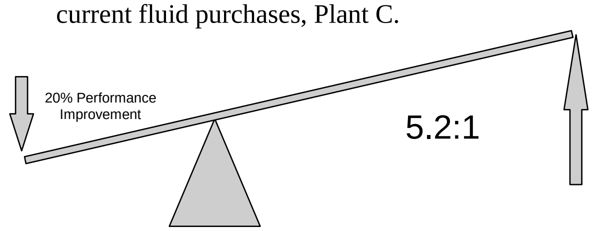
Performance Area	Annual benefit from 20% improvement
Tool purchases	$150,000
Scrap	$91,700
Rework	$12,500
Process cycle time/downtime	a
TOTAL ANNUAL BENEFIT	$241,700

a – not considered significant and/or relevant by plant

Implications

The financial impacts of metalworking fluids at Plant C are significantly greater than the purchase costs. Hidden life-cycle costs are about 5.5 times greater than the purchase costs. Fluid performance improvements of as little as 20% could produce savings more than 5 times purchase costs. Thus, there is significant potential to improve plant financial

Figure 3-13. Performance leverage: ratio of benefits from improved fluid performance to cost of current fluid purchases, Plant C.



performance by improving MWFs and MWF management.

Much of the hidden costs are "hard" costs that have a direct impact on plant profitability. The greatest cost is for fluid clean-up. While some of this cost is personnel time, the vast majority (79%) is for purchase, laundering, and disposal of absorbent products. Thus opportunities to reduce misting and overspray of MWF could have a significant affect on plant profitability.

Similarly, much of the estimates performance leverage involved "hard" costs. This is particularly true for extended tool life, where a 20% improvement would reduce tooling purchases by about $150,000 per year. Even reduction in scrap includes material costs that would be reduced through improved fluid performance.

Chapter IV

Conclusions and Recommendations

Total Costs can be Many Times Greater than Purchase Costs

The financial impact of metalworking fluids extends far beyond their purchase price. Results from the three studies of smaller manufacturers suggest that the combined effect of hidden costs and performance leverage could range from 1-10 times the purchase cost of the fluids (Table 4-1). These results are consistent with previous estimates for chemicals, which have suggested financial impacts of from one to seven times purchase costs (Mishra 1997, Votta et al 1998).

The greatest factors contributing to hidden costs include electricity, chemical additives, fluid clean-up, and waste treatment and disposal (Table 4-1). The most significant sources of performance leverage were extended tool life and improved product quality (resulting in reduced scrap and rework). Though performance leverage effects on process downtime and production cycle time were difficult to estimate, evidence suggests that these benefits could be significant in some plants.

Costs Vary Significantly from Plant-to-Plant

However, results also suggest that the ratios, the major costs, and the major performance benefits, can vary significantly from plant to plant. The three plants in this study were all small to mid-size metalworking facilities in Illinois. Nevertheless, hidden cost ratios varied from 1.5:1 to 5.5:1 and performance leverage ratios varied from 0.3:1 to 5.2:1. For hidden costs, the major factors contributing to those costs were very different at each of the plants (Table 4-1). The reasons for variation in the hidden cost ratio suggest that a higher ratio does not, by itself, indicate higher costs for the plant. In fact, in some cases, as fluid management improves fluid purchases may decrease while the hidden cost ratio increases.

Table 4-1. Summary of hidden costs and performance leverage for three case studies.

Hidden Costs: Ratio of Hidden Costs to Fluid Purchase Costs

PLANT	RATIO	GREATEST COSTS
Plant A	3.5:1	Electricity, chemical additives
Plant B	1.5:1	Waste disposal
Plant C	5.5:1	Fluid clean-up

Performance Leverage: Ratio of 20% Performance Benefits to Fluid Purchase Costs

PLANT	RATIO	GREATEST BENEFITS
Plant A	2:1 to 5:1	Tool purchases, scrap/rework, process cycle time
Plant B	0.3:1	Tool rework
Plant C	5.2:1	Tool purchases, scrap

Some of the apparent reasons for variation in hidden costs among plants include:

1. Plants with large central fluid systems may spend more on electricity and system maintenance, yet save on fluid purchases and product scrap/rework because of superior control of fluid quality.
2. Some plants require more fluid additives because of the nature of the machining that is being performed. Also, some plants purchase fluids with additives already in the fluid, while others choose to add the additives separately.
3. Plants can have very different maintenance levels and schedules. For example, while Plants B and C are similar in many ways, Plant B spends relatively little time and resources on fluid clean-up, while Plant C devotes a great deal of time and resources to clean-up. The difference in plant cleanliness was obvious in these plants. Thus, while this increases the hidden cost ratio for Plant C, Plant B is deferring these costs – which may show up in the future as shorter equipment life, higher health and safety costs or lower sale price on plant and equipment.
4. Some plants can take advantage of corporate volume purchases. Plant B attributes some of their lower costs to corporate purchase agreements that provide significantly lower prices on items such as absorbent materials.

Some of the apparent reasons for variation in performance leverage among plants include:

1. Performance leverage estimates may be very sensitive to the perspectives of plant personnel, since we relied upon these personnel to identify relevant benefits from fluid improvement. For example, in one plant, personnel considered MWF performance to be critical to product quality while personnel in another plant considered it largely irrelevant. We had no way to confirm the accuracy of these assessments.
2. All plants agreed that tooling costs were related to MWF performance, yet benefit estimates varied significantly. This is because some plants buy replacement tooling while others rework tooling in-house. This not only results in very different cost estimates but shifts the potential savings from “hard” costs (new tooling) to “soft” costs (personnel).

The TCO Estimation Method is Practical

The TCO estimation method developed for this research appeared to work well, producing reasonably accurate results with a relatively small input of personnel time. The 8-step process was specifically designed to produce estimates in a relatively short period of time without extensive demands on personnel, yet produce results that are accurate enough to guide management decision-making. It is intended to be used by companies to produce results within two weeks under the direction of an experienced analyst.

While each case study in this report took considerably longer than two weeks, we believe that this was due to the time required for the researchers to:

1. Become familiar with the study facility and the production process.
2. Identify and develop working relationships with key personnel in the plant.
3. Work out the proper estimation methods for each cost item, including more extensive research on wastewater treatment costs and electricity consumption for pumps.
4. Work out proper presentation methods for cost tables, figures, and notes.

Thus, we believe the TCO estimation method as documented in this report is likely to perform well for many companies within a two-week time-frame provided that:

1. The work is performed under the direction of a full-time, experienced project leader who is already familiar with the production process.
2. Key plant personnel (purchasing, materials handling, engineering, operations, EH&S, etc.) are involved. Involvement of most personnel should not exceed about 2-5 hours, though a few may need to devote from 10-20 hours during the study period.
3. The project scope is limited to a smaller production facility or one section of a larger production facility that uses a limited number of metalworking fluids.

Recommendations

The three case studies in this report found that both hidden costs and performance leverage estimates varied considerably between plants. More case studies are needed before the TCO for metalworking fluids can be accurately characterized. Moreover, very few TCO studies have been performed on chemicals other than metalworking fluids. Research is needed to characterize the range of total costs across a wide array of commonly used industrial chemicals. Such results are likely to lead to better management decision-making with regard to waste-minimization opportunities.

The TCO estimation method used in this study is similar to methods used by others and has proven to be practical (CSP 1999 p4.7; Ostrenga 1992, Pojacek 1997). Greater businesses application of the TCO estimation method should improve environmental and economic performance. It may be possible to include TCO assessment as part of technical assistance programs currently offered to businesses by WMRC and similar agencies. It may also be possible to encourage businesses to undertake TCO assessment themselves through workshops or other venues at which the method can be demonstrated.

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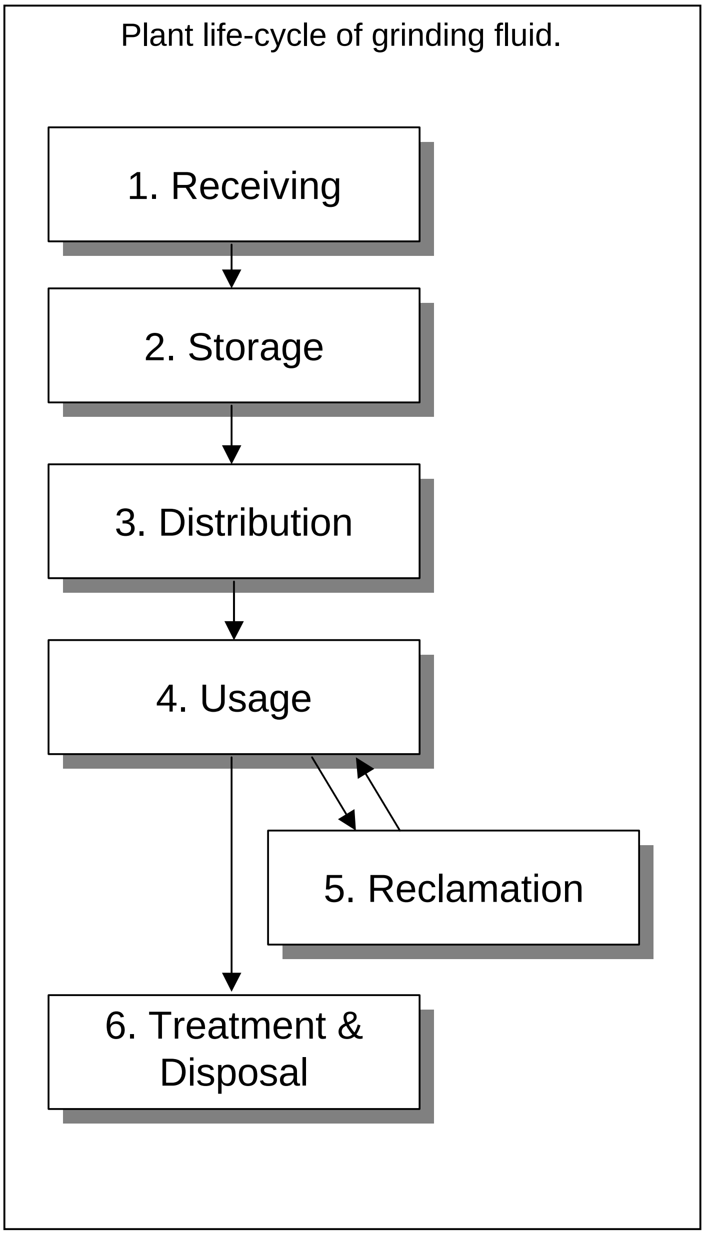
Appendix 1

Plant A

Grinding Operation

Plant A - Grinding Operation

Cost Details by Life-cycle Stage



1. Receiving

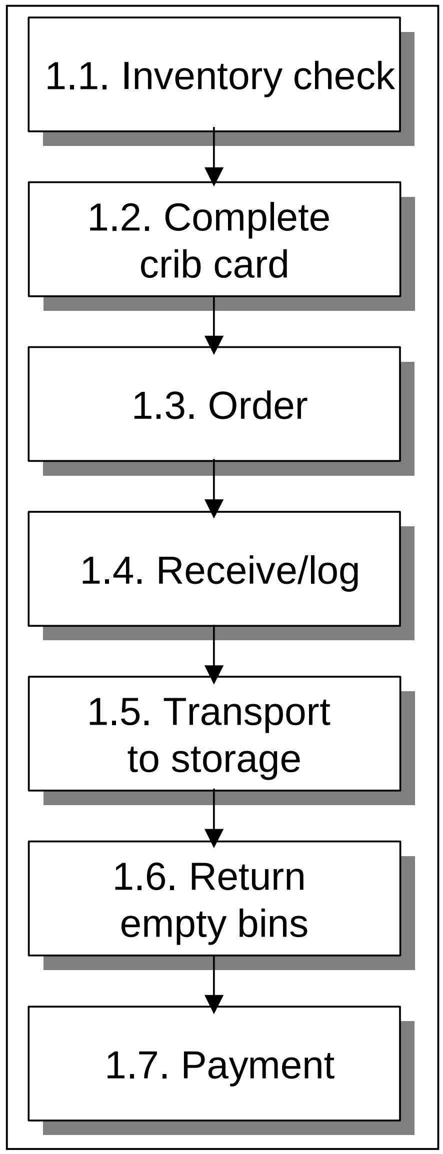

1.1. Inventory check
1.2. Complete crib card
1.3. Order
1.4. Receive/log
1.5. Transport to storage
1.6. Return empty bins
1.7. Payment

Table A-1. Identification of cost inputs: Receiving, Plant A, Year 2001

	Personnel						Inputs			Outputs	Auxiliary Operations	Intermittent Operations
ACTIVITY	Facilities Engineering	Receiving	Purchasing	Supplier	Materials Handling	Accounting	Materials	Equipment	Energy			
1.1 Inventory check	X			X			Inventory log					
1.2 Complete crib card	X						Crib card					
1.3 Order			X				PO					Re-bid contract
1.4 Receive/log		X					PO Packing slip					
1.5 Transport to storage					X			Fork truck			Fork truck maintenance	
1.6 Return empty bins					X		Empty bin	Fork truck			Fork truck maintenance	
1.7 Payment						X	Invoice Packing Slip					

Table A-2. Cost estimates: Receiving, Plant A, Year 2001

	Personnel	Inputs			Auxiliary Operations	Intermittent Operations	Total	Supplier Costs
ACTIVITY		Materials	Equipment	Energy				
1.1 Inventory check	$6,000		`				$6,000	$3,750
1.2 Complete crib card	$2,100						$2,100	
1.3 Order	$350					$400	$750	
1.4 Receive/log	$175				$800		$975	
1.5 Transport to storage	$175		$29				$204	
1.6 Return empty bins	$175		$29				$204	
1.7 Payment	$350						$350	
Total	$9,325		$59		$800	$400	$10,584	$3,750

Receiving

Cost Notes:

1.1 Inventory check
Personnel
Fac eng. 3 hr/wk x $40/hr x 50 wk/yr = $6,000
Supplier 3 hr/wk x $25/hr x 50 wk/yr = $3,750

1.2. Complete crib card
Personnel
Fac eng. 1.5 hr/order x $40/hr x 35 orders/yr = $2,100

1.3. Order
Personnel
Purchasing. 0.25 hr/order x $40/hr x 35 orders/yr = $350

Intermediate Operations.
Purchasing. 10 hr/year x $40/hr = $400

1.4. Receive and Log
Personnel
Receiving 0.25 hr/order x $20/hr x 35 orders/yr = $175

Aux. Oper.
EH&S = $800 (see General Note A)

1.5. Transport to storage
Personnel
Mat. Hand. 0.25 hr/order x $20/hr x 35 orders/yr = $175

Equipment
Fork truck 0.25 hr/order x $3.35/hr x 35 orders/yr = $29 (see General Note B)

1.6. Return empty bins
Personnel
Mat. Handling 0.25 hr/order x $20/hr x 35 orders/yr = $175

Equipment
Fork truck 0.25 hr/order x $3.35/hr x 35 orders/yr = $29 (see General Note B)

1.7. Payment
Personnel
Acct. 0.25 hr/order x $ 40/hr x 35 orders/yr = $350

2. Storage

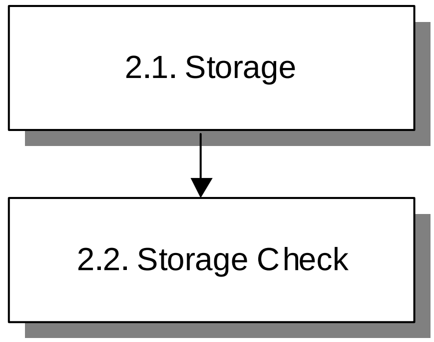


Table A-3. Identification of cost inputs: Storage, Plant A, Year 2001

	Personnel						Inputs			Other Costs	Auxiliary Operations	Intermittent Operations
ACTIVITY	Facilities Engineering						Materials	Equipment	Energy			
2.1 Storage										Space and inventory costs	EH&S	
2.2. Storage Check	X											

Table A-4. Cost estimates: Storage, Plant A, Year 2001

ACTIVITY	Personnel	Inputs	Other	Auxiliary Operations	Intermittent Operations	Total	Supplier Costs
2.1 Storage			$1,178	$800		$1,978	
2.2. Storage Check	$3,000					$3,000	
Total	$3,000		$1,178	$800		4,978	

Storage

Cost Notes:

2.1 Storage

Other Costs

Space 225 ft^2 x \$1.5/ ft^2/yr = \$338

Inventory 3 bins x \$4,000/bin x 7% = \$840

Aux. Oper.

EH&S = \$800 (see General Note A)

2.2. Storage Check

Personnel

Fac eng. 1.5 hr/wk x \$40/hr x 50 wks/yr = \$3000

3. Distribution

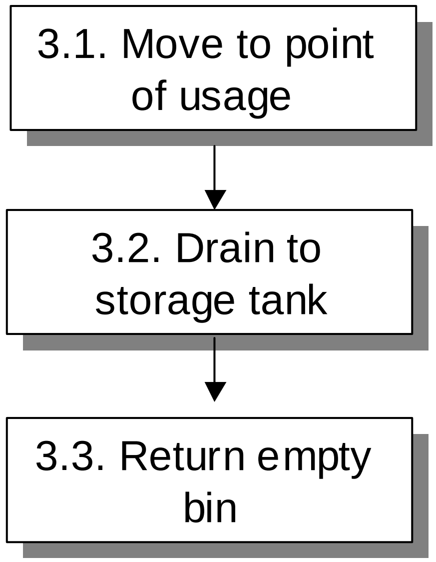


Table A-5 Identification of cost inputs: Distribution, Plant A, Year 2001

	Personnel				Inputs			Outputs	Auxiliary Operations	Intermittent Operations
ACTIVITY	Materials Handling				Materials	Equipment	Energy			
3.1 Move to point of usage	X					Fork truck			Fork truck maintenance	
3.2. Drain to storage tank.	X							Empty bin		
3.3 Return empty bin to shipping	X			X		Fork truck			Fork truck maintenance	

Table A-6. Cost estimates: Distribution, Plant A, Year 2001

	Personnel	Inputs			Auxiliary Operations	Intermittent Operations	Total	Supplier Costs
ACTIVITY		Materials	Equipment	Energy				
3.1 Move to point of usage	$200		$34				$234	
3.2. Drain to storage tank.	$200						$200	
3.3 Return empty bin to shipping	$100		$17				$117	
Total	$500		$50				$550	

Distribution

Cost Notes:

3.1. Move to point of usage

Personnel

Mat. Hand. 0.2 hr/wk x $20/hr x 50 wks/yr = $200

Equipment

Fork truck 0.2 hr/wk x $3.35/hr x 50 wk/yr = $34 (see General Note B)

3.2. Drain to storage tank

Personnel

Mat. Hand. 0.2 hr/wk x $20/hr x 50 wks/yr = $200

3.3. Return empty bin to shipping

Personnel

Mat. Hand. 0.1 hr/wk x $20/hr x 50 wks/yr = $100

Equipment

Fork truck 0.1 hr/wk x $3.35/hr x 50 wk/yr = $17 (see General Note B)

4. Usage

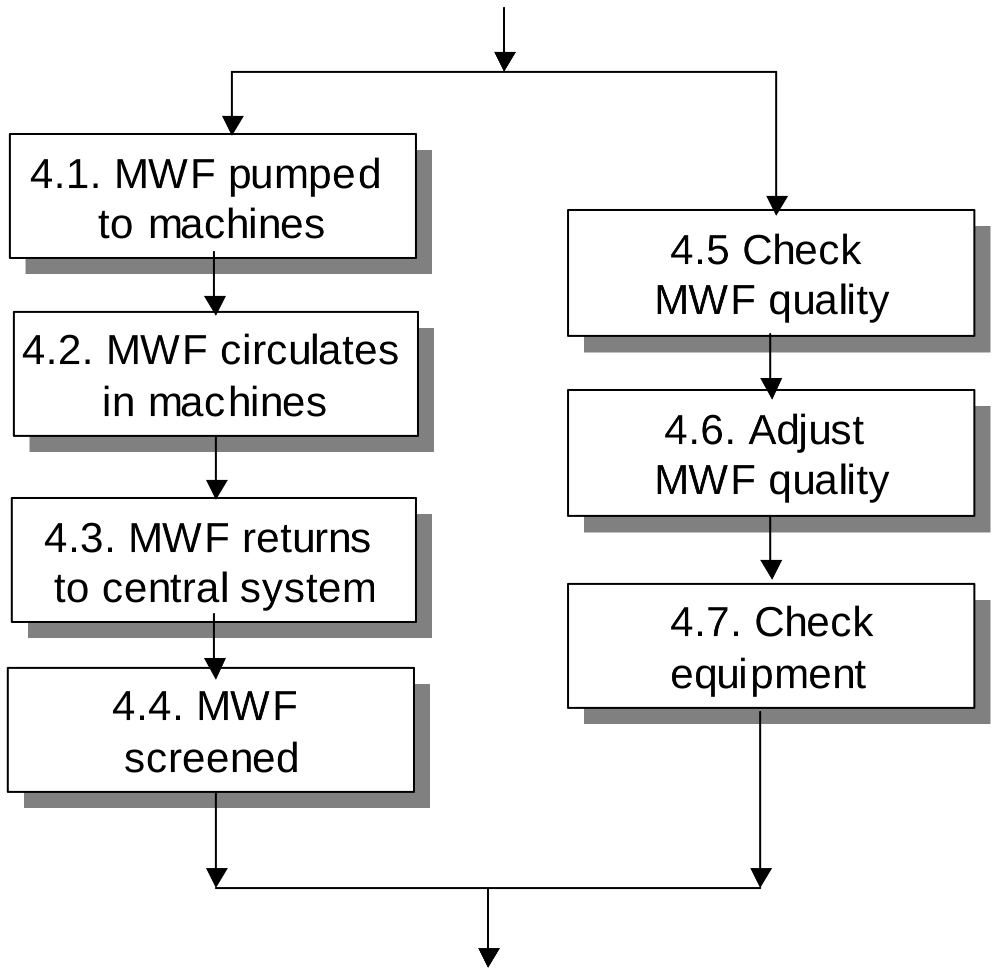

4.1. MWF pumped to machines
4.2. MWF circulates in machines
4.3. MWF returns to central system
4.4. MWF screened
4.5 Check MWF quality
4.6. Adjust MWF quality
4.7. Check equipment

Table A-7. Identification of cost inputs: Usage, Plant A, Year 2001

	Personnel						Inputs			Outputs	Auxiliary Operations	Intermittent Operations
ACTIVITY	Facilities Engineering	Mainten.	Supplier				Materials	Equipment	Energy			
4.1 MWF pumped to machines								Motors, pumps, piping	Electricity for pumps			Equipment maintenance
4.2 MWF circulates in machines											Towel laundering, gloves, EH&S	
4.3 MWF returns to central system												Clean trenches
4.4. MWF screened								Motors, pumps, piping, screen, etc.	Electricity for pumps	Swarf	Swarf mgt. & disposal	
4.5 Check MWF quality			X								Lab support	
4.6 Adjust MWF quality	X						MWF, RO water, additives					
4.7 Check equipment		X										

Table A-8. Cost estimates: Usage, Plant A, Year 2001

	Personnel	Inputs			Auxiliary Operations	Intermittent Operations	Total	Supplier Costs
ACTIVITY		Materials	Equipment	Energy				
4.1 MWF pumped to machines			$21,086	$56,420		$3,900	$81,406	
4.2 MWF circulates in machines					$15,350		$15,350	
4.3 MWF returns to central system						$6,500	$6,500	
4.4. MWF screened			$15,314	$23,508	$6,469	$45,338	$90,628	
4.5 Check MWF quality							$0	$14,750
4.6 Adjust MWF quality	$5,500	$96,061					$101,561	
4.7 Check equipment	$1,719						$1,719	
Total	$7,219	$96,061	$36,399	$79,929	$21,819	$55,738	$297,164	$14,750

Usage

Costs Notes

4.1 MWF pumped to machines

Equipment

Annual depreciation on motors, pumps, piping = $21,086

Energy

Electricity 3 pumps x 60 hp/pump x 0.7463 kw/hp x 8,400 hr x $0.05/kwh = $56,420

Intermittent Operations

Annual rebuilding of motors and pumps (parts and labor) = $3,900

(

4.2. MWF Circulates in machines

Auxiliary Operations

Towel laundering, gloves = $13,750 (percent of annual cost judged to be associated with MWF exposure in grinding operation

EH&S = $800 (see General Note A)

4.3. MWF returns to central system

Intermittent Operations – clean trenches

Personnel 240 hours x $25/hr = $6,000

Equipment $500

4.4. MWF screened

Equipment

Annual depreciation on motors, pumps, piping = $15,314

Energy

Electricity 3 pumps x 25 hp/pump x 0.7463 kw/hp x 8,400 hr x $0.05/kwh = $23,508

Auxiliary Operations

Swarf disposal = $6,469

Intermittent Operations

Annual rebuilding of motors, pumps, screening system (parts and labor) = $45,338

4.5 Check MWF Quality

Supplier

Personnel 2 hr/day x 5.5 day/wk x 50 wk/ yr x $25/hr = $13,750

Lab costs $1,000

4.6. Adjust MWF Quality

Personnel

Fac. Eng. 0.5 hr/day x 5.5 day/wk x 50 wk/ yr x $40/hr = $5,500

Materials

RO Water 825,000 gal x $0.02/gal = $16,500

Other chemical additives $79,561

4.7. Check Equipment

Personnel

Maint. 0.25 hr/day x 5.5 day/wk x 50 wk/ yr x $25/hr = $1,719

5. Reclamation

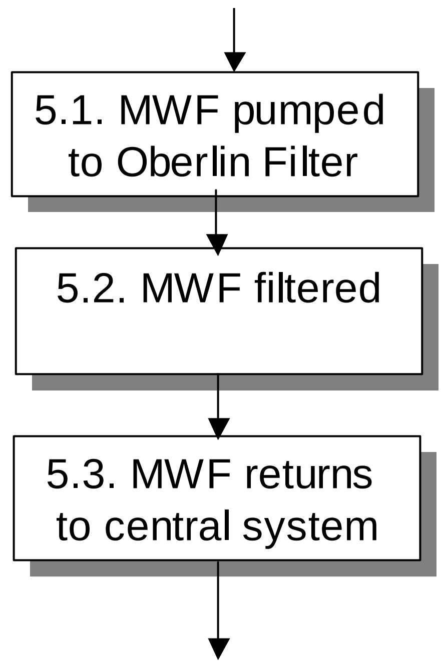


Table A-9. Identification of cost inputs: Reclaim, Plant A, Year 2001

	Personnel						Inputs			Outputs	Auxiliary Operations	Intermittent Operations
ACTIVITY	Grind area	Mainten.	Supplier				Materials	Equipment	Energy			
5.1 MWF pumped to filter	X							Motors, pumps, piping	Electricity for pumps			Equipment maintenance
5.2 MWF filtered								Filter		Swarf	Swarf disposal, EH&S	Equipment maintenance
5.3 MWF returns to central system												

Table A-10. Cost estimates: Reclaim, Plant A, Year 2001

	Personnel	Inputs			Auxiliary Operations	Intermittent Operations	Total	Supplier Costs
ACTIVITY		Materials	Equipment	Energy				
5.1 MWF pumped to filter	$2,750		$1,029	$6,157		$1,300	$11,236	
5.2 MWF filtered			$2,500		$2,956	$1,540	$6,196	
5.3 MWF returns to central system								
Total	$2,750		$3,529	$6,157	$2,956	$2,840	$18,322	

Reclamation

Cost Notes:

5.1. MWF pumped to filter

Personnel

Grind area 0.5 hr/day x 5.5 day/wk x 50 wk/ yr x $20/hr = $2,750

Equipment

Annual depreciation on motors, pumps, piping = $1,029

Energy

Electricity 1 pump x 75 hp/pump x 0.7463 kw/hp x 2,200 hr x $0.05/kwh = $6,157

Intermittent Operations

Annual rebuilding of motors and pumps (parts and labor) = $1,300

5.2. MWF filtered

Equipment

Annual depreciation on filter equipment = $2,500

Auxiliary Operations

Swarf disposal = $2,156

EH&S = $800 (see General Note A)

Intermittent Operations

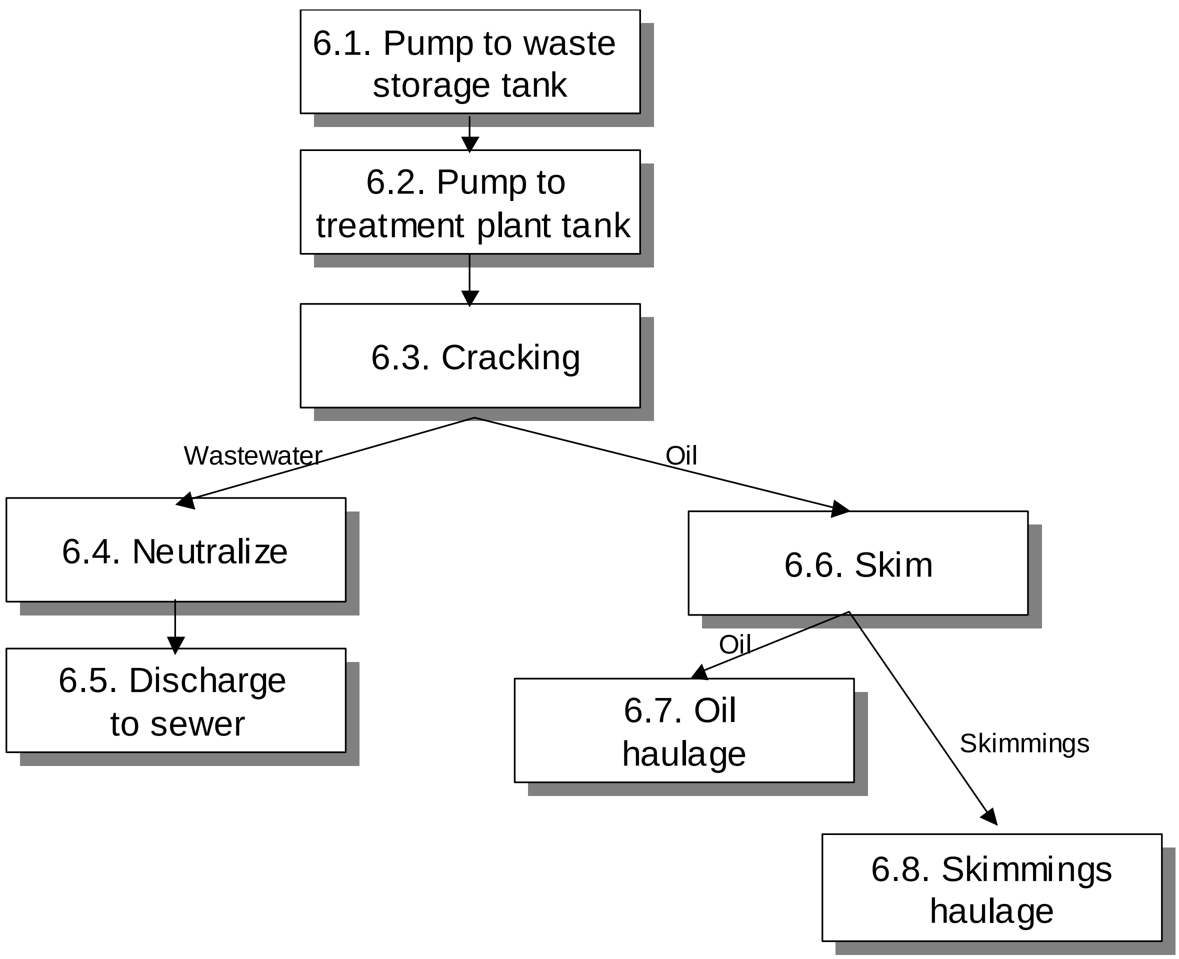
Equipment maintenance (parts and labor) = $1,540

5.3 MWF returns to central system

no significant costs

6. Treatment and Disposal

See General Notes (last page) for cost information related to wastewater treatment



Overall Hidden Costs

Table A-11. Overall hidden cost estimates: Grinding Fluids, Plant A, Year 2001 (does not include $100,000 annual cost of fluid.

Activity	Personnel Total	Material	Equipment	Utilities	Aux. Oper.	Inter. Oper.	Other	TOTAL	Supplier Absorbed
1.1 Inventory check	$ 6,000	$ -	`	$ -	$ -	$ -	$ -	$ 6,000	$ 3,750
1.2 Complete crib card	$ 2,100	$ -	$ -	$ -	$ -	$ -	$ -	$ 2,100	$ -
1.3 Order	$ 350	$ -	$ -	$ -	$ -	$ 400	$ -	$ 750	$ -
1.4 Receive/log	$ 175	$ -	$ -	$ -	$ 800	$ -	$ -	$ 975	$ -
1.5 Transport to storage	$ 175	$ -	$ 29	$ -	$ -	$ -	$ -	$ 204	$ -
1.6 Return empty bins	$ 175	$ -	$ 29	$ -	$ -	$ -	$ -	$ 204	$ -
1.7 Payment	$ 350	$ -	$ -	$ -	$ -	$ -	$ -	$ 350	$ -
2.1 Storage	$ -	$ -	$ -	$ -	$ 800	$ -	$ 1,178	$ 1,978	$ -
2.2 Storage Check	$ 3,000	$ -	$ -	$ -	$ -	$ -	$ -	$ 3,000	$ -
3.1 Move to point of usage	$ 200	$ -	$ 34	$ -	$ -	$ -	$ -	$ 234	$ -
3.2. Drain to storage tank	$ 200	$ -	$ -	$ -	$ -	$ -	$ -	$ 200	$ -
3.3. Return empty bin	$ 100	$ -	$ 17	$ -	$ -	$ -	$ -	$ 117	$ -
4.1. MWF pumped to machines	$ -	$ -	$ 21,086	$ 56,420	$ -	$ 3,900	$ -	$ 81,406	$ -
circulates in machines	$ -	$ -	$ -	$ -	$ 15,350	$ -	$ -	$ 15,350	$ -
4.3. MWF returns to central system	$ -	$ -	$ -	$ -	$ -	$ 6,500	$ -	$ 6,500	$ -
4.4. MWF screened	$ -	$ -	$ 15,314	$ 23,508	$ 6,469	$ 45,338	$ -	$ 90,628	$ -
4.5 Check MWF Quality	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 14,750
4.6. Adjust MWF Quality	$ 5,500	$ 96,061	$ -	$ -	$ -	$ -	$ -	$ 101,561	$ -
4.7. Check Equipment	$ 1,719	$ -	$ -	$ -	$ -	$ -	$ -	$ 1,719	$ -
5.1. MWF pumped to Oberlin Filter	$ 2,750	$ -	$ 1,029	$ 6,157	$ -	$ 1,300	$ -	$ 11,236	$ -
5.2. MWF filtered	$ -	$ -	$ 2,500	$ -	$ 2,956	$ 1,540	$ -	$ 6,996	$ -
5.3 MWF returns to central system	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
6.0 Treatment and disposal	$ -	$ -	$ -	$ -	$ 20,001	$ -	$ -	$ 20,001	$ -
TOTAL	$ 22,794	$ 96,061	$ 40,038	$ 86,086	$ 46,376	$ 58,978	$ 1,178	$ 351,509	$ -

General Notes

A. EH&S – EH&S costs were estimated using a “top-down” approach. One plant and one corporate employee perform EH&S functions for the grinding operation. For each, the percentage of their annual time devoted to the grinding operation and/or grinding fluids was estimated. Then the proportion of this time devoted to each step in the grinding fluid life-cycle was estimated. Salary data were then used to derive a cost estimate for this time.

B. Fork truck costs – The company preferred to combine equipment, operating, and maintenance costs in a single hourly cost for fork truck operation. The hourly figure includes depreciation, maintenance, and fuel costs.

C. Electricity for pumps – Electricity consumption to power pumps was roughly estimated assuming 746 watts per horsepower for each motor. However, many factors can alter actual power consumption. Various scenarios were run using PSAT 200 (Pumping System Assessment Tool, Oak Ridge National Laboratory, 2000 – available at http://public.ornl.gov/psat/). Results suggest that the 1 hp = 746.3 watts assumption may be accurate within a factor of 2.

D. Wastewater treatment costs – Data on wastewater treatment costs at the plant were not available. An independent assessment of such costs were beyond the scope of this project. Instead, recent USEPA research was used to estimate costs (USEPA, 2000). Approximately 1.7 million gallons are treated each year, of which approximately 8% is discharge from the grinding operation under study. The plant uses a batch, emulsion-breaking process. This is most closely approximated by the “Batch oil-emulsion breaking” process described by USEPA (USEPA, 2000, Table 11-8, page 11-27). USEPA’s cost equation for this process produces an annual operating cost estimate of 14.3 cents/per gallon. Plant personnel agreed that this was probably a reasonable estimate. However, it was agreed that the estimate is probably accurate only with about a factor of 2. In addition, this estimate does not include depreciation on equipment.

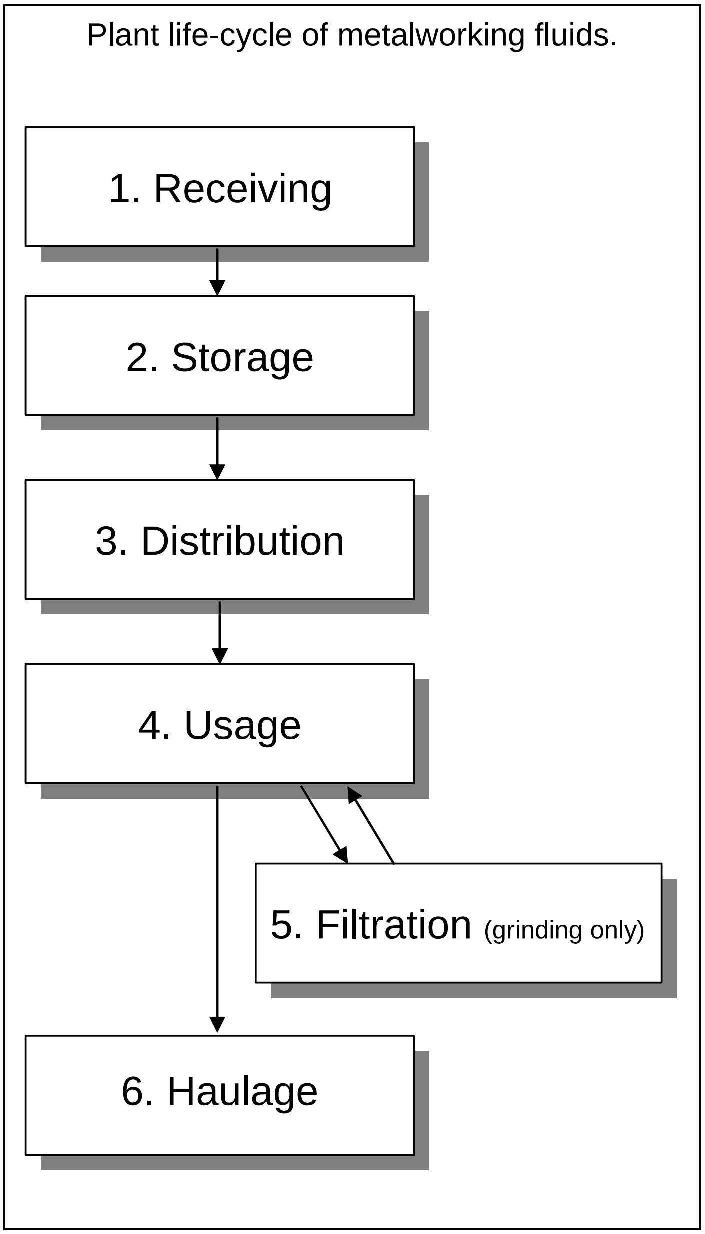
Appendix 2

Plant B

Metal Products Fabricator

Plant B – Metal Parts Fabrication

Cost Details by Life-cycle Stage



1. Receiving

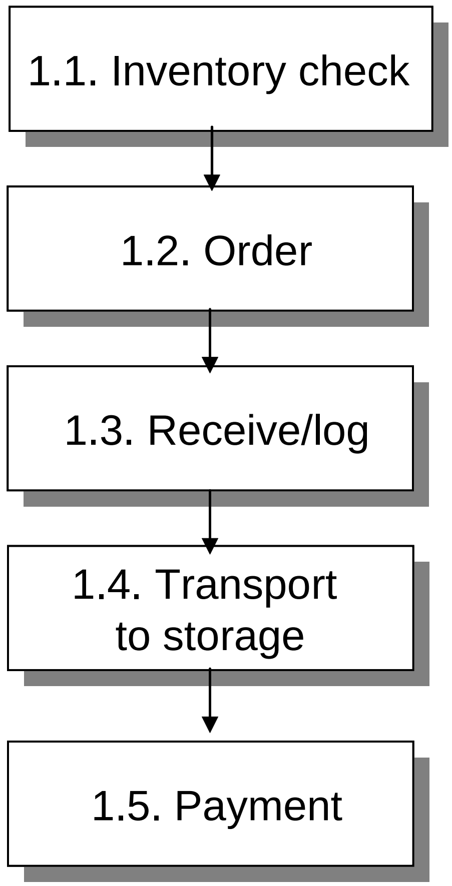

1.1. Inventory check
1.2. Order
1.3. Receive/log
1.4. Transport to storage
1.5. Payment

Table B-1. Identification of cost inputs: Receiving, Plant B, Year 2001

	Personnel					Inputs			Outputs	Auxiliary Operations	Intermittent Operations
ACTIVITY	Operations	Maintenance	Purchasing	Receiving	Accounting	Materials	Equipment	Energy			
1.2 Inventory check/ Paperwork	X	X									
1.2 Order			X								
1.3 Receive/log				X						EH&S	
1.4 Transport to storage /Return empty bins				X			Fork truck				
1.5 Payment					X						

Table B-2. Cost estimates: Receiving, Plant B, Year 2001

	Personnel	Inputs			Auxiliary Operations	Intermittent Operations	Total	Supplier Costs
ACTIVITY		Materials	Equipment	Energy				
1.3 Inventory check/ Paperwork	$1,860		`				$1,860	
1.2 Order	$750						$750	
1.3 Receive/log	$675				$300		$975	
1.4 Transport to storage /Return empty bins	$400		$100				$500	
1.5 Payment	$0						$0	
Total	$3,685		$100		$300		$4,085	

Receiving

Cost Notes:

1.1 Inventory check and paperwork

Personnel

Operations.	2 hr/yr x $30/hr = $60
Maintenance	90 hr/yr x $20/hr = $1,800

1.2. Order

Personnel

Purchasing	30 hr/yr x $25/hr = $750

1.3. Receive and Log

Personnel

Receiving	15 hr/yr x $20/hr = $300
Purchasing	15 hr/yr x $25/hr = $375

Aux. Oper.

EH&S	10 hr/yr x $30/hr = $300

1.4. Transport to storage/return empty bins

Personnel

Receiving	20 hr/yr x $20/hr = $400

Equipment

Fork truck	20 hr/yrx $5/hr = $100 (see General Note A)

1.5. Payment

Personnel

Acct.	(see General Note B)

2. Storage

2.0. Storage

Table B-3. Identification of cost inputs: Storage, Plant B, Year 2001

	Personnel						Inputs			Other Costs	Auxiliary Operations	Intermittent Operations
ACTIVITY	Facilities Engineering						Materials	Equipment	Energy			
2.0 Storage										Space and inventory costs	EH&S	

Table B-4. Cost estimates: Storage, Plant B, Year 2001

ACTIVITY	Personnel	Inputs	Other	Auxiliary Operations	Intermittent Operations	Total	Supplier Costs
2.0 Storage				$300		$300	
Total				$300		300	

Storage

Cost Notes:

2.1 Storage

Other Costs

Space There is excess space in the plant, so considered negligible.

Inventory Minimal inventory, so considered negligible.

Aux. Oper.

EH&S = periodic storage area inspection $300

3. Distribution

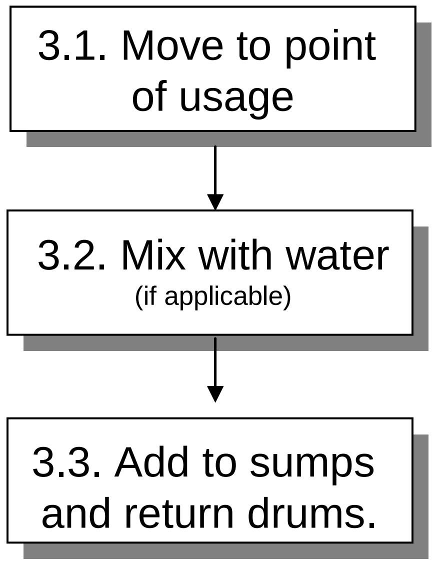


Table B-5 Identification of cost inputs: Distribution, Plant B, Year 2001

	Personnel				Inputs			Outputs	Auxiliary Operations	Intermittent Operations
ACTIVITY	Maintenance	Press Oper.			Materials	Equipment	Energy			
3.1 Move to point of usage	X	X				Fork Truck				
3.2. Mix with water.	X	X								
3.3 Add to sump	X	X								

Table B-6. Cost estimates: Distribution, Plant B, Year 2001

	Personnel	Inputs			Auxiliary Operations	Intermittent Operations	Total	Supplier Costs
ACTIVITY		Materials	Equipment	Energy				
3.1 Move to point of usage	$3,860		$500				$4,360	
3.2. Mix with water.	$3,860				$150		$4,010	
3.3 Add to sump	$3,860						$3,860	
Total	$11,580		$500		$150		$12,230	

Distribution

Cost Notes:

3.1. Move to point of usage

Personnel

Maintenance 180 hr/yr x $20/hr = $3,600

Press Oper.. 13 hr/yr x $20/hr = $260

Equipment

Fork truck 100 hr/yr x $5/hr = $500 (see General Note A)

3.2. Mix with water

Personnel

Maintenance. 180 hr/yr x $20/hr = $3,600

Press Oper.. 13 hr/yr x $20/hr = $260

Aux. Oper.

EH&S $150

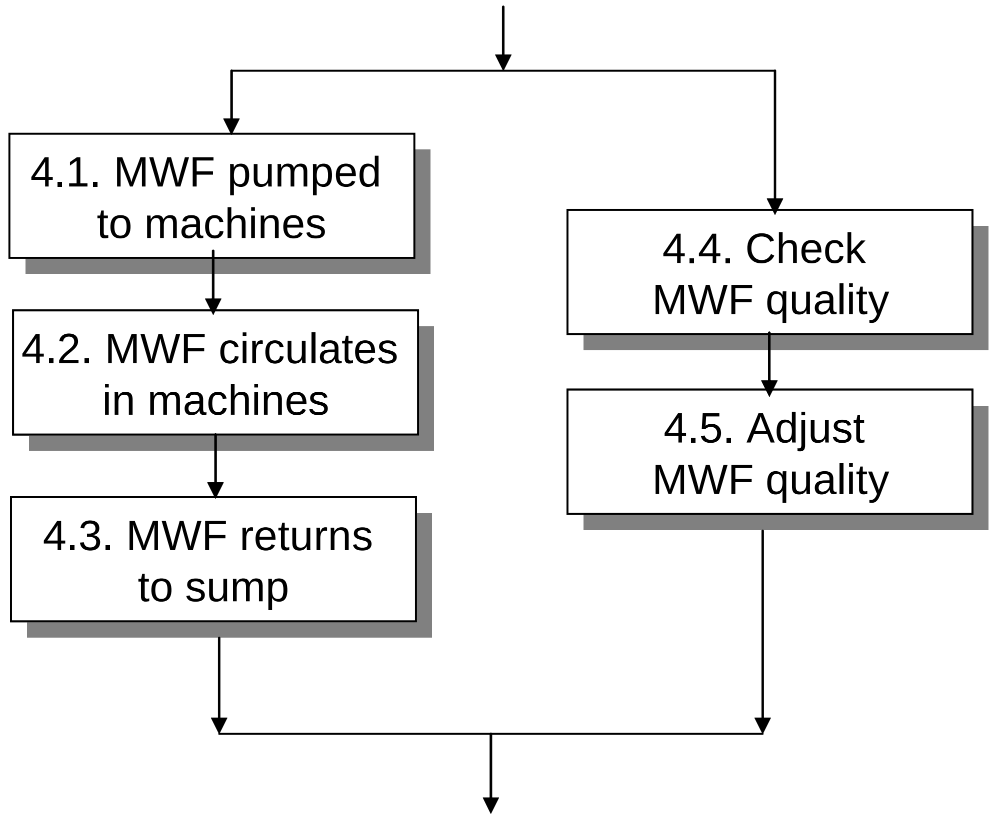
3.3. Add to sumps and return empty drums

Personnel

Maintenance. 180 hr/yr x $20/hr = $3,600

Press Oper.. 13 hr/yr x $20/hr = $260

4. Usage



4.1. MWF pumped to machines
4.2. MWF circulates in machines
4.3. MWF returns to sump
4.4. Check MWF quality
4.5. Adjust MWF quality

Table B-7. Identification of cost inputs: Usage, Plant B, Year 2001

	Personnel						Inputs			Outputs	Auxiliary Operations	Intermittent Operations
ACTIVITY	Machine Operator						Materials	Equipment	Energy			Equipment maintenance
4.1 MWF pumped to machines								Motors, pumps	Electricity for motors			
4.2 MWF circulates in machines							Absorbents			Absorbents	Towel laundering, gloves, EH&S	
4.3 MWF returns to sump												
4.4 Check MWF quality	X											
4.5 Adjust MWF quality	X						Additives					

Table B-8. Cost estimates: Usage, Plant B, Year 2001

	Personnel	Inputs			Auxiliary Operations	Intermittent Operations	Total	Supplier Costs
ACTIVITY		Materials	Equipment	Energy				
4.1 MWF pumped to machines			$1,040	$1,191		$720	$2,951	
4.2 MWF circulates in machines					$19,518		$19,518	
4.3 MWF returns to sump								
4.4 Check MWF quality	$760						$760	
4.5 Adjust MWF quality	$760	$1,292					$2,052	
Total	$1,520	$1,292	$1,040	$1,191	$19,518	$720	$25,281	

Usage

Costs Notes

4.1 MWF pumped to machines

Equipment

Annual depreciation on motors, pumps, piping = $1,040

Energy

Electricity 21,280 hp-hr/yr x 0.746 kw/hp $0.075/kwh = $1,191

Intermittent Operations

Annual cleaning of grinding central system

Maintenance. 36 hr/yr x $20/hr = $720

Rebuild motors and pumps

Annual rebuilding of motors and pumps (parts and labor) = insignficant

(

4.2. MWF Circulates in machines

Auxiliary Operations

Absorbants for clean-up = $5,000
Disposal of absorbants = $1,224
Towel laundering, gloves = $12,694 (percent of annual cost judged to be associated with MWFs)
EH&S = $600

4.3. MWF returns to central system

No significant costs

4.4. Check MWF Quality

Personnel

Machine Op. 38 hr/yr x $20/hr = $760

4.5. Adjust MWF Quality

Personnel

Machine Op. 38 hr/yr x $20/hr = $760

Materials

Other chemical additives $1,292

5. Reclamation

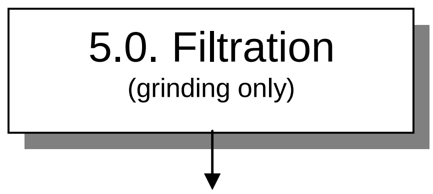


Table B-9. Identification of cost inputs: Reclaim, Plant B, Year 2001

	Personnel						Inputs			Outputs	Auxiliary Operations	Intermittent Operations
ACTIVITY	Maintenance						Materials	Equipment	Energy			
5.0 Filtration	X						Filter Paper	Filter	For pumps		Swarf disposal, EH&S	Equipment maintenance

Table B-10. Cost estimates: Reclaim, Plant B, Year 2001

	Personnel	Inputs			Auxiliary Operations	Intermittent Operations	Total	Supplier Costs
ACTIVITY		Materials	Equipment	Energy				
5.0. Filtration	$1,800	$800			$942		$3,542	
Total	$1,800	$800			$942		$3,542	

Reclamation

Cost Notes:

5.0. Filtration

Personnel

Maintenance. 90 hr/yr x $20/hr = $1,800

Materials

Filter paper = $800

Equipment

Equipment fully depreciated. Plant did want to further cost this equipment.

Energy

Already accounted for in Usage.

Auxiliary Operations

Swarf disposal = $792
EH&S = 5 hr/yr x $30/hr = $150

6. Disposal

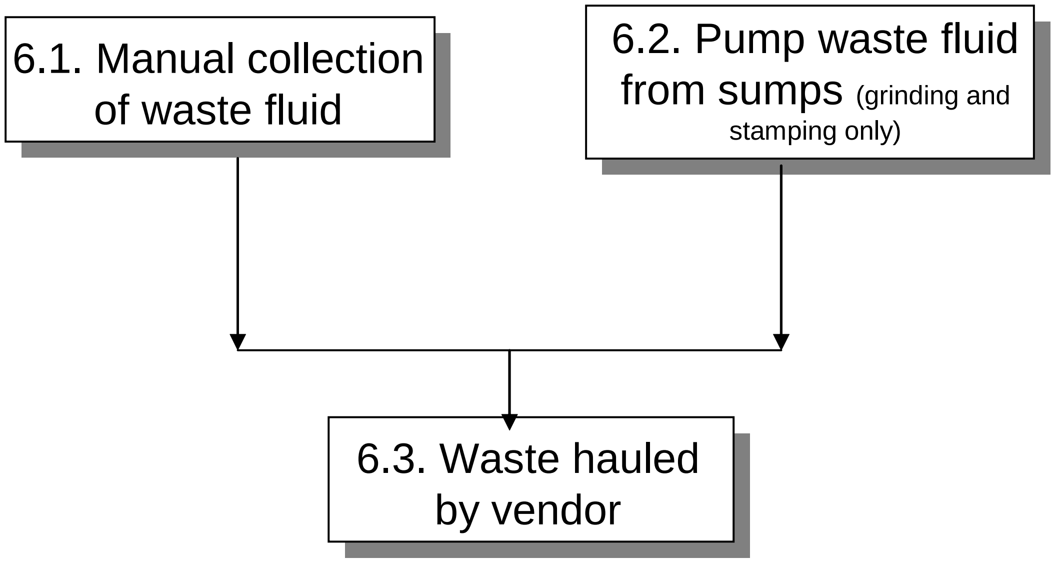

6.1. Manual collection of waste fluid
6.2. Pump waste fluid from sumps (grinding and stamping only)
6.3. Waste hauled by vendor

Table B-11. Identification of cost inputs: Disposal, Plant B, Year 2001

	Personnel						Inputs			Outputs	Auxiliary Operations	Intermittent Operations
ACTIVITY	Maintenance						Materials	Equipment	Energy			
6.1 Manual collection of waste fluid	X							"Oil sucker"				
6.2. Pump waste fluid from sumps.	X							Motors, pumps, piping	For pumps			
6.3. Waste hauled by vendor											Contract hauling, EH&S	

Table B-12. Cost estimates: Disposal, Plant B, Year 2001

	Personnel	Inputs			Auxiliary Operations	Intermittent Operations	Total	Supplier Costs
ACTIVITY		Materials	Equipment	Energy				
6.1 Manual collection of waste fluid	$12,600		$400				$13,000	
6.2. Pump waste fluid from sumps.	$1,800		$450				$2,250	
6.3. Waste hauled by vendor	$3,600		$500		$31,755		$35,855	
Total	18,000		$1,350		$31,755		$31,105	

Disposal

Cost Notes:

6.1. Manual collection of waste fluid

Personnel

Maintenance 630 hr/yr x $20/hr = $12,600

Equipment

Annual depreciation on 2 oil suckers = $400

Materials

Filter paper = $800

6.2. Pump waste fluid from central sumps (grinding and stamping only)

Personnel

Maintenance. 90 hr/yr x $20/hr = $1,800

Equipment

Annual depreciation on motors, pumps, piping = $450

Energy

Considered insignificant.

Auxiliary Operations

Swarf disposal = $792
EH&S = 5 hr/yr x $30/hr = $150

6.3. Waste hauled by vendor

Personnel

Maintenance 180 hr/yr x $20/hr = $3,600

Equipment

Annual depreciation on waste oil tanks = $500

Auxiliary Operations

Waste haulage = $30,255
EH&S = 5 hr/yr x $30/hr = $150

Overall Hidden Costs

Table B-13. Overall hidden cost estimates: Metalworking Fluids, Plant B, Year 2001 (does not include $65,000 annual cost of fluids).

Activity	Personnel	Material	Equipment	Utilities	Aux. Oper.	Inter. Oper.	TOTAL
1.1 Inventory check	$,860	$ -	$ -	$ -	$ -	$ -	$ 1,860
1.2 Order	$ 750	$ -	$ -	$ -	$ -	$ -	$ 750
1.3 Receive/log	$ 675	$ -	$ -	$ -	$ 300	$ -	$ 975
1.4 Transport to storage	$ 400	$ -	$ 100	$ -	$ -	$ -	$ 500
1.5 Payment	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2.0. Storage	$ -	$ -	$ -	$ -	$ 300	$ -	$ 300
3.1 Move to point of usage	$ 3,860	$ -	$ 500	$ -	$ -	$ -	$ 4,360
3.2. Mix with water	$ 3,860	$ -	$ -	$ -	$ 150	$ -	$ 4,010
3.3. Add to sumps	$ 3,860	$ -	$ -	$ -	$ -	$ -	$ 3,860
4.1. MWF pumped to machines	$ -	$ -	$ 1,040	$ 1,191	$ -	$ 720	$ 2,951
4.2. MWF circulates in machines	$ -	$ -	$ -	$ -	$ 19,518	$ -	$ 19,518
4.3. MWF returns to sumps	$ -	$ -	$ -	$ -	$ -	$ -	$ -
4.4 Check MWF Quality	$ 760	$ -	$ -	$ -	$ -	$ -	$ 760
4.6. Adjust MWF Quality	$ 760	$ 1,292	$ -	$ -	$ -	$ -	$ 2,052
5.0. Filter grinding fluid	$ 1,800	$ 800	$ -	$ -	$ 942	$ -	$ 3,542
6.1. Manually collect waste fluid	$ 12,600	$ -	$ 400	$ -	$ -	$ -	$ 13,000
6.2. Pump waste fluid from sumps	$ 1,800	$ -	$ 450	$ -	$ -	$ -	$ 2,250
6.3. Haul waste fluid	$ 3,600	$ -	$ 500	$ -	$ 31,755	$ -	$ 35,855
TOTAL	$ 6,585	$ 2,092	$,990	$ 1,191	$ 52,965	$ 720	$ 96,543

General Notes

A. Fork truck costs – The company preferred to combine equipment, operating, and maintenance costs in a single hourly cost for fork truck operation. The hourly figure includes depreciation, maintenance, and fuel costs.
B. All accounting functions were performed off site by a corporate office. Although accounting functions represent a cost for the corporation, they are not directly billed to the plant. Plant management preferred to omit these costs from the study.
C. EH&S – EH&S costs were estimated using a "top-down" approach. One employee performs EH&S functions for the plant. The percentage of time devoted to each metalworking fluid life-cycle stage was estimated. Salary data were then used to derive a cost estimate for this time.
D. Electricity for pumps – Electricity consumption to power pumps was roughly estimated assuming 746 watts per horsepower for each motor. However, many factors can alter actual power consumption. Various scenarios were run using PSAT 200 (Pumping System Assessment Tool, Oak Ridge National Laboratory, 2000 – available at http://public.ornl.gov/psat/). Results suggest that the 1 hp = 746.3 watts assumption may be accurate within a factor of 2.

Appendix 3

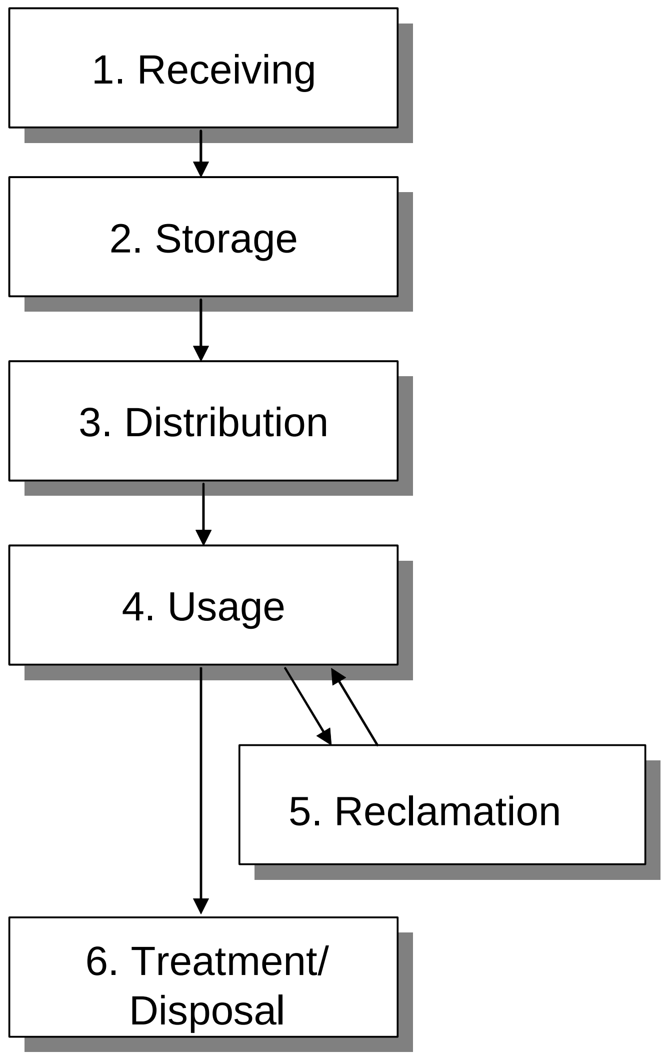
Plant C

Metal Products Fabricator

Plant C – Metal Parts Fabrication

Cost Details by Life-cycle Stage

Plant life-cycle of metalworking fluids.



1. Receiving

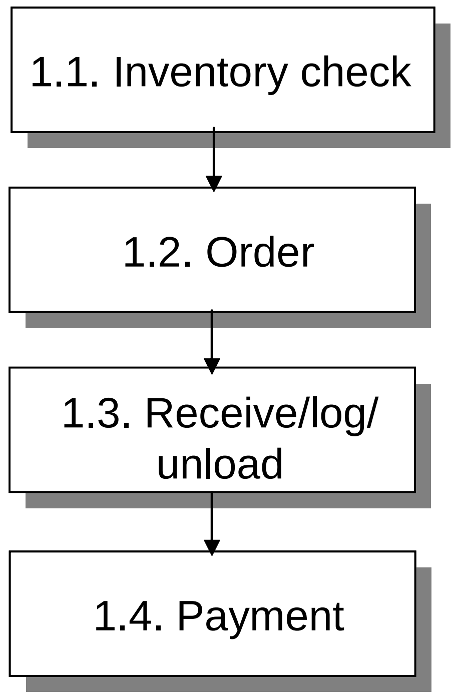

1.1. Inventory check
1.2. Order
1.3. Receive/log/ unload
1.4. Payment

Table C-1. Identification of cost inputs: Receiving, Plant C, Year 2002

	Personnel					Inputs			Outputs	Auxiliary Operations	Intermittent Operations
ACTIVITY	Mft. Support	Purchasing	Rec. Clerk			Materials	Equipment	Energy			
1.4 Inventory check/ Paperwork	X										
1.2 Order		X									
1.3 Receive/log/ unload	X		X				Fork truck			EH&S	
1.4 Payment		X									

Table C-2. Cost estimates: Receiving, Plant C, Year 2002

	Personnel	Inputs			Auxiliary Operations	Intermittent Operations	Total
ACTIVITY		Materials	Equipment	Energy			
1.1. Inventory check/	$938						$938
1.2 Order	$150						$150
1.3 Receive/ log/unload	$775		$63		$1,882		$2,710
1.4 Payment	$150						$150
Total	$2,013		$63		$1,882		$3,947

Receiving

Cost Notes:

1.1 Inventory check and paperwork

Personnel

Mft. Support. .75 hr/wk x 50 wk/yr hr/yr x $25/hr = $938/yr

1.2. Order

Personnel

Purchasing 0.5 hr/mo x 12 mo/yr x $25/hr = $150/yr

1.3. Receive and Log

Personnel

Rec. Clerk 0.5 hr/mo x 12 mo/yr x $25/hr = $150/yr

Mft. Support 0.5 hr/wk x 50 wk/yr x $25/hr = $625/yr

Aux. Oper.

EH&S $1,872 (see General Note C)

Equipment

Fork truck 0.5 hr/wk x 50 wk/yr x $2.50/hr = $63/yr (see General Note A)

1.4. Payment

Personnel

Purchasing 0.5 hr/mo x 12 mo/yr x $25/hr = $150/yr (see General Note B)

2. Storage

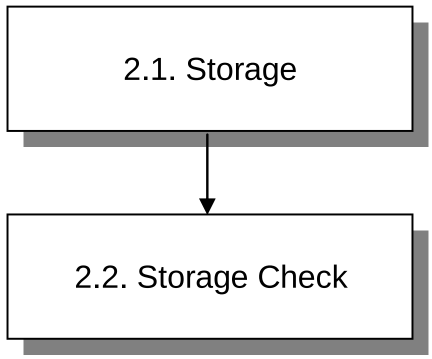


Table C-3. Identification of cost inputs: Storage, Plant C, Year 2002

	Personnel						Inputs			Other Costs	Auxiliary Operations	Intermittent Operations
ACTIVITY	Facilities Engineering						Materials	Equipment	Energy			
2.1 Storage										Space costs		
2.2 Storage Check										Space costs	EH&S	

Table C-4. Cost estimates: Storage, Plant C, Year 2002

ACTIVITY	Personnel	Inputs	Floor Space	Auxiliary Operations	Intermittent Operations	Total
2.1 Storage			$468			$468
2.2 Storage Check				$936		$936
Total			$468	$936		$1,404

Storage

Cost Notes:

2.1 Storage

Other Costs

Space 150 ft2 x $0.26/ft2/mo x 12 mo/yr = $468

Inventory Minimal inventory, so considered negligible.

2.2 Storage Check

Aux. Oper.

EH&S $936 (periodic storage area inspection – see General Note C)

3. Distribution

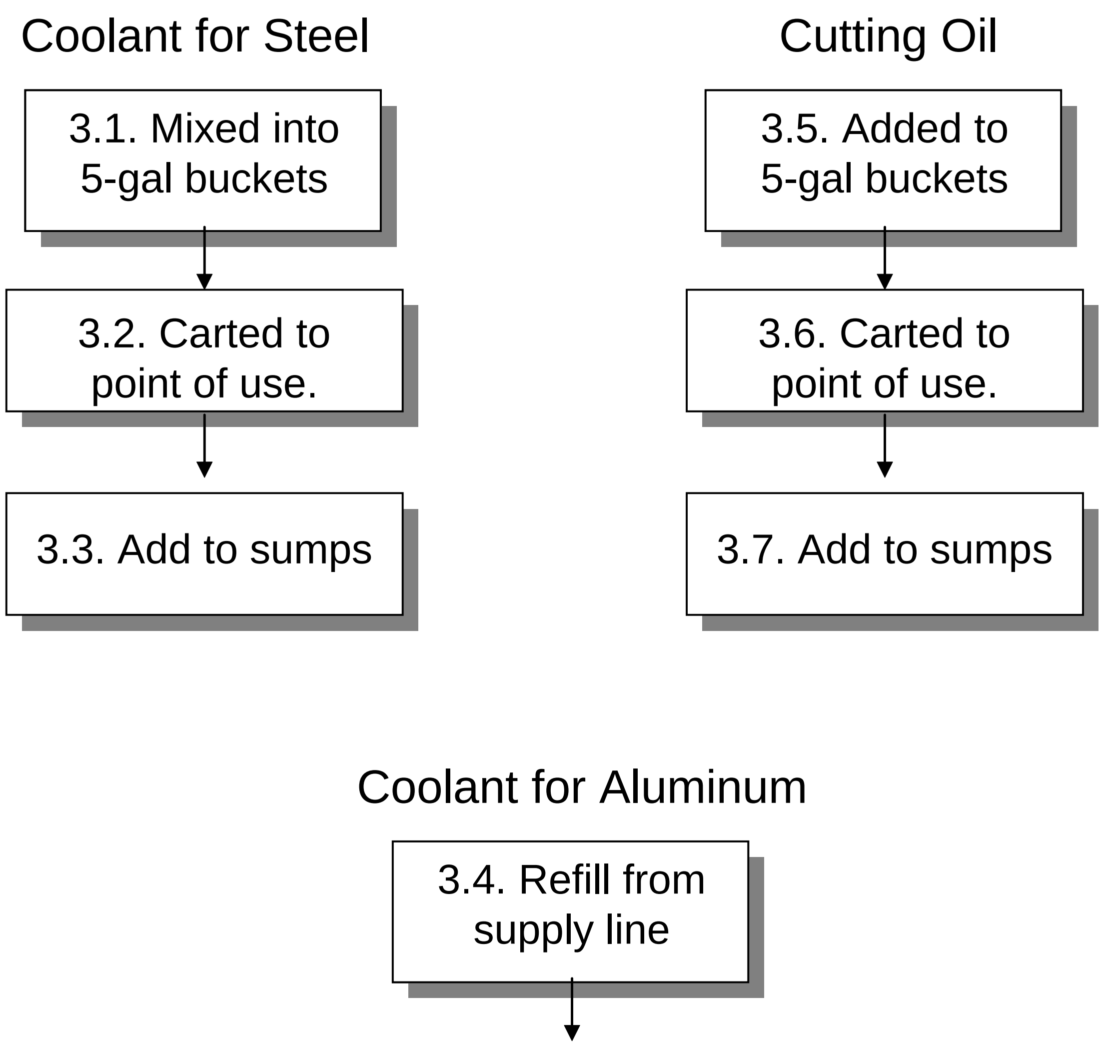


Table C-5 Identification of cost inputs: Distribution, Plant C, Year 2002

	Personnel				Inputs			Outputs	Auxiliary Operations	Intermittent Operations
ACTIVITY	Operator				Materials	Equipment	Energy			
3.1 Mixed into 5-gal. buckets	X				R.O. Water	Auto-mixer			EH&S	
3.2. Carted to point of use..	X									
3.3 Add to sump	X									
3.4 Refill from supply line	X					Supply lines and pumps				
3.5. Added to 5-gal. buckets.	X									
3.6. Carted to point of use.	X									
3.7. Add to sump	X									

Table C-6. Cost estimates: Distribution, Plant C, Year 2002

	Personnel	Inputs			Auxiliary Operations	Intermittent Operations	Total
ACTIVITY		Materials	Equipment	Energy			
3.1 Mixed into 5-gal. buckets	$701	$1,752	$50		$936		$3,439
3.2. Carted to point of use..	$701						$701
3.3 Add to sump	$701						$701
3.4 Refill from supply line	$501		$1,000				$1,501
3.5. Added to 5-gal. buckets.	$1,041						$1,041
3.6. Carted to point of use.	$1,041						$1,041
3.7. Add to sump	$1,041						$1,041
Total	$5,729	$1,752	$1,050		$936		$9,467

Distribution

Cost Notes:

3.1. Mix into 5-gal. bucket

Personnel

Operator. 0.167 hr/mo/machine x 12 mo/yr x 14 machines x $25/hr = $701/yr

Material

RO water 21,895 gal/yr x $0.08/gal= $1,752/yr

Equipment

Auto-mixer $500/10 yr lifetime = $500/yr

Aux. Oper.

EH&S $936 (see General Note C)

3.2. Cart to point of use

Personnel

Operator. 0.167 hr/mo/machine x 12 mo/yr x 14 machines x $25/hr = $701/yr

3.3. Add to sump

Personnel

Operator. 0.167 hr/mo/machine x 12 mo/yr x 14 machines x $25/hr = $701/yr

3.4. Refill from supply line

Personnel

Operator. 0.167 hr/mo/machine x 12 mo/yr x 10 machines x $25/hr = $501/yr

Equipment

Supply lines and pumps $10,000/10 yr lifetime = $1,000/yr

3.5. Add to 5-gal. bucket

Personnel

Operator. 0.0833 hr/wk/machine x 50 wk/yr x 10 machines x $25/hr = $1,041/yr

3.6. Cart to point of use

Personnel

Operator. 0.0833 hr/wk/machine x 50 wk/yr x 10 machines x $25/hr = $1,041/yr

3.7. Add to sump

Personnel

Operator. 0.0833 hr/wk/machine x 50 wk/yr x 10 machines x $25/hr = $1,041/yr

4. Usage

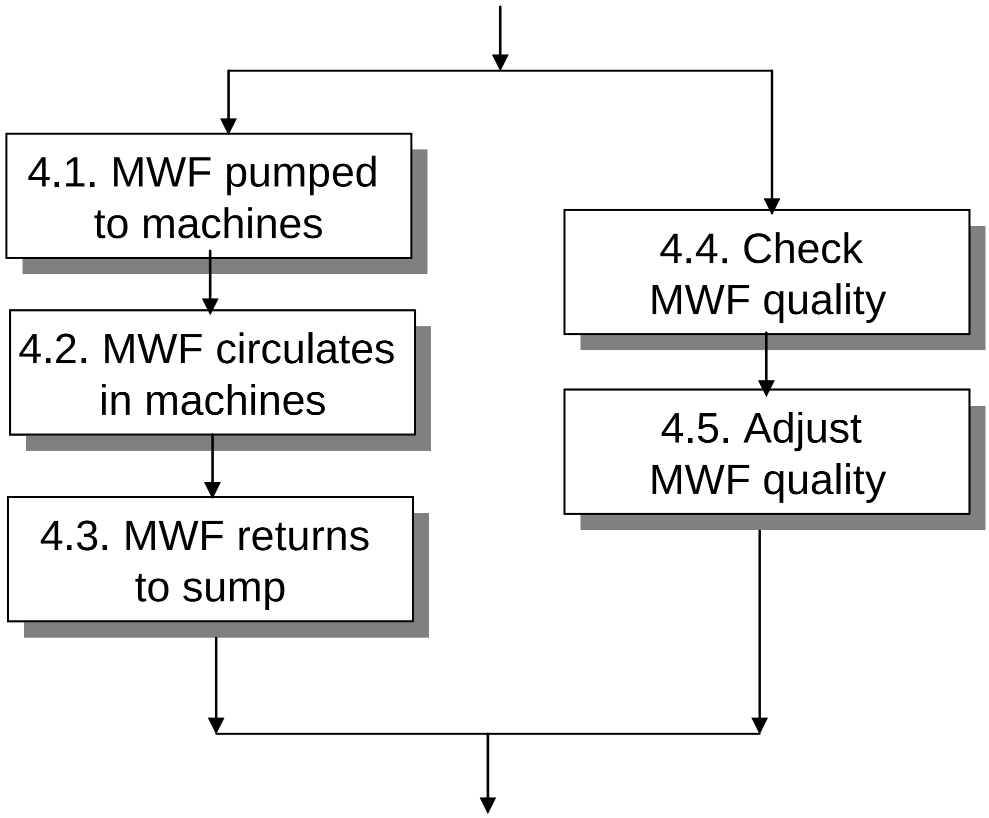

4.1. MWF pumped to machines
4.2. MWF circulates in machines
4.3. MWF returns to sump
4.4. Check MWF quality
4.5. Adjust MWF quality

Table C7. Identification of cost inputs: Usage, Plant C, Year 2002

	Personnel						Inputs			Outputs	Auxiliary Operations	Intermittent Operations
ACTIVITY	Operator						Materials	Equipment	Energy			
4.1 MWF pumped to machines									Electricity for pumps			
4.2 MWF circulates in machines										Waste fluid/ Absorbants	Clean-up, Towel laundering, gloves, EH&S	
4.3 MWF returns to sump												
4.4 Check MWF quality	X							Refractometer				
4.5 Adjust MWF quality	X						R.O. Water					

Table C-8. Cost estimates: Usage, Plant C, Year 2002

	Personnel	Inputs			Auxiliary Operations	Intermittent Operations	Total	Supplier Costs
ACTIVITY		Materials	Equipment	Energy				
4.1 MWF pumped to machines				$8,176			$8,176	
4.2 MWF circulates in machines					$107,930		$107,930	
4.3 MWF returns to sump								
4.4 Check MWF quality	$10,625		$100				$10,725	
4.5 Adjust MWF quality	$21,250	$7,006					$28,256	
Total	$31,875	$7,006	$100	$8,176	$107,930		$155,087	

Usage

Costs Notes

4.1 MWF pumped to machines

Electricity

10 machines x 1.75 hp/machine x 5,000 hr/yr= 87,500 hp-hr/yr
10 machines x 0.75 hp/machine x 4,000 hr/yr = 30,000 hp-hr/yr
4 machines x 0.75 hp/machine x 7,200 hr/yr= 21,600 hp-hr/yr hp
10 machines x 2 hp/machine x 4000 hr/yr = 80,000 hp-hr/yr
Cost 219,100 hp-hr/yr x 0.7463 kw/hp $0.05/kwh = $8,176/yr

4.2. MWF Circulates in machines

Auxiliary Operations – clean-up and spill management

Absorbants for clean-up = $10,000
Disposal of absorbants = $30,000
Towels, uniforms, rugs - laundering = $30,000
Gloves = $12,000
Mopping – 0.5 hr/day/machine = $21,250/yr
EH&S = $4,680 (see General Note C)

4.3. MWF returns to central system

No significant costs

4.4. Check MWF Quality

Personnel

Machine Op. 0.25 hr/wk/machine x 50 wk/yr x 34 machines x $25/hr = $10,625

Equipment

Refractomer ($400/item x 10 items)/4 yr life = $100/yr

4.5. Adjust MWF Quality

Personnel

Machine Op. 0.5 hr/wk/machine x 50 wk/yr x 34 machines x $25/hr = $21,250

Materials

RO water 87,579 gal/yr x $0.08/gal = $7,006/yr

5. Reclamation

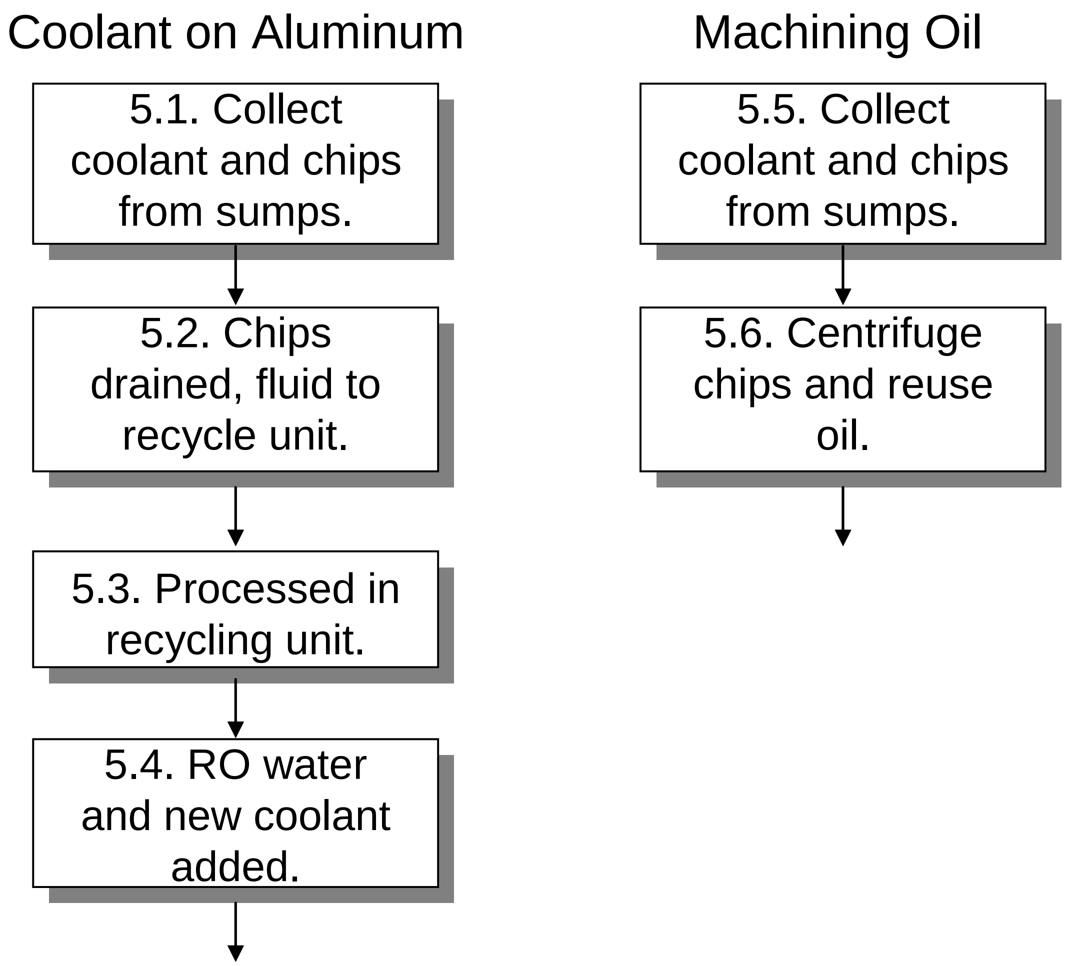


Table C-9. Identification of cost inputs: Reclaim, Plant C, Year 2002

	Personnel						Inputs			Outputs	Auxiliary Operations	Intermittent Operations
ACTIVITY	Operator	Recycle Op.	Chipper				Materials	Equipment	Energy			
5.1. Collect coolant and chips from sumps	X							Sump sucker				
5.2 Chips drained, fluid to recycle unit	X											
5.3 Processed in recycling unit		X						Coolant recycler	Electricity for pumps		EH&S	
5.4. RO water and new coolant added												
5.5. Collected from sumps and drip pa ns	X											
5.6. Centrifuge chips and reuse oil			X					Centrifuge	Electricity for centrifuge			

Table C-10. Cost estimates: Reclaim, Plant C, Year 2002

	Personnel	Inputs			Auxiliary Operations	Intermittent Operations	Total
ACTIVITY		Materials	Equipment	Energy			
5.1. Collect coolant and chips from sumps	$3,000		$20				$3,200
5.2 Chips drained, fluid to recycle unit	$501						$501
5.3 Processed in recycling unit	$6,250		$2,500	$98	$4,680		$13,528
5.4. RO water and new coolant added							
5.5. Collected from sumps and drip pa ns	$3,125						$3,125
5.6. Centrifuge chips and reuse oil	$20,000		$2,000	$90			$22,090
Total	$32,876		$4,520	$188	$4,680		$42,264

Reclamation

Cost Notes:

5.1. Collect coolant and chips from sumps

Personnel

Machine Op. 1 hr/mo/machine x 12 mo/yr x 10 machines x $25/hr = $3,000

Equipment

Sump sucker - $2,000 cost over 10 year life x 10% use = $20.

5.2. Chips drained, fluid to recycle unit

Personnel

Machine Op. 0.167 hr/mo/machine x 12 mo/yr x 10 machines x $25/hr = $501

5.3. Processed in recycling unit

Personnel

Recycle Op. 1 hr/day x 5 day/wk x 50 wk/yr x $25/hr = $6,250

Equipment

Recycling unit - $25,000 cost over 10 year life = $2,500.

Energy

Electricity for recycler – 1,959 kwh/yr x $0.05/kwh = $98.

Auxiliary Operations

EH&S = $4,680

5.4. RO water and new coolant added – RO water cost accounted for in step 3.1.

5.5. Collect from sumps and drip pans

Personnel

Machine Op. 0.25 hr/wk/machine x 50 wk/yr x 10 machines x $25/hr = $3,125

5.6. Centrifuge chips and reuse oil

Personnel

Chipper. 4 hr/day x 4 day/wk x 50 wk/yr x $25/hr = $20,000

Equipment

Centrifuge - $20,000 cost over 10 year life = $2,000.

Energy

Electricity for centrifuge – 1,791 kwh/yr x $0.05/kwh = $90.

6. Treatment & Disposal

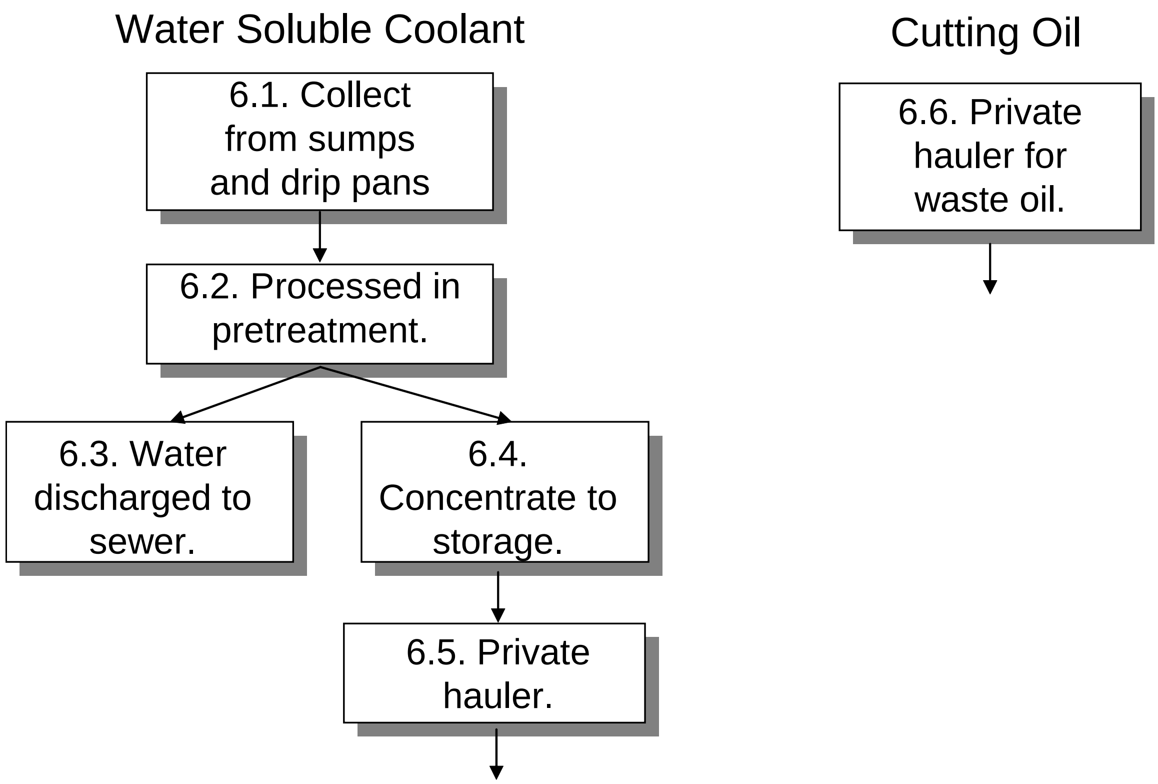


Table C-11. Identification of cost inputs: Treatment & Disposal, Plant C, Year 2002

	Personnel						Inputs			Outputs	Auxiliary Operations	Intermittent Operations
ACTIVITY	Operator						Materials	Equipment	Energy			
6.1 Collect from sumps and drip pans.	X							Sump sucker				
6.2. Process in pretreatment.								Pretreatment plant				
6.3. Water discharged to sewer.												
6.4. Concentrate to storage												
6.5. Private hauler for concentrate.											Waste hauling	
6.6. Private hauler for waste oil.											Waste hauling EH&S	

Table C-12. Cost estimates: Reclaim, Plant C, Year 2002

	Personnel	Inputs			Auxiliary Operations	Intermittent Operations	Total
ACTIVITY		Materials	Equipment	Energy			
6.1 Collect from sumps and drip pans.	$4,200		$90				$4,290
6.2. Process in pretreatment.			$3,000				$3,000
6.3. Water discharged to sewer.							
6.4. Concentrate to storage							
6.5. Private hauler for concentrate.					$3,800		$3,800
6.6. Private hauler for waste oil.					$3,675		$3,675
Total	$4,200		$3,090		$7,475		$14,765

Disposal

Cost Notes:

6.1. Collect from sumps and drip pans

Personnel

Machine Op. 1 hr/mo/machine x 12 mo/yr x 14 machines x $25/hr = $4,200

Equipment

Sump sucker - $2,000 cost over 10 year life x 45% use = $90.

6.2. Process in pretreatment

Equipment

Total pretreatment costs assumed to be 5 cents per gallon x 60,000 gal/yr = $3,000/yr

6.3. Water discharged

No cost for discharge

6.4. Concentrate to storage

Minimal cost

6.5. Private hauler for concentrate

Aux. Oper.

Hauler - 3,800 gal/yr x $1/gal = $3,800/yr

6.6. Private hauler for waste oil

Aux. Oper.

Hauler – 5,100 gal/yr x $0.17/gal = $867/yr

EH&S = $2,808 (see General Note C)

Overall Hidden Costs

Table C-13. Overall hidden cost estimates: Metalworking Fluids, Plant C, Year 2002 (does not include $41,000 annual cost of fluids).

Activity	Personnel	Material	Equipment	Utilities	Space	Aux. Oper.	Inter. Oper.	TOTAL
1.1. Inventory check	$938							$938
1.2 Order	$150							$150
1.3 Receive/log/ unload	$775		$63			$1,882		$2,710
1.4 Payment	$150							$150
2.1 Storage					$468			$468
2.2 Storage Check						$150		$150
3.1 Mixed into 5-gal. buckets	$701	$1,752	$50			$936		$3,439
3.2. Carted to point of use..	$701							$701
3.3 Add to sump	$701							$701
3.4 Refill from supply line	$501		$1,000					$1,501
3.5. Added to 5-gal. buckets.	$1,041							$1,041
3.6. Carted to point of use.	$1,041							$1,041
3.7. Add to sump	$1,041							$1,041
4.1 MWF pumped to machines				$8,176				$8,176
4.2 MWF circulates in machines						$107,930		$107,930
4.3 MWF returns to sump								
4.4 Check MWF quality	$10,625		$100					$10,725
4.5 Adjust MWF quality	$21,250	$7,006						$28,256
5.1. Collect coolant and chips from sumps	$3,000		$20					$3,200
5.2 Chips drained, fluid to recycle unit	$501							$501
5.3 Processed in recycling unit	$6,250		$2,500	$98		$4,680		$13,528

5.4. RO water and new coolant added							
5.5. Collected from sumps and drip pa ns	$3,125						$3,125
5.6. Centrifuge chips and reuse oil	$20,000		$2,000	$90			$22,090
6.1 Collect from sumps and drip pans.	$4,200		$90				$4,290
6.2. Process in pretreatment.			$3,000				$3,000
6.3. Water discharged to sewer.							
6.4. Concentrate to storage							
6.5. Private hauler for concentrate.						$3,800	$3,800
6.6. Private hauler for waste oil.						$3,675	$3,675
TOTAL	$76,692	$8,758	$8,823	$8,363	$468	$123,829	$226,933

General Notes

A. Fork truck costs – The company preferred to combine equipment, operating, and maintenance costs in a single hourly cost for fork truck operation. The hourly figure includes depreciation, maintenance, and fuel costs.

B. All accounting functions were performed off site by a corporate office. Although accounting functions represent a cost for the corporation, they are not directly billed to the plant. Plant management preferred to omit these costs from the study.

C. EH&S – EH&S costs were estimated using a "top-down" approach. One employee performs EH&S functions for the plant. The percentage of time devoted to each metalworking fluid life-cycle stage was estimated. Salary data were then used to derive a cost estimate for this time.

D. Electricity for pumps – Electricity consumption to power pumps was roughly estimated assuming 746 watts per horsepower for each motor. However, many factors can alter actual power consumption. Various scenarios were run using PSAT 200 (Pumping System Assessment Tool, Oak Ridge National Laboratory, 2000 – available at http://public.ornl.gov/psat/). Results suggest that the 1 hp = 746.3 watts assumption may be accurate within a factor of 2.

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