Environment, Safety, and Health (ESH) Cost Model Development Report (ESHA002/S67)

SEMATECH
Technology Transfer #97093350A-ENG

Environment, Safety, and Health (ESH) Cost Model Development Report (ESHA002/S67)

Technology Transfer #**97093350A-ENG**
SEMATECH
September 30, 1997

Abstract: This report describes the results of SEMATECH's ESHA002 technology development project to construct a financial model that profiles the cost impact and profitability potential of environment, safety, and health (ESH) activities. These results draw from a series of pilot studies conducted within the semiconductor manufacturing industry and are designed to help process engineers and ESH specialists understand the economic impact that ESH activities have on manufacturing performance. Although the model can be applied to new product and technology designs, this report focuses on its use as a tool for evaluating existing manufacturing process designs and alternative process options. The model and user's guide are in Technology Transfer #97093349A-ENG (available to SEMATECH member companies only).

Keywords: Cost Modeling, Cost of Ownership, Manufacturing Management, Cost Analysis, Resource Management

Authors: Anthony Veltri (Oregon State University)

Approvals: Walter Worth, Program Manager
Bob Duffin, ESH Director
Laurie Modrey, Technical Information Transfer Team Leader

Table of Contents

List of Figures

List of Tables

1 EXECUTIVE SUMMARY

This document presents a financial model that profiles the cost impact and profitability potential of environment, safety, and health (ESH) activities. The ESH Cost Model tool

1. Accounts for activities that drive ESH costs
2. Estimates their financial impact
3. Allocates the costs to the manufacturing process responsible for cost generation
4. Calculates the incremental cost difference between an existing process and alternative process options, after tax cash flows, and net present value

In addition, the tool helps process engineers and ESH specialists perform sensitivity analyses. To construct the financial framework, ESH cost factor identification/accounting/estimation literature was reviewed. Cost factors were converted from the literature into a meaningful framework and pilot-tested to verify usefulness. Emphasis was placed on using an ESH activity-based cost (ABC) accounting methodology and an ESH life-cycle costing (LCC) technique to provide a foundation for constructing the ESH cost framework. The cost model is aimed at process engineers to assist them in better understanding the economic impact that ESH activities have on manufacturing performance and at design engineers to help them make product and process design decisions up-front at an early stage in the product/process life cycle to prevent later expenses. Design and process engineers are aware of ESH costs, but unsure about the magnitude of their economic impact and ways to minimize these costs. Although design and process engineers may have limited experience in ESH cost modeling, they are in the most strategic position to provide relevant and significant cost information on the quantitative and qualitative impacts of the process and to offer insights into less tangible activities that tend to be obscured from the perspective of finance personnel and ESH specialists. The results of pilot studies designed to validate the model's usefulness indicated that the ESH cost model is a useful tool for a) understanding the ESH cost burdens associated with existing and alternative manufacturing activities, b) calculating their financial and economic impact over the anticipated life-cycle of the existing process and the proposed alternative, and c) maintaining a balance between ESH priorities and competing business performance factors.

2 BACKGROUND, PURPOSE, AND SCOPE

2.1 Background

The semiconductor industry has traditionally focused on cost, yield, and operational logistics as the primary drivers for manufacturing decision-making. However, ESH issues are also becoming important cost drivers for focusing decision-making. Historically, ESH costs have not been adequately addressed up-front by design and process engineers, resulting in higher operational and downstream costs. ESH issues have resulted in major post-installation modifications of manufacturing processes because ESH issues were not considered up-front when making product and process design choices. ESH activities can significantly increase overall wafer manufacturing costs, necessitating careful accounting and appropriate linkage with manufacturing processes responsible for wafer generation. The inability to account for and link ESH cost to the manufacturing process forces process engineers, and ESH specialists to make critical business and operational decision (i.e., which products to manufacture, which technologies and processes to employ, and which chemicals and materials to use) with an incomplete understanding of total economic impact. In addition, the semiconductor manufacturing industry has recently formulated a 15-year national technology roadmap of ESH needs that are primarily directed toward achieving low cost product and process solutions. This ESH Cost Model provides an important measurement tool and supports the SIA *Technology Roadmap for Semiconductors*.

2.2 Purpose and Scope

The purpose of this ESH cost modeling project was to construct a model that profiles the cost impact and profitability potential of ESH activities. It is designed to help design and process engineers and ESH specialists estimate ESH costs for all phases of the manufacturing process life-cycle. Although the model can be applied to new product and technology designs and total factory costing, this document focuses on its use as a tool for evaluating existing and alternative manufacturing process options. The tool calculates the incremental cost difference between an existing process and alternative process options, after tax cash flows, and net present value. It can also be used to help process engineers and ESH specialists perform sensitivity analyses.

3 RESEARCH METHODOLOGY AND RESULTS

The strategies for conducting the research were to 1) review ESH cost factor accounting literature, 2) convert cost factor literature information into a meaningful framework, and 3) pilot-test the framework to verify its usefulness. The following information explains the activities supporting each research strategy and their essential results.

3.1 Review of Literature

The review of literature assessed ESH cost factor identification/accounting/estimation literature published since 1985. Specifically, the review focused on research published in refereed and non-refereed journals and on research completed or underway in the public and private sectors. The objective of the literature review was to provide SEMATECH with information that explains how the ESH Cost Model is grounded in past research and how the project will go beyond this research in important ways. A two-dimensional scheme was used to categorize the published studies. Dimension I focused on studies that identified cost factors and activity drivers associated with ESH practice. Dimension II focused on studies that presented a way of accounting, estimating, and calculating the impact that ESH costs have on business cash flow. The content of each study was assessed according to a set of criteria and categorized into one of the two dimensions. The following conclusions were formulated based on the findings extrapolated from the literature review:

- Private sector companies are not as effective as they would like to be in profiling the cost impact and profitability potential of ESH activities and using the information for maintaining a balance between ESH priorities and competing business performance factors. It is essential for organizations to understand the economics of environment, safety and health practices, yet such understanding is rare. The information supporting such decision-making should come from design and process engineers, who are in a strategic position to supply essential data. However, if the ESH specialist does not provide process engineers with tools to model ESH cost, they cannot contribute effectively to decision-making.

- Critical business and operational decisions are incompletely made when ESH costs are not disclosed throughout the life-cycle of products and processes. It is essential for organizations to account for and link the activities that drive ESH costs to the products and manufacturing processes that generate them. A clear understanding of their total economic impact enhances decision-making capabilities concerning which products to manufacture, which technologies and processes to employ, and which chemicals and materials to use.
- Conventional accounting practices are a critical barrier to understanding ESH costs because they tend to hide ESH costs in general overhead accounts and fail to account for the full range of ESH life-cycle costs so that those costs can be allocated to the product or manufacturing process responsible for their generation. Conventional cost accounting practices tend to focus on aggregating ESH cost factors.

3.2 Framework Development

After considering the conclusions formulated from the literature review, a framework was constructed for selecting and placing ESH cost factors and associated activity drivers into a useful structure that could be tested. Emphasis was placed on using an activity based cost (ABC) accounting methodology and an abbreviated life-cycle cost (LCC) analysis technique to provide the foundation for the ESH cost model. ESH cost factors and associated activities were then identified and grouped according to a specified life-cycle phase (i.e., upfront, acquisition, use/disposal, post disposal, and closure). Because activity based cost accounting and life cycle costing can mean different things to different semiconductor manufacturers, definitions were developed to clarify any misinterpretations. The definitions of terms were developed based on a review of ABC, LCC, and ESH cost accounting literature.

For this project, ESH ABC accounting is defined as a methodology for assigning costs to activities that drive ESH costs occurring in a specified manufacturing process. The basic premise of ESH activity based cost accounting is to assign a cost to individual ESH activities. ESH costs are allocated to each manufacturing process based on its demand for ESH activities. In ESH activity based costing, both direct costs (easily identified and measured) and indirect costs (intangible and difficult to measure) can be allocated to the process responsible for the cost generation. As a result, cost factors and associated activities that were historically considered a part of general overhead type costs could be identified, estimated, and allocated more accurately. Once completed, these costs can be targeted for determining cost minimization options, preferably up-front in the design/engineering stage of the manufacturing process. Most semiconductor manufacturers struggle with the allocation of ESH costs associated with a manufacturing process due to the aggregate nature of the available data. ESH activity based costing removes this distortion and provides more representative cost information about ESH direct and indirect costs.

ESH LCC analysis is defined as a technique for analyzing both the capital and activity-driven ESH type inputs of a manufacturing process throughout its life-cycle and determining ways to enhance economic performance. The ESH life-cycle cost analysis technique has five phases, including an incident section. The following defines each life-cycle phase.

Phase I – Upfront. The phase concerned with profiling the ESH risk and cost burdens associated with a new, current, or upgraded product, manufacturing process, equipment set, technology, or factory site over its life-cycle and designing improvement options that maintain a balance between ESH priorities and other competing process/factory business performance factors.

Phase II – Acquisition. The phase concerned with obtaining ESH permits and procuring ESH capital equipment for the process and factory site to control hazardous exposures, prevent/control pollution, maintain regulatory compliance, and enhance business performance.

Phase III – Use/Disposal. The phase concerned with productively using and disposing of process resources in a manner that prevents injury/illness and environmental incidents and reduces pollution and waste.

Phase IV – Post-Disposal. The phase concerned with monitoring the disposal of waste after the waste has left the control of the manufacturing process and internal factory site and has been transferred to another company for management.

Phase V – Closure. The phase concerned with retiring a factory site at the end of its useful life and preparing the area for other productive uses.

Incidents. The costs incurred as a result of environmental contamination, pollution, alteration, occupational injury/illness, and non-compliance fines that adversely affect the manufacturing process, internal factory and external environment.

Figure 1 provides an example of the integration of the five ESH life-cycle phases and the thirteen ESH cost factors.

3.3 Pilot Studies

3.3.1 Pilot Study Strategy

The purpose of the pilot studies was to test the efficacy (i.e., effectiveness and efficiency) of the ESH Cost Model and clarify decisions about its reliability so that necessary refinements could be made. An ABABAB multiple baseline research design was used. The strategy was to develop the initial model, test it, make necessary refinements based on knowledge gained from the initial test, and then test the redeveloped version. A total of 20 pilot tests were conducted ranging from pre-operational, operational, and post-operational concerns. The pilot studies were conducted with SEMATECH member companies and focused on evaluating 1) the cost model framework, 2) the software, and 3) ways to practically implement the model.

Table 1 Research Method – ABABAB Multiple Baseline Design

	A	B	A	B	A	B	A
Process Test	Develop Conceptual Framework Rev. 0	Test Rev. 0	Modify Rev. 0 and Redevelop Rev. 1	Test Rev. 1	Modify Rev. 1 and Redevelop Rev. 2	Test Rev. 2	Modify and Redevelop ... Final Model Rev. N

N = 20. Cost data from the various pilot studies were extracted to illustrate the type of information that can be used to enhance decision-making capabilities. This information can be reviewed in Section 3.3.2.

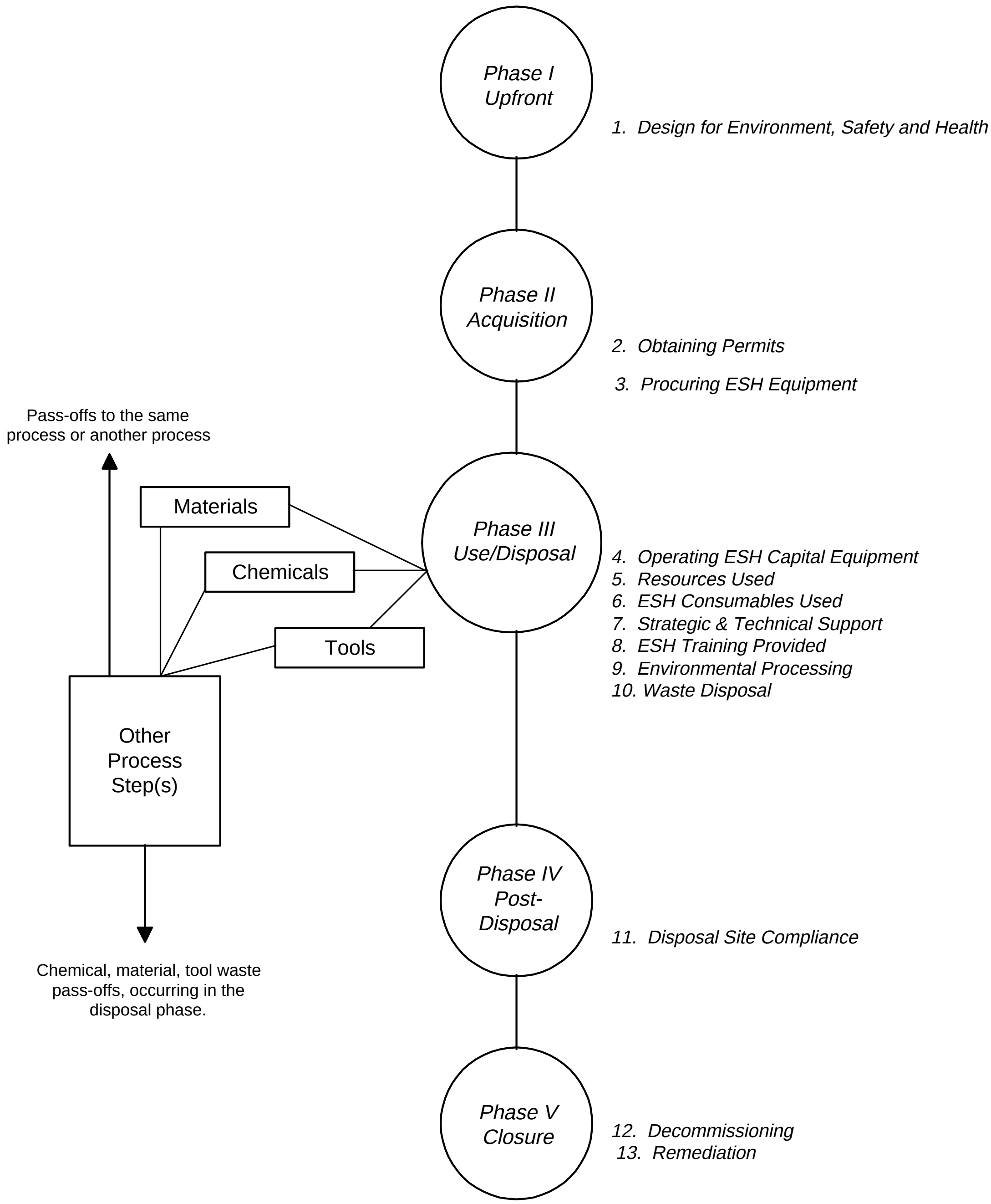

Figure 1 ESH Life-Cycle Phases, Cost Factors, and Activity Drivers

3.3.2 Pilot Study Findings

3.3.2.1 Qualitative Results

The results of the pilot studies found that the ESH Cost Model is a useful decision-oriented, low maintenance tool for

1. Understanding the ESH cost burdens associated with existing and alternative manufacturing activities, calculating their financial and economic impact over the anticipated life-cycle of the existing process and the proposed alternative, and making business decisions that maintain a balance between ESH priorities and competing business performance factors.
2. Providing annual and life-time ESH costs associated with a particular life-cycle phase, cost factor and activity driver, including ESH cost per wafer.
3. Providing an ESH cost breakdown by process staff, ESH staff, other in-company personnel, and outside consultants.
4. Removing distortions from conventional cost data and providing more representative cost information about indirect costs.

3.3.2.2 Pilot Study Quantitative Results

This section presents the quantitative results of the pilot studies and illustrates the type of information that can be used to enhance decision-making capabilities. Table 2 provides an estimated annual and lifetime ESH cost summary analysis. The ESH Cost Model application profiles the ESH costs of an existing process and compares it to an option and then estimates the profitability potential of the selected option. A three-year manufacturing process life was selected and medium values for an annual number of wafers manufactured, manufacturing process life, and ESH phase and cost factors were extrapolated from the various pilot studies for the cost analysis. Table 3 provides existing, proposed, incremental savings (costs) and a current value summary. a 15% MARR, 40% corporate tax rate, and a five-year straight line depreciation rate were used to compute the cost analysis summary. In Table 3, ESH costs are broken down by lifecycle phase and associated cost factor. At the bottom of the after-tax cash flow column, the total indicates a positive cash flow value. However, this calculation assumes the value of money to be equal to 0%. The adjacent column is the Net Present Value (NPV) of this after-tax cash flow assuming the value of money to be equal to 12%. When the value of money is considered, the decision options change because the cash flow value is now negative.

Table 2 Estimated Annual and Lifetime ESH Cost Summary Analysis

Default Values Used:			
Manufacturing Process Life = 3 years	**Low**	**Median**	**High**
Annual Number of Wafers	120,000	450,000	660,000
Over Process Lifetime	(600,000)	(2,250,000)	(3,300,000)

ESH Phase Cost Summary

	Existing Process A				Alternative Process B			
	Lower	**Median**	**Upper**	**Median % of Costs**	**Lower**	**Median**	**Upper**	**Median % of Costs**
I. UPFRONT	0	1,000	1,200	0.4%	1,000	5,000	10,000	5.2%
(1-time costs)	(0)	(5,000)	(6,000)	(0.4%)	(1,000)	(25,000)	(100,000)	(5.3%)
II. ACQUISITION	2,000	90,000	150,000	41%	0	22,000	140,000	23.0%
(1-time costs)	(10,000)	(450,000)	(750,000)	(40.9%)	(0)	(110,000)	(700,000)	(23.2%)
III. USE/DISPOSAL	60,000	125,000	350,000	57%	50,000	65,500	250,000	68.6%
(5 yrs life)	(300,000)	(625,000)	(1,250,000)	(56.8%)	(250,000)	327,500	(1,250,000)	(68.9%)
VI. POST DISPOSAL	0	1,000	2,000	0.4%	0	500	3,200	0.5%
(10 yrs life)	(0)	(10,000)	(20,000)	(0.9%)	(0)	(5,000)	(32,000)	(1.1%)
V. CLOSURE	0	2,000	3,000	0.9%	0	2,500	5,000	2.6%
(1-time cost at end)	(0)	(10,000)	(10,000)	(0.9%)	(0)	(12,000)	(25,000)	(2.5%)
Total		219,000				95,500		
		(1,100,000)				(475,000)		

Existing Process A
Estimated Median Annual Cost/Wafer = 0.48

Alternative Process B
Estimated Median Annual Cost/Wafer = 0.21

Table 3 Existing and Alternative Incremental (Cost) Savings and NPV Summary

Default Values Used:

Minimum Attractive Rate of Return (MARR) = 12%

Corporate Tax Rate = 40%

Depreciation Life = 5 years

Existing and Proposed Incremental Saving (Costs) and NPV Summary

	Existing ESH Costs	Proposed ESH Costs	Incremental Savings or (Costs)	Tax Rate = 40% After Tax Flow	NPV of After Tax Flow	Summary by Area of NPV After Tax Flow
Pre-Operational Cost Area	Sunk Costs					-91,641
Phase I. UPFRONT (One-time cost)	1,000	25,000	-25,000	-15,000	-15,000	
1. Design for ESH Study	1,000	25,000	-25,000	-15,000	-15,000	
Phase II. ACQUISITION (One-time cost)	90,000	110,000	-110,000	-64,000	-76,641	
2. Permits	13,500	10,000	-10,000	-6,000	-6,000	
3. Capital	76,500	100,000	-100,000	-100,000	-100,000	
Annual Depreciation	0	-18,000	18,000	7,200	25,956	
Estimated Salvage Value	7,650	-10,000	10,000	6,000	3,405	
Operational Cost Area						85,745
Phase III. USE/DISPOSAL (Annual costs)	125,000	65,500	59,500	35,700	85,745	
4. Operating ESH Capital	4,000	2,000	2,000			
5. Resources Used	56,000	26,000	30,000			
6. ESH Consumables Used	4,000	2,000	2,000			
7. ESH Support	10,000	5,500	4,500			
8. ESH Training	5,000	5,000	0			
9. Environmental Processing	5,000	5,000	0			
10. Waste Disposal	41,000	20,000	21,000			
Post-Operational Cost Area						932
Phase IV. POST DISPOSAL (Annual costs)	1,000	500	500	300	1,695	
11. Managing Disposal Site Compliance	1,000	500	500			
Phase V. CLOSURE (One-time costs)	10,000	12,000	-2,000	-1,200	-763	
12. Decommissioning	7,500	10,000	-2,500			
13. Remediation	2,500	2,000	500			
Total After-Tax NPV =			**Total =**	**29,900**		
				Total NPV =	**-4,963**	**-4,963**

4 PRACTICAL WAYS TO IMPLEMENT

4.1 Process for Using the Model

The results of the pilot studies found that the process for conducting an ESH cost analysis should include the following steps:

1. Select an ESH Cost Analysis Application
   a. Existing versus proposed manufacturing process cost analysis
   b. New technology cost comparison
   c. Factory site cost analysis
2. Evaluate the application with respect to the following:
   a. Feasibility (economics, operational logistics)
   b. Tangible and intangible benefits (competitive business performance, sustainable development principles, compliance enhancement, waste reduction)
3. Determine the objective(s) and the way the results of the study will be used. This determination provides a frame of reference for the study and defines the interrelationships among the other ESH (e.g., Design for ESH) tools. Examples of possible objectives include the following:
   a. To participate in making ESH design and operating decisions up-front at an early stage in the process life-cycle to prevent later problems, roadblocks, and expenses.
   b. To assess ESH cost of activities that take place over the life cycle of a process and link them with other business issues.
   c. To identify ESH costs and determine ways to reduce their economic impact.
4. Identify key personnel to participate in the ESH financial analysis (i.e., design/process engineers, ESH specialists, finance/purchasing) and explain their roles and responsibilities and they way the information will be used and kept confidential.
5. Construct a process flow diagram of the existing manufacturing process. The diagram should include any derivative process flows that are related to the primary manufacturing process. For example, if the process generates wastes that are treated somewhere else in the internal factory environment and then disposed of externally (off-site), the process diagram should show that waste stream. Then conduct an inventory analysis of inputs and outputs (e.g., material and energy) and outputs (air emissions, water effluents, solid waste, and hazardous waste) that occur during the process.
6. Collect cost data on the existing process using the ESH Cost Model software. (Contact SEMATECH for ways to acquire). The software is designed to automatically calculate the incremental differences between the existing and proposed process. In addition, all ESH cost information is translated to an annual and lifetime cost basis.
7. Perform gap analysis of data collected. Meet with key personnel participating in the financial analysis to ensure that all relevant and significant costs have been identified and estimated and are reasonably accurate. The success of ESH costing does not depend on identifying and accurately estimating all of the costs that a process generates. Rather, its approach is to

ensure that relevant and significant ESH cost information is arranged and made available to the process engineers and financial specialists.

8. Present and validate results and then select those significant and relevant ESH cost factors that require attention. Then determine ESH process change options and record cost estimates. The identification of ESH options (investments) and the calculation of their estimated costs including the after tax cash flow produced by the investment over its economic life are automatically calculated.

SEMATECH Technology Transfer
2706 Montopolis Drive
Austin, TX 78741

http://www.sematech.org