Business of Safety

SH&E Life-Cycle Cost Model

An internal study from the semiconductor manufacturing industry: Part 2

By Anthony Veltri, Daren Dance and Michael Nave

AS THE SECOND HALF OF A TWO-PART SERIES examining the development and use of an SH&E life-cycle cost model, this article addresses implementation. Specifically, it discusses the reasons behind SH&E cost modeling, with attention to making economic choice decisions among mutually exclusive alternatives. The article also discusses how to design and implement an SH&E economic choice cost modeling initiative, and presents a template of SH&E life-cycle phases, cost factors and activity drivers to capture and estimate costs.

The underlying assumption for this study was that fabrication managers can leverage manufacturing performance advantages by profiling the cost of SH&E issues and practices associated with existing manufacturing technology and process designs and mutually exclusive alternative solutions over their productive and economic life cycle. As noted in Part 1 (*PS,* June 2003, pp. 23-32), several leveraging opportunities were found as a result of this study.

1) A refined understanding of the manufacturing technology and process sources and circumstances that tend to drive internal SH&E life-cycle costs.

2) A more complete and objective data set on internal SH&E costs, enabling improvements to manufacturing technology and process designs.

3) A new way of eliminating customary cost-of-ownership bias by providing more representative direct and indirect SH&E cost information.

4) An enhanced way of determining which SH&E management strategies and technical tactics to pursue and what level of financial resources will be required.

5) A new structure in which fashioning and promoting SH&E issues and practices become a way of making business decisions about manufacturing technology and processes—and in which business needs associated with manufacturing technology and processes become a way of making SH&E business decisions.

An abridged life-cycle assessment method that incorporated activity-based costing and present value financial analysis techniques was used to construct the model and conduct the study. This method was selected because it provided an enhanced way of comparing, in real time, mutually exclusive alternatives and identified the most significant and useful SH&E costs linked to existing manufacturing technology and process designs and proposed alternative solutions. In addition, the amount of time consumed by the assessment will be small enough that it has a good chance of being carried out and its recommendations implemented.

Reasons Behind SH&E Cost Modeling

This study found that semiconductor fabrication companies desired SH&E cost modeling capability for four key reasons: 1) budgeting and cost control; 2) measuring compliance performance; 3) determining reimbursements and setting fees; and 4) making economic choice decisions. Each use is briefly discussed; however, this study specifically focused on using SH&E cost modeling as a way to make economic choice decisions among mutually exclusive alternatives.

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Table 1

Manufacturing Technologies/Processes & Mutually Exclusive Alternatives Tested

Manufacturing Technology/Process	Mutually Exclusive Alternative	Present Value
1) Preplasma Enhanced Deposition of the Inner Layer Dielectric (ILD) Clean	A) N-methylpyrrlidone (NMP)	$659,746
	B) Cryogenic Aerosol System (CAS)	$150,324
2) Deep Ultraviolet (DUV) Lithography and Pattern Transfer	A) Chemical-Vapor Deposition (CVD)	$734,960
	B) Dry Plasma-Polymerized Methylsilane (PPMS)	$389,974
	C) Top-Surface Imaging (TSI)	$669,986
3) Copper Metalization	A) Tungsten Chemical Vapor Deposition (TCVD)	$56,085
	B) Physical-Vapor Deposition (PVD)	$57,734
	C) Electroplating Deposition (EPD)	$247,699
4) Wafer Spent Rinse Water Recycling	A) No Recycle Strategy (NRS)	$10,036,384
	B) Recycle Strategy (RS)	$7,450,959

Budgeting & Cost Control

A distinct group of semiconductor companies desired information on the annual costs of confronting and managing SH&E issues and practices linked to the overall factory site and/or linked to specific manufacturing technologies and processes as a basis to estimate future costs in preparing budgets. This group sensed that once SH&E budgets were approved, cost information would then serve as a control feedback to budgets. Using this information, SH&E specialists could better manage costs and identify and avoid ineffective and inefficient practices. For example, with appropriate cost information, SH&E specialists could:

• Compare captured costs and benefits associated with SH&E strategies and activities, identify value-added strategies and activities to pursue and non-value-added strategies and activities to eliminate, and make decisions to reduce resources devoted to strategies and activities that are not cost effective.

• Compare and determine reasons for variances between actual and budgeted costs of certain SH&E strategies and activities.

• Compare cost changes over time for certain SH&E strategies and activities, and identify their causes and financial impact.

Measuring Compliance Performance

Some semiconductor companies desired information on the efficiency and cost-effectiveness of regulatory compliance efforts as a means of improving the economic value of maintaining and enhancing those efforts. Because of the high costs to maintain compliance, these companies sensed that measuring compliance efforts would become a way of improving functional efficiency and cost effectiveness. Functional efficiency would be measured by relating outputs (e.g., compliance enhancements) to resource inputs.

While effectiveness is measured by the degree to which compliance enhancements are met, this would then be combined with cost information to show cost effectiveness. Thus, the economic value of compliance efforts can be evaluated with:

• measures of compliance efforts that include the costs of resources used to design and implement activities;

• measures of accomplishments that are outputs (quality of regulatory enhancements provided) and outcomes (results of regulatory compliance practice efforts);

• measures that relate efforts to organizational compliance accomplishments, such as cost of compliance per unit of nondefective output.

Determining Reimbursements & Setting Fees

Other companies are seeking SH&E cost information as a basis for setting fees (chargebacks) and reimbursements. However, fees and costing are two different concepts. Setting fees was a policy matter often governed by a company's internal financial cost-allocation policies. Thus, fees of SH&E services did not necessarily equal the cost of the service determined under a particular set of cost chargeback policies. Nevertheless, estimating the cost of services was an important consideration in setting service fees and in calculating reimbursements for strategic and technical advisory services provided to design/process and fabrication functions. Even if fees or reimbursements do not recover the full costs due to financial cost-allocation policies, fabrication managers need to be aware of the difference between cost and fees. With this information, SH&E specialists can properly inform fabrication managers and design/process engineers about the costs of providing SH&E advisory services.

Making Economic Choice Decisions

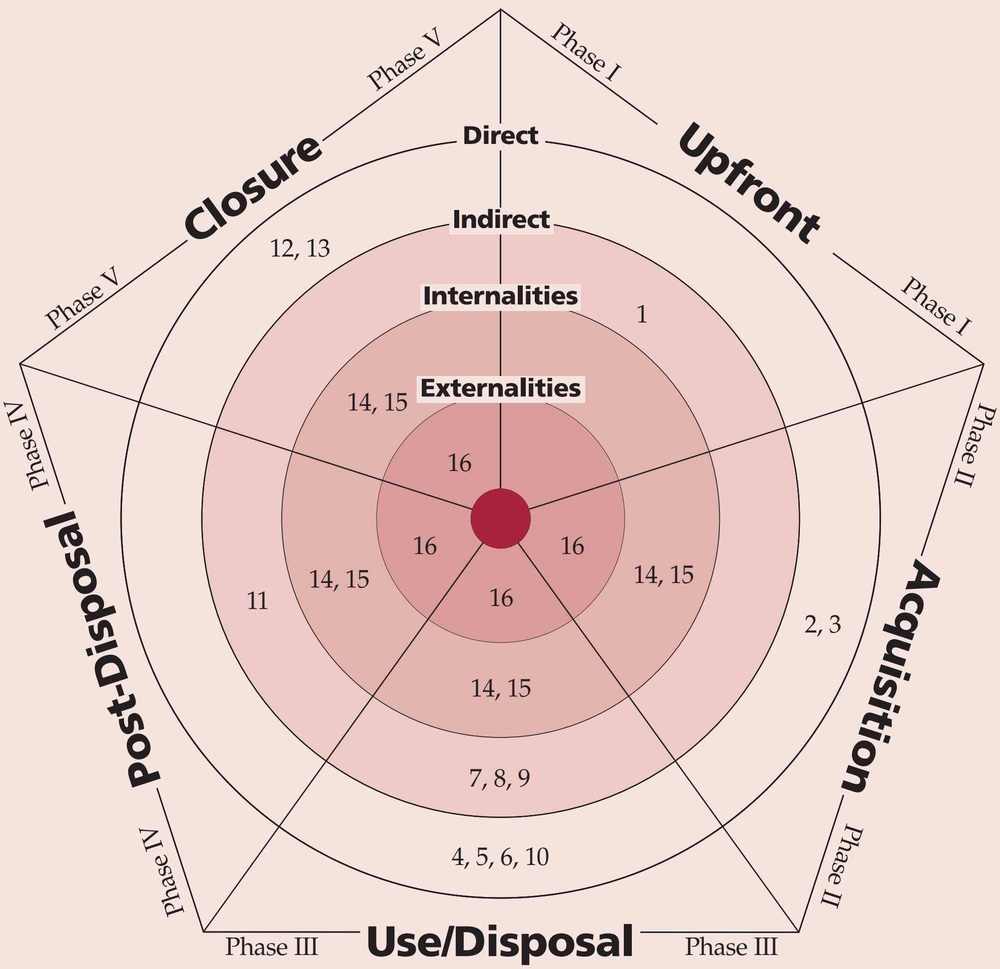
Often, manufacturing managers, design/process engineers, and SH&E and financial specialists must choose among alternatives that are mutually exclusive and linked to manufacturing technology and process designs, such as choices of process materials, manufacturing methods and waste treatment methods. This decision process was the chief driver of this study. Table 1 displays the manufacturing technologies and process designs studied using these types of decisions. This figure includes discounted present values for each alternative with comprehended SH&E costs.

In addition to providing present value calculations, other benefits of this study included a refined understanding about ways to minimize environmental impacts, reduce contingent safety liabilities, ensure compliance and reduce wasteful use of natural resources. This study influenced decision-making capabilities for redesigning processes; substituted reg-

Figure 1

Template SH&E Aspect Costs

Usual and potentially hidden SH&E life-cycle cost factors and activity drivers associated with new, existing or upgraded manufacturing technology and process designs.



Direct Cost Factor (level 1): Costs that tend to be easily identified and measured, and are certain to exist.

Indirect Cost Factor (level 2): Costs that tend to be intangible and difficult to measure, and are seldom accounted for; however, they are certain to exist.

Internalities (level 3): Costs incurred as a result of an SH&E incident; these costs tend to be direct and indirect, and are certain to exist.

Externalities (level 4): Costs incurred as a result of an SH&E incident; these costs tend to be passed on to others outside the organization, and are certain to exist.

1) Design for SH&E
2) SH&E capital review—signoff, fees, process, re-engineering
3) SH&E permit, review, fees, process re-engineering
4) SH&E cost of ownership operations (CoO)
5) Resources used
6) SH&E consumables
7) Strategic/technical support
8) SH&E training
9) Environmental processing
10) Waste shipping
11) Managing waste site compliance
12) Decommissioning
13) Remediation
14) SH&E incident costs
15) Noncompliance costs
16) Environmental incident impacts

ulated inputs with unregulated (and perhaps less harmful) ones; eliminated some process waste; modified supplier relationships; and reduced material safety exposures.

Based on this study's findings, when asked to make an economic choice decision among mutually exclusive alternatives, those involved should follow three implementation guidelines:

1) Economic choice decisions should be a part of the financial management system and, to the extent practicable, should provide SH&E cost and potential profitability data about the firm's new, existing and upgraded products, technologies, processes and services over their productive or economic life cycle.

2) Economic choice decisions should be a calculation element that is part of the firm's overall cost of asset/resource ownership modeling. Understanding the SH&E cost portion of the manufacturing technology or process cost of ownership helps make the business case for SH&E practices; it also provides useful information for internal and external users who are concerned about the way in which a firm focuses on cost reduction, yield quality and operational logistics as the principal driver of enhanced manufacturing performance.

3) Economic choice decisions should flow from a basic data source. This source should consist of a reasonable list of SH&E life-cycle phases, cost factors and activity drivers that can be linked to existing manufacturing technology and process design and to alternative solutions. Figure 1 provides the list used in this study to capture and estimate SH&E costs and to make economic choice decisions. The list includes direct costs (i.e., easily identified and calculated or directly assigned to a manufacturing technology or process design with a high degree of

accuracy) and indirect costs (i.e., intangible and difficult to calculate or directly assign with a high degree of accuracy).

Designing an SH&E Economic Choice Decision-Making Initiative

A four-stage approach was used for making economic choice decisions within this study; it represents essentially what needs to be in order to ensure a rigorous analysis.

Stage 1: Planning

1) Determine what range of the firm's manufacturing technologies and processes will be included in the assessment; classify their SH&E aspects (i.e., occupational safety and health, ergonomics, eco-human toxicity, air emissions, wastewater, solid waste, hazardous waste, energy use, natural resource depletion); and distinguish their current and potential impacts (causes incidents/accidents, damages property, uses natural resources, requires energy, contaminates soil, exposes hazards) linked to the aspect in such a way that a meaningful assessment can be conducted.

2) Identify key personnel (design/process engineers, technicians, SH&E professionals, finance, maintenance, purchasing specialists) to participate, explain the strategic and technical boundaries of the study, describe how confidential information will be treated and how results will be used; and define their roles and responsibilities. Establishment of an integrated project team is critical to management of the assessment. A project chair with an appropriate level of knowledge, skills and experience must lead the assessment. The team should be cross-functional and should possess key management skills: strategy formulation, technical, finance, engineering (design/process), legal, procurement, SH&E and community relations.

3) Construct a flow diagram of the primary-process and derivative-process, specifically depicting and describing the upstream inputs and downstream outputs and their SH&E aspects and associated impacts. For example, if the manufacturing technology or process step generates toxic wastes that require special handling, treatment and offsite disposal, the diagram should show that waste stream, including its origin, as well as abatement equipment, disposal method and safety precautions and interventions.

Stage 2: Data Collection & Estimation

4) Collect and estimate SH&E costs for the existing manufacturing technology and/process under study. The most sig-

SH&E Life-Cycle Costs: Upfront

This phase is concerned with profiling the SH&E risk and cost burdens associated with a new, current or upgraded product, technology, process or service over its life cycle and designing improvement options that maintain a balance between SH&E priorities and other competing process/factory business performance factors. The cost of upfront analysis includes all early stage risk and cost-burden study to bring it to a form for decision making.

Designing for SH&E *(one-time cost).* Consideration of SH&E concerns at an early stage in the design engineering of products, technologies, processes and services to prevent later risk and cost burdens. It has become recognized that the design engineering of products, technologies, processes and services has three stages in which SH&E characterization and cost profiling might occur.

1) **Permit Review/Approval** *(indirect cost).* Activities performed to study the procedural and performance requirements of the permit, conduct environmental impact studies, and make application, lobby for gaining community approval and signoff on permit contract.

2) **Permit Fee** *(direct cost).* The direct cost associated with the permit.

3) **Process Re-Engineering** *(direct cost).* Activities performed for re-engineering and remodeling the manufacturing process infrastructure to comply the procedural and performance requirements of the permit, including capital-related SH&E equipment, installation and utility hookup expenses.

SH&E Life-Cycle Costs: Acquisition

This phase is concerned with profiling the cost burdens associated with obtaining SH&E permits and procuring SH&E capital equipment for the product, technology, process or service required to control hazardous exposures, prevent/control pollution, maintain regulatory compliance and enhance business performance. The costs of a capital asset include both its purchase price and all other costs incurred to bring it to a form and location suitable for its intended use.

Obtaining SH&E Permits *(one-time cost).* Costs associated with obtaining permits (e.g., wastewater discharge, air emissions, handling, storing, transporting hazardous substances and associated wastes). Examples include:

1) **Permit Review/Approval** *(indirect cost)*, Activities performed to study the procedural and performance requirements of the permit, conduct environmental impact studies, and make application, lobby for gaining community approval and sign-off on permit contract.

2) **Permit Fee** *(direct cost).* The direct cost associated with the permit.

3) **Process Re-Engineering** *(direct cost).* Activities performed for re-engineering and remodeling the manufacturing process infrastructure to comply the procedural and performance requirements of the permit, including capital-related SH&E equipment, installation and utility hook-up expenses.

Procuring SH&E Capital *(one-time cost).* Costs associated with acquiring capital equipment-areas-structures for the manufacturing process or factory site, such as:

- Emission/effluent control equipment for reducing, neutralizing or minimizing the volume, toxicity or hazardous properties of process waste *(direct cost).*
- Emission/effluent monitoring devices for providing periodic or continuous surveillance, detecting and recording of exposures to process hazards *(direct cost).*
- Reclaim equipment for separating process waste for reuse *(direct cost).*
- Treatment/storage/disposal facility—equipment for the treatment, storage, recycling or disposal of waste generated by the process, including the consolidation of waste until shipping *(direct cost).*

1) **Equipment Review/Signoff** *(indirect cost).* Activities performed to study SH&E capital equipment alternatives; qualify suppliers; develop, negotiate, signoff on equipment contracts; and make ready the factory and manufacturing process to receive equipment.

2) **Equipment Cost** *(direct cost).* Direct costs associated with SH&E capital equipment, including spare parts.

3) **Process Re-Engineering** *(direct cost).* Activities performed for re-engineering and remodeling the manufacturing process infrastructure to accommodate SH&E capital, including equipment installation and utility hookup expenses.

nificant data for modeling the cost of SH&E issues and practices can be obtained from the manufacturing site; some data can be obtained from trade associations and previous industry cost-of-ownership studies. Costs and prices can be collected from various sources, including periodicals, and phone and face-to-face interviews with industry specialists. When cost estimates are unavailable, reasonable estimates must be produced; these values should be based on the volume of key-resource inputs and unit prices, and on estimates from design/process engineers, SH&E specialists, and finance and purchasing

SH&E Life-Cycle Costs: Use/Disposal

This phase is concerned with profiling the cost burdens associated with protecting and productively using and disposing of process resources in a manner that prevents injury/illness and environmental incidents and that reduces pollution and waste.

Operating SH&E Capital (CoO) *(annual occurring over productive/economic life; direct cost).* Costs associated with operating/owning SH&E capital (e.g., equipment, areas, structures). Examples of costs include utilities, labor, supplies/materials and maintenance.

Resources Used *(annual occurring over productive/economic life; direct cost).* Cost of resources consumed by the product, technology, manufacturing process or factory site that have SH&E life-cycle concerns.

SH&E Consumables Used *(annual occurring over productive/economic life; one-time cost)*. Annual cost of consumables used by the product, technology, process or factory site that is SH&E related such as:

•Safety, industrial hygiene, ergonomics or equipment—supplies for providing employee protection against exposures to process hazards *(direct cost).*

•Environmental protection supplies for preventing/controlling environmental incidents *(direct cost).*

•Environmental packaging equipment—supplies for consolidating-protecting-improving the handling of waste *(direct cost).*

•HazMat management equipment—supplies for providing environmental incident response and recovery services *(direct cost).*

•Fire protection equipment—supplies for providing fire prevention and incident control services *(direct cost).*

•Security equipment—supplies for providing process and factory site monitoring and surveillance *(direct cost).*

•License/certificates for complying with SH&E regulations *(direct cost).*

Providing Strategic/Technical Support *(annual occurring over productive/economic life).* Costs associated with providing SH&E strategic and technical support to the manufacturing process or factory site. Examples include:

•Strategic management activities such as SH&E process strategic planning, re-engineering, auditing SH&E process implementation and managing contracts *(indirect cost).*

•Technical support activities such as identifying, evaluating and controlling exposures to hazards, environmental-emission monitoring and processing, and safety and industrial hygiene inspections; advising on regulatory compliance matters; assisting in manifesting and recordkeeping procedures *(indirect cost).*

•Research/development activities such as testing, conducting studies and creating innovative ways to protect and use process resources productively *(indirect cost).*

SH&E Training *(annual occurring over productive/economic life)*. Costs associated with providing SH&E training support to the process or factory site such as:

•SH&E law required for maintaining compliance with laws and regulatory standards *(indirect cost).*

•SH&E process specific for developing special SH&E competencies and capabilities *(indirect cost).*

Environmental Processing *(annual occurring over productive/economic life).* Costs associated with implementing pollution prevention, reuse, treatment and disposal strategies such as:

•Source reduction by process optimization activities used for limiting pollution before it occurs. Methods include modification of end product to eliminate waste, revised operating practices, process modification changes in raw materials, technology and equipment *(indirect cost).*

•Reclaim activities used for reusing and recycling a waste based on a closed- and open-loop system *(indirect cost).*

•*Closed Loop.* Implies no further processing of a waste material; it is fed directly into the process step.

•*Open Loop.* Implies the material must be processed (e.g., separating a particular component) prior to being reused.

•Abatement activities used to control the physical and/or chemical characteristics of a waste *(indirect cost).*

•Dilution activities used to change the physical and/or chemical characteristics of a waste after its use to reduce the material's volume and toxicity (*indirect cost*).

•Waste treatment prior to disposal activities used to change the physical and/or chemical characteristics of a waste after its use to reduce the material's volume and toxicity and to improve handling and storage *(indirect cost).*

•Waste consolidation—packaging activities used to consolidate and store waste before shipping *(indirect cost).*

•Waste exchange activities used or required to transfer or sell waste to a brokerage that could use the waste as a raw material *(indirect cost).*

•Waste shipping and disposal activities for transporting and disposing of a waste *(direct cost).*

personnel. When cost estimates differ among sources, a gap analysis should be conducted and an average or consensus estimate assumed. Precision of cost information supplied should be reasonable estimates and useful in making decisions. At the same time, unnecessary precision and refinement of data should be avoided.

5) Perform a gap analysis of uncertain cost estimates for the existing manufacturing technology and/process that deviates from expected or anticipated cost ranges. When gaps are identified, a limited fact-finding activity should be implemented to improve cost estimates.

It should be noted that all activity-based life-cycle costing requires some estimation. Estimates of some SH&E costs are typically uncertain because of imprecision in both underlying cost data and modeling assumptions. Because such uncertainty is basic to any type of cost modeling analysis, its effects should be analyzed to uncover reasons and the nature of uncertainty. In analyzing uncertain data, reasonable estimates of probabilities should be used whenever possible. Any major limitations of the analysis because of uncertainty surrounding the data or assumptions should be discussed. Reasonable cost estimates can provide meaningful results if they are consistently applied to all cost uncertainties under consideration. The quality of the results obtained is determined by the quality of the estimates used.

6) Formulate SH&E improvement alternative solutions and record cost estimates for each.

Stage 3: Present Results

7) Present the economic choice decision study report that introduces the existing manufacturing technology and process design and alternative solutions, their internal and external environmental impacts, level of significance and the organization's means to control or improve. A summary-analysis sheet delineating SH&E costs for existing and alternative solutions should be presented. Costs and profitability potential should be reported in monetary terms and estimated over the productive/economic life cycle of the technology or process being evaluated. The life-cycle costs reported should include direct and indirect (i.e., upfront, acquisition, use/disposal, post-disposal and closure) costs. Sensitivity analysis can also be performed for certain cost factors and activity drivers so that the effect of price changes can be studied and forecast.

Stage 4: Post-Implementation Lookback

8) Whereas an upfront cost analysis assists as a control mechanism, a post-implementation lookback is a diagnostic tool to evaluate the overall effectiveness of the change. A post-implementation review should be conducted three to 12 months after a change has become operational, and regularly thereafter. The goal is to assess whether the alternative change option is performing as planned.

Adoption and use of SH&E cost modeling, specifically making economic choice decisions among mutually exclusive alternatives, has the potential to improve the relationship between any firm's SH&E and economic performance. Profiling the SH&E financial impact of the firm's products, technologies, processes and services, highlighting certain cost drivers, and making a business case about new SH&E control solutions should increase confidence that investments in improvement solutions were correct. The ultimate reality is that use of SH&E economic choice decision modeling will, over time, only be as good or sustainable as the underlying business reasons—the economic benefits to the implementing firm—that justifies them to senior-level executives.

In addition to providing SH&E cost and potential profitability data about a firm's new and existing products, technologies, processes and services over

SH&E Life-Cycle Costs: Post-Disposal

This phase is concerned with profiling the cost burdens associated with monitoring the disposal of waste after it has left the control of the manufacturing process and internal factory site and is transferred to another company for management.

Managing Waste Site Compliance *(annual occurring over productive/economic life).* Costs associated with ensuring that waste site disposal procedures are managed in a manner that maintains compliance with governing contracts and federal and state regulations. Examples include:

1) **Waste Site Review/Selection** *(indirect cost)*. Activities performed to review and select disposal site alternatives, and to develop, negotiate and sign-off on waste disposal contract agreements.

2) **Compliance Monitoring** *(indirect cost)*. Activities performed to ensure that the procedural and performance requirements of the contract and federal and state regulations are met.

SH&E Life-Cycle Costs: Closure

This phase is concerned with profiling the cost burdens associated with retiring the product, technology, manufacturing process or factory site at the end of its useful life and preparing the area for other productive uses.

Decommissioning *(one-time cost).* Costs associated with retiring the manufacturing process or factory site following its useful life. Examples include:

1) **Decommissioning Review** *(indirect cost)*. Activities performed for profiling the SH&E risk and cost burdens associated with retiring the manufacturing process or factory site.

2) **Dismantling/Cleanup** *(indirect cost)*. Activities required to disassemble components used in the manufacturing process, arrange for disposal and conduct cleanup procedures.

3) **Component Shipping and Disposal** *(direct cost)*. Costs incurred for transporting and disposing of dismantled components.

Remediation *(one-time cost).* Costs associated with remediating and preparing the area for other productive uses.

1) **Remediation Plan** *(indirect cost)*. Activities required to develop ways to prepare the area for other productive uses.

their productive or economic life cycle, SH&E cost modeling should be designed to accommodate any special cost information needs that may arise due to unusual or special situations (e.g., cost of new regulatory requirements, nongovernment organizational concerns, environmental incidents, injuries/illnesses, certain risk and contingent liability issues). If such information is needed on a regular basis, appropriate cost modeling procedures should be constructed to provide it. The researchers believe this study is generalizable to all types of private- and public-sector firms.

Impact of Economic Choice Decision Making on the Semiconductor Industry

In other industries, basic manufacturing facilities are already in place, and process improvements are added only incrementally to enable new product, technology or productivity improvements. The semiconductor industry, however, must reinvent its manufacturing processes on a three- to five-year cycle to meet new product and technology demands. Thus, even during market downturns, companies invest in new plants, technologies and equipment. Use of SH&E economic choice decision making is expected to expand as companies consider their options for new plant and equipment investments and the associated SH&E aspects. This use will accelerate as the majority of manufacturing shifts from 200mm silicon wafers to 300mm wafers over the next five years. The industry currently has nine 300mm production facilities in operation. Based on recent announcements, one can project that 37 such facilities will eventually be in operation. Fully equipped, these facilities will represent an investment of nearly $50 billion. Construction has started on about half of this planned investment (Vogler).

As the data in Part 1 show, small investments during the design and construction of a semiconductor facility can have large benefits. The current economic downturn is causing companies to review their multibillion-dollar investments in great detail in order to create the most-productive facilities at the lowest possible operating cost; as part of this review, many are investing time and energy to model costs linked to new designs. At the same time, geographical differences in SH&E applications are shrinking as a result of perceived cost, performance and benefit analysis. For example, a new factory in Singapore is using exactly the same performance standards as sister facilities in France and Italy. Such standardization lowers the cost of equipment procurement and improves operational planning, as all facilities have the same performance capability.

In summary, the semiconductor industry is embarking on the largest investment in plant and equipment in its history. Following the International Technology Roadmap for Semiconductors (ITRS 2001), this investment will likely continue for the next 10 to 15 years (SIA). Cost-benefit analyses of all aspects of this investment, including the SH&E economic choice decision capability resulting from this research, are being used to lower operating costs and to provide standard performance capabilities. ■

SH&E Life-Cycle Costs: Incidents

The area concerned with profiling the cost burdens associated with environmental contamination, pollution, alteration, occupational injury/illness and noncompliance fines that adversely affect the manufacturing process, internal factory and external environment. Examples include:

Internalities. Incidents that only affect the internal manufacturing process and tend to result in 1) an adversity or disablement to a resource; 2) incurred direct and indirect costs; and 3) production interruption. Examples of these types of costs include:

•*Direct Costs.* Those costs that can be easily identified and calculated or directly assigned to the incident with a high degree of accuracy; examples include employee financial compensation (both current and reserved), damaged manufacturing property resources, capital replacement expenditures, incident fines and legal expenses.

•*Indirect Costs.* Those costs that are intangible and difficult to calculate in the short term; examples include incident investigation, production delays, loss of training investment, loss of future contribution of employee, replacement of resources, claims management, incident response/recovery/remediation and business resumption.

Externalities. Internal incidents that affect the outside environment and tend to result in 1) air, water, soil pollution; 2) resource depletion/degradation; 3) chronic/acute health effects; 4) environmental habitat alteration; and 5) social/economic welfare effects.

•*Direct Costs.* Those costs that are easily identified and calculated or directly assigned to the incident with a high degree of accuracy; examples include financial compensation for damaged environmental resources, fines and legal expenses.

•*Indirect Costs.* Those costs that are intangible and difficult to calculate in the short term; examples include incident investigation, incident recovery/remediation costs and claims management.

Noncompliance Fines Facilitation. Citations issued for failing to comply with federal, state or local environmental, safety and health regulations.

•*Direct Costs.* Those costs that can be easily identified and calculated or directly assigned to the fine with a high degree of accuracy; examples include financial payment for the citation, making the facility and the process ready to comply including any capital expenditures, materials, labor, legal fees and research.

•*Indirect Costs.* Those costs that can be intangible and difficult to calculate in the short term; examples include activities needed to study and contest the fine.

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