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SEMATECH

2706 Montopolis Drive · Austin, Texas 78741-6499 · 512-356-3500

April 28, 1995

Mr. Lionel (Skip) Johns
Assoc. Dir. for Tech. Policy
OSTP
OEOB
Washington, D.C. 20500

Dear Mr. Johns:

I am pleased to provide you with this advance copy of the 1994 SEMATECH Annual Report. I believe you will find it to be an informative affirmation of our successful partnership with the Department of Defense.

Semiconductor manufacturing leadership is critical to America's national defense and our national economy. SEMATECH has played an important role in helping the U.S. semiconductor industry and the U.S. semiconductor equipment industry regain world marketshare leadership from Japan. At the same time, SEMATECH has delivered state-of-the-art technology that DOD needs to fulfill its mission of protecting our national security. SEMATECH continues to be one of DOD's core R&D programs that enables the military to obtain critical technology to increase weapons system capability, reliability and cost effectiveness.

As you know, SEMATECH's Board of Directors announced last summer that the consortium would end direct federal funding after FY 1996. SEMATECH needs full funding for FY 96 to finish its technology programs already underway and to ensure an orderly transition to the next phase of government-industry cooperation. The Department of Defense was included in the planning for the transition and fully supports it.

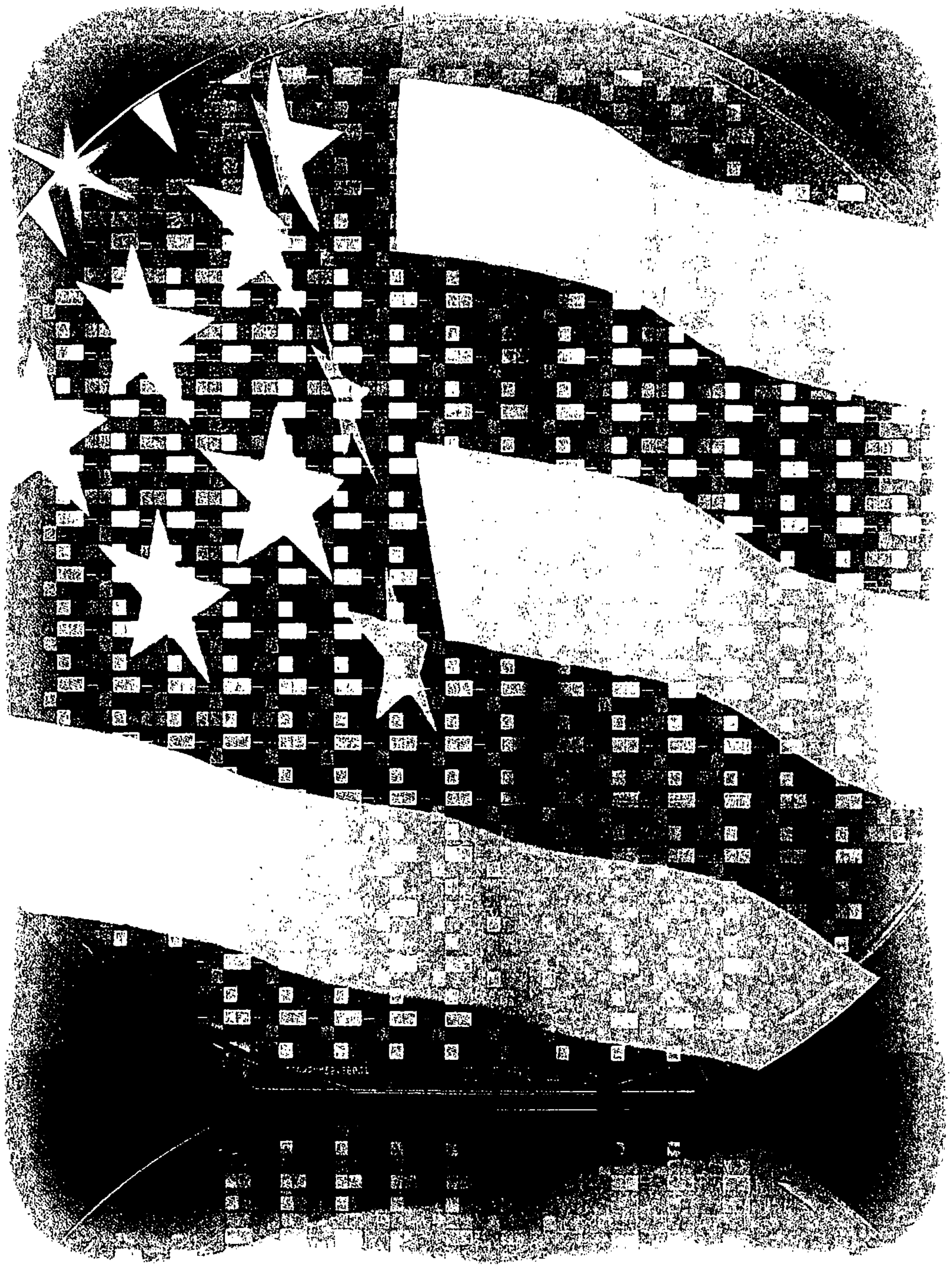
SEMATECH's member companies are committed to continuing the consortium and will match FY 1996 funding dollar-for-dollar just as they have always done. After FY 96, the member companies will directly fund SEMATECH's operational costs. SEMATECH will continue to work with the federal government, primarily through the auspices of the Semiconductor Technology Council, to help coordinate R&D investments in this critical industry.

Thank you for your support and your interest in SEMATECH. Please do not hesitate to call on us if you have any questions or need additional information. Our new telephone number is 202-737-0904. We look forward to working with you in 1995.

Sincerely,

Mark Nelson
Director of Government Relations

SEMATECH



1994
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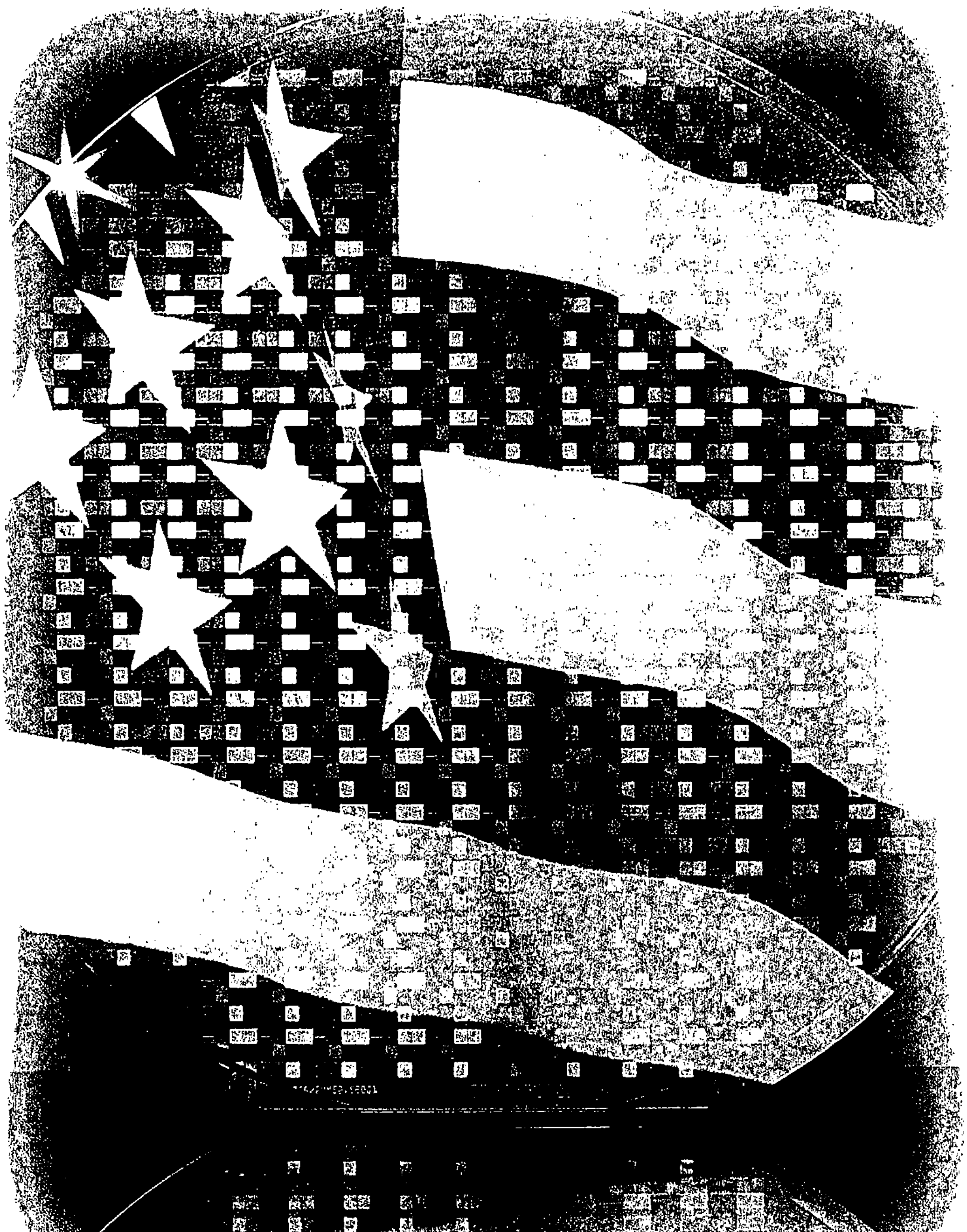
Report



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SEMATECH

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SEMATECH

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May 8, 1995

Mr. Lionel (Skip) Johns
Assoc. Dir. for Tech. Policy
OSTP
OEOB
Washington, D.C. 20500

Dear Mr. Johns:

Enclosed you will find SEMATECH's 1994 Environment, Safety and Health Status Report. The document highlights how SEMATECH is meeting the environmental intent of Congress as specified in the language of the Armed Services Conference Committee Report on the Department of Defense Authorization Act for Fiscal Year 1994. Further, the report specifically illustrates how SEMATECH invested more than $20 million in environmentally-sensitive manufacturing programs ($11 million more than the amount allocated by Congress).

Because of your interest and involvement in environmental affairs, I thought you might be interested in seeing the report. For more information, contact Ann Marett; her address and phone number is located on page one of the report. Call me if you need additional copies.

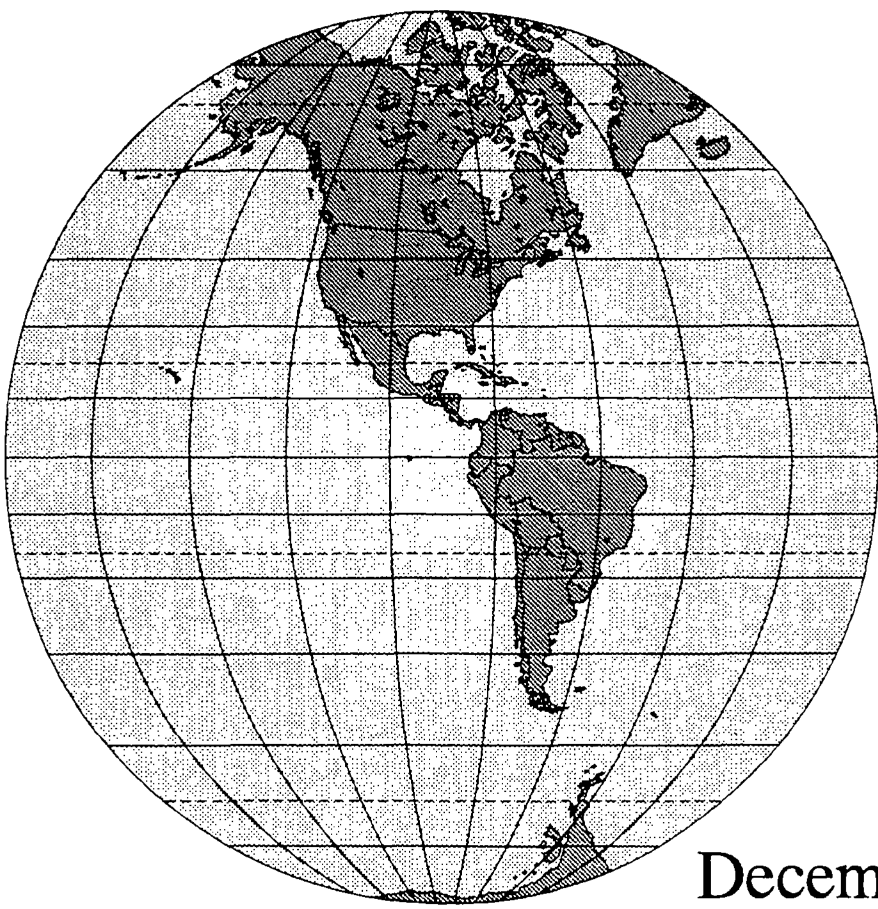
Sincerely,

Karen Ellis

Karen Ellis
Government Relations Specialist

SEMATECH

Status Report: Environment, Safety, Health Programs



December 1994

TABLE OF CONTENTS

SEMATECH'S 1994 ENVIRONMENT, SAFETY, HEALTH PROGRAMS

1 Introduction 1

2 Issues and Challenges 5

3 Project Summary 15

4 SEMATECH's Priority Programs 29

5 National Technology Roadmap for Semiconductors (ESH Section) 57

Appendix I 77

SEMATECH Partnership Programs

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Introduction

1

1 INTRODUCTION

This document details how SEMATECH is meeting the intent of Congress as specified in the language of the Armed Services Conference Committee Report on the DOD Authorization Act for Fiscal Year 1994. Some of the 1994 program highlights include:

- A continued emphasis throughout the SEMATECH organization on environment, safety and health issues and technology development resulted in more than $20 million invested in 46 projects. Approximately 20 full-time ESH professionals on staff teamed with another 100 plus engineers and technicians to work on issues ranging from eliminating hazardous chemicals in the manufacturing process to finding industry-wide solutions to reduce air emissions.

- The SEMATECH ESH staff was instrumental in revising the ESH section of the National Technology Roadmap for Semiconductors. This included ESH Director H. Ray Kerby serving as co-chair of the Technical Working Group and coordinating meetings and input from industry, suppliers and academia throughout the year.

- Throughout 1994 SEMATECH ESH played a key role in the development of consensus guidelines for the semiconductor industry. As active participants in the Semiconductor Equipment & Materials International (SEMI) Standards Facilities and Safety Committee, SEMATECH ESH members assisted in generating more than eight ESH technology guidelines. As a result of the increased importance that has been placed upon the ESH component of the industry roadmap and SEMATECH's increased participation, the Facilities and Safety focus was recently elevated to division status.

- SEMATECH co-hosted three international symposia held in the U.S. which brought together teams of leading experts to exchange information and develop next steps on water conservation, global warming and ergonomics.

- SEMATECH played a key role in the first international summit which brought together world environmental technologists to discuss Total Quality Environmental Management Programs, standards, regulations and policies, ergonomics, equipment safety and take-back strategies. SEMATECH teamed with the Semiconductor Industry Association to present the U.S. story.

- SEMATECH tested an experimental cleaning tool for a quartz-lined furnace which uses a heated air process to vacuum clean the furnace. If proven commercially feasible, this could significantly reduce the use of hydrofluoric acid in the manufacture of computer chips.

- The consortium leveraged national resources by successfully negotiating and initiating the first ESH CRADA project (photocatalytic oxidation of organic emissions) with the National Renewable Energy Laboratory in Golden, Colorado.

- SEMATECH contracted with the Semiconductor Research Corporation (SRC) to investigate six ESH/process topics at five universities. Project areas include water conservation, aqueous photoresist, CVD process optimization, plasma destruction of perfluoro compounds (PFCs) and alternatives to PFCs which are potential global warming agents. In addition, SEMATECH funded approximately $11 million of university research through SRC, an industry consortium.

- Fifteen contracts were initiated for 16 ESH projects. Four projects were completed including the associated 10 technology transfer deliverables.

- Coordinated approximately 30 Focus and Project Technical Advisory Board meetings which brought together top environment, safety and health professionals from our member companies to consult on technology development projects.

- More than 30 presentations throughout the country were made to update industry, academia and supplier communities on SEMATECH ESH programs or the National Roadmap.

The following sections specifically document how SEMATECH invested more than $20 million in environmentally-sensitive manufacturing programs ($11 million more than the amount allocated by Congress):

Section

2 **SEMATECH ESH Project Summary** is a compilation of the technology projects with a specific ESH benefit. SEMATECH has invested more than $20 million in these 46 projects in 1994.

3 **SEMATECH's Priority Programs** detail the seven projects designated as ESH priorities by SEMATECH member companies.

4 **SEMATECH's ESH Strategic Plan** for 1995 is detailed in this section.

5 **National Technology Roadmap for Semiconductors.** The ESH Section of the industry roadmap is included.

Issues and Challenges

2

2 ISSUES AND CHALLENGES

The U.S. semiconductor industry is moving decisively toward designing for environmentally-sensitive manufacturing processes and materials. SEMATECH has played a key role in coordinating efforts on an industry-wide basis to reach a consensus on priority programs.

The National Technology Roadmap for Semiconductors was revised and published in 1994 and is included in this book in Section 4.

Following is a discussion of issues and challenges facing our industry and the SEMATECH strategy for addressing them.

2 ISSUES AND CHALLENGES

To achieve major improvements in the ESH performance of the factory, equipment, processes, and products, there is a critical need to put ownership of solutions into the hands of those who are developing and building the equipment and facilities for chip manufacturing or packaging. The ESH community must support this ownership with aggressive programs to provide design methodology, analytical models and tools, and technical programs of unique or broad-based ESH technology. The following list summarizes the key technology needs :

1. Comprehensive mass balance, cost of ownership, and risk assessment capabilities are needed to achieve a complete Design for Environment, Safety, and Health (DFESH) in chip fabrication and packaging. These tools, procedures, and guidelines need to be integrated with the tools used by engineers for future process, chemistry, and equipment selection methodology.

2. Eliminating chemicals, using lower hazard chemicals, and using process chemicals more efficiently are some of the techniques needed to reduce the hazards and environmental emissions impact of process and packaging chemicals.

3. Abatement technology improvements, in their effectiveness across a range of chemicals and in their cost of ownership, are needed to further reduce emissions, especially during the first half of the 15-year strategic period outlined in the National Technology Roadmap for Semiconductors.

4. Energy management and technology are needed to adequately reduce equipment and facility energy consumption. The roadmap goal in 1998 is to maintain 1993 levels of energy per unit area of silicon.

5. Cost-effective water conservation technologies are needed. This includes more efficient water use in processes and ultrapure water recycling.

6. Worker protection improvements are needed in equipment and facility ergonomics standards. The industry needs to reduce its dependence on cleanroom garments and personal protective equipment.

To achieve the Roadmap requirements, ESH programs will be championed and co-developed by SEMATECH'S ESH Department and the rest of SEMATECH's manufacturing thrust groups. Resources in the ESH Department are dedicated to:

1. Develop DFESH tools, including mass balance, cost of ownership, and risk assessment tools, for use by SEMATECH thrusts, by equipment suppliers, and by engineering management at producer facilities

2. Develop short- and long-term air abatement solutions for several classes of gaseous emissions

3. Implement other projects including water, energy, and worker protection (using Roadmap requirements and the ESH Focus Technical Advisory Board to set priorities)

Strategic Plan

— To "build in" ESH solutions, ESH improvements will continue to be incorporated into the technical objectives of thrust and cross-thrust projects. Chemical reduction, water and energy conservation, ergonomics improvements, and DFESH tool use will be emphasized.

— Member companies' and suppliers' interest and involvement will be promoted to improve ownership, technology insertion, and effective solutions.

— An ESH Supplier Advisory Council will continue to bring an equipment, chemical, worker protection, and supplier perspective to the Roadmap and program strategy.

— Many universities, federal labs, and other government agencies have ESH programs, especially in the environmental areas. Taking advantage of these resources and focusing them on ESH issues for this industry is important, especially to address needs beyond 2-3 years. The thrust will work to focus on ESH through SCOEs, an ESH Center of Competence, and/or other mechanisms.

— There is ESH technology, which is potentially adaptable to the semiconductor industry, that is being used or developed in other industries and/or other countries. Benchmarking efforts will look to these sources. The ESH thrust will maintain the ESH portion of the National Roadmap through the ESH Technology Working Group (TWG) and other sources, and it will measure overall progress against the Roadmap. It is especially important over the next 2-3 years to baseline environmental parameters including energy, water, and chemical use/emissions to be able to measure progress.

Programs

Design for Environment, Safety, and Health Tools—The key tools and models that will be developed in the ESH thrust include cost of ownership, mass balance, risk assessment, and equipment by-product characterization. The 1994 cost of ownership modeling for chemicals will be extended to include energy/water and will be incorporated into the SEMATECH Cost of Ownership model. With supplier involvement, mass balance modeling and methodology will be developed for and applied to major equipment. Chemical risk assessment modeling will provide a tool for weighing all risk elements when comparing alternative chemical use solutions. By-product analysis of key etch and CVD tools, followed by analysis of all 0.25mm tools late in the strategic period, will enhance mass balance capability and reduce safety hazards.

Hazardous Chemical Use Reduction—The National Roadmap calls for reducing the use of three lists of chemicals (approximately 60 compounds) used in mask making, lithography, cleaning, lead frame plating, deflashing, and soldering. In addition, the Roadmap calls for reducing the use of perfluoro compounds (used as etchants), silane (used in deposition), and thermoplastic (as opposed to thermoset) packaging. To complement member company phase-out of solvent-based negative photoresists, SEMATECH will address minimizing ≤0.35mm lithography chemical use by developing nonethylene-glycol-based resists (for silicon and mask), by reducing resist dispense per wafer by 4-fold, and by sponsoring research in aqueous-based photoresists. The work will also develop chemical reprocessors, safer alternatives for dopants and silane, and alternatives to long-lived gases (the perfluoro compounds). An investment in long-term exploratory research will investigate additive process technologies and other innovative technologies that offer potentially major ESH improvements.

Emissions Reduction—To provide more effective and lower cost abatement of air emissions early in the strategic period, several parallel efforts will be pursued. Efficiency and cost studies will be done of corrosive scrubber operating parameters. The studies will help determine the optimal operating conditions, performance limitations, incompatible systems, and costs. Organic emission abatement system data collection will provide benchmark, cost of ownership, and performance information primarily for current volatile organic compounds thermal treatment technology. This will provide baseline information for developing future technologies with specific cost reduction goals. Feasibility studies for and the development of low-cost emerging technologies will be pursued.

Near-term perfluoro compound abatement is being addressed with thermal treatment technology. Long-term plasma treatment and recovery technology are being evaluated to reduce cost. The solutions developed will be used to reduce emissions beyond the levels achieved in the next few years by chemical use reduction. Point-of-use abatement (equipment level) will be considered and implemented where cost effective.

Energy Reduction—There is not a formal program in place yet, but a total budget focus and management program will be developed at SEMATECH. The Facilities Council has taken the lead to this point. The high energy consumption equipment areas are sensitive to the need in National Roadmap for 1998 to not increase energy per m^2 of silicon over 1993 levels. Facility energy consumption in cleanroom air conditioning is a large energy component that should be systematically studied for technology improvement. A baseline study and strategy needs to be developed.

Water Reduction—Water conservation is an acute problem in some manufacturing locations and is a growing chronic problem across the industry. There is a coordinated effort in this area between ESH and the Materials and Bulk Processes, Facilities, and Contamination Free Manufacturing thrusts. Planned activities include a baseline of water use, a pilot of ultrapure water recycling technology, a determination of purity requirements, and an optimization of process use. The overall objective is a 50% reduction in water use per m^2 of silicon processed in 1998 over 1988.

Worker Protection/Ergonomics—The program strategy is to further isolate the process from the person, by using such techniques as enclosed tools (e.g., the Advanced Wet Station), minienvironments, and realtime, online exposure monitoring technologies. The use of minienvironments will reduce the reliance on garments to prevent contamination of the process. From an ergonomics standpoint, an ideal factory layout will be developed to optimize people and product flow. Ergonomic and safety factors will be designed into the 300mm automated wafer handling systems, including intra- and interequipment transport and loading and software and hardware interlocks.

Critical Decisions

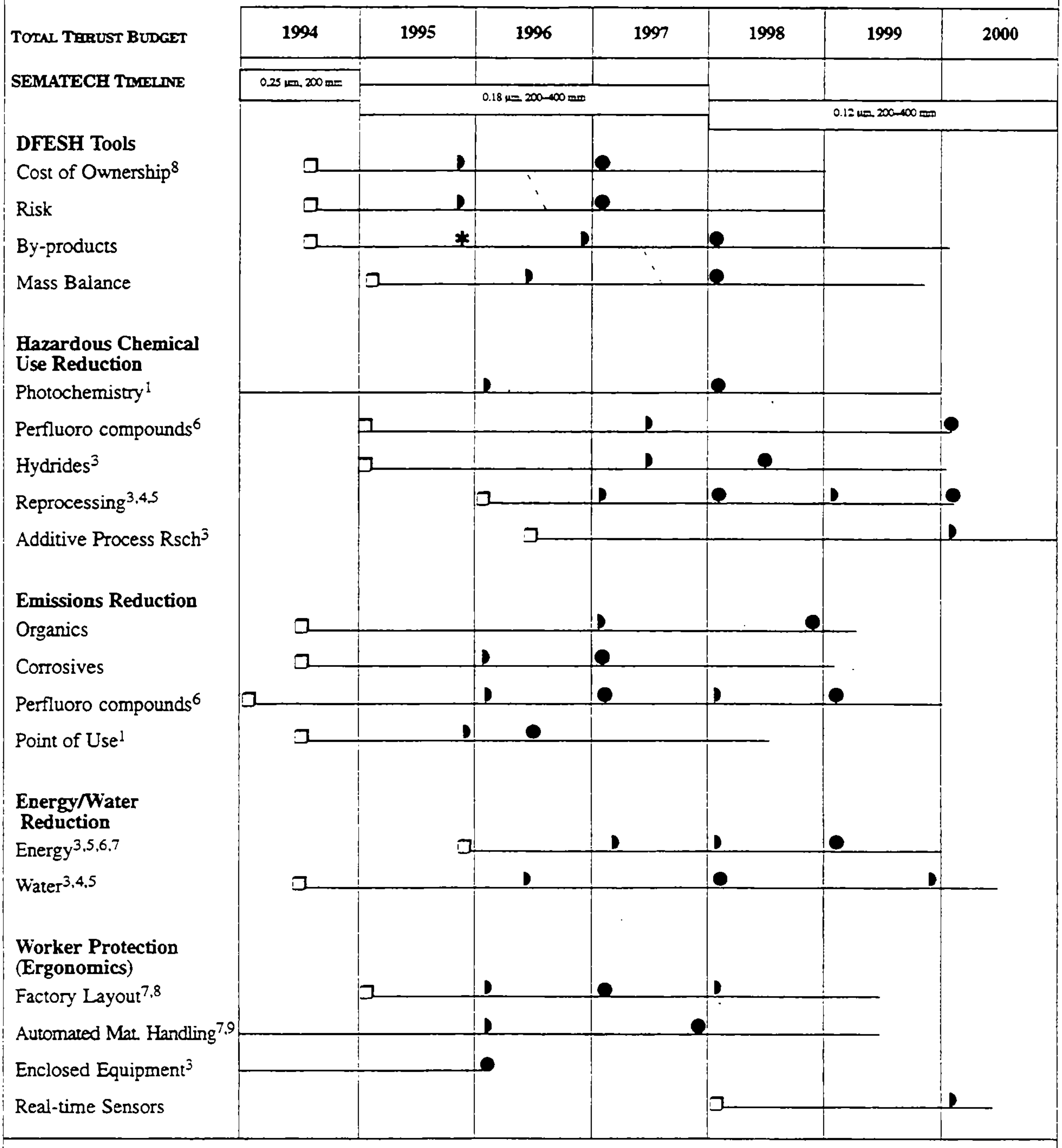
The means to implement the National Roadmap and the SEMATECH strategy must be adapted to the changing resources including federal programs, suppliers, and member companies.

Coordinated Effort

— The ESH Technical Working Group and Supplier Advisory Council provide important coordination as well as strategic and technology issue perspective across the industry.
— Close coordination with the Semiconductor Industry Association ESH Committee is an important ongoing mechanism of two-way ESH communications with semiconductor producers.

- The Semiconductor Safety Association and Semiconductor Industry Association are ongoing partners with SEMATECH in ESH symposia.
- The MCC electronics industry ESH roadmap is coordinated with, and refers to, the ESH National Technology Roadmap for Semiconductors.
- To support member company interests, the ESH thrust will coordinate strategy and technology input to the EPA Common Sense Initiative program in the electronics industry.
- Member company ESH research and development efforts will be coordinated and leveraged with ESH thrust projects whenever possible.
- Coordination will continue with the National Center for Manufacturing Sciences environmental sensor development program to prevent duplication of effort.

SEMATECH Strategic Plan ESH Roadmap



* Note: Programs that are championed by or co-developed with:

1. Lithography
2. Packaging and Assembly
3. MBP
4. CFM
5. Facilities
6. Interconnect
7. Future Factory
8. Modeling and Statistical Methods
9. Manufacturing Systems Development

❐ Start ✔ Proof of Concept ◗ 1st Prototype ▲ Qualification or Valid/Char ✱ Info Avail. ■ End

◆ Decision ✖ Pilot Line ● Prod. Deliv.

Shade – completed by end of 3Q94 _ _ _ Contributes to follow-on project

SEMATECH ESH Programs

Project Summary

3

3 SEMATECH ESH PROJECT SUMMARY

This section contains a compilation of the technology projects with a specific ESH benefit.

SEMATECH has invested more than $20 million in these 46 projects.

In 1993, SEMATECH implemented a program which analyzes the environmental benefit of all of our technology programs. A set of 10 criteria was developed by which to judge each program.

The criteria are used at SEMATECH Project Advisory Board meetings to assess the ESH content of all new projects. If a project meets one or more of these criteria, we have assigned a percentage factor which reflects our estimate of the proportion of the total program cost to produce the ESH benefit. These criteria are consistent with the ESH section of the industry roadmap. This process was developed in Q4 1992 and formalized in Q1 1993.

Criteria are:

1. Potential for eliminating, substituting, or decreasing usage of hazardous materials

2. Continuously improve control of hazards such as employee exposures, high temperatures, high voltages, fire or explosion potential

3. Recycle, recover, or reprocess water, energy, or hazardous materials

4. Consume less energy or conserve resources

5. Characterize or identify reaction by-products for proper handling and disposal

6. Improve abatement or destroy hazardous pollutants from processes

7. Improve monitoring or detection of hazardous pollutants from processes

8. Improve tracking of hazardous materials that will provide data for understanding of consumption, emissions, and wastes

9. Reduce the volume of waste material per area of silicon processed, and reduce the use of non-renewable resources

10. Improve ergonomic aspects of tools, software, and equipment

1994 Projects with Environment, Safety & Health Objectives

Project No.	Project Name	ESH Objective	ESH Approach
CONTAMINATION FREE MANUFACTURING			
S49	Minienvironment Project	Ergonomic considerations for minienvironments as they relate to production.	Develop a safety standard for minienvironments,
S51	High Sensitivity Sensors	Prevent the release of corrosive gas into the environment, optimize chemical consumption.	Develop real time moisture sensors to prevent failure due to corrosion. Optimize chemical and water consumption using metal sensors.
S51	Organic Contamination and Impact	Better methods for analysis can provide earlier warning and better detection of hazardous materials.	Provide better methods for measuring potentially hazardous organics.
S51 Task 5	Wafer Cleaning	Where feasible, demonstrate effectiveness of dilute chemistries and reduce water use.	Support ESH needs where feasible by exploring reduced chemical and water use.
S59	Plasma Modeling	Improved utilization of etch gas chemistries.	Obtain a fundamental understanding of plasma etch chemistry leading to an improved utilization of etch gases and/or replacement of gases currently used with chemistries that are more environmentally safe.

1994 Projects with Environment, Safety & Health Objectives

Project No.	Project Name	ESH Objective	ESH Approach
INTERCONNECT			
E50	AMAT Omega Oxide Etch Equipment Improvement Program	Reduce concentration of perfluoro compounds (PFC) by destroying 90% of C_2F_6 before it leaves the exhaust stream.	Contract with supplier on use of combustion decomposition unit to understand the process of PFC.
E51	Advanced Polisilicon Etch	Improvement of throughput. Ergonomics: make tool easier to maintain by improving tool.	Ironman approach: Split up time, where 8 hours of the day is spent in engineering (upgrading, running experiments, etc.); and the 16 hours left are used in cycling tool to test the upgrades.
E53	Gap Fill Interlevel Dielectric	SEMI S2-93 Certification	Certify to SEMI S2-93 guidelines and implement any recommended improvements.
E55	Collimated PVD TiN	Extend and preserve the environmentally friendly physical vapor deposition (PVD) technology, in lieu of chemical vapor deposition (CVD), for the titanium/titanium nitride (Ti/TiN) contact and via liner application by demonstrating competitive technical and cost capability.	Extend and preserve the environmentally friendly PVD technology, in lieu of CVD, for the Ti/TiN contact and via liner application by demonstrating competitive technical and cost capability.
E56	Varian Electrostatic Chuck (ESC)	Implement and successfully test appropriate high voltage and temperature exposure interlocks according to SEMI S2-93 while developing a high temperature electrostatic chuck (ESC).	Implement and successfully test appropriate high voltage and temperature exposure interlocks according to SEMI S2-93 while developing a high temperature ESC.
E57	LAM 9600 Equipment Improvement Project	To improve stripper module and etch in order to eliminate many or all of the solvents.	Defect reduction and reliability improvement through the use of an Ironman methodology and process development and capability demonstration.
E59	Hi-density Plasma Enhanced Chemical Vapor Deposition	SEMI S2-93 Certification, C_2F_6 emission reduction.	Certify to SEMI S2-93 guidelines and implement any recommended improvements. Process chemistry investigation. Purchase or modify tool hardware to reduce C_2F_6 emissions.

1994 Projects with Environment, Safety & Health Objectives

Project No.	Project Name	ESH Objective	ESH Approach
E64	Speedfam Equipment Improvement Program	SEMI S2-93 Certification	Certify to SEMI S2-93 guidelines and implement any recommended improvements.
E66	Westech 372M	SEMI S2-93 Certification	Certify to SEMI S2-93 guidelines and implement any recommended improvements.
J91	Low Temperature CVD TiN	Select new chemicals with less toxic or hazardous properties.	Funding precursor supplier for Toxic Substance Control Act review and documentation for Material Safety Data Sheet, reaction products analysis, shelf life and handling analysis, and abatement study.
J103	Chemical Downstream Etch/ Elimination of Phosphoric Acid Joint Development Program	The dry strip of nitride film in a Locos isolation process will eliminate the use of hot phosphoric acid.	Develop the best of breed chemical downstream etch tool(s) to replace the use of hot phosphoric acid for nitride strip.
J131	Rodel Consumables Characterization Project	Increasing the removal rate for sheet thermal oxide chemical-mechanical polishing will increase throughput and decrease slurry consumption.	A systematic investigation of the effect of various consumable sets on established polishing performance metrics will be conducted. Design of Experiment methodology will be used to characterize the effect of varying pad manufacturing parameters on polishing performance.
J132	CVD TiN	SEMI S2-93 Certification	Certify to SEMI S2-93 guidelines and implement any recommended improvements.
S112	Chemical Mechanical Polishing (CMP) Development	Conduct a feasibility study to explore alternate chemistries for metal polishing. The objective is to find less hazardous chemicals to reduce employee exposure and disposal costs. Reduce the use of existing slurry by improving process performance.	Screen potential chemistries to determine which ones may be non-hazardous.

1994 Projects with Environment, Safety & Health Objectives

Project No.	Project Name	ESH Objective	ESH Approach
LITHOGRAPHY			
J51	Positive Deep UV Resist	Develop, optimize and commercialize a resist for 0.35um lithography that uses a safer solvent. Improve monitoring or detection equipment for ppb solvent detection.	Complete dissolution studies required to convert to the safer solvent, propylene glycol mono methyl ether acetate (PGMEA) or ethyl lactate for the less safe solvent DIGLYME®. Conduct feasibility testing of analytical and collection technologies to detect ppb levels of amines.
J112 A, B, D	Mask Process and Cleaning	Identify an aqueous developable photoresist for e-beam exposure that has equivalent or better performance than the solvent-developed photoresist currently in use. Replacement resist will likely be non-ethylene glycol-based.	Provide cooperative development/evaluations of advanced resists/ processes for mask writing and soft defect inspection/cleaning capability.
J120	0.25um Resist Development	Ensure resist development for 0.25um lithography. Uses a safer solvent alternative to DIGLYME®. Improve monitoring or detection equipment for ppb solvent detection.	Complete dissolution studies required to convert to the safer solvent PGMEA or ethyl lactate. Conduct feasibility testing of analytical and collection technologies to determine best available methods.
200-001	Point-of-Use Volatile Organic Compound (VOC) Abatement at Resist Coat Operation	Collaborate with SEMATECH's ESH Department to develop facility-wide cost/impact models for VOC abatement technologies. Demonstrate technical feasibility for point-of-use abatement at the photoresist coat operation.	Reduce facility-wide VOC emission and/or abatement cost by developing VOC cost/impact models and demonstrating a point-of-use VOC abatement system for photoresist coat applications.
200-002	Advance Track Modeling	Design and build coater bowl inserts that improve exhaust flow dynamics and allow for the separation of the bowl exhaust and the resist drain that reduces the amount of solvent in the stream exhaust.	Use Massachusetts Institute of Technology Finite Element Analysis software to design inserts. Fabricate inserts. Verify flow improvements of member beta sites.

1994 Projects with Environment, Safety & Health Objectives

Project No.	Project Name	ESH Objective	ESH Approach
S118	Resist Minimization	Supply the member company community with prototype(s) performance capability to use less than 1.0 milliliters of resist for a 200mm wafer coat/per level that is transferable to other wafer size configurations. Benefits are reduction in waste (-4x) to dispose (ESH), reduction of track cost of ownership, insertion potential to various tools and wafer processes.	Conduct multiple parallel feasibility prototype development, and evaluations done on one track tool at SEMATECH. Resist application technique(s) studied using different technologies through university/suppliers will increase chance of success. Performance data will be reviewed to determine most promising concept(s) approach. Best approach(es) must have potential to implement into current resist track tools (add on/upgrade kit). Hardware product development practicality via cost of ownership and return on investment analysis.

1994 Projects with Environment, Safety & Health Objectives

Project No.	Project Name	ESH Objective	ESH Approach
MATERIALS & BULK PROCESSES			
E47	Batch Cluster Tool	To reduce the amount of hydrogen fluoride (HF) used and the amount of corrosive HF produced. Also, to reduce worker exposure to HF.	In collaboration with suppliers and member companies, evaluate existing tool configurations.
E58	Clean-Cluster Applications Development	Decrease energy, gas and chemical use and effluent emissions as compared to stand-alone batch processing.	Assess and improve the tool's environmental impact with respect to power, gas, and chemical use.
E61	SEMITHERM VTP 1500	1. Consume less energy or conserve resources. By reducing cycle time less energy will be used to operate the tool. 2) Model-based temperature control: reduced temperature stabilization time (reduce cycle time). 3) Model fast cooling of the furnace and its effect on cost of ownership (work on reducing cycle time).	Survey industry fab managers for business requirement inputs. Define technical and supplier development objectives which will satisfy member company technical and business requirements. Prove out new process approach.
J64	Point-of-Use Chemical Generation (POUCG)	(1) Install a wet deck with POUCG for HF, HCl, NH_4OH, ozone at an industry site. (2) Performance characterization to include chemical assay, particles, metals, oxide integrity, and surface cleanliness. (3) Collect reliability and cost of ownership data.	Reduce hazards associated with transportation and distribution of chemicals.
J80	Advanced Wet Station	Enhance worker safety through redundant chemical isolation via a mini-environment. Environmental impact will be reduced from current levels by a decrease in consumable and waste as follows: DI water - 40%, SC1 & SC2 chemicals - 80%, volumetric HF waste - 90%.	Consumables are the #1 driver for cost-of-ownership in wet wafer processing. These same inputs directly impact ESH. A rigorous cost-of-ownership model has been developed and sensitivity analysis applied to identify factors that will be optimized to lower cost-of-ownership and maximize ESH impact.
J95	Low Temperature Silicon	Reduce the requirements for energy, process gas consumption, and effluent emissions. Evaluate the improvements.	Baseline the single wafer epi tool's environmental impact compared to the batch epi tool's and define processes to reduce this impact.

1994 Projects with Environment, Safety & Health Objectives

Project No.	Project Name	ESH Objective	ESH Approach
J100	Stand Alone Rapid Thermal Processor	To reduce, conserve and minimize thermal requirements for processing of wafers by improving heating uniformity and by reducing cycle time (improving throughput of the tool).	Rapid Thermal Processor will be evaluated for temperature measurement and control capability and cost-of-ownership analysis. Uniform yet efficient heating of the wafers and throughput will be key factors for improving tool performance. The tool will lower the thermal requirements substantially when compared to conventional resistance heating furnace operations.
S76	Rapid Thermal Processor Install	Reduce the energy and material consumption of the installed base RTP tool set. Improve the overall viability of RTP as compared to the higher energy consuming alternatives (batch processing).	Understand current RTP problem set at member company locations. Work with leading RTP supplier to improve tool set, practices and procedures that will reduce scrap, test runs, and monitor wafer consumption. Improve the overall productivity, in effect reducing the energy and materials required.
S79	Cryogenic Aerosol Cleaning	The feasibility study for cryogenic aerosol wafer cleaning was initiated based on the positive ESH benefits, as well as improved cleaning capabilities for post etch residue removal on advanced devices.	The cryogenic clean has no disposal issues because it uses argon and nitrogen gases. The cryogenic process can replace typical wet chemical cleaning processes that do have disposal costs/risks associated with them, for a significant cost savings.
S58/E67	Post Oxide Chemical Mechanical Polishing Clean	Traditional oxide CMP cleaning processes use a scrubbing process with chemical to remove CMP defects. Reduced chemical and DI water use is a benefit to this process.	Completed process development work on the scrubbing system to reduce the amount of chemical and DI water required to perform the clean, thus reducing chemical consumption by 15% and DI water use by 25%. Set a goal for mid-1995 to develop a DI water recycling system for the tool to reduce DI water use by 60%.
S120	0.25μm/0.18μm Rapid Thermal Processor Component Technology	Improve RTP component technology so that RTP tools can be used to replace furnaces.	With a stronger RTP component technology, more RTP tools will be used in preference to vertical furnaces. RTP tools consume less electrical energy (approximately 17,500 kwH per year) than vertical furnaces.

1994 Projects with Environment, Safety & Health Objectives

Project No.	Project Name	ESH Objective	ESH Approach
S116	Process Water Recycling	Determine current status of process water recycling technology, assess industry needs, establish focus for future research and development. Generate a computer based cost model using current recycle technology and cost options, to include an assessment of the benefits and risks of water recycling.	Survey the domestic industry to provide members with a benchmark. Develop computer-based cost model. Assess recycle benefits and risks. Coordinate the technology focus with member companies, universities, national labs and suppliers.

1994 Projects with Environment, Safety & Health Objectives

Project No.	Project Name	ESH Objective	ESH Approach
		ENVIRONMENT, SAFETY & HEALTH	
S66	Air Emissions Monitoring and Treatment	Lower cost-of-ownership (CoO) and increase performance capability to measure, treat and reduce air emissions. Demonstrate optimum performance with lowered CoO. Develop semiconductor specific abatement technology to protect the environment and conserve energy.	Optimization of existing and emerging abatement equipment, emissions reduction, pollution prevention. Benchmark sensors suited for point-of-use and stack-level semiconductor fab emissions. Determine optimum scrubber efficiencies.
S67	ESH Risk Assessment Methodology Software Tool	Develop a decision methodology for relative risk assessment of hazardous materials based on ESH considerations. This tool will: 1. Evaluate the risk of process/material alternatives for the semiconductor industry. 2. Communicate risk decisions to users. 3. Address management cost/benefit issues.	Perform a benchmark study to evaluate current available risk methodologies including regulatory agency checklists. Correlate the benchmarking information and design a complete flowchart and logic description of a computerized risk methodology tool, then finalize a computerized template. Conduct beta site tests and validate the software tool. Train and provide the finished product to member companies.
S68	Characterize Process By-Products	Develop methodologies to collect by-products data and characterize air emission and waste by-products for identified priority processes. Provide understanding of by-products in order to improve selection of proper personal protective equipment, waste disposal options and appropriate treatment technologies. Share results with other process database to predict process by-products (long term). Provide template methodology for future process by-products characterization.	Use gas chromatograph/mass spectroscopy and Fourier transform infrared analysis to identify the compounds. Develop sampling and analytical methodologies.
S69	Reduce Emissions of Global Warming	Increase efficient use and decrease emissions of potential global warming semiconductor processing materials.	Baseline current semiconductor industry and supplier market data. Develop efficiency and by-products test methods. Demonstrate abatement equipment feasibility. Research alternative etch chemistries and PFC reaction kinetics in plasma.

1994 Projects with Environment, Safety & Health Objectives

Project No.	Project Name	ESH Objective	ESH Approach
S70	Design for Environment, Safety & Health	Incorporate pollution prevention and Design for Environment, Safety & Health (DFESH) in tool and process development. Develop DFESH guidelines for member companies' use. Provide tool for proactive planning and design of equipment and processes.	Define and include pollution prevention in the technology roadmap and critical success factors for technology thrust areas. Conduct Life Cycle Assessment (LCA) of semiconductor manufacturing. Review existing member company systems for ESH incorporation and review. Develop and deliver Design for Environment and LCA training program.
S71	Silane Safety Improvement	Best industry engineering practices will be identified and disseminated enabling improved worker safety. Risks associated with engineering control methods will be evaluated and disseminated enabling data driven about silane issues. The silane replacement strategy which shows the highest probability of successful development will be identified.	Determining if replacing silane for silicon deposition is necessary and if there is a viable path toward replacement. Benchmark and disseminate best industry engineering control practices. Assess risks associated with engineering controls. Identify possible silane alternatives. Select, estimate cost, schedule and probability of successful development will be identified.
955-002	Clean Air Act Technology	Benchmark hazardous air pollutant emissions from wafer fabs. Methods of reducing air emissions such as chemical substitution, process changes, and abatement equipment will be evaluated. This information will be used to formulate a strategy for Maximum Achievable Control Technology requirements under the 1990 Clean Air Act Amendments.	Survey semiconductor manufacturers, equipment suppliers, and environmental regulatory agencies to determine current status of hazardous air pollutant emissions.
955-003	Alternative Dopant	Benchmark alternatives to hydride-based dopants.	Survey semiconductor manufacturers, implant vendors, source suppliers for potential safer dopant sources.
955-004	ESH Strategic Alignment	Revise Industry ESH Roadmap. Develop SEMATECH ESH Strategic Implementation Plan. Invest in additional longer term ESH resesarch projects.	Fund Semiconductor Research Corporation research: two water conservation projects, one aqueous photoresist development project, and one chemical vapor deposition process optimization project. Host roadmap workshops, staff and develop strategic plan.

SEMATECH's Priority Programs

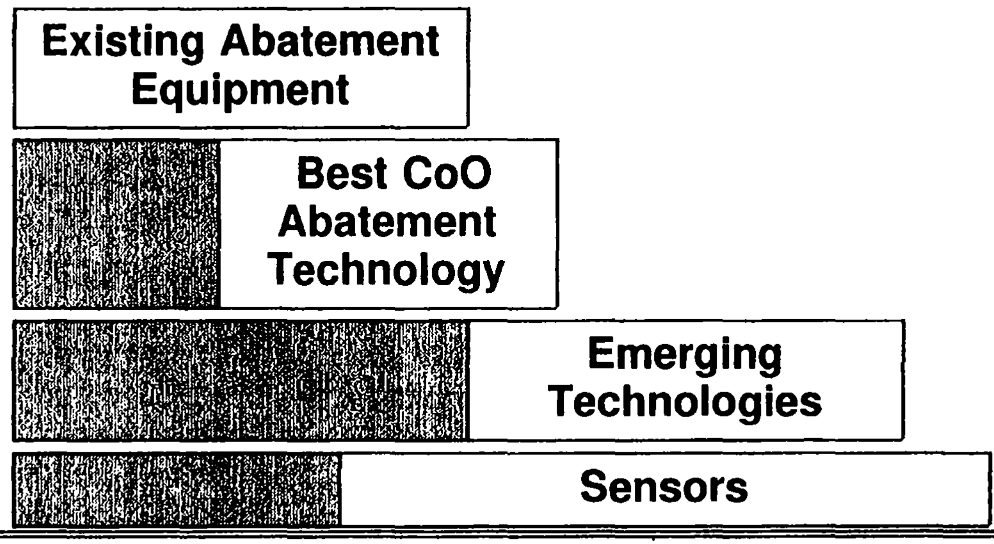
4

4 SEMATECH'S PRIORITY PROGRAMS

This section details the seven projects designated as priorities by SEMATECH member companies.

S66: AIR EMISSIONS MONITORING

ROADMAP ALIGNMENT

Technology Element	0.35μm 1995	0.25μm 1998	0.18μm 2001	0.12μm 2004	0.10μm 2007	0.08μm 2010
Emission Reduction	Use abatement to reduce emissions, as necessary, until source reductions take effect					
Focused Use Reduction List A, B,C	Decrease 50% from 1988 emissions level (A)		Reduce 80% from 1988 emissions (B) Reduce 80% from 1988 emissions below permit trigger (C)			
S66 Technology Development						

IN R&D IN USE

PROJECT: S66 AIR EMISSIONS TREATMENT AND MONITORING

Project Dates: August 1994-October 1995

Project Background:

A: Scrubbers designed for industry in general don't meet the high efficiency levels demanded by the semiconductor industry. In general the emissions are too dilute and the scrubbers are not designed to handle multiple streams of chemicals.

B: Commercially-available devices for control of volatile organic compound (VOC) emissions have an unknown cost of ownership and variable performance and reliability. Additionally, there are a number of different strategies that will effectively reduce air emissions, including point-of-use abatement, alternative treatment technologies and pollution prevention through source reduction.

C: General VOC abatement technologies are not developed for semiconductor industry-specific applications.

D: Currently, the accepted analytical techniques for measuring air emissions are extractive procedures which frequently present reliability and accuracy problems. Additionally, regulations are unclear about the impact of emissions monitoring requirements.

Objectives:

1. Optimize operating and design parameters and removal efficiencies for wet scrubbing of corrosive inorganic gas emissions.

2. Determine CoO and performance characterization of existing VOC abatement technologies.

3. Evaluate, fund and manage the development of cost effective emerging technologies to improve destruction or treatment of semiconductor process emissions.

4. Benchmark real-time exhaust stack, process and fence-line air monitoring methods (fixed and portable).

Tasks:

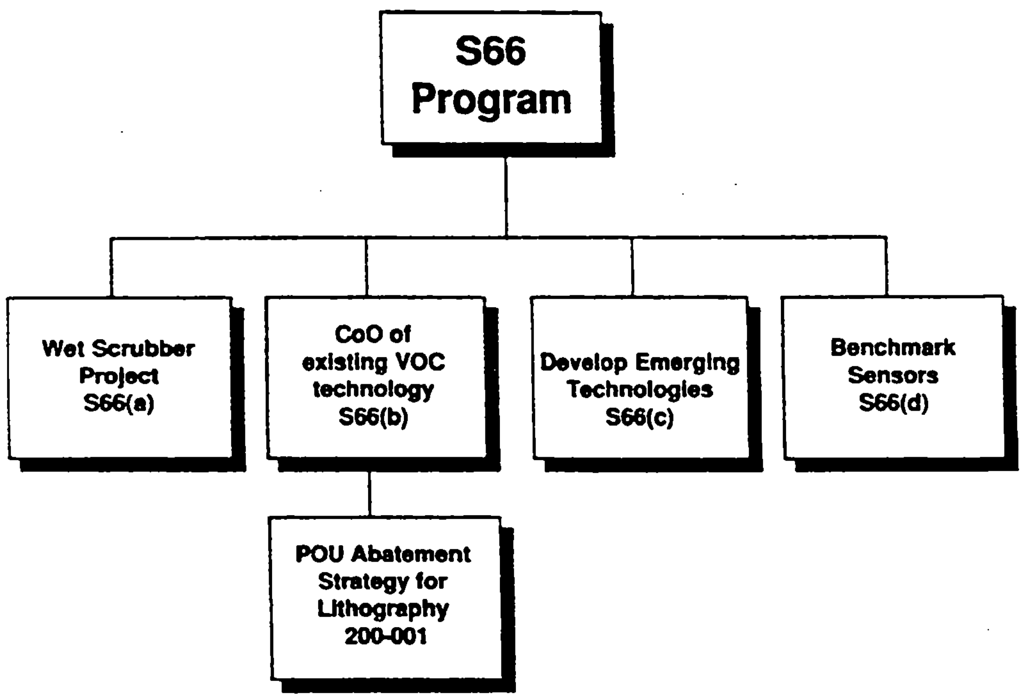
1. Literature search, bench-scale and pilot testing (beta sites), scrubber modeling and optimization, design and guidance documents.

2. Characterize the performance and reliability of existing VOC abatement technologies and determine CoO comparisons. Determine cost of ownership for 10 emerging technologies based on supplier data. Provide modeling tools to determine optimum abatement strategy.

3. Determine feasibility of PCO technology for four semiconductor air emissions streams on a bench-scale basis. Demonstrate technology at a member company site. Determine by-products and engineering parameters.

4. Benchmark performance and projected cost of sensor technologies for monitoring air emissions. Provide recommendations for future development effort for emissions monitors as well as projecting potential impacts of emissions monitoring regulations.

S66: Air Emissions Treatment and Monitoring



1994 Accomplishments:

1. Conducted a one-day workshop to share common scrubber issues. Topics such as packing density, height, damper positions, transport phenomena, and maintenance were discussed.

2. Measured performance of six VOC abatement devices using GC/FID and FTIR techniques. Completed the research and compilation of pollution prevention/emissions reduction techniques for the industry.

3. Completed CRADA agreement between NREL and SEMATECH. NREL completed the assembly of the PCO test unit under a joint CRADA with SEMATECH.

4. Completed benchmark study of emissions monitoring devices.

Partnerships:

S66a - Wet Scrubber Project -- The selected supplier has subcontracted process modeling to Brookhaven National Lab

S66c - Developing Emerging Technologies Project -- SEMATECH has a CRADA with NREL on a cost share basis.

Terminology:

CoO	cost of ownership
CRADA	Cooperative Research & Development Agreement
FTIR	fourier transform infrared
GC/FID	gas chromatograph/flame ionization detector
NREL	National Renewable Energy Laboratory
PCO	photocatalytic oxidation technology
VOC	volatile organic compound

S67: RISK ASSESSMENT METHODOLOGY

ROADMAP ALIGNMENT

Technology Element	0.35µm 1995	0.25µm 1998	0.18µm 2001	0.12µm 2004	0.10µm 2007	0.08µm 2010
Cost of Ownership	Use Cost Model to drive toward low cost process, tool, factory, DFESH solutions					
Cost/m2 of Si processed	Model completed	Model applied to chemicals	Energy/ water use; Incorp. DFESH tools into dev/pkg	Full Cost Accouting		
Risk Assessment	Provide for systematic, data driven ESH decision making Incorporate tool into dev/pkg/proc/tool/facility					
Relative Risk Calculation	Chemical Model Completed	Chemical Analysis Completed	Incorporation of DFESH tools into dev/pkg/proc/tool/facility			

PROJECT: S67 RISK ASSESSMENT METHODOLOGY AND ESH COST OF OWNERSHIP AND RETURN ON INVESTMENT

Project Dates: September 1993-May 1995

Project Background:

There are very few comprehensive environment, safety and health risk models for use in selecting chemicals to be used in semiconductor manufacturing. There are also no ESH cost of ownership accounting systems. Although some European countries have initiated some programs, most of them are in their developmental stages.

Objective:

S67a - Develop a decision methodology for relative risk assessment of hazardous materials based on ESH considerations. This tool will:

1. Evaluate the risk of process/material alternatives for the semiconductor industry.

2. Communicate risk decisions to users.

3. Address management cost/benefit issues.

S67b - ESH CoO/ROI Develop a two-phased model for understanding the economic impact that ESH costs have on manufacturing productivity. The model's two major elements consist of:

1. Identifying calculating cost factors associated with ESH practice.

2. Converting cost information into a meaningful model.

Tasks:

S67a - Risk Assessment Methodology

No.	Milestone
1.	Benchmark available models/systems
2.	Develop template framework for risk methodology
3.	Complete computerized software tool
4.	Conduct beta/validation test
5.	Compile and document finished tool
6.	Conduct ESH risk tool training

S67b - ESH Cost of Ownership and Return on Investment Cost Model

<u>No.</u> <u>Milestone</u>

1. Conduct literature review of ESH cost determinants
2. Identify cost factors
3. Estimate cost factors
4. Conduct beta-site testing
5. Develop final model
6. Incorporate prototype model into SEMATECH CoO

1994 Accomplishments:

S67a -

1. A Benchmarking Summary Report which described the attributes of each software tool identified was accomplished. The report included an analysis of the software tool's functional capabilities, user interface, software capabilities and hardware requirements.

2. A draft template framework for the software tool was completed. The report's purpose was to describe the characteristics of the software tool. Also, the major software components used both to specify the system architecture, and to track specific requirements are presented in this document.

3. The comprehensive template's purpose was to provide a complete flowchart and logic description of the computerized risk methodology tool. This template provided a detailed description of the screen and report formats proposed for CARRI, as well as the proposed risk and hazard elements. A set of algorithms for determining the exposure, hazard, and relative risk of various processes used in the semiconductor industry was presented, along with a listing of the processes and chemicals which were proposed for the standard version of the software.

S67b -

1. A review of the literature assessing Environmental Safety and Health (ESH) cost factor identification-estimation-accounting literature published since 1985 was accomplished. The objectives of this report were to explain how ESH CoO/ROI modeling was grounded in past research and provided the framework for understanding factors that drive ESH costs and ways for accounting for these costs.

2. An ESH cost factor triangle (organizational hierarchy) and a conceptional framework for understanding factors that drive ESH costs were completed.

Partnerships:

Sandia National Laboratories shared the methodology of their Eco-Sys risk model.

Terminology:

CARRI	Computerized Assessment of Relative Risk Inventory
CoO	cost of ownership
EORM	Environmental Occupational Risk Management
PTAB	Project Technical Advisory Board
ROI	return on investment

S68 PROCESS BY-PRODUCTS CHARACTERIZATION

ROADMAP ALIGNMENT

Technology Element	0.35μm 1995	0.25μm 1998	0.18μm 2001	0.12μm 2004	0.10μm 2007	0.08μm 2010
By-products analysis	On key etch and CVD	On all tools	Incorporate DFESH tools into dev/pkg/proc/tool/facility			
S68 Methodology Development						
S68 Process Characterized						

In R&D   In Use

PROJECT: S68 CHARACTERIZE PROCESS BY-PRODUCTS

Project Dates: May 1994-October 1995

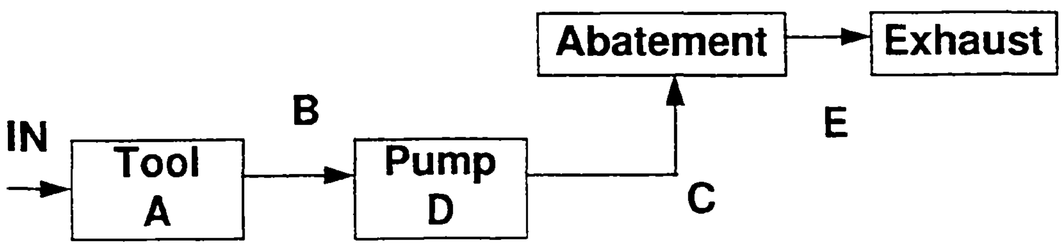
Project Background:

Some chemicals used in semiconductor manufacturing are transformed into by-products during processing. The identity of these compounds has not been verified, making mass balance difficult to perform. Furthermore, the positive identity of these chemicals aids in the proper selection of personal protective equipment and waste treatment.

Objective:

Use mass spectrometry and FTIR to analyze etch and CVD by-products in the reaction chambers, pre- and post-pumps, in pump fluids, and pre- and post-abatement units. Develop sampling and analytical plans for future analyses. Collect information in a database.

SAMPLING PLAN (TOOL)



Chamber		A	(chamber air and particulates during preventive maintenance)
Pump	(Before)	B	(pump foreline)
	(After)	C	(pump exhaust)
	(Itself)	D	(pump fluid and residual particulates)
Exhaust	(Before)	E	(emission and waste)

Tasks:

1. Conduct literature search for previous studies.

2. Develop sampling and analytical plans.

3. Analyze and quantify the by-products up to 95% mass balance for metal, poly, nitride, oxide and tungsten, TEOS and nitride CVD processes.

1994 Accomplishments:

1. Obtained qualitative results for eight pieces of etch and CVD equipment. Carbonyl fluoride, which was not previously predicted, was identified during plasma cleaning. This chemical is highly water soluble and easily removed through the scrubbing process.

2. Completed instrument calibration for 24 compounds.

3. Completed draft sampling and analytical plan.

4. Literature search identified some metal etch by-products and pump fluid contaminants.

Terminology:

CVD	chemical vapor deposition
FTIR	fourier transform infrared
TEOS	tetraethylorthosilicate

S69: REDUCE GLOBAL WARMING

ROADMAP ALIGNMENT

Technology Element	0.35μm 1995	0.25μm 1998	0.18μm 2001	0.12μm 2004	0.10μm 2007	0.08μm 2010
Hazardous Chemical Use Reduction	Reduce use and waste at point of use through....					
Perfluoro Compounds			Reduce emissions to 1990 levels		Alternative compounds available	
S69 Technology Development	Combustion Thermal/ Chemical Plasma Recovery/Recycle Alternative Chemistries					

IN R&D IN USE

PROJECT: S69 REDUCTION OF GLOBAL WARMING AGENTS

Project Dates: January 6, 1994-August 31, 1995

Project Background:

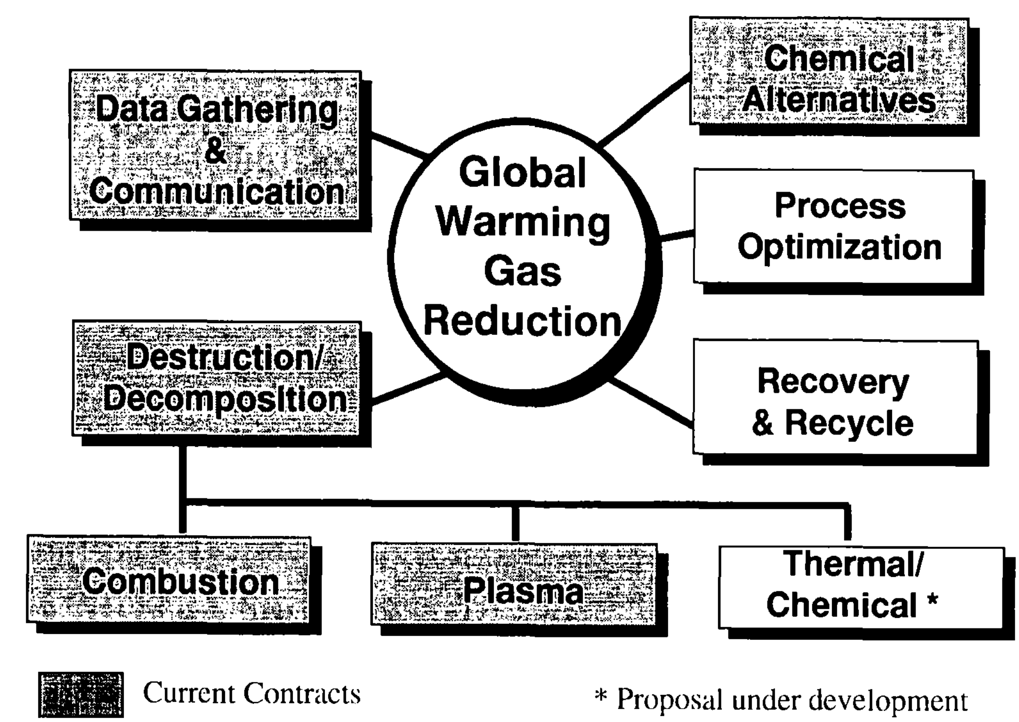
The perfluoro compounds (PFCs), such as CF_4, C_2F_6, NF_3 and SF_6, used in the plasma etch and CVD chamber cleaning processes are very stable and strong infrared absorbing chemicals. This makes them excellent greenhouse gases and potential contributors to global warming, and consequently subjects them to the EPA's Climate Change initiatives.

This project has embarked on a mission to communicate this issue to all parties concerned, to develop a PFC information data base, and to evaluate the alternatives for reducing the use as well as the emissions of these gases to the atmosphere.

Objective:

To evaluate and encourage the emerging technological options for reducing the use and emissions of PFCs to the atmosphere. Options include alternative chemistries, process optimization, recovery/recycle, combustion, plasma destruction and chemical/thermal reaction.

Project Strategy



Tasks:

1. Develop a U.S. semiconductor industry PFC use/emissions baseline.

2. Collect, analyze and summarize all existing PFC abatement device data.

3. Construct a computer model for evaluating the net global warming benefit, considering all direct and indirect effects, of an abatement device.

4. Develop a generic sampling/test plan to make future abatement device evaluations more comprehensive, comparable and statistically meaningful.

5. Evaluate a combustion unit from a supplier on a process tool in terms of PFC destruction efficiency, cost of ownership and by-products of combustion.

6. Evaluate a combustion unit from a supplier which is being developed to handle solids-laden PFC emissions.

7. Search for replacement chemicals for use in etch and CVD chamber clean processes.

8. Study the kinetics of PFC break down in plasmas to improve PFC conversion in process tools as well as abatement devices.

1994 Accomplishments:

1. SEMATECH sponsored a two-day global warming conference attended by 100 plus representatives from the equipment suppliers, gas suppliers, abatement device manufacturers, microchip manufacturers, EPA and academia.

2. Issued interim report for the beta-site evaluation of one of the combustion units presenting the results for the three-week intensive testing.

3. Made a presentation of the PFC issue and the technology alternatives for dealing with the problem at a SEMATECH-sponsored equipment engineering workshop and a SEMI/SEMATECH-sponsored Process Tool Suppliers meeting.

4. Completed global warming net benefit model and generic sampling/test plan.

5. Completed draft report of abatement device data summary.

6. Issued a white paper on global warming as it impacts the semiconductor industry. SEMATECH document 93112074A-TR.

Partnerships:

1. Developed the scope for two, multi-year, university research efforts -- one on a study of PFC kinetics in plasmas and one on alternative etch chemicals. MIT was selected to do this research.

2. Signed agreement with Semiconductor Research Corporation (SRC) to manage these two university contracts for SEMATECH.

3. Continued to work with EPA's Climate Change Division to supply technical and cost data for further discussion on the issues.

Terminology:

EPA	Environmental Protection Agency
MIT	Massachusetts Institute of Technology
PFCs	perfluoro compounds
CVD	chemical vapor deposition
SRC	Semiconductor Research Corporation

S70: DESIGN FOR ENVIRONMENT, SAFETY & HEALTH

ROADMAP ALIGNMENT

Technology Element	0.35µm 1995	0.25µm 1998	0.18µm 2001	0.12µm 2004	0.10µm 2007	0.08µm 2010
Tool and Factory Mass Balance	Develop mass balance to allow for identification of risks and improvements in process, tool, and factory design					
Cost of Ownership	Use Cost Model to drive toward low-cost process, tool, factory, DFESH solutions					
Risk Assessment	Provide for systematic, data driven ESH decision making					
Hazardous Chemical Use Reduction/m^2Si	Reduce use and waste at the point of use through process efficiency, reuse, substitution, additive technologies, etc.					
Emissions Reduction	Use abatement to reduce emissions, as necessary, until source reductions take effect					
Energy/Water Reduction	Reduce natural resources required to produce a wafer					
Worker Protection/ Ergonomics	Continuous improvement of worker protection and drive toward elimination of stress factors, accidents, and injuries					

PROJECT: S70 DESIGN FOR ENVIRONMENT, SAFETY AND HEALTH

Project Dates: May 1994-May 1996

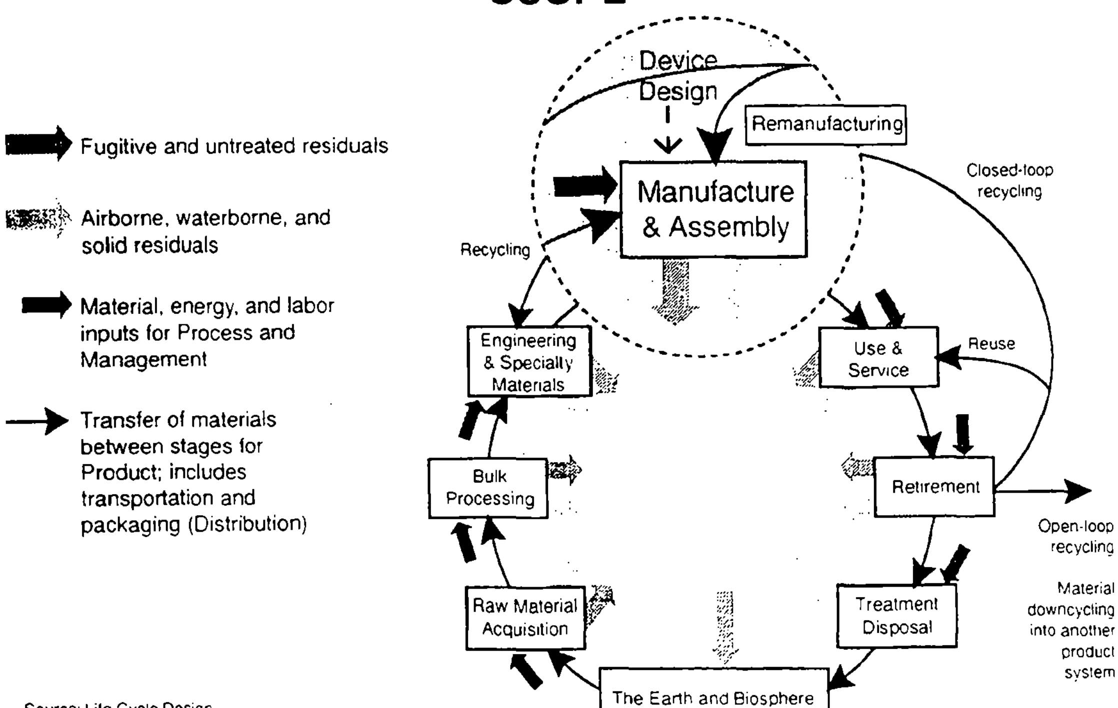
Project Background:

There are no comprehensive Design for Environment, Safety and Health tools to help industries integrate ESH with R&D and manufacturing processes.

Objectives:

1. Develop a semiconductor industry Design for Environment, Safety and Health strategy.
2. Determine a set of semiconductor industry metrics and provide an assessment of the current state of the industry.
3. Develop a tool and factory materials/energy balance and incorporate it into a software tool.
4. Create DFESH training and communications tools to educate member company and suppliers on DFESH and how to integrate it into their business culture.

SCOPE



Source: Life Cycle Design Guidance Manual EPA/600/R-92/226

Tasks:

Objective 1

- White paper report on DFESH in semiconductor industry
- DFESH tool matrix
- DFESH areas of opportunity report
- Final report with DFESH strategy

Objective 2

- Set of metrics
- Final report with current state of industry

Objective 3

- Survey of existing modeling, data collection, and software methodologies
- Model
- Software tool
- Evaluation criteria report & reliability plan
- Beta-site testing/reliability report
- Final software tool
- Software training program
- Maintenance and distribution plan

Objective 4

- Management training module
- R&D and manufacturing training module
- Supply & procurement training module
- Supplier training module
- Final training package

1994 Accomplishments:

1. A supplier has been selected. Negotiations are proceeding.

2. CRADA negotiations have been initiated with Los Alamos National Laboratories.

Terminology:

R&D	research and development
CRADA	Cooperative Research and Development Agreement
DFESH	Design for Environment, Safety and Health

PROJECT: S71 SILANE SAFETY IMPROVEMENT

Project Dates: November 1993-June 1994

Project Background:

Silane is a key source of material for silicon deposition in silicon chips. The cost of ownership for the use of and the incidents resulting from silane is estimated to be high. Further, many different methods for controlling the hazards of silane are used.

Objective:

Survey silane users to benchmark silane engineering controls and incident data. The project also attempted to identify a less hazardous material to replace silane.

Tasks:

1. Survey silane users, producers and distributors to benchmark common engineering control practices and identify effective practices.

2. Survey silane users, producers and distributors to assess the risks associated with silane use and to document silane incidents, including costs and injuries.

3. Identify a silane replacement strategy that shows the highest probability of successful development.

4. Determine if replacing silane for silicon deposition is necessary and if there is a viable path toward replacement.

1994 Accomplishments:

1. Completed the project on time and within budget.

2. Identified numerous noteworthy practices utilized by different industries, to reduce the cost and severity of the incidents.

3. Identified potential opportunities in the point-of-use hydride technology for silane delivery.

4. Conducted a Silane Safety Workshop which was well attended.

Tech Transfer Reports:

94062405A-ENG Silane Safety Improvement Project, S71 Final Report

PROJECT: S116 PROCESS WATER RECYCLING

Project Dates: June 1994-December 1995

Project Background:

A: The semiconductor manufacturing community is committed to decreasing the amount of water consumed to support the manufacture of wafer devices. In March 1994, in cooperation with SIA and SSA (Semiconductor Safety Association), SEMATECH sponsored an international symposium of water management and conservation in the semiconductor industry. A total of more than 130 representatives from the United States, Europe and Japan participated in this effort to share information on related technologies and strategies. It was the consensus of those in attendance that a joint approach was the most effective way to expedite technological advancement in water conservation and that advances in this area had a universal benefit. For this reason, information should be generously shared and built upon. A commitment was made to continue communication on this subject to ensure a coordinated research effort.

B. At present there is no comprehensive decision-making tool to characterize the consumption and disposal of water throughout the facility. A water balance model tool would facilitate the analysis of current site water/wastewater flow and allow users to evaluate the overall impact of implementation of water conservation strategies.

C. State-of-the-art sensors for total organics in ultrapure water systems are inadequate for the real-time detection of organic contaminants specific to process water recycle systems. This limitation impacts both the design and control of recycle systems, allowing certain undesirable organics to pass through the recycle system, increasing the risk of wafer contamination during the rinse process.

D: The chemical processes associated with recycle water purification systems are not well characterized. Research into the basic chemical processes utilized in purification systems will identify opportunities for the optimization of current technology and development of new technologies for recycle purification systems.

Objectives:

1. Develop an integrated water conservation program to promote common program goals and minimize redundancy in research and development.

2. Develop a decision methodology for the characterization of current industry water/wastewater systems and evaluate the impact of water conservation measures.

3. Provide in-situ realtime sensor technology for the analysis of organic contaminants in process water recycle systems.

4. Coordinate with universities, national labs and suppliers to promote the development of cost-effective technologies to optimize recycle purification systems.

Tasks:

1. Survey semiconductor industry to benchmark current water conservation practices and determine future requirements. Coordinate with major academic and industrial contributors to develop a integrated industry strategy to reduce water consumption. Strategy will encompass fabrication equipment & process optimization as well as process water recycle and reclaim strategies.

2. Develop a comprehensive decision support tool to characterize water use and disposal in a semiconductor facility. Perform system analysis on typical semiconductor facility to evaluate water usage/ wastewater generation at the tool, system and factory level. Develop prototype model for beta-site testing, revise and develop interface to produce final software tool.

3. Determine specifications for organic sensors for use in process water recycle systems. Assess the current status of organic sensor technology in both market and research sectors. Benchmark performance and cost of available sensor technologies and feasibility of current sensor research projects.

4. Develop optimum control strategies for recycle systems, characterize chemical balance for current recycle purification processes and identify opportunities for new purification technologies.

1994 Accomplishments:

1. Completed benchmark survey to review current status and future requirements in water conservation. Preliminary evaluation of survey data indicates technology gaps in the area of wafer rinse process optimization, recycle sensor technology and recycle purification processes.

2. Developed water conservation program to promote common industry focus and integrate current activities in the area of water conservation. Established core team of investigators and contributors, first team meeting to be held in Q1- 1995.

3. Coordinated with the working groups of the National Technology Roadmap for Semiconductors and member technical community to generate common industry goals and metrics.

4. Developed a prototype cost model to provide the industry with a standard for calculating the cost of Ultrapure water used in the wafer rinse process. Cost standard will standardize the cost assessment of water conservation strategies.

National Technology Roadmap for Semiconductors

(ESH Section)

5

5 NATIONAL TECHNOLOGY ROADMAP FOR SEMICONDUCTORS (ESH SECTION)

The SEMATECH ESH staff was instrumental in updating the ESH section of the National Technology Roadmap for Semiconductors. This included ESH Director H. Ray Kerby serving as co-chair of the Technical Working Group and coordinating meetings and input from industry, suppliers and academia throughout the year.

The ESH portion of the roadmap has been reprinted in the following section.

Environment, Safety, and Health

In the last 20 years, the semiconductor industry has played a pivotal role in developing technology to improve the environment. Millions of trees have been saved as computer chips enabled businesses to operate with electronic mail and paperless factories. Computer chips in teleconferencing systems, modems, and fax machines have saved millions of travel miles which, in turn, has lessened air pollution. Most of the cars on the road today have electronic control systems making them more fuel efficient and less polluting. Radar systems heralding early storm warnings have saved thousands of lives and given emergency agencies time to protect homes and the environment. Each generation of smaller, faster computer chips uses less power, which contributes toward U.S. industry's management of energy resources. And the industry uses more efficient production techniques and processes, reducing waste generation.

To ensure this trend continues, the semiconductor industry has collaborated on an aggressive plan to manage complex environmental issues related to technology development. The goal is to design and manufacture each new generation of chips by using less chemicals, water, and energy, and by generating less waste.

Scope

There are many driving forces for change in Environment, Safety, and Health (ESH) technology. Paramount is the long-standing industry commitment for continuous improvement in ESH performance based on identified need and cost-effective technology solutions. Key external driving forces include the following:

- The command and control regulations at all levels of government will continue and increase while there will be a relative increase in voluntary and incentive-based programs.
- The realities of cost and relative risk improvement will be used more than in the past at all levels of decision making.
- Nontraditional factors will become more influential, such as more public-disclosure types of regulations, environmental equity, community-based concerns, international environmental and market-driven requirements, and total life-cycle concerns.

The scope and needs in this roadmap are aimed at developing a timely technology-based response to the driving forces.

This ESH Technology Working Group (TWG) report covers the focus areas shown in Figure 11. This report treats both the semiconductor wafer fabrication facility and the semiconductor assembly and test facility as synonymous. Inputs to either facility are chemicals, energy, and water, and worker protection planning and implementation (including ergonomics). Ergonomics broadly covers the person/machine/facility interaction for safety. "Worker protection" refers to reducing risk to employees from potentially harmful physical and chemical agents. Outputs of the facility are the controlled emissions that are channeled to exhaust and waste handling systems and the fugitive emissions that escape from either production tools or the chemical supply system.

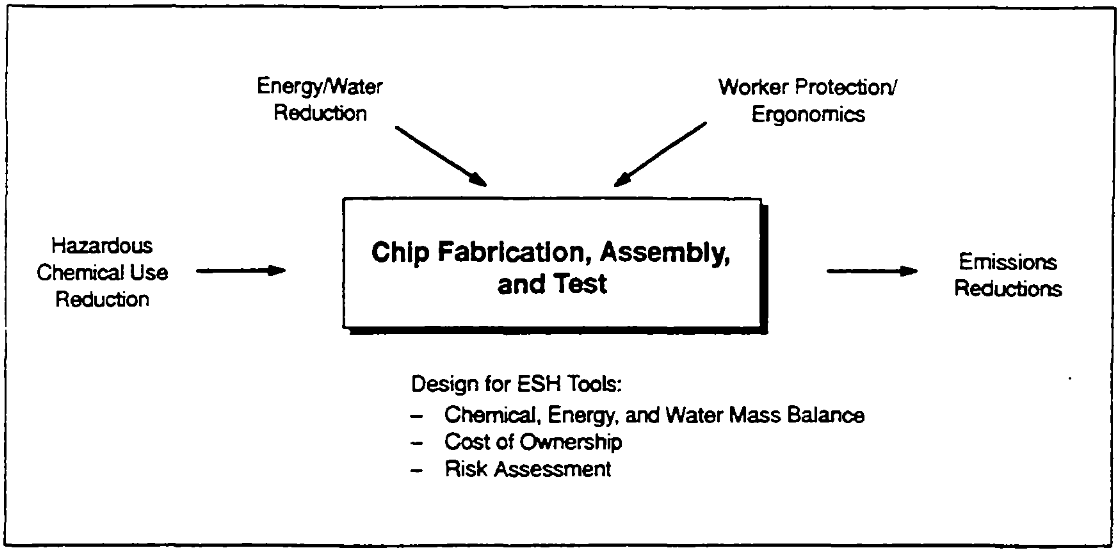


Figure 11 Environment, Safety, and Health Technology Focus Areas

Tools to support the management of the input to and output from a facility are also shown in Figure 11. Chemical, energy, and water mass balance will support reducing chemicals and effluent, and sizing facility exhaust and waste handling systems. Cost of ownership (CoO) includes the purchase, use, management, disposal, and liability costs. Risk assessment indicates the relative risk of hazardous materials based on ESH considerations. These tools are critical to an overall design for environment, safety, and health methodology by which ESH considerations and constraints can be integrated with process and product design.

Current Technology Status

The semiconductor industry has achieved many ESH successes, such as maintaining low rates of injury and illness, reprocessing acids, reducing use of potentially hazardous materials and ozone-depleting substances, developing tool and facility safety standards, implementing process hazard reduction programs, and instituting voluntary chemical phase-out programs. However, more programs need to be identified, prioritized, and implemented.

Figure 12 shows that some progress beyond the 0.50 µm technology level is being made in hazardous chemical use reduction, reduced emissions, and tool and factory mass balance. Very little progress has been made beyond the 0.50 µm technology level with regard to CoO, hazardous chemical risk assessment, and ergonomics. Currently, ESH costs are typically buried in facilities or overhead costs. The ergonomic design is basically the same for both 0.35 µm and 0.50 µm facilities. Ergonomic design requirements for process tools and wafer handling systems will be driven by increasing wafer size rather than by decreasing feature size.

Tool and factory mass balance, as well as improvements in emissions monitoring, are being driven by the national Clean Air Act amendments and local permitting authorities. The other driver is the economic need to more accurately size facilities' exhaust and waste treatment systems. Equipment suppliers are being requested to provide mass balance analysis of the 0.50 µm and 0.35 µm processes that run on their tools. Tool-resident, real-time mass balance analysis that is accessible by the factory computer-integrated manufacturing (CIM) system is not a standard feature for 0.50 and 0.35 µm tools.

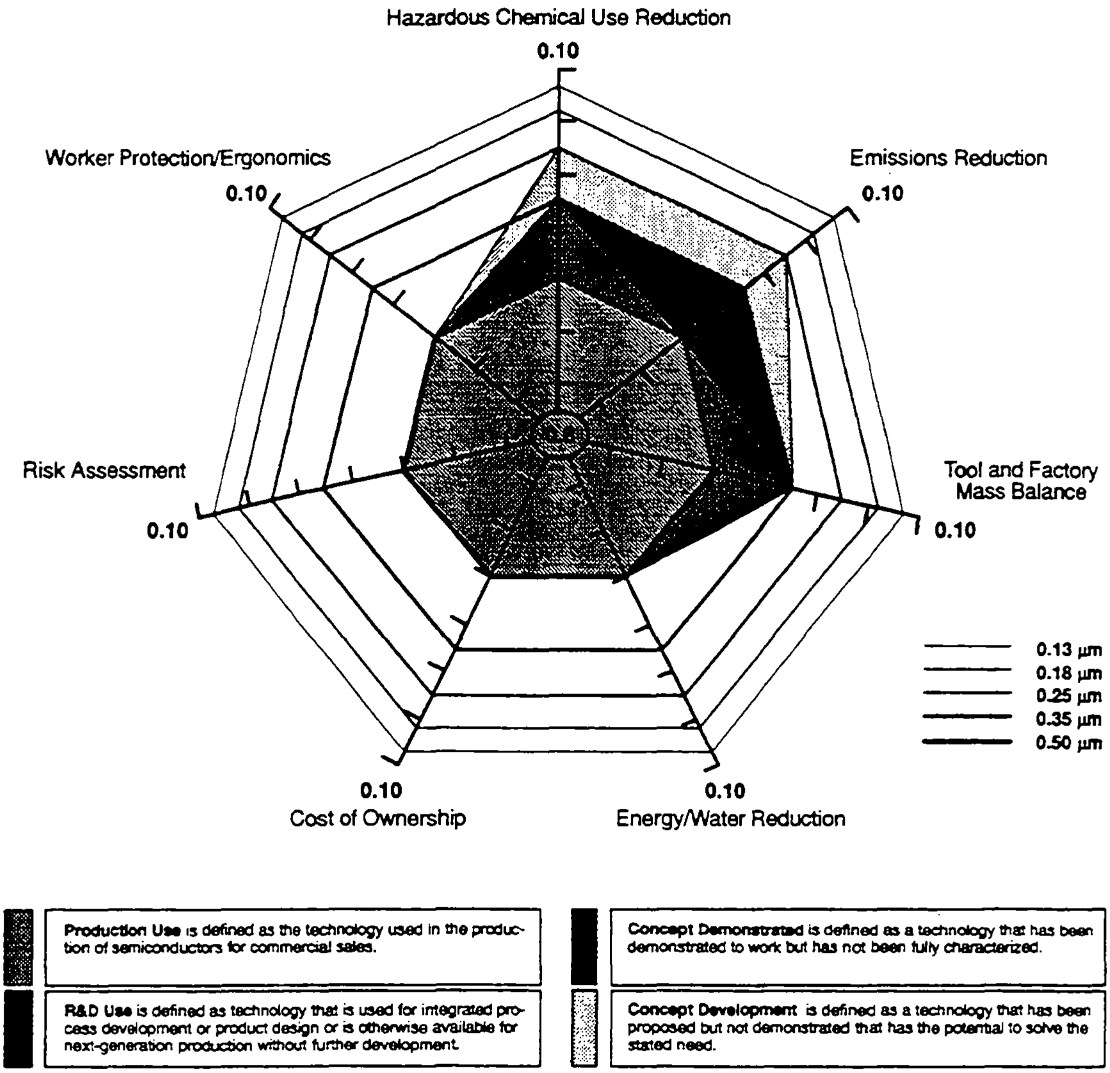


Figure 12 Environment, Safety, and Health Performance Envelope

Significant progress is being made in reducing the use of hazardous chemicals. Ozone-depleting substances (ODS) and targeted ethylene glycol ethers (EGE) are rapidly disappearing from semiconductor wafer manufacturing and assembly processes. Alternative chemicals and safer delivery methods are being sought for silane, dopants, and hazardous solvents and degreasers used in equipment cleaning and product assembly processes. Emission abatement technology, process optimization, and replacement chemicals are needed for atmospherically long-lived process gases, such as perfluoro compounds. Advanced wafer cleaning methods that use either significantly less chemicals or none at all have been demonstrated, although much research is still needed.

There is room for significant improvement in energy consumption per m^2 of silicon wafer processed. Equipment manufacturers generally do not hear this as a significant customer requirement, so there is no significant development of energy-saving technology underway. The cost of energy and the debate of the effects of CO_2 generation on global warming are motivating improvements beyond current levels.

Water consumption per m^2 of silicon processed continues to increase with each technology generation. Water costs, water availability, and community concerns drive the need to conserve water. Efficient use of water in processes and cost-effective recycling of ultrapure water in facilities are strategic needs that require more emphasis.

Online, continuous personal exposure sensors with instantaneous readouts and 99% accuracy are not available for practical use. To isolate human contamination, workers must wear cleanroom garments that may contribute to stress. There is increased attention to ergonomic designs to further protect equipment maintenance workers.

Roadmap of Technology Needs

The ESH roadmap of needs is shown in Table 10. The strategic intent is to integrate preventive ESH solutions into process, equipment, and facility engineering. A comprehensive design for environment, safety, health (DFESH) paradigm shift will take place when utilizing the tools and technology developments on the roadmap.

Table 10 Environment, Safety, and Health Technology Requirements

	1995 0.35 μm	1998 0.25 μm	2001 0.18 μm	2004 0.13 μm	2007 0.10 μm	2010 0.07 μm
Design for Environment, Safety, and Health Paradigm Shift						
ESH Community Ownership	→					Factory/Supplier Ownership
Mostly End-of-Pipe Hazardous Chemical Emissions Abatement	→					Use Reduction
Tool and Factory Mass Balance	*Develop mass balance to allow for identification of risks and improvements in process, tool, and factory design.*					
Models available	On key tools	On all tools and factories →				
By-products analysis	On key etch and CVD tools	On all tools	Incorporate DFESH tools into development/packaging/process/tool/facility →			
Mass balance	Tool suppliers provide data	Online reporting and analysis	Incorporate DFESH tools into development/packaging/process/tool/facility →			
Cost Of Ownership	*Use cost model to drive toward low-cost process, tool, factory, DFESH solutions.*					
Cost/m^2 of Si processed	Model completed	Model applied to chemicals	Energy/water use; Incorporate DFESH tools into development/packaging/process/tool/facility	Full Cost accounting		
Risk Assessment	*Provide for systematic, data-driven ESH decision making.*					
Relative Risk calculation	Chemical model completed	Chemical analysis completed	Incorporate DFESH tools into development/packaging/process/tool/facility →			

Table 10 continued Environment, Safety, and Health Technology Requirements

	1995 0.35 μm	1998 0.25 μm	2001 0.18 μm	2004 0.13 μm	2007 0.10 μm	2010 0.07 μm
Hazardous Chemical Use Reduction / m^2 Si	*Reduce use and waste at the point of use through process efficiency, reuse, substitution, additive technologies, etc.*					
Ozone Depleting Substance Use in Process	Total phase out →					
Targeted Ethylene Glycol Ethers	Total phase out →					
Chemical List A (Focused Use Reduction List)		Decrease 50% from 1988 use	Cyanide-free plating		Pb-free solder systems	Additive processes
Chemical List B (General Release, Disposal List) Reduce / m^2 Si		No-clean technologies for packaging	< Reportable limits or 50% of 1988 use	< Reportable limits or 25% of 1988 use		Additive processes
Chemical List C (Focused Air Emissions List) Reduce / m^2 Si			Reduce 50% from 1988 use or below permit triggers			Additive processes
Perfluoro Compounds			Source reduce to 1990 emission levels by 2000		Non-perfluoro compound available	
Hydrides	Safest practice implementation		Point-of-use generation		Safe alternatives available	
Plastics		Replace thermoset with thermoplastic packaging	Nontoxic flame retardants in packaging			

Table 10 continued Environment, Safety, and Health Technology Requirements

	1995 0.35 µm	1998 0.25 µm	2001 0.18 µm	2004 0.13 µm	2007 0.10 µm	2010 0.07 µm
Emissions Reduction	*Use abatement to reduce emissions, as necessary, until source reductions take effect*					
Chemical List A (Focused Use Reduction List)	Decrease 50% from 1988 emissions		Cyanide-free plating			
Chemical List B (General Release, Disposal List) Reduce / m^2 Si			Reduce 80% from 1988 emissions			
Chemical List C (Focused Air Emissions List) Reduce/m^2 Si			Reduce 80% from 1988 emissions or below permit triggers			
Perfluoro Compounds			< 1990 emission levels in 2000			
Energy / Water Reduction	*Reduce natural resources required to produce wafers and devices*					
Water (gal/m^2 of Si)		Decrease 50% from 1988 usage				
Energy (Jou/m^2 of Si)		No increase from 1993	Reduce by 10% overall from 1993		Reduce by 50% overall from 1993	
Worker Protection / Ergonomics	*Continue improving worker protection and drive toward eliminating stress factors, accidents, and injuries*					
Ergonomics	SEMI tool interface ergonomics guidelines			Reduce reliance on garments to isolate people from processes/product in new facilities		Eliminate reliance on garments to isolate people from processes/product in new facilities
Worker Protection		Process worker isolation from hazardous materials All liquid cleans in 100% enclosed tools	Online, realtime monitoring of worker exposures			

List A (Focused Use Reduction List)

Benzene
Cadmium and Cadmium Compounds
Carbon Tetrachloride
Chloroform (Trichloromethane)
Chromium and Chromium Compounds
Cyanide Compounds and Hydrogen Cyanide
Lead and Lead Compounds
Mercury and Mercury Compounds
Methyl Isobutyl Ketone
Methyl Ethyl Ketone
Methylene Chloride (Dichloromethane)
Nickel and Nickel Compounds
Tetrachloroethylene (Perchloroethylene)
Toluene
1,1,1 Trichloroethane (Methyl Chloroform)
Trichloroethylene
Xylenes (All Isomers)

List B (General Release, Disposal List)

1,1,1 Trichloroethane (Methyl Chloroform)
1,2 Dichlorobenzene
1,2,4 Trichlorobenzene
Acetone
Ammonia
Ammonium Nitrate (Solution)
Ammonium Sulfate (Solution)
Copper
Copper Compounds
Ethylbenzene
Ethylene Glycol
Freon 113
Glycol Ethers
Hydrochloric Acid
Hydrogen Fluoride
Lead
Methanol
Methyl Ethyl Ketone
Methyl Isobutyl Ketone
Methylene Chloride (Dichloromethane)
N-Butyl Alcohol
Nickel Compounds
Nitric Acid
Phenol
Phosphoric Acid
Sulfuric Acid
Tetrachloroethylene (Perchloroethylene)
Toluene
Trichloroethylene
Trichlorofluoromethane
Xylene (Mixed Isomers)

List C (Focused Air Emissions List)

1,1,1 Trichloroethane (Methyl Chloroform)
1,4 Dichlorobenzene
1,2,4 Trichlorobenzene
1,3 Butadiene
1,4 Dioxane
Acetonitrile
Antimony Compounds
Arsenic (Arsine)
Compounds
Carbon Tetrachloride
Catechol
Chlorine
Chlorobenzene
Chloroform (Trichloromethane)
Chromium Compounds
Cobalt Compounds
Cresols/Cresylic Acid
Cyanide Compounds
Diborane
Dimethyl formamide
Ethyl Benzene
Ethylene Glycol
Glycol Ethers
Hydrochloric Acid
Hydrofluoric Acid
Hydroquinone
Isopropyl Alcohol
Lead Compounds
Methanol
Methyl Isobutyl Ketone
Methyl Ethyl Ketone
Methyl Tert Butyl Ether
Methyl Methacrylate
Methyl Chloride
Methylene Chloride (Dichloromethane)
Nickel Compounds
Phenol
Phosphine
Phosphorus
Tetrachloroethylene (Perchloroethylene)
Toluene
Trichloroethylene (TCE)
Xylenes

Tool and Factory Mass Balance

The factory mass balance tool will provide the database and insight needed for tracking and improving chemical and natural resource consumption. Online information on all tools will benefit both process and ESH management. For example, there is now an effort that will develop the methodology for determining the by-products of a process. This methodology will be used initially on representative etch and chemical vapor deposition (CVD) tools. Process tool suppliers and users need to aggressively use this methodology for existing and new tools until the by-products are understood.

When the mass balance models and the by-products analysis methodologies have matured, they need to be incorporated into the tools along with chemical volume input monitoring. This will provide automatic realtime mass balance data that can be accessed by the factory CIM system. CIM systems should have the capability to generate a total factory mass balance analysis for chemicals, energy, and water using the mass balance input from each tool.

Cost of Ownership/Risk Assessment

A cost of ownership tool is needed to understand all elements of cost and ultimately manage ESH total cost as a business cost element.

Risk assessment methodology will allow total risk comparisons of alternative chemicals and implementation schemes. Initial work in this area is underway to adapt a scientific methodology for the semiconductor industry.

Hazardous Chemical Use Reduction

The hazardous chemical use reduction needs are tailored to eight groups of chemicals (see Lists A, B, and C on page 73). Past industry efforts to eliminate ozone-depleting substances and target ethylene glycol ethers have dramatically reduced the use of these chemicals and will lead to their total phase out in the near future. The Potential Solution section enumerates possible ways other chemical use can be reduced or managed, but there is much room for innovation. Point-of-use (POU) chemical generation could also result in chemical use and possible hazard reduction.

List A chemicals have technical Roadmap focus because of their significant emission, disposal, and hazard characteristics. The goal for some chemicals on List A continues beyond the voluntary effort many industry companies now have underway. List B contains the chemicals used in the industry in larger quantity, which need technical roadmap focus because of their emission, disposal, and associated hazard challenges. List C contains materials that need technology focus because of their air emission characteristics.

These lists are subject to change throughout the Roadmap period. They were developed as part of the National Roadmap work and are intended to provide specificity for the broad range of R&D activities that will reduce use. For example, reducing chemical use and optimizing processes should be the primary direction for R&D programs. Until the use reduction results take effect, a secondary approach would be using abatement systems sized for single or multiple tools to reduce emissions of compounds from Lists A, B, and C. The industry goal should be to achieve very low (approaching zero) air pollutant emissions and benign emissions of the toxic chemicals. New wafer cleaning methods that use either dilute chemistries or no liquid chemicals need to be developed for 0.18 μm/2001 and follow-on technology levels. Also, in 0.07 μm/2010, additive processes need to be implemented.

In the global scheme, perfluoro compounds emissions of the industry are a very small potential contributor to possible global warming. However, the industry supports the need to actively pursue effective abatement, reduced usage, and possible long-range alternatives. Hydrides, including silane, need "safe-use" technology and management, since they are critical materials to the industry. Safe alternatives will require significant research if the hydrides are ever to be totally replaced.

Emissions Reduction

Emissions reduction, especially during the first half of the Roadmap period, depends upon cost-effective tactical abatement technology to complement chemical use reduction of the materials discussed above.

Energy/Water Reduction

Energy and water reduction programs need both a short- and a long-term focus. Cost-effective water use reduction through process and tool design changes and recycling systems needs to be developed and put in place for the industry to achieve a 50% reduction in 0.25 µm factories. The consideration for minimizing water consumption needs to occur during process and tool development. The energy level per wafer required by a next-generation tool should be an important cost and conservation consideration. The goal should be to either maintain it at the same level or decrease it through 1998. Later in the Roadmap period, facilities should be more energy-efficient, leading to overall energy savings goals of 10% by 0.18 µm/2001 and 50% by 0.10 µm/2007 from 1993 baseline levels.

Worker Protection/Ergonomics

Workers will be better protected through chemical and physical hazard management, but other opportunities exist as well. Ergonomics, in a broad sense, is important for health and safety. Ergonomics drives the need for automated handling of larger wafers. Emphasis is needed on safe maintenance processes for enclosed tools and minienvironments. The industry needs to continue improving the quality of the work environment, so that the need for personal protective equipment and special garments is minimized. The technology of exposure monitoring of workers should progress to allow for online, realtime measurements. SEMI ESH guidelines should be developed and updated as technology evolves. Also, the move to POU chemical generation and POU abatement systems could result in a more chemically-safe environment.

Potential Solutions

As indicated in Table 11, the potential ESH needs and solutions impact other TWG technologies. Many of the solutions need to be driven within those TWG processes.

Table 11 Environment, Safety, and Health Potential Solutions

Element Thrust	*Tool and Factory Mass Balance*	*Cost of Ownership*	*Risk Assessment*	*Hazardous Chemical Use Reduction*	*Emissions Reduction*	*Energy/ Water Reduction*	*Worker Protection/ Ergonomics*
Design and Test	Incorporate DFESH as part of design constraints.					Design for low power consumption.	Ergonometric design of ECAD tool physical environment.
ESH	Characterize by-products. Develop chemical, energy, and water mass balance.	Develop ESH cost of ownership.	Develop risk assessment methodology.	Monitor and advise on hazardous chemical use reduction progress.	Develop abatement technologies.	Monitor energy and water reduction program.	Develop realtime sensors for personal monitors. Improve SEMI S2 implementation.
Factory Integration	Implement CIM insitu chemical mass balance.	Use chemical cost of ownership to select chemicals.	Complete risk assessment ranking of all chemicals.	Reduce chemical use. Reduce chemical hazards through improved controls, warning systems, and material compatibility. Reprocess chemicals.	Develop abatement technologies.	Reduce energy use. Recycle, reclaim water. Reduce air requirements for cleanrooms.	Increase use of minienvironments. Decrease reliance on garments to prevent contamination. Develop low pressure gas delivery systems. Implement automated wafer handling.
Interconnect	Implement mass balance on all tools. Identify and compile all by-products data.	Use chemical cost of ownership to select chemicals.	Complete risk assessment ranking of all chemicals.	Develop additive processes. Optimize etch processes to min. chemical waste. Reduce use of PFCs. Reprocess chemicals.	Reduce emissions of perfluoro compounds.	Tool suppliers reduce energy use/wafer.	Improve equipment ergonomic design. Reduce manual preventive maintenance of equipment.
Lithography	Implement mass balance on all tools.	Use chemical cost of ownership to select chemicals.	Complete risk assessment ranking of all chemicals.	Develop additive technologies. Use aqueous based litho systems. Reduce solvent use in processing. Reduce solvent and heavy metals use in mask making.	Reduce solvent emissions.	Tool suppliers reduce ventilation requirements of litho tracks.	Reduce manual preventive maintenance of equipment. Eliminate odors. Improve equipment ergonomic design.

Table 11 continued Environment, Safety, and Health Potential Solutions

ELEMENT THRUST	TOOL AND FACTORY MASS BALANCE	COST OF OWNERSHIP	RISK ASSESSMENT	HAZARDOUS CHEMICAL USE REDUCTION	EMISSIONS REDUCTION	ENERGY / WATER REDUCTION	WORKER PROTECTION / ERGONOMICS
Materials and Bulk Processes	Implement mass balance on all tools. Identify and compile all by-products data.	Use chemical cost of ownership to select chemicals.	Complete risk assessment ranking of all chemicals.	Extend chemical use life. Use no-clean technologies. Use dilute chemistries. Optimize processes. Seek safe alternatives to hydrides. Develop additive processes.	Reduce gas and solvent emissions.	Tool suppliers reduce energy use/wafer. Reduce water usage thru optimization and recirculation.	Enclose all liquid-clean tools. Improve equipment ergonomic design.
Assembly and Packaging	Implement mass balance on all tools. Identify and compile all by-products data.	Use chemical cost of ownership to select chemicals.	Complete risk assessment ranking of all chemicals.	Use cyanide-free plating. Use Pb-free solder systems. Reduce solvent use. Use thermoplastics. Use nontoxic flame retardants. Reduce organics in binders.	Reduce solvent emissions.	Reduce energy use to manufacture packages.	Improve equipment ergonomic design.
Process Integration, Devices, and Structures	Incorporate DFESH as part of design constraints.	Use chemical cost of ownership to select chemicals.	Complete risk assessment ranking of all chemicals.	Invent steps that eliminate chemicals and cleaning processes. Develop additive technologies.			Ergonometric design of ECAD physical environment.

PRIORITY/DIFFICULTY OF EFFORTS

The priority of technology needs is shown in Table 12. Each need is designated by either an *R* for research or *D* for development and is timed when the ESH TWG feels that it can be implemented.

Breakthroughs are needed to find safe hydride alternatives, develop alternative cleaning processes, and develop additive processes. (Additive processes add material only to selected areas of the wafer and eliminate or reduce the need for masking, etch, and cleaning.)

Table 12 Priority of Environment, Safety, and Health Technology Needs

		HIGH PRIORITY	*SECONDARY PRIORITY*
BREAK THROUGH NEEDED— SHOW-STOPPERS	**0.18 µm/ 2001 Needs**	Cost-effective, reliable, integrated, specific chemical sensors (D)	Low pressure gas system (R)(D)
	0.13 µm/ 2004 Needs	Alternative cleaning processes (R)	
	0.10 µm/ 2007 Needs	Hydride alternatives (R)	Nonhazardous emission semiconductor manufacturing tool (R) Perfluoro compound alternatives (R) Pb-free solder
INNOVATION NEEDS	**0.07 µm/ 2010 Needs**	Additive process technology (R)	
CONCEPTS EXIST, BUT NEED TO BE PROVEN	**0.35 µm/ 1995 Needs**	Chemical mass balance and by-products (D)	Risk assessment (D)
	0.25 µm/ 1998 Needs	Integrated POU abatement at tool (D)	Cost equivalent ultrapure water recycle (D)
	0.13 µm/ 2004 Needs	Integration of DFESH into semiconductor product design (D)	Wafer cleaning without hazardous chemicals. (D)

(R) Research *(D) Development*

CROSSCUT TECHNOLOGY NEEDS

The needs for those technologies that are not addressed by a formal TWG are shown in Table 13. Training/education was added because the ESH TWG felt that to achieve the requirements roadmap, the level of ESH awareness needed to be raised in all areas of the semiconductor industry.

If more than one need is shown for a technology, the priority is shown in parentheses, with 1 being the highest priority.

Table 13 Priority of Environment, Safety, and Health Crosscut Technology Needs

( ) = indicates priority

	METROLOGY	CONTAMINATION-FREE MANUFACTURING
0.25 µm/ 1990 Needs	(1) Online realtime chemical monitoring (2) DI water recycle process control	(2) SEMI minienvironment ergonomic guideline
0.18 µm/ 2001 Needs		(1) ISO ESH standards compatibility Reduced gowning requirements in cleanroom
	MATERIALS	MODELING / SIMULATION
0.35 µm/ 1995 Needs		(1) Chemical, energy, and water mass balance (1) Risk assessment (1) CoO (2) Chemical use optimization
0.25 µm/ 1990 Needs	(4) Cyanide-free plating (3) Non-heavy-metal opaquing of masks	
0.18 µm/ 2001 Needs		(2) DFESH integrated with semiconductor design tools
0.10 µm/ 2007 Needs	(1) Hydride alternative (2) Pb-free solder	
	QUALITY AND RELIABILITY	STANDARDS
0.35 µm/ 1995 Needs		(2) SEMI ergonomic guideline
0.25 µm/ 1990 Needs	Validate ultrapure water and chemical quality specifications	(2) SEMI S2 certification process (1) ESH CoO (3) Maintain updated SEMI ESH guidelines consistent with technology development
0.18 µm/ 2001 Needs		(1) ISO ESH standards compatibility Testing and analytical methodologies
	TRAINING / EDUCATION	
0.35 µm/ 1995 Needs	Train semiconductor process development engineers and suppliers on DFESH	

POTENTIAL PARADIGM SHIFTS

To achieve the goals of the Roadmap, ESH ownership must exist at the highest management level throughout the industry. Examples of actions are as follows:

- Integrate and implement DFESH elements in all aspects of tool, process, and facility design and management.
- Investigate new forces that drive ESH activities in the industry beyond meeting regulations and acquiring permits.
- Eliminate the reliance on garments to isolate people from product in new facilities.
- Significantly reduce the use of hazardous chemicals in wafer manufacturing and assembly processes.
- Develop feasible additive processes.

SUMMARY

The key elements for ESH continuous improvement are the reduction of hazardous chemicals use, the reduction of energy and water use, and the evolution of worker protection/ergonomics programs, including the application of ergonomics in tool and factory design and operation. The key tools needed are chemical, energy, and water mass balance, ESH cost of ownership,[9] and risk assessment. They should be used systematically by suppliers and producers to achieve DFESH.

As ESH awareness continues to build in the semiconductor community, this learning needs to be incorporated into the equipment, device, and factory design models. ESH concerns need to be addressed in the earliest stages of technology, process, product development, factory design, and manufacturing.

This ESH roadmap, successfully implemented, will continue to enhance the industry as a data-driven, cost-conscious, proactive leader in environmental protection, worker safety, and health programs.

Appendix I

SEMICONDUCTOR RESEARCH CORPORATION

COOPERATIVE RESEARCH

August 4, 1994

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SEMATECH FUNDS FOUR NEW ENVIRONMENTAL RESEARCH PROJECTS TO BE MANAGED BY THE SEMICONDUCTOR RESEARCH CORP.

– Research to be Conducted at Four Universities: U. of Arizona, N. C. State, Stanford and U. of Texas –

AUSTIN, TEX. AND RESEARCH TRIANGLE PARK, N.C. – SEMATECH has funded four new university-based environment, safety and health (ES&H) research projects. The Semiconductor Research Corp. (SRC) has worked closely with SEMATECH to define these projects and put them in place. The projects will be managed by the SRC.

Two projects will focus on water use in the semiconductor manufacturing process, the third relates to chemical use, and the fourth will study the lithography process.

"Our goal is to initiate these new projects immediately," said H. Ray Kerby, SEMATECH's director of environment, safety and health. "The semiconductor industry is committed to environmental quality. The addition of these projects to this year's research agenda is a good example of that commitment."

"The SRC currently funds and manages 28 research projects with identified ES&H objectives at 15 universities around the United States," said Larry W. Sumney, SRC president and CEO. "By putting these projects in place, the SRC is responding directly to priority research needs expressed by the SRC's participating companies and organizations."

SEMATECH's 1994 contract with the SRC is now approximately $11 million, which is used to fund long-range research at universities and other research institutions.

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SEMATECH will spend approximately $20 million this year on environmental technology development programs. The SRC's total research budget is $28 million, of which approximately $1.6 million is invested in projects related to the environment, safety and health.

The four new environment, safety & health projects are:

• University of Arizona – Developing tools and techniques to overcome technical obstacles related to ultra-pure water recycling and discharge minimization in semiconductor manufacturing.

• Stanford University – Providing critical models, methodologies and sensors to optimize surface preparation and deionized water rinses. This will achieve lower water use and costs in semiconductor manufacturing, as well as better overall performance (including yield, throughput and reliability).

• North Carolina State University – Determining methods to sense emissions which might be environmentally harmful and optimizing processes and equipment to reduce emissions.

• University of Texas – Developing new resist materials designed to minimize the environmental impact of the lithography process. This research will include an exploration of new imaging chemistry that could provide a means for water-borne coating and development.

SEMATECH and the SRC are working together to achieve industry-wide ES&H goals set forth in the National Technology Roadmap for Semiconductors, coordinated through the Semiconductor Industry Association.

SEMATECH, a consortium of 11 major U.S. semiconductor companies, seeks to develop semiconductor manufacturing technology to keep the U.S. industry competitive. It is based in Austin, Texas.

The SRC is a consortium of more than 60 semiconductor companies and government agencies. It plans and implements an integrated program of pre-competitive research conducted at 62 North American universities, national laboratories and research institutions. The SRC is based in Research Triangle Park, N.C.

# # # #

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Water Conservation High Priority for High Tech

AUSTIN, Texas, August 4, 1994 -- At one time conventional wisdom held that high-quality groundwater was a renewable resource. Not many people believe that any more.

The semiconductor industry, which consumes large quantities of water to manufacture computer chips, is moving water conservation and recycling programs very high on its priority list.

Because of water's perceived abundance and its relatively low cost, water conservation has not received the same level of attention as waste minimization and chemical substitution. All of that has changed in the 1990s.

Chipmakers reclaim some of their water and use it in plant cooling systems or in irrigation...even in some non-critical manufacturing processes. But reclaimed water is not generally used to rinse impurities off silicon wafers during the numerous steps required to manufacture computer chips; the rinsing process requires ultra-pure water.

SEMATECH recently funded water research projects at two U.S. universities. The University of Arizona in Tucson is focusing on a recycle and waste minimization project in ultra-pure water systems. Stanford University is working on a project related to process water requirements and optimization, with the ultimate goal of lowering water use and costs. The Semiconductor Research Corp. (SRC) worked closely with SEMATECH to define these projects and put them in place. The SRC is managing these two programs for SEMATECH.

The long-term goal of the University of Arizona project is to develop the tools and techniques needed to overcome the technical obstacles related to ultra-pure water recycling and discharge minimization in the semiconductor industry.

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The Stanford program will provide critical models, methodologies and sensors to optimize surface preparation and de-ionized water rinses. This will achieve lower water use and costs in semiconductor manufacturing, as well as better overall performance, including yield, throughput and reliability.

These two projects complement a program on process water recycling which SEMATECH initiated in October 1993. The objective of that program is to determine the current status and assess future needs, establish a standard for the cost of recycle systems, and determine both the benefits and risks of recycle systems. The approach includes a comprehensive, computer-based cost model and a benefit and risk assessment tool.

"Water conservation and recycling has been included as a technology requirement on the National Technology Roadmap for Semiconductors," said H. Ray Kerby, SEMATECH's director of environment, safety and health programs. The technology roadmap was developed by the Semiconductor Industry Association in conjunction with SEMATECH and the SRC.

"These two university-based research projects have a strategic fit with the industry roadmap," according to SRC President and CEO Larry Sumney. "The project results will be applicable to many of the technology focus areas such as Future Factory and Contamination Free Manufacturing."

Earlier this year, SEMATECH co-sponsored the International Clean Water Conference in San Jose, Calif. Both the Semiconductor Industry Association and the Semiconductor Safety Association worked with SEMATECH to promote water conservation awareness and discussion within the industry. The objective was to accelerate the technology of industrial water management through a collaborative effort.

"We are fully aware that there is a bottom to the well and that the well could run dry if we don't do something," says Frank Squires, SEMATECH's chief administrative officer. "As we continue to focus on this issue, we realize that there has been a great deal of individual effort. But since there has been little communication and sharing of information on this subject, SEMATECH is forging a coordinated effort of information exchange."

In addition to the international symposium, SEMATECH plans to share the results of its environmental, safety and health research programs on a global basis.

Although SEMATECH does not release the dollar amount of any of its contracts, these two new projects bring SEMATECH's annual contract with the SRC in 1994 to approximately $11 million to fund long-range research at more than 30 universities and research institutions across the country.

As part of its mission to solve the technical challenges of keeping the U.S. number one in the global semiconductor industry, SEMATECH is on target this year to spend approximately $20 million on major environmental, safety and health programs.

The programs--more than 30 this year alone--reflect the commitment of the consortium, its member companies and the federal government to develop and demonstrate environment, safety and health-conscious manufacturing technologies.

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EDITOR'S NOTE:

SEMATECH, a consortium of 11 major U.S. semiconductor companies and the Department of Defense, seeks to develop semiconductor manufacturing technology to keep the U.S. industry competitive. It is based in Austin, Texas.

The SRC is a consortium of more than 60 semiconductor companies and government agencies. It plans and implements an integrated program of pre-competitive research conducted at 62 North American universities, national laboratories and research institutions. The SRC is based in Research Triangle Park, N.C.

COOPERATIVE
RESEARCH

November 2, 1994

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SEMATECH FUNDS TWO NEW ENVIRONMENTAL RESEARCH PROJECTS TO BE MANAGED BY THE SEMICONDUCTOR RESEARCH CORP.

– Research to be Conducted at MIT –

AUSTIN, TEX. AND RESEARCH TRIANGLE PARK, N.C. – SEMATECH has funded two new university-based environment, safety and health (ES&H) research projects. The Semiconductor Research Corp. (SRC) worked closely with SEMATECH to define these projects and will manage them.

Research for the projects will take place at the Massachusetts Institute of Technology (MIT) in Cambridge, Mass., and will seek to reduce emissions from the semiconductor manufacturing process that may be harmful to the environment.

"These new projects, as well as previous SEMATECH-SRC ES&H projects, demonstrate the semiconductor industry's commitment to environmental quality and efforts to minimize the impact of the semiconductor manufacturing process," said H. Ray Kerby, SEMATECH's director of environment, safety and health.

"The more than 60 participating companies and organizations that make up the SRC have indicated that ES&H is a priority research need," said Larry W. Sumney, SRC president and CEO. "In response to our customers, the SRC will add these new projects at MIT to a growing list of SRC-managed ES&H research projects at 15 U.S. universities."

The new environment, safety & health projects at MIT are:

• Study of PFC Emission and Abatement for Plasma Processes – this research will measure and model the kinetics of perfluorocompounds (PFCs) released from

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plasma processes used in the manufacture of microelectronics. The research will also develop and test abatement processes to lessen these emissions. PFCs are suspected of contributing to global warming.

• Non-Perfluorocompound Replacements for Wafer Etching and PECVD Chamber Cleaning – this research will investigate alternatives for the PFC gases used in two main processes of semiconductor manufacturing, wafer etching and plasma enhanced chemical vapor deposition (PECVD) chamber cleaning.

SEMATECH and the SRC are working together to achieve industry-wide ES&H goals set forth in the National Technology Roadmap for Semiconductors, coordinated by the Semiconductor Industry Association.

SEMATECH's 1994 contract with the SRC is approximately $11 million, which is used to fund long-range research at universities and other research institutions. By the end of this year, SEMATECH will have spent approximately $20 million on environmental technology development programs. The SRC's total research budget this year is $28 million, of which approximately $1.6 million is invested in ES&H projects.

SEMATECH, based in Austin, Tex., is a consortium of 11 major U.S. semiconductor companies that seeks to develop manufacturing technology to keep the U.S. semiconductor industry competitive.

The SRC is a consortium of more than 60 semiconductor companies and government agencies. It plans and implements an integrated program of pre-competitive research conducted at 62 North American universities, national laboratories and research institutions. The SRC is based in Research Triangle Park, N.C.

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NREL NEWS

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NREL, SEMATECH SEEK TO CURB AIR EMISSIONS

Golden, Colo., September 2, 1994 – The U.S. Department of Energy's National Renewable Energy Laboratory (NREL) and SEMATECH, the semiconductor manufacturing research consortium, today announced a cooperative research and development agreement (CRADA) to explore the feasibility of the semiconductor industry using an emission abatement technology based on ultraviolet light.

The technology, photocatalytic oxidation, is under development at NREL and International Technology Corporation of Knoxville, Tenn. It uses ultraviolet light and a catalyst to destroy volatile organic compounds. SEMATECH, based in Austin, Texas, is considering the technology to destroy volatile organic compounds generated by semiconductor manufacturing processes. Photocatalytic oxidation could further reduce air emissions as well as lower operating costs for semiconductor makers.

"The agreement is part of SEMATECH's proactive effort to identify and use improved waste treatment technologies that reduce emissions to the environment," said NREL project manager Craig Turchi.

"This is yet another example of the semiconductor industry collaborating with government to develop leading-edge technology," said H. Ray Kerby, SEMATECH's director of environment, safety and health. "One of SEMATECH's priority environmental programs is the treatment and monitoring of air emissions. This is a very complex program, and we believe teaming with NREL could provide us with additional technology to protect the environment."

The photocatalytic system consists of a reactor vessel, an acid gas scubber, an exhaust blower and other system components such as monitoring instruments and controllers. Air emission streams are fed into the reactor where ultraviolet light activates the catalyst, titanium dioxide, initiating a chemical reaction that destroys compounds before being emitted to the atmosphere.

Under the CRADA, NREL will perform laboratory and on-site tests on various air emission streams identified by SEMATECH. SEMATECH will then compare the effectiveness and cost of photocatalytic oxidation with other waste-minimizing technologies that are under consideration for commercialization.

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SEMATECH RECEIVES TWO ENVIRONMENTAL AWARDS FROM CITY OF AUSTIN

AUSTIN, Texas (July 6, 1994) --The City of Austin honored both SEMATECH and one of the company's employees with Environmental Awareness Awards at a June 29 ceremony. The awards recognized individuals and groups at SEMATECH who have made "significant contributions to the protection and preservation of Austin's environment." Representing the third and fourth environmental honors for SEMATECH this year, the awards were sponsored by the City of Austin Environmental Board, Resource Management Commission and the Solid Waste Advisory Commission.

SEMATECH received the Non-profit Organization Award for the company's on-site recycling program. D. W. Brown, a SEMATECH employee, received the Beth Brown Boettner Award for individual Achievement. Brown, an equipment engineer was recognized for his volunteer efforts in collection of water samples at Onion Creek and McKinney Falls in Austin. These samples were used to help verify water quality and that swimming was safe in McKinney Falls.

The SEMATECH Recycling Council was recognized for excellence in solid waste management. Although the employees have practiced recycling since the consortium's start-up, SEMATECH's volunteers increased efforts a year ago toward awareness among co-workers, who began to recycle record volumes of paper, plastic, aluminum, metals, glass and chemicals. They also hit the streets of the Montopolis community to pick up trash and join the neighbors in keeping the area clean.

"We now reduce, reuse or recycle practically every one of our resources," said Frank Squires, chief administrative officer and sponsor of the recycling program. "The lessons we're learning are being applied in the community and throughout our industry."

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Employees developed a rallying message for their environmental work and painted it on the outside of the SEMATECH facility in three-foot letters for motorists passing on Oltorf Street to see. The message, "SEMATECH Recycling: Preserving More Than American Jobs," is intended to build on the consortium's overall mission of solving the technical challenges required to keep the U.S. number one in the global semiconductor industry.

"Focusing on how to recycle our resources is a fundamental factor in running our businesses cleaner and more efficiently," noted Squires.

Environmental accomplishments contributing to SEMATECH's winning the award included:

• Employee volunteers organized a SEMATECH Recycling Council to coordinate the efforts and track the results.

• An internal audit was conducted to identify how to recycle more products, then employees were kept up-to-date on their recycling progress.

• The Recycling Center, a collection point for numerous recyclable materials, was designed and built on-site.

• An awareness campaign of good recycling habits was conducted among employees, including placement of boxes for collecting recyclable paper at all desks and conference rooms.

• Buying Recycled Products Corporate Guideline was established, allowing SEMATECH to purchase recycled products, even if at an increased cost of up to five percent more than non-recycled products. However, SEMATECH ultimately realized a cost savings of nearly $1.3 million during 1993 through purchases of such goods as reclaimed oil, reclaimed wafers and paper goods.

• Sixty tons of recycled copier machine paper were purchased, saving about 1,020 mature pulp trees.

• Thirty-five tons of recyclable office paper and cardboard were collected and sent to the paper mill, saving another 595 trees.

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• Styrofoam cup usage has been reduced and emphasis placed on employees' resuse of plastic cups throughout the facility.
• Neighborhood groups toured the facility's operations and discussed environmental safety with employees.
• Lessons learned for improving the environment are being shared with the community through such allies as the Capital Area Corporate Recycling Council, an organization of corporate and private businesses that exchange information and techniques for improving their environmental efforts.
• SEMATECH member companies are acting as both resources and recipients for lessons to be learned in how to develop and demonstrate environment, safety and health-conscious manufacturing technologies.

SEMATECH's local recycling success reflects the commitment of the consortium, its member companies and the federal government to develop and demonstrate environment, safety and health-conscious manufacturing technologies.

The programs range from reducing facility operation emissions, including global warming agents, to conserving energy and improving safety practices. The initiatives are synchronized with a 15-year national technology "roadmap" that was influenced by SEMATECH and others in the semiconductor industry to include a section focusing specifically on environment, safety and health issues.

"We're establishing a roadmap that targets a semiconductor manufacturing process with zero environmental impact," Squires said. "Our recycling progress at all product levels can significantly contribute to achieving that goal."

SEMATECH is a consortium of U.S. semiconductor manufacturers and the Department of Defense which conducts research in semiconductor manufacturing technology. Its mission is to solve the technical challenges to keep the U.S. number one in the global semiconductor industry.

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