

12/15/05

Dr. Diana Bauer and April Richards  
National Center for Environmental Research  
Environmental Protection Agency  
Washington, D.C. 20005

Dear Dr. Bauer and Ms. Richards:

Enclosed is our report entitled *NCER Funded Awards to Reduce Pollution over the Lifecycle of Electronic Products*. It was written at the Environmental Protection Agency during the period 24 October 2005 through 15 December 2005. Preliminary work was completed in Worcester, Massachusetts, prior to our arrival in Washington, D.C. Copies of this report are simultaneously being submitted to Professors Tahar El-Korchi and Brigitte Servatius for evaluation. Upon faculty review, the original copy of this report will be cataloged in the Gordon Library at Worcester Polytechnic Institute. We appreciate the time that you have devoted to us and wish you the best in the future.

Sincerely,

---

Jonathan Bolt

---

Amanda Lewis

---

Anthony Saccoccia

Project Number: TEL-9998

# **NCER Funded Research to Reduce Pollution over the Lifecycle of Electronic Products**

An Interactive Qualifying Project Report submitted to:  
Professor Tahar El-Korchi  
Professor Brigitte Servatius  
WORCESTER POLYTECHNIC INSTITUTE  
in partial fulfillment of the requirements for the  
Degree of Bachelor of Science  
by:

**Jonathan Bolt**

**Amanda Lewis**

**Anthony Saccoccia**

In Cooperation with:  
Diana Bauer, PhD and April Richards P.E.  
of the  
National Center for Environmental Research  
Office of Research and Development  
Environmental Protection Agency



Date: December 15, 2005

Approved:

**Professor Tahar El-Korchi, Advisor**

**Professor Brigitte Servatius, Advisor**

## **Abstract**

This project was supported by the National Center for Environmental Research (NCER), a division of the Environmental Protection Agency (EPA). NCER funds environmentally friendly research in many areas including electronics, which is one of the fastest growing global industries. Sixteen NCER funded awards involving the manufacture, use, and disposal of electronics were focused on. Qualitative and quantitative assessments were performed on these awards using information from background research, award folders, and expert interviews. Conclusions drawn from the analyses displayed the research's impacts on academia, industry, and the environment.

# Acknowledgements

First and foremost, we would like to thank EPA for providing us with the opportunity to do this project.

Special thanks go to our liaisons, Diana Bauer and April Richards, and our advisors, Professors Tahar El-Korchi and Brigitte Servatius, for their support and guidance through the project.

We would like to express our gratitude to EPA representatives: Scott Bartos, Kathy Hart, Clare Lindsay, Katharine Osdoba, and Kathleen Vokes. They gave us insight on how EPA works and answered many of the difficult questions we came across.

Finally, we would like to thank all of the principle investigators and graduate students who took time out of their busy schedules to be interviewed. They are as follows: Reggie Caudill, James DeYoung, David Dornfeld, Noah Hershkowitz, Grace Li, Andy Lin, Li Lin, Scott McCray, Cynthia Murphy, Edward Sommer Jr., Valerie Thomas, John Warner, J.G. Wijmans, and C.P. Wong.

# Table of Contents

<b>EXECUTIVE SUMMARY .....</b>	<b>1</b>
<b>INTRODUCTION .....</b>	<b>4</b>
<b>THE ELECTRONICS SECTOR .....</b>	<b>7</b>
POLLUTANTS .....	9
THE EFFECTS OF POLLUTANTS .....	10
GOVERNMENT POLICIES AND REGULATIONS .....	12
<b>EPA AWARDS, PROGRAMS AND PARTNERSHIPS .....</b>	<b>15</b>
NATIONAL CENTER FOR ENVIRONMENTAL RESEARCH AWARDS .....	15
<i>People, Prosperity, and the Planet Award (P3)</i> .....	15
<i>Technology for a Sustainable Environment (TSE)</i> .....	16
<i>Small Business Innovation Research (SBIR)</i> .....	17
RELATED PROGRAMS .....	18
<i>Design for the Environment (DfE)</i> .....	19
ENERGY STAR .....	20
Resource Conservation Challenge .....	21
Climate Partnership for the Semiconductor Industry .....	23
WasteWise .....	23
<b>GREEN MANUFACTURING ALTERNATIVES .....</b>	<b>26</b>
<b>RESEARCH METHODS .....</b>	<b>27</b>
<b>DATA COLLECTION .....</b>	<b>30</b>
FINDING PROPOSALS .....	30
AWARD FOLDERS .....	32
INTERVIEW SCHEDULING .....	32
INTERVIEW PROCESS .....	33
EPA REPRESENTATIVE MEETINGS .....	34
CHANGES TO QUESTIONNAIRES .....	35
QUANTITATIVE ESTIMATION .....	36
<b>DATA ANALYSIS .....</b>	<b>38</b>
MEETING INFORMATION .....	38
<i>Clare Lindsay: Office of Solid Waste</i> .....	39
<i>Kathy Hart: Office of Pollution Prevention</i> .....	40
<i>Kathleen Vokes: Office of Pollution Prevention</i> .....	42
<i>Scott Bartos: Office of Atmospheric Programs</i> .....	44
<i>Katharine Osdoba: ENERGY STAR</i> .....	45
AWARD IMPACTS .....	47
<i>Materials Stage</i> .....	48
<i>Manufacturing Stage</i> .....	49
<i>Use Stage</i> .....	56
<i>End-Of-Life Stage</i> .....	56
<i>Lifecycle Analyses</i> .....	61
DISCUSSION .....	64
<b>CONCLUSIONS .....</b>	<b>65</b>
ACADEMIA .....	65
INDUSTRY .....	68
ENVIRONMENT .....	71
<b>RECOMMENDATIONS .....</b>	<b>74</b>

<b>REFERENCES .....</b>	<b>77</b>
<b>BIBLIOGRAPHY .....</b>	<b>81</b>
<b>APPENDIX A – ENVIRONMENTAL PROTECTION AGENCY (EPA).....</b>	<b>88</b>
<b>APPENDIX B – NATIONAL CENTER FOR ENVIRONMENTAL RESEARCH (NCER) .....</b>	<b>91</b>
<b>APPENDIX C – GLOBAL WARMING POTENTIAL (GWP).....</b>	<b>93</b>
<b>APPENDIX D - ONLINE DATABASES.....</b>	<b>94</b>
<b>APPENDIX E – INTERVIEW/MEETING QUESTIONNAIRES.....</b>	<b>95</b>
INTERVIEW INTRODUCTION .....	95
PRINCIPAL INVESTIGATOR TSE/P3 INTERVIEW QUESTIONNAIRE .....	96
PRINCIPAL INVESTIGATOR SBIR INTERVIEW QUESTIONNAIRE.....	97
GRADUATE STUDENT INTERVIEW QUESTIONNAIRE.....	98
EPA REPRESENTATIVE MEETING QUESTIONNAIRE .....	99
<b>APPENDIX F – EPA REPRESENTATIVE MEETINGS .....</b>	<b>100</b>
APPENDIX F 1 – BARTOS, SCOTT (OFFICE OF ATMOSPHERIC PROGRAMS).....	100
APPENDIX F 2 – HART, KATHY (OFFICE OF POLLUTION PREVENTION).....	103
APPENDIX F 3 – LINDSAY, CLARE (OFFICE OF SOLID WASTE) .....	106
APPENDIX F 4 – OSDOBA, KATHARINE (ENERGY STAR) .....	110
APPENDIX F 5 – VOKES, KATHLEEN (OFFICE OF POLLUTION PREVENTION).....	114
<b>APPENDIX G – PI CASE STUDIES.....</b>	<b>116</b>
CAUDILL, REGGIE J. – APPENDIX G 1 .....	116
<i>Appendix G 1.1: Award Review (P3 SU831815)</i> .....	116
<i>Appendix G 1.2: Interview</i> .....	118
DEYOUNG, JAMES (MiCELL) – APPENDIX G 2 .....	122
<i>Appendix G 2.1: Award Review (SBIR EPD05052)</i> .....	122
<i>Appendix G 2.1: Interview</i> .....	124
DORNFELD, DAVID – APPENDIX G 3.....	128
<i>Appendix G 3.1: Award Review (TSE R831456)</i> .....	128
<i>Appendix G 3.2: Interview</i> .....	130
DOYLE, FIONA M. – APPENDIX G 4 .....	134
<i>Appendix G 4.1: Award Review (TSE R829627)</i> .....	134
HERSHKOWITZ, NOAH – APPENDIX G 5 .....	137
<i>Appendix G 5.1: Award Review (TSE R831459)</i> .....	137
<i>Appendix G 5.2: Interview</i> .....	139
LAVE, LESTER B. – APPENDIX G 6 .....	143
<i>Appendix G 6.1: Award Review (TSE R826740)</i> .....	143
LIN, LI – APPENDIX G 7.....	145
<i>Appendix G 7.1: Award Review (TSE R829598)</i> .....	145
<i>Appendix G 7.2: Interview</i> .....	147
MCCRAY, SCOTT B. (BENDRES RESEARCH) – APPENDIX G 8.....	151
<i>Appendix G 8.1: Award Review (SBIR 68D70053)</i> .....	151
<i>Appendix G 8.2: Interview</i> .....	153
MURPHY, CYNTHIA F. – APPENDIX G 9 .....	156
<i>Appendix G 9.1: Award Review (TSE R828208)</i> .....	156
<i>Appendix G 9.2: Interview</i> .....	158
NIKLES, DAVID – APPENDIX G 10 .....	163
<i>Appendix G 10.1: Award Review (TSE R826728)</i> .....	163
SAMPATH, W. S. – APPENDIX G 11.....	165
<i>Appendix G 11.1: Award Review (TSE R826119)</i> .....	165

SOMMER JR., EDWARD J. (NATIONAL RECOVERY INSTITUTE INC.) – APPENDIX G 12 .....	167
<i>Appendix G 12.1: Award Review (SBIR EPD04058)</i> .....	167
<i>Appendix G 12.2: Interview</i> .....	169
THOMAS, VALERIE – APPENDIX G 13 .....	172
<i>Appendix G 13.1: Award Review (TSE R829585)</i> .....	172
<i>Appendix G 13.2: Interview</i> .....	174
WARNER, JOHN C. – APPENDIX G 14.....	178
<i>Appendix G 14.1: Award Review (P3 SU831894)</i> .....	178
<i>Appendix G 14.2: Interview</i> .....	180
WIJMANS, J. G. (MEMBRANE TECHNOLOGY AND RESEARCH INC.) – APPENDIX G 15 .....	185
<i>Appendix G 15.1: Award Review (SBIR 68D70051)</i> .....	185
WONG, C. P. – APPENDIX G 16.....	188
<i>Appendix G 16.1: Award Review (TSE R831489)</i> .....	188
<i>Appendix G 16.2: Interview</i> .....	190
<b>APPENDIX H: GRADUATE STUDENT INTERVIEWS.....</b>	<b>194</b>
LI, GRACE – APPENDIX H 1 .....	194
LIN, ANDY – APPENDIX H 2 .....	196
<b>APPENDIX I: TABLE OF IMPACTS .....</b>	<b>198</b>

# Index of Tables and Figures

FIGURE 1: PRODUCTION OF A PRINTED WIRING ASSEMBLY .....	8
FIGURE 2: LIFECYCLE OF ELECTRONICS PRODUCTS .....	10
FIGURE 3: EPA PROGRAMS AND THEIR AREA OF EFFECT.....	25
TABLE 1: AWARDS REVIEWED.....	31
TABLE 2: INTERVIEW RESULTS.....	32
TABLE 3: EPA REPRESENTATIVE MEETINGS .....	35
FIGURE 4: EPA REPRESENTATIVES AND THEIR DEPARTMENTS .....	38
FIGURE 5: NCER FUNDED AWARDS AND AREAS OF IMPACT .....	47
FIGURE 6: THE CHIP MAKING PROCESS .....	49
TABLE 4: SOME ENVIRONMENTAL RELEASES FROM THE PCB INDUSTRY FOR 2003 .....	51
TABLE 5: LEAD USAGE IN THE U.S. IN 2003 .....	56
FIGURE 7: EPA ORGANIZATION CHART .....	90
FIGURE 8: NCER ORGANIZATION CHART .....	92
TABLE 6: FLUORINATED GASES USED TO MANUFACTURE SEMICONDUCTORS .....	93



# Executive Summary

The manufacture of electronics uses large amounts of raw materials and energy, while releasing millions of pounds of hazardous waste into the environment per year. The energy required to use these products usually requires burning fossil fuels, which releases toxic gases into the atmosphere. Electronics contain lead, mercury, and other dangerous substances, which can contaminate soil and groundwater if not properly recycled or disposed of. Research is being done, including work funded by the National Center for Environmental Research (NCER), to reduce pollution produced during the lifecycle of electronics.

The goal of this project was to determine the impacts of NCER funded research relating to electronics pollution. We focused on three NCER programs: People, Prosperity, and the Planet (P3), Technology for a Sustainable Environment (TSE), and Small Business Innovation Research (SBIR). The impacts of these programs were split into specific impacts on academia, industry, and the environment. We performed extensive background research on the existing pollution problem in the electronics sector and related governmental regulations and Environmental Protection Agency (EPA) programs.

From 1997 to 2004, a total of 16 awards funded by the three considered programs were related to electronics pollution. The award folders were summarized and interviews were conducted with the principle investigators (PI) performing the research. From this information, the quantitative impacts of these awards were determined. The TSE and P3 awards resulted in 59 publications, 8 curricula changes affecting 402 students, and funded 39 graduate students. All 16 awards resulted in 9 patents being issued with an additional

3 pending and the participation of 18 known industrial partners. According to the awards, 13 chemicals used in the manufacture of electronics could be reduced, replaced, or recycled. An estimated 14,000,000,000,000 pounds of waste and the use of 970,000 million liters of water per year could be eliminated by this research assuming that it could be implemented now.

The qualitative impacts of these awards were also considered. The spread of information through publications and course changes had a significant effect on academia. The effects of this research on funded graduate students, who are the future of teaching and industry, were also considered. The main impact on industry was the strengthening of relations between the electronics sector and EPA. Industry has become more accepting of environmentally friendly technologies over the past decade because of EPA and NCER funded research. The majority of environmental data was estimated, since the most of the considered technologies are too new and need further testing to be implemented in industry. These innovations should play a larger role in electronics manufacturing and recycling in the next five to ten years.

The considered NCER funded programs had positive impacts on the electronics sector, but we developed several recommendations to improve them. Since electronics are the fastest growing industry in the United States, NCER funding in electronics research should be increased. We noticed that some aspects of the lifecycle of electronics were being under funded. Out of the sixteen awards we studied, only two dealt with the materials used to make these products. Funding in materials research should be increased because it is a very important stage in the lifecycle of electronics that is currently being overshadowed by manufacturing and recycling research. There could

be two reasons for the low amount of funded awards concerning materials: either no proposals are being submitted or none are being funded by NCER. We recommend that NCER perform a funding study to determine which is the case. Subjects lacking strong proposals should be advertised well and several improvements to the NCER website were suggested. Our final recommendation applies to EPA. The United States is exporting large amounts of used electronics overseas to be reused or recycled. This is becoming a serious environmental problem because many of the products are being stripped for parts and end up in developing countries that have no means to properly dispose of them. EPA should conduct an in-depth study on this subject, which could be used to support regulations on the export of these products.

# Introduction

Modern society has become increasingly reliant on electronics, such as computers and cell phones. With this increase, manufacturers are expanding production to meet demand. Electronics require many resources to manufacture and generate hazardous wastes both during production and disposal. As larger amounts of these products are manufactured, serious environmental problems are arising from the resulting resource consumption and pollution.

In 1970, the Environmental Protection Agency (EPA) was created by Congress and the White House in response to public demand for cleaner water, air, and land. It encourages the research of innovative technologies and alternatives to make the manufacture and disposal of electronics a more environmentally-friendly process. This can be done, in part, through green engineering, or "...the design, commercialization, and use of processes and products, which are feasible and economical while minimizing 1) generation of pollution at the source and 2) risk to human health and the environment" [1]. EPA provides competitive grants supporting research for green engineering, which can decrease and even eliminate the use of hazardous materials and production of hazardous waste.

For the past three decades, EPA has been actively supporting its mission, "to protect human health and the environment" [2]. In order to accomplish this goal, the agency is divided into twenty-two departments with differing concentrations [3]. The Office of Research and Development, specifically the National Center for Environmental Research (NCER), is sponsoring this project to investigate the productivity of its grant programs.

People, Prosperity, and the Planet Award (P3), Technology for a Sustainable Environment (TSE), and Small Business Innovation Research (SBIR) programs are sponsored and supported by NCER and will be the focus of this project. P3 and TSE are competitive grant programs available to academic institutions. Under P3, teams of students compete for awards to develop sustainable solutions to problems facing the earth and its residents. TSE promotes the development of alternative methods to resolve pollution problems before they occur. There are also partnerships between NCER and industry, such as SBIR. This is a competitive contract designed to financially aid small businesses in performing environmentally friendly research.

In addition to the NCER funded programs mentioned, there are grants, programs, and partnerships funded by other divisions of EPA. These programs include Design for the Environment (DfE), ENERGY STAR, Resource Conservation Challenge, Climate Partnership for the Semiconductor Industry, and WasteWise. The DfE Program is a working relationship between individual industry sectors and EPA meant to reduce pollution related human health and environmental risks. The ENERGY STAR Program was created by EPA to reduce consumer energy usage by marking energy efficient commercial products. Resource Conservation Challenge increases awareness of the hazards associated with the disposal of electronics. Climate Partnership for the Semiconductor Industry is a voluntary partnership between EPA and the semiconductor industry to reduce greenhouse gas emissions. Case studies focused on the electronics industry are being conducted through WasteWise. Using these studies, areas where the pollution can be reduced are found and analyzed. These programs are all linked to the awards funded by NCER to accomplish EPA's goal of preserving the environment.

As previously stated, there is an existing pollution problem caused by the manufacture and disposal of electronics products. EPA realizes the magnitude of this problem and, in an effort to reduce environmental impacts, has funded the eight research initiatives described. The goal of this project is to determine the impacts of awards funded by NCER, specifically P3, TSE, and SBIR. Focusing on the electronics sector qualitative and quantitative evaluations will be performed to determine the impacts of specific grants on academia, industry, and the environment.

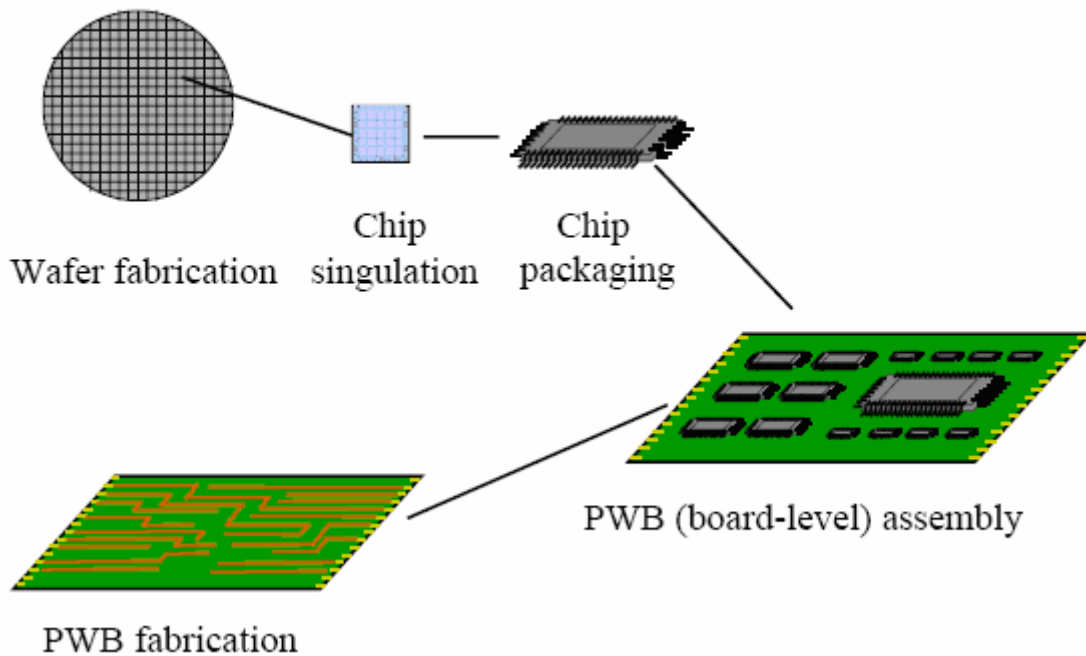
To successfully complete this project, background research was conducted to gain an understanding of the electronics industry, the pollution problem resulting from it, and relevant EPA funded research.

## **The Electronics Sector**

The main products of the electronics sector are semiconductors, printed circuit boards (PCB's), and printed wiring assemblies (PWA's) which are used in virtually all electronic devices, such as computers, DVD players and cell phones.

The base material for semiconductor fabrication is silicon (Si), which is manufactured in wafers of varying diameters and thicknesses. Very thin layers of silicon dioxide (SiO<sub>2</sub>) are applied to these wafers, which are then etched. The resulting semiconductors are used as microchip bases because they possess a conductivity between that of an insulator and a good conductor. Single chips are cut out of the wafers, attached to metal frames, and packaged in plastic or ceramic materials [5].

Printed circuit boards are made of multiple layers of polymer composite materials. These layers are laminated together and a pattern of copper or another conductive substance is added to the outside surfaces [5]. Holes are then drilled into the boards and made conductive using metal foils or electroplating. Printed wiring assemblies incorporate a PCB's with chips and other components, such as resistors and capacitors adhered to both sides. This can be done either by soldering the components directly or soldering a component's legs on the opposite side of holes in the circuit board [6]. See Figure 1: Production of a Printed Wiring Assembly. While these electronic products are small, substantial amounts of material and energy are required for their manufacture.



**Figure 1: Production of a Printed Wiring Assembly**

<http://www.wtec.org/loyola/ebm/views/murphy2.pdf>

Before silicon can be used to make a semiconductor, it must be purified. To produce one kilogram of purified silicon, 9.4 kilograms of raw silicon are required. An additional 280 kilograms of chemicals, metals, and gasses is required for each kilogram of pure silicon produced. Large amounts of water are also necessary for this process. An estimated 4.75 to 7.1 gallons of purified water is required to produce a one square centimeter semiconductor. Therefore, even a 2 gram 32Mb DRAM computer chip requires 8.45 gallons of purified water to manufacture. As a result, a typical semiconductor factory may use two to three million gallons of water a day. [7]

Another significant requirement is energy, as one silicon wafer requires 2130 kWh to produce. This amount of energy is equivalent to burning 3.5 lbs of fossil fuel and could power a 100 Watt light bulb for 887 days. Typically 95 to 99% pure chemicals,



elemental gasses, and water are required for semiconductor manufacture. Separation and purification processes require additional energy. Assembly and packaging also add to energy consumption. [7]

The above statistics are specific to the production of semiconductors and are only a lower bound for material and energy usage. Further processes to create PCB's and PWA's, such as electroplating, etching, and soldering, demand more energy and raw materials. The chemical, water, energy, metal, and elemental gas requirements to create an electronic device are massive compared to the size of the finished product.

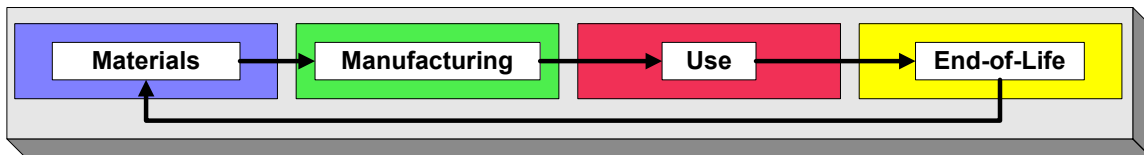
## ***Pollutants***

Hazardous wastes are produced as a byproduct of the manufacture and end-of-life disposal of electronics products. The most common pollutants in the manufacture of semiconductors are organic solvents and organic solvent vapors. Large amounts of these wastes are produced, as numerous cleaning steps using organic solvents are required for each semiconductor. Organic solvent wastes contain chlorofluorocarbons (CFC's), which are recognized as ozone-depleting substances (ODS's). Additional effluents from semiconductor manufacture include several types of acid, while solid wastes consist of heavy metals and used epoxy [8].

PCB manufacture also results in a large number of effluents, including organic solvents, vinyl polymers, metals, cyanides, sulfates, acids, and ammonia. Air pollution from this process contains chlorine, ammonium, flux vapors, and organic solvent vapors. Scrap materials and plating sludges are the main solid wastes produced. Soldering fumes are the primary air pollutants from PWA manufacture, while acids, alkalines, organics solvents, and fluxes make up the main effluents [9].

There are several further dangers of electronics waste that must be considered. Unsatisfactory safety regulations can lead to serious accidents and unintended contamination. Accidental leakages can also result in hazardous exposure. For example, an unintentional release of hazardous gas when changing tanks can contaminate a facility and expose numerous people to harmful chemicals.

While electronics manufacturing produces large amounts pollution, waste resulting from the remainder of a product's lifecycle also needs to be considered. This lifecycle consists of materials, manufacturing, use, and end-of-life stages (See Figure 2: Lifecycle of Electronics Products). The extraction and transportation of hazardous materials can contaminate areas far from the manufacturing facilities. Producing electricity to use a product burns fossils fuels releasing potent global warming gasses. Incinerating used electronics products produces toxic fumes. To effectively assess the pollution produced by electronics, all stages of the lifecycle must be taken into account.



**Figure 2: Lifecycle of Electronics Products**

### ***The Effects of Pollutants***

The ecosystem is very sensitive, to even small changes, so the introduction of pollution can be devastating. Effluents and heavy metals from sludges can seep into soil and contaminate groundwater. Disposing of industrial and post-consumer waste, especially in landfills, is difficult because it contains lead and other hazardous materials. An additional concern is the tendency of grouping multiple electronics manufacturers in the same geographic location, such as Silicon Valley. While doing this can reduce

transportation costs, it also concentrates large amounts of pollution in a relatively small area.

Two more widespread concerns caused by electronics related pollution are global climate change and the deterioration of the ozone layer. Global climate change, or global warming, is an increasingly serious problem. As solar radiation reflects off the earth, greenhouse gasses, such as carbon dioxide (CO<sub>2</sub>), absorb and reemit a portion of this infrared energy. The energy is dispersed in all directions, rather than away from the planet, resulting in an increase of the earth's temperature [10]. This temperature change could alter climates around the globe and in extreme cases, melt the polar ice caps. The effects of greenhouse gasses are measured using a Global Warming Potential (GWP) calculation, which compares a specific gas to CO<sub>2</sub> (See Appendix C – Global Warming Potential (GWP)). Carbon tetrafluoride (CF<sub>4</sub>), which is used in plasma etching, has a GWP of 5700 and can remain in the atmosphere from 500 to 500,000 years. CF<sub>4</sub> and other greenhouse gasses account for the 3,000,000 metric tons of CO<sub>2</sub> equivalent produced annually by the U.S. semiconductor industry [10]. Hazardous vapors containing ODS's from electronics production are also eating away at the ozone layer. This allows more ultraviolet rays to strike the earth, affecting human health. Electronics pollution has additional adverse effects on human health.

The long term effects of hazardous materials on human health are the most unpredictable and potentially dangerous. Electronics pollution contains persistent bioaccumulative toxins (PBT's), which can stay in the environment for prolonged periods of time and accumulate in the human body [11]. Substances containing lead are “ranked as one of the most hazardous compounds (worst 10%) to ecosystems and human health”,

[12] but are still used extensively in electronics. The United States electronics industry releases 100,000 pounds of lead compounds into the environment every year [13]. Other substances related to electronics production, such as cadmium, methanol, and hydrochloric acid have been known to cause cancer, developmental, and reproductive problems.

## ***Government Policies and Regulations***

It is the responsibility of federal government to manage this problem through environmental policies and regulatory actions. Through the twentieth century, hazardous waste has become a serious and fast growing problem. Early hazardous waste policies attempted to regulate pollution production and clean up existing waste sites. Few significant strides in reducing the amount of waste produced were made, even though this was also an important goal. While these government actions eased the public mind in the short term, they did not fully acknowledge long term pollution reduction goals [13]. As a result, there are large amounts of hazardous waste sites that still need to be cleaned.

As government agencies, specifically the Department of Energy (DoE) and Department of Defense (DoD), increased in size, they were required to abide by industrial pollution policies. Under these public codes, DoD and DoE faced growing waste removal and recycling costs. In addition, these regulations slowed government projects, such as converting military bases for civilian use. Federal agencies were forced to reevaluate their waste management and environmental protection programs, which greatly influenced the environmental policies and regulations of the nineteen sixties and seventies. As a result, modern policies are placing a higher emphasis on environmentally friendly processes, such as green engineering. These techniques have the potential to

reduce input materials, reduce wastes produced, and prove more cost effective than conventional methods [14].

Industry had been subject to hazardous waste policies and regulations much longer than government agencies. As a result, it was researching and developing more environmentally friendly methods long before the federal government. Government agencies found themselves far behind industry in the area of green technology. EPA is working to close this information gap between government and industry by awarding research based awards and contracts.

Environmental policies are always evolving due to rapid advancements in industry. New regulations and amendments to old ones have been greatly influenced by EPA and research it has funded. For example, the Clean Air Act of 1970 enforced National Ambient Air Quality Standards in every state. Amendments to the act in 1990 broadened its scope to consider acid rain and ozone depletion in addition to its regulatory responsibilities [15]. The Resource Conservation and Recovery Act focuses on controlling waste from the “cradle-to-grave” of a product. This approach accounts for all aspects of waste production, including “generation, transportation, treatment, storage, and disposal” [16]. Reducing pollution at every stage in the lifecycle of an electronic product is much more effective than just regulating it during manufacture and end-of-life disposal. The Pollution Prevention Act passed in 1990, recognizes source reduction as “more desirable than waste management or pollution control” [16]. This cost effective method, is focused on decreasing pollution at its source. Reducing the amounts of energy, water, and materials required by electronics and their manufacture can be done through recycling and sustainable technologies [16]. Environmental policies as a whole, center

on pollution regulation and management, but are showing more preventative and long term goals. This shift in focus is due in part to the effects of innovative research being funded by EPA.

## **EPA Awards, Programs and Partnerships**

EPA is the lead enforcer of environmental regulations and pollution standards. However, it is also a leader in promoting the research of green alternatives to conventional industrial processes. The Office of Research and Development (ORD) funds eighteen programs organized under seven topic headings [17], which promote working relationships academia, industry, and government.

### ***National Center for Environmental Research Awards***

ORD is broken down into nine sections. The National Center for Environmental Research (NCER) is this project's sponsor and supports avant-garde environmental research. NCER funds three award programs, specifically People, Prosperity, and the Planet Award (P3), Technology for a Sustainable Environment (TSE), and Small Business Innovation Research (SBIR) which link industry and academia.

### **People, Prosperity, and the Planet Award (P3)**

The three pillars of sustainability recognized by EPA are **p**eople, **p**rosperity, and the **p**lanet. The P3 Award connects the three pillars through mutual goals of the public and private sectors. This partnership is designed to aid research teams of undergraduate and graduate students in applying their knowledge to practical problems. [18]

The P3 award has two phases. Teams of researchers compete for an initial grant in the first phase and compete for the actual P3 Award in the second. Once a team receives the initial grant of \$10,000, the researchers are allotted an academic year to explore, create, and design their project. These projects are presented to EPA in

Washington, D.C. and the winner receives an additional \$75,000 to further the design and execution of their project [18].

P3 competitors are encouraged to seek assistance from the government and non-government organizations, as well as the scientific community to help develop a project. These diverse sources are meant to provide a broad range of information and strengthen the bond between public and private sectors. The actual companies and organizations involved depend on the nature of the project proposal. [18]

The topic of a P3 Award is open ended and can focus on a variety of fields from agriculture to energy. The only specifications are that each project needs to address an environmental problem and a feasible way to solve it [18]. In light of this, many P3 projects are addressing current issues, such as pollution in the electronics sector. A team from the New Jersey Institute of Technology participated in the 2004 P3 program. They submitted a project entitled, “P3 Design of a National Electronics Product Reuse and Recycling System” [19]. This project addressed the design of a national system to recycle household electronics [19].

## **Technology for a Sustainable Environment (TSE)**

Technology for a Sustainable Environment (TSE) is an academic research award program focused on pollution prevention. It is managed as a partnership between EPA and the National Science Foundation (NSF) though funded exclusively by one or the other [20]. Since its creation in 1994, TSE has promoted the use of green chemistry and engineering [21].

Green chemistry involves reducing or eliminating the use and production of hazardous compounds by encouraging the use of non-hazardous chemicals and designing



new industrial processes [21]. The objective of a 2003 TSE award entitled “A New Approach for Reducing Global Warming Emissions from Plasma etching by Controlling Ion Energy Neutral Flux” was to reduce fluorocarbon gas emissions during the semiconductor manufacturing process [22].

To apply for a TSE award, applicants must be from an academic institution or non-profit organization and project proposals must address environmental issues [23]. Additionally, the proposals are subject to peer reviews on the basis of technical merit and their relevance to EPA’s and NSF’s missions [23]. Applicants are encouraged to develop innovative ideas to solve pollution problems and promote interaction between industry and researchers. In 2003, the TSE program funded 45 awards worth a total of 9.5 million dollars, which includes 3.5 million from EPA [24]. On average, the recipients of EPA’s TSE awards receive between \$200,000 and \$300,000 [24].

## **Small Business Innovation Research (SBIR)**

Since the creation of the Small Business Innovation Development Act in 1982, federal agencies have played a vital part in strengthening of small businesses [25]. EPA is one of eleven federal agencies that participate in the Small Business Innovation Research (SBIR) program [26]. This program provides competitive funding to small businesses to investigate and develop environmental friendly technologies [26]. Like P3, the SBIR program consists of two phases. The first phase involves exploratory research, while second is focused more on commercialization. From 2001 to 2004, four hundred and fifty SBIR proposals were received by NCER and forty-four of those were funded for phase one [26].

The first phase is a six-month trial period, when the proposed ideas are thoroughly researched. Each small business accepted for phase one funding is given \$70,000 to assist the investigation of the proposal. After this trial period, EPA should be able to establish if a project is feasible. If a particular company is able to conduct the specified research and whether sufficient progress has been made to suggest that this project could be successful are considered [27].

The purpose of phase two is to further develop and commercialize the technology researched in phase one. Phase two funding is only available to those businesses that successfully completed phase one research. From 2001 to 2004, fourteen SBIR projects, 32% of completed phase one projects, received phase two funding [28]. Phase two projects receive an additional \$225,000. This funding greatly increases a small business' research capabilities, which otherwise would be financially limited [28].

National Recovery Technologies Inc. is a manufacturer of recycling equipment and has taken a particular interest in recycling e-waste. In 2003, a Phase I SBIR was awarded to National Recovery Technologies Inc. to study the recycling of computer scrap [29]. The goal of this research was to determine if recyclers could salvage highly pure polymers using a high-speed, automated sorting system [29]. EPA felt that this was a worthwhile investment, as the infrastructure for handling e-waste in the United States is not yet developed.

### ***Related Programs***

The divisions of EPA share the common goal of protecting human health and the environment. Many times one award can be used in support of funding another by building off of past research. Past projects can also help spark new thinking and ideas for

future research. The Design for the Environment (DfE), ENERGY STAR label, Resource Conservation Challenge, Climate Partnership for the Semiconductor Industry, and WasteWise are programs with directives and goals that go hand in hand with the awards funded by NCER.

## **Design for the Environment (DfE)**

The Design for the Environment (DfE) Program was created in 1992, to provide industry and other organizations with the information to make educated decisions on environmental issues [30]. It is a voluntary partnership with industry that encourages business sectors to be mindful and aware of health and environmental considerations. The mission of the DfE Program is to “promote pollution prevention and other risk reduction activities in industrial sectors” [30].

To achieve this mission, DfE works with industry to gain an understanding of environmental and health impacts. It initiates the development of cost-effective ways to implement new technologies for cleaner and safer surroundings. DfE promotes pollution prevention and source reduction at the beginning, middle, and end of the manufacturing processes [30]. The DfE Program recognizes the challenges that face many businesses, such as staying competitive. It helps industry in incorporating environmental problems into design decisions. In the future, DfE hopes to become a regular part of industrial risk management and decision-making [30].

The DfE Program has thirteen different areas for partnerships, one of which is with the electronics industry. This specific partnership investigated the environmental impacts, performance, and cost of cathode ray tubes (CRT) versus liquid crystal displays (LCD's) in computer monitors. LCD's and other flat panel displays are gaining

popularity and could soon overcome conventional displays. This is a very relevant study since the environmental impacts of CRT's versus LCD's has not been fully investigated [31].

The goal of the DfE Computer Display Partnership is to generate data to aid electronics equipment manufacturers and suppliers in decision making. To accomplish this, the partnership is planning to use Cleaner Technologies Substitutes Assessments (CTSA's) and life-cycle assessment approaches. CTSA's evaluate ecological risk, energy and resource use, performance, and costs [31].

## **ENERGY STAR**



Every time someone goes to buy a new appliance, they are overwhelmed by choices. Often times a sales person will mention that buying an ENERGY STAR labeled device will save money because it uses less energy. The ENERGY STAR program is supported by the federal government, with a mission to increase energy efficiency [32].

ENERGY STAR was introduced in 1992 by EPA as a voluntary labeling program meant to promote energy-efficient products. Monitors and computers were the first devices to be labeled ENERGY STAR compliant due to their large consumer market. In 1995, the program expanded to include residential heating and cooling equipment, along with other office equipment. In 1996, the Department of Energy was introduced as an ENERGY STAR partner, which included major home appliances, lighting, and home electronics in the program. Now the ENERGY STAR label can be found on most in-home devices and even new homes themselves can be certified as ENERGY STAR efficient [33].

There are currently over 8000 private and public sector organizations committed to the ENERGY STAR partnership. It is estimated that more than \$10 billion in energy costs was saved by consumers, businesses, and organizations through this program in 2004 [33]. ENERGY STAR can also be linked to the development of energy saving innovations such as light emitting diode traffic lights, low energy use standby modes, and energy efficient fluorescent lighting. By March of 2005, over 350,000 new homes in the United States received the ENERGY STAR label and 10% of homes built in 2004 qualify as ENERGY STAR compliant [33].

The reduction of energy usage through the purchase of ENERGY STAR labeled products may allow for a decline in energy production. Producing electricity involves burning fossil fuels, so using less electricity can ultimately reduce greenhouse gas emissions. When used as a decision making factor in purchasing electronics, the ENERGY STAR program saves both cost and energy.

## **Resource Conservation Challenge**

The Resource Conservation Challenge program recognizes electronics are the fastest growing, but least recycled products on the market. Working with national partners, Resource Conservation Challenge examines the environmental concerns with the lifecycle of electronics, specifically personal computers and cell phones [34].

The main goals of the Resource Conservation Challenge are to develop methods to decrease wastes produced during the manufacture, use, and end-of-life stages of electronics. This is being done by developing and implementing reusable and recyclable electronics. The programs being implemented to execute this plan are: Plug-In to

eCycling, Electronic Production Environmental Assessment Tool, and Federal Electronics Challenge [34].

Plug-In to eCycling is a national endeavor to collect and recycle used electronics in the United States. This program is a major component of EPA's Resource Conservation Challenge and Product Stewardship Program. The three main focuses of Plug-In to eCycling are: to provide the public with information about electronics recycling, promote a sense of responsibility for safe recycling in industry, and establish new ways to investigate safe recycling. [35]

The Electronic Production Environmental Assessment Tool (EPEAT) will be used to evaluate the environmental performance of electronics through their lifecycles. EPEAT was created in 2004 by representatives from 31 organizations, which include Apple Computer, Electronic Industries Alliance, EPA, and Noranda Recycling Inc., to satisfy the growing need of industry to environmentally assess electronics. Initially, EPEAT will address the proper disposal of computers and monitors, which fail the Federal Hazardous Waste Test. Eventually, EPEAT will expand to include other electronic products, such as cellular telephones. The University of Tennessee is currently developing a "calculator" that will allow program participants to measure the benefits of environmentally sound management of electric equipment. [36]

The Federal Electronics Challenge (FEC) urges federal facilities and agencies to buy greener electronic products and dispose of old electronics in an environmentally friendly way. FEC is seeking to transform federal facilities and agencies into environmental leaders of the future. [37]

## **Climate Partnership for the Semiconductor Industry**

EPA's Climate Partnership for the Semiconductor Industry uses a pollution prevention strategy to reduce high global warming potential (GWP) greenhouse gases, especially perfluorocarbons (PFC's). The semiconductor industry is the main focus since the manufacture of semiconductors releases many PFC's. Since it was launched in 1996, this voluntary program has been very successful and serves as an example for other countries such as Japan and Korea. [38]

The goal of the climate partnership is to help semiconductor companies study PFC's releases and how to reduce them. Although PFC's are not the only gas emissions, EPA and its partners feel that they are a key pollutant to concentrate on. The semiconductor industry, with the help of EPA, is dedicated to reducing PFC emissions in America by 10% of their 1995 level, by the year 2010. [38]

In order to meet this goal, EPA has challenged the semiconductor industry to measure, record, and reduce high GWP gasses. With strong support from EPA, the industry has evaluated and implemented new technologies in four key areas: process improvement and source reduction, alternative chemicals, the capture and reduction of harmful chemicals, and the use of fewer high pollution technologies. [38]

## **WasteWise**

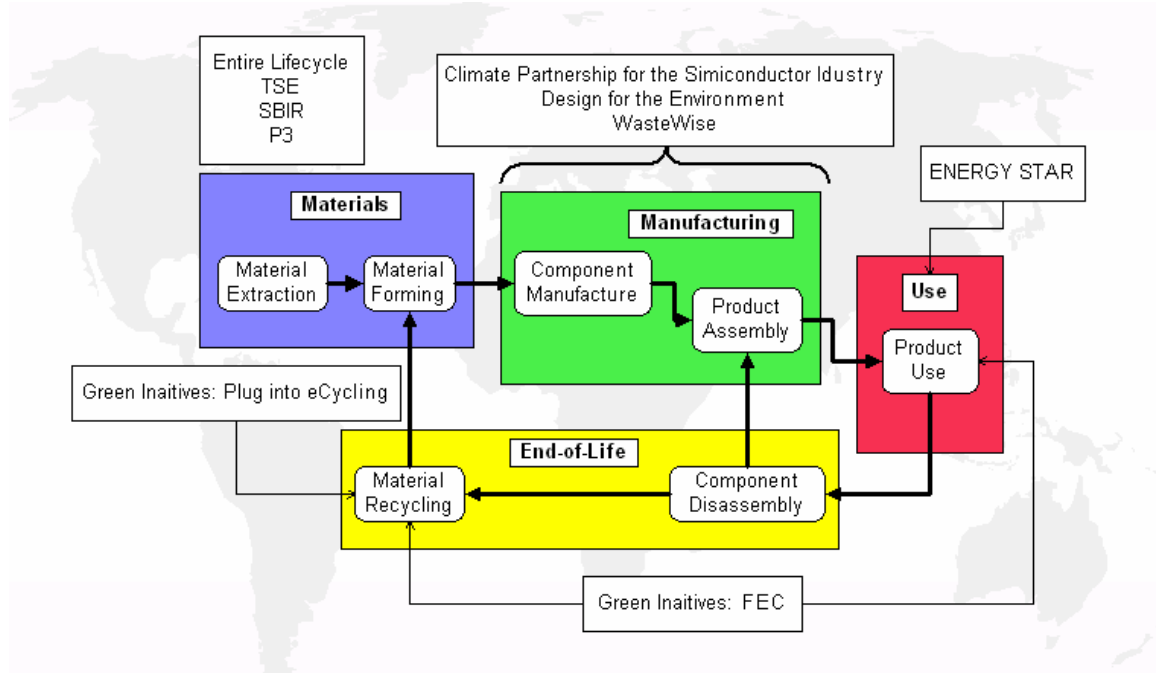
WasteWise is a nationwide partnership with industry seeking to reduce solid waste by developing alternative manufacturing processes. The companies involved in this voluntary program seek to reduce costs through eliminating solid and industrial waste production. These companies also benefit from the publicity offered by EPA publications, case studies, and events.

WasteWise is broken down into individual targeted initiatives with specific goals. The program currently has a total of 1429 partners from 54 industry sectors, and 246 endorsers from 15 industry sectors. Joining WasteWise costs nothing, but EPA does request an annual report stating the tons of waste produced, associated cost of savings, and how the program is being advertised to employees, customers, and suppliers [39]. The WasteWise program works with 81 partner and endorser companies from the electronics and electronic equipment industry. Companies as large as AT&T and Panasonic have enrolled in an effort to preserve environment. These companies donate reusable products to nonprofit organizations, recycle equipment that cannot be reused, purchase remanufactured electronic devices, and contract suppliers to lease electronics [40]. Other ideas to reduce pollution are establishing take-back programs for electronics and redesigning these products so they can be more easily upgraded or remanufactured.

In addition to taking an active approach in waste reduction, the WasteWise program provides information through research and case studies. For example, a computer and electronics recycling study was done in Minnesota sponsored by the Matsushita Electric Corp. of America (Panasonic). This project characterized product brand names, types, weights, compositions, and ages for future recycling initiatives. Scott H. Shapleigh, the Environmental Coordinator of the Airpax Corporation, is quoted as saying, "WasteWise provided a way to systematically identify solid waste reduction opportunities and translate pounds reduced into dollars saved. The partner meetings, list server, and technical support make it easy to succeed" [41]. The WasteWise program encourages companies to work together to address the growing problem of industrial waste. Figure 3: EPA Programs and their Area of Effect shows the discussed EPA



programs and their main areas of effect.



**Figure 3: EPA Programs and their Area of Effect**

## Green Manufacturing Alternatives

Industry is constantly developing new methods, devices, and substances to replace those that are no longer useful or practical. CFC's are the preferred organic solvents in the manufacture of electronics, but heavy regulations have been placed on their use because they are ozone depleting substances. Hydrochlorofluorocarbons (HCFC's), methyl chloroform, N-propyl bromide, and chlorobromomethane or bromochloromethane are some of the leading replacements. Industry is also investigating green alternatives for the substrates and conductive coatings in PCB's. One reoccurring problem is that these and other new chemicals are changing so frequently that chronic toxicity testing cannot be done. There is therefore no guarantee that workers exposed to these chemicals will not have health difficulties [42].

The industry is also researching methods to recover input materials, specifically organic solvents and metals. Organic solvents can be conserved and reused by implementing a closed loop system, involving hoods, fans, and stills. Using an active carbon system, 90% of these solvents can be capture and recycled. Heavy metals can be recovered and formed into metal sheets eliminating 95% of sludge from the waste stream. Electro-filtering, or regenerative electro winning, can almost eliminate effluents in segregated metal-bearing streams [42]. Using these methods, two of the larger waste outputs, organic solvents and heavy metals, can be reduced to minimal standards.

Those wastes which cannot be separated should be disposed of in secure landfills. EPA is currently performing research and extending funding to organizations seeking to improve these systems. In the future, green research and technologies should become more common in the electronics sector through the work of EPA.

## Research Methods

The goal of this project is to evaluate the impact of research, funded by the National Center for Environmental Research (NCER), in addressing current and future pollution issues in the electronics sector. In order to accomplish this goal, multiple research techniques, which include archival data research, interviewing, meeting with Environmental Protection Agency (EPA) representatives, and creating case studies will be employed. From this information, quantitative and qualitative assessments of the impacts of NCER funded research on academia, industry, and the environment will be conducted.

NCER has an extensive archive of People, Prosperity, and the Planet, Technology for a Sustainable Environment, and Small Business Innovation Research grants awarded, which will be our main source of information. This project focuses specifically on the electronics sector, which will narrow down the thousands of grants to a workable number, such as ten per program. For each grant NCER sponsors, annual and final reports evaluating its productivity are required [43]. These reports should provide insight to the research being done as well as contact information for Principle Investigators (PI's) who conducted it. These PI's will likely become the interviewees. Award information and archival data should provide a basis for a quantitative analysis of award effects in all three areas.

PI's and EPA representatives are experts in specific areas and can offer substantial amounts of information; therefore an emphasis will be placed on interviews. The interview process should be very flexible and the interviewer should acknowledge that they have bias over the subject selection, recording the responses given, as well as

interpreting the content of the interview [44]. The interviews should be done within the first half of the term to allow enough time to analyze the results. A reasonable goal would be to do five to ten interviews per week depending on the number of PI's and their availability.

Before beginning the interview process, a list of questions will be established to ask each interviewee. It is important that questions be consistent to produce comparable results [44]. Depending on the first few interviews, the questions will be subject to change or refinement based on ideas previously not taken into consideration. The answers from these questions will be noted by at least two individuals, time and personal permitting, to be reviewed at a later time. Phone interviews will be conducted for PI's and graduate students who cannot schedule a face to face meeting.

Meetings with EPA representatives should provide valuable background information about EPA funded programs and awards. EPA representatives from different departments in the agency will be chosen by our liaisons to give an overall view of the work performed by EPA and the interdependence of its departments. These meetings should be scheduled for the first weeks of the term to allow the results to be analyzed. This, however, will depend on the number of offices our liaisons set up meetings with.

A case study is an in-depth examination of a single person, company, or organization. For this project, PI case studies will be assembled using information from award reports and interviews. Compiling all accessible information about a PI into a case study should make it easier to assess the research he or she is performing. Case studies of companies in the electronics sector may also describe the implementation and impacts of new technology.

Archival data, interviews, meetings, and case studies are effective methods of gathering and organizing information on NCER funded awards. Once all this information is assessed, it will be applied to determine the impacts, in different contexts if necessary, of NCER funded projects.

## **Data Collection**

Obtaining information was the most time intensive part of this project. All relevant grants were located and summarized. PI interviews were conducted to get more specific information about grant research. Meetings were held with EPA representatives to gain a background on other programs related to electronics. Quantitative estimation was also used to calculate the potential environmental impacts of NCER funded research, if it was implemented.

## ***Finding Proposals***

To find awards relevant to the electronics sector, a keyword topic search was performed in NCER's extensive archive of funded awards. This search covered all three of NCER's award programs: the People, Prosperity, and the Planet (P3), Technology for a Sustainable Environment (TSE), and Small Business Innovation Research (SBIR). Some of the keywords used were: "electronics", "pollution prevention", and "waste reduction". Initially this search returned only 7 TSE and 2 SBIR awards. A more in-depth exploration was necessary, as the goal was ten awards from each program. NCER has alphabetical listings of awards in each of its programs. These lists were browsed by hand and additional awards were chosen. In the end, sixteen awards were identified, specifically 10 TSE, 4 SBIR, and 2 P3 (See Table 1: Awards Reviewed). With the help of our liaisons, the award folders were located and physically retrieved.

**Table 1: Awards Reviewed**

PI	University or Small Business	Program	Title	Completion
Reggie J. Caudill	New Jersey Institute of Technology	P3	Design of a National Electronics Product Reuse and Recycling System	May-04
James P. DeYoung	MiCell Technologies, Inc.	SBIR	Wafer Level Supercritical Carbon Dioxide-Based Metal Deposition for Microelectronic Applications	Jun-06
David Dornfeld	University of California-Berkley	TSE	Comprehensive Tools to Assess Environmental Impacts of and Improve the Design of Semiconductor Equipment and Processes	Nov-05
Fiona M. Doyle	University of California-Berkley	TSE	Electrolysis and Ion Exchange for the in-Process Recycling of Copper from Semiconductor Processing Solutions	Apr-04
Noah Hershkowitz	University of Wisconsin-Madison	TSE	A New Approach for Reducing Global Warming Emissions from Plasma Etching by Controlling Ion Energy Neutral Flux	Nov-06
Lester B. Lave	Carnegie Melon University	TSE	Environmental Input-Output Life Cycle Assessment: A Tool to Improve Analysis of Environmental Quality and Sustainability	Sep-01
Li Lin	Statue University of New York at Buffalo	TSE	Material Selection in Green Design and Environmental Cost Analysis	Sep-05
Scott B. McCray	Bendres Research	SBIR	Development of a Membrane – Based System for the Recovery and Reuse of Solvents	Jul-99
Cynthia Murphy	University of Texas at Austin	TSE	Development of Life Cycle Inventory Modules for Semiconductor Processing	Mar-05
David Nikles	University of Alabama	TSE	Solventless, Electron Beam-Cured Acrylate Coating Formulations for Flexible Magnetic Media Manufacture	Sep-01
W.S. Sampath	Colorado State University	TSE	Microstructural, Morphological and Electrical Studies of a Unique Dry Plasma Metal Deposition for Printed Circuit Boards (PCB's)	Sep-00
Edward J. Sommer, Jr.	National Recovery Technologies, Inc. (NRT)	SBIR	Improving the Recyclability of Computer Scrap and Other E-Wastes	Jun-06
Valerie Thomas	Princeton University	TSE	Electronic Tags for Product Environmental Management	Dec-05
John C. Warner	University of Massachusetts Lowell	P3	Photocrosslinked Immobilization of Polyelectrolytes for Template Assisted Enzymatic Polymerization of Conjugated Polymers	May-04
J.G. Wijmans	Membrane Technology and Research, Inc. (MTR)	SBIR	Recovery of Perfluoroethane from Chemical Vapor Deposition Operations in the Semiconductor Industry	Sep-99
C. P. Wong	Georgia Technology Research Corp.	TSE	Environmentally Benign Lead-Free Electrically Conductive Adhesive for Electronic Packaging Manufacturing Processing	Dec-06

## ***Award Folders***

Each award folder contained the initial grant proposal, financial records, peer reviews, and annual progress reports. Some included copies of publications and completed awards usually had final reports. An equal number of awards were given to each group member to summarize. These write-ups were reviewed by all three group members and made to fit a template to account for formatting and organizational differences. The template included standard PI and award information, while the body of the writing was organized under the subject headings: background, objectives, approach, results, and conclusions. These grant summaries can be found in Appendix G – PI Case Studies.

## ***Interview Scheduling***

PI contact information, phone number and e-mail address, was found in the award folders. Each PI was called at the number provided to schedule an interview. If someone was unavailable, a message was left on their answering machine. Several days later, anyone who could not be reached and did not call back was e-mailed. There were several PI's that could not be interviewed. Mr. Wijman's grant ended six years ago and his work has since moved in another direction. For these reasons, he did not wish to be interviewed. Mr. Sampath was initially contacted by e-mail, but was unresponsive to scheduling requests. Several others were too busy to be interviewed in our time frame. These include Ms. Doyle, Mr. Lave, and Mr. Nikles. The scheduled interviews were put into a spreadsheet displaying dates and times (See Table 2: Interview Results).

**Table 2: Interview Results**

<b>Name</b>	<b>Program</b>	<b>Called</b>	<b>E-mailed</b>	<b>Interviewed</b>	<b>Date Interviewed</b>
Reggie J. Caudill	P3		y	y	Nov. 9, 2005



Maurie Cohen	P3	y	y	n/a	
James P. DeYoung	SBIR	y	y	y	Nov. 14, 2005
David Dornfeld	TSE	y		y	Nov. 9, 2005
Fiona M. Doyle	TSE	y	y	n	
Noah Hershkowitz	TSE	y	y	y	Nov. 29, 2005
Lester B. Lave	TSE	y	y	n	
Grace Li	TSE	y		y	Nov. 17, 2005
Andy Lin	TSE	y		y	Nov. 16, 2005
Li Lin	TSE	y	y	y	Nov. 17, 2005
Scott B. McCray	SBIR	y		y	Nov. 14, 2005
Cynthia Murphy	TSE	y	y	y	Nov. 7, 2005
David Nikles	TSE	n	y	n	
W.S. Sampath	TSE	y	y	n	
Edward Sommer, Jr.	SBIR	y	y	y	Nov. 16, 2005
Valerie Thomas	TSE	y	y	y	
John C. Warner	P3	y		y	Nov. 9, 2005
J.G. Wijmans	SBIR	y	y	n	
C. P. Wong	TSE	y	y	y	Nov. 17, 2005

## ***Interview Process***

The interview process had three parts: preparation, the interview itself, and the write up. A list of interview questions was developed based on the questionnaire used by the 2004 EPA IQP group. The purpose of these interviews was to obtain valuable information that was not in the award folders. Therefore, questions such as “What is the potential for this project [research]?” and “Did your work prompt any follow-up research or patents?” were asked. Each PI was also asked if there was anyone, specifically any graduate students, that should be contacted for more information relevant to an award. Before each interview, the summary of the corresponding award was read. Any parts of the questionnaire that could be answered using award information were.

The interview itself was conducted by one group member while the other two took notes. After the interview, the PI’s responses were typed up by the interviewer using the questions as a guide. The other two group members then added their

information and reviewed the write up. After a final review, it was e-mailed back to the PI to make sure their answers were adequately recorded. If not, the PI could make changes and send it back. The final PI interview responses can be found in Appendix G – PI Case Studies.

## ***EPA Representative Meetings***

Face to face meetings with EPA representatives were meant to provide background information on other programs of EPA which dealt with electronics (See Table 3: EPA Representative Meetings). One meeting was done in the NCER office, while the other four occurred in EPA offices in Washington D.C. and Virginia. Background information about the representative's program was reviewed before each meeting, usually through the EPA website. Although originally intended as interviews, these meetings did not go as planned because many of the representatives gave pre-made presentations. As this information was presented, the majority of the prepared questions were answered. Any remaining questions were asked at the end.

These meetings were much more informal than the interviews. Since the representatives answered most of our questions in their presentations, no formal questioning was done. This allowed all three group members to take notes. The representatives worked for EPA, so they directed us to useful online resources sponsored by their departments. Our liaisons were also at the all of the meetings and asked their own questions. In the end, these meetings were informative and provided information useful to this project.

After the meeting, one group member would type the initial draft of the write up. Unlike in the interviews, the meeting information did not strictly follow the questionnaire.

The information was summarized in the order it was given, not using the prepared questions as a guide. The initial draft was sent to the other group members, who added their information. After all group members contributed, the write up was given a final review and then sent back to the EPA representative to make sure their thoughts were recorded accurately. The final meeting summaries can be found in Appendix F – EPA Representative Meetings.

**Table 3: EPA Representative Meetings**

<b>Office</b>	<b>Representative</b>	<b>Meeting Date</b>
EPA - Office of Solid Waste	Clare Lindsay	Oct. 31, 2005
EPA - Office of Pollution Prevention	Kathy Hart	Nov. 9, 2005
EPA - Office of Pollution Prevention	Kathleen Vokes	Nov. 9, 2005
EPA - Office of Atmospheric Programs	Scott Bartos	Nov. 10, 2005
EPA - ENERGY STAR	Katharine Osdoba	Nov. 15, 2005

## ***Changes to Questionnaires***

After a few interviews, it became apparent that some important information was being overlooked using the original questionnaire. Initially, one set of questions was used for every PI, regardless of the program their award fell into. After the first SBIR interview, we realized that none of the academic questions were applicable to this type of grant. The original questions were separated into an SBIR questionnaire, which focused more on industry, and a P3/TSE questionnaire, which focused more on academics. In addition, “can you tell us a little bit about yourself?” was added as an icebreaker at the beginning of each interview. This provided background information about how the PI’s became involved in their research.

Questions about academic aspects of the grant were also added to the TSE/P3 questionnaire, focusing on classes that were created or modified because of the research. The questions: “how often is this class taught, how long it has it been taught, and how

many students are in it?” were added to the questionnaire. This information is necessary to understand the impacts of NCER funded research on academia. Feedback from the PI’s interviewed was also taken into account. Several asked exactly what our project was, so an introduction was written to start every remaining interview with (See Appendix E: Interview Introduction).

The EPA representative meeting questionnaire was discarded. Due to the nature of the meetings, the questionnaire was not used during them or in the summaries. The original meeting questionnaire can be found in (Appendix E: EPA Representative Meeting Questionnaire).

### ***Quantitative Estimation***

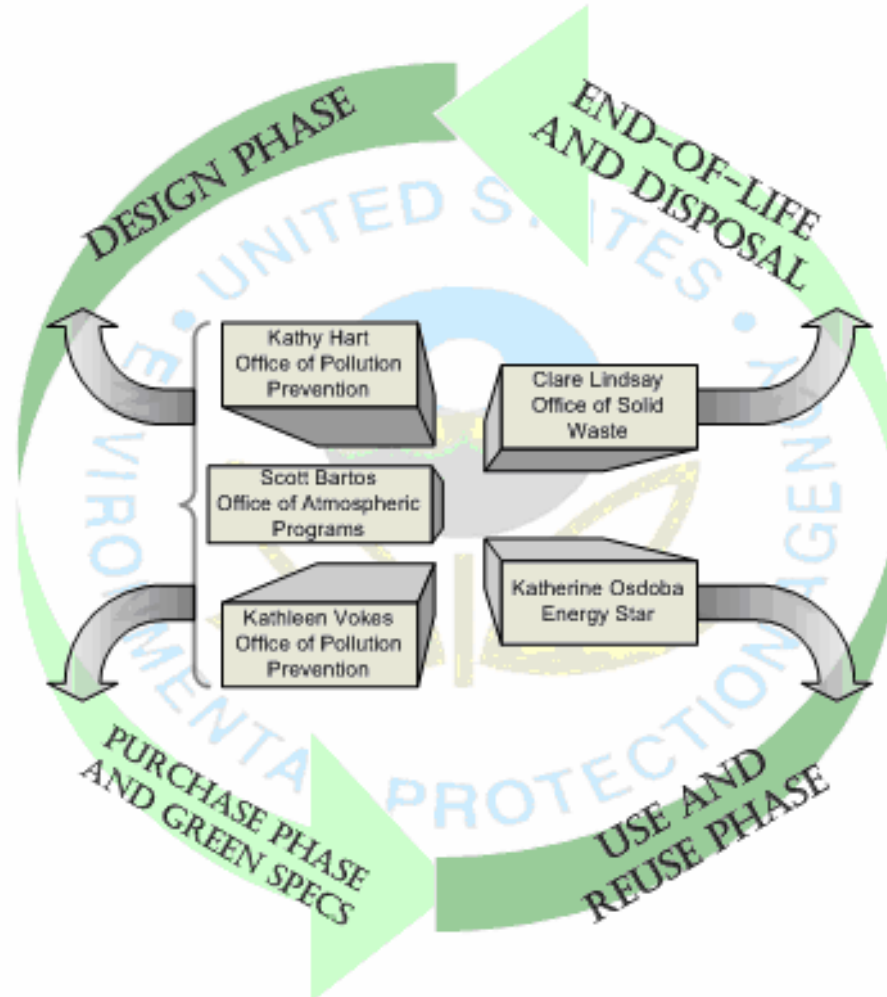
Quantitatively evaluating the industrial and environmental impacts of NCER funded grants is a very difficult task. The majority of the completed research is relatively new and has not been implemented in industry. This process requires additional research, testing, and can take years to occur. Even work that has been accepted by industry is challenging to evaluate. Many companies are not willing to share their data, fearing that it could give their competitors an advantage. For example, one of the PI’s that was interviewed couldn’t even say the names of his industrial partners due to contract restrictions. EPA requires companies to report their pollution releases, but even this information is two to three years old. The materials and manufacturing processes used in the electronics sector are changing and evolving so rapidly that the majority of accessible industrial data is several years old.

This project utilizes quantitative estimation to assess the potential environmental impacts of NCER funded awards. The goal is to estimate the environmental benefits if

this research is eventually implemented. Many of the PI's annual and final reports contain research results and possible conclusions. The most up to date industrial and environmental data was found using online databases (See Appendix D - Online Databases). With the PI's results and the online data, an estimation of a grant's effect, if it was implemented, can be made.

# Data Analysis

## Meeting Information



**Figure 4: EPA Representatives and their Departments**

Face to face meetings with EPA representatives were meant to provide background information on other EPA departments and programs. Figure 4: EPA Representatives and their Departments shows the representatives that were met with and their departments. These meetings tied together and validated the background research already done and provided valuable information that could only be obtained through experts. The following is an analysis of only this expert information, which will prove

helpful in drawing conclusions and making recommendations. The unabridged meeting summaries can be found in Appendix F – EPA Representative Meetings and many of the EPA programs mentioned are thoroughly discussed in the background section of this paper.

### **Clare Lindsay: Office of Solid Waste**

The first meeting was held on Oct. 31, 2005 with Clare Lindsay of the Office of Solid Waste (OSW). The main focuses of OSW are Plug into eCycling, EPEAT, the Federal Electronics Challenge, and Certification Systems for Electronics Recyclers. Ms. Lindsay stated that EPA can regulate waste disposal, but has little power over recycling. It is trying to establish sound practices for electronics recycling and use them to influence future industry standards. This plan accounts for both the short-term, by establishing recycling programs, and long-term, by influencing future recycling standards. Many obsolete electronics are being sent out of the United States, to less developed countries for reuse (Africa) or recycling (South Asia). This is a closely watched trend, as poorly managed electronics recycling can pose a greater pollution risk than disposal in a properly managed landfill.

Electronics pollution is growing fast and efficient ways to manage and recycle it need to be developed now, before it becomes a more serious problem. As a result, there is heavy political pressure for recycling and reusing electronics even though they only account for 1% of municipal solid waste. Ms. Lindsay's opinion was that product stewardship is the future of the electronics industry in this area. She defined this as a process where manufacturers, retailers, and consumers all have responsibilities the end-of-life handling of used electronics. This encourages manufacturers to make, retailers to

sell, and consumers to buy more environmentally friendly products. Green manufacturing processes, design for reuse, and incentives for recycling should prove useful in future product stewardship programs.

Ms. Lindsay also gave possible definitions for project success. She stated that many times the number of hits on a web site, brochures handed out, or partners in a program will be used to quantitatively evaluate success. Specific data, such as the number of products recycled in a given program, is more useful, but harder to get. It seems that as industrial information gets more accurate and useful, it also gets more difficult to obtain. One would most likely need industrial partners, either through an EPA program, or grant research to have access to specific, current industrial data.

This project utilized quantitative estimations based on the information available to predict the effects of grant research. Ms. Lindsay noted that even with estimations such as these, it is difficult to determine what specific award or program is the motivating factor behind any resulting pollution reduction. Multiple manufacturing processes may be changing at once and relatively new research may become obsolete before it can be implemented. It should also be considered that the company might make similar changes without the help of an EPA program or research.

### **Kathy Hart: Office of Pollution Prevention**

On November 9, 2005 a meeting was held with Kathy Hart of the Office of Pollution Prevention and Toxics (OPPT). OPPT uses its expertise to work with industry and promote technologies that are cleaner, more cost-effective, and perform better. This research is very helpful to industry, as most industrial research is already focused on increasing performance and cost effectiveness. OPPT only funds research on existing



and emerging technology, not developing new equipment or methods. Advice is then given on implementing possible alternatives. This research is most effective when a technology or process is in its infancy and can be easily altered. Prediction tools, such as analogous chemical tests and other models are commonly used.

The main subject of this meeting was the Design for the Environment (DfE) program. It focuses more on pollution reduction than regulation and works with industry to identify the greatest pollution problems and possible alternatives. The DfE program uses many approaches to perform research, including: life-cycle assessments (LCA's), alternatives assessments, formulation improvement, cleaner technologies substitutes assessments (CTSA's), and integrated environmental management systems. Ms. Hart elaborated on LCA's, alternative assessments, and CTSA's. LCA's take a long time to complete, but show wastes produced through individual steps along a product's lifecycle. The largest pollution problems can then be identified and evaluated. Alternatives assessments evaluate "drop in" alternatives that can be implemented without changing an entire production process. These assessments focus more on toxicity of substances and can be done faster than LCA's. CTSA's take risk and performance comparisons into account and provide possible alternatives.

The OPPT collaborates with all industries, most of which come to EPA for assistance. Ms. Hart mentioned that lead solder will soon be banned in the European Union. As a result, many companies have come to OPPT for help in researching environmentally friendly alternatives. Complying with governmental pollution regulations has associated fees, such as permits and worker safety expenses. In many cases, it is more cost effective to just stop using hazardous materials. This is an

important point, as reducing the costs associated with using hazardous materials is motivating industry to invest in more green alternatives. Ms. Hart felt there has been a change in the attitudes of industry over the ten years she has been working for EPA. Industry has become more accepting of environmental friendly technologies. Many companies have realized that doing the right thing from an environmental standpoint usually leads to reduced costs, so reducing or eliminating hazardous materials makes sense from a business point of view.

Ms. Hart also mentioned how DfE electronics partnerships are going to benefit immensely when the Electronic Products Environmental Assessment Tool (EPEAT) is completed. It should prove helpful in conducting LCA's and evaluating pollution problems.

### **Kathleen Vokes: Office of Pollution Prevention**

Kathleen Vokes was also present at the OPPT meeting. She is using alternatives assessments to provide quick answers concerning the use of hazardous chemicals. Her main focus is brominated flame retardants, such as pentabromodiphenyl ether. This substance is a major environmental concern because it has been found in animals, household dust, and even humans. The European Union and parts of the United States have banned pentabromodiphenyl ether and investigations are currently underway to determine how this chemical spread through the environment.

Ms. Vokes also gave examples of how OPPT is making a difference in the electronics sector. When asked about judging the success of her office, Ms. Vokes began by saying that the questions being asked and approaches taken are factors in the ability to determine success. An example is the OPPT's computer display life-cycle assessment,

which compared cathode ray tube (CRT's) and liquid crystal display (LCD's) monitors. LCD's take up less space, are more aesthetically pleasing, and use much less energy than conventional CRT displays. OPPT correctly predicted that LCD's would overcome CRT's. OPPT research later revealed that the amount of energy required to manufacture an LCD almost offsets the energy saved during its use. This and other work was aimed at moving the developing LCD industry towards greener manufacturing techniques.

This assessment had to take global production into consideration since there are more foreign than domestic LCD manufacturers. While it was difficult to get data from these foreign manufacturers, the LCA was still completed. Shortly after, a statement was issued by Japanese manufacturers claiming that they could decrease the energy necessary to manufacture their LCD's by fifty percent within six months. Despite not being mentioned in the statement, OPPT knew it was a big part of this development and began getting calls from other companies to do similar studies.

Quantitative data was also mentioned as a way to determine success. Ms. Vokes said that some numbers are easy to measure, such as the amount of lead solder used per year. While quantities like this may be easy to measure, getting the measurements from industry is more difficult. Industrial surveys are also used to determine the number of companies utilizing alternative manufacturing processes. For example, an OPPT survey showed that only 10% of companies in a specific industry were utilizing an environmentally friendly alternative. Two years later this number reached 30 to 35%. The Government Performance and Results Act was also mentioned. This program relates achievements to budget expenditures to get measurable, numerical outcomes.

## **Scott Bartos: Office of Atmospheric Programs**

On Nov. 10, 2005 a meeting was held with Scott Bartos of the Office of Atmospheric Programs. Mr. Bartos is working on reducing non-CO<sub>2</sub>, high global warming potential (GWP) gas emissions through the Climate Protection Program. While his department of EPA sponsors many programs, Mr. Bartos focused on the Climate Partnership for the Semiconductor Industry. Twenty one semiconductor companies are currently partners in the program and about four to eight use or release high GWP gases. This voluntary partnership benefits both industry and EPA.

Industry is conducting much of its own research. For example, it was discovered that chemical vapor deposition (CVD) chambers were being cleaned for too long to account for error margins. Industrial research led to the development of an endpoint detector that could determine when the chamber was clean. This simple device reduced the amount of cleaning gases used and released as air pollution. Industrial research is also being done on abatement control devices and capture membranes.

The chemicals used for cleaning are also improving. C<sub>2</sub>F<sub>6</sub> gas was used in cleaning operations in the manufacture of semiconductors. It has a high GWP and can stay in the atmosphere for hundreds of years. From 1995 to present, C<sub>2</sub>F<sub>6</sub> has been replaced by NF<sub>3</sub>, which is now commonly used in the semiconductor industry. Cleaning processes using NF<sub>3</sub> instead of C<sub>2</sub>F<sub>6</sub> are shorter, more efficient, and can result in a 99% reduction of green house gas emissions. Mr. Bartos called the widespread use of NF<sub>3</sub> as a replacement for other gasses the highlight of the partnership. Infrared cameras that can detect global warming gases have also been developed by industry. These cameras are currently being used to find SF<sub>6</sub> leaks, which are otherwise undetectable, in electronics manufacturing facilities. Stopping these leaks will reduce the needless release of

hazardous gasses into the atmosphere. These technologies and replacements were researched and developed by industry.

Mr. Bartos mentioned that many electronics fabrication and assembly factories (FAB's) in the U.S. are closing. Manufacturing is being moved to foundry FAB's overseas, specifically in Asia, where semiconductors can be mass produced. This is being done for economic reasons, not because the companies are trying to move their pollution somewhere else. Mr. Bartos identified this as an important trend because it is more difficult to track an industry if it is continually changing locations.

Mr. Bartos also relayed information about some of the ways industry is protecting its workers from toxic chemicals. Clean rooms, double walled containers, multiple cleanings, and the use of robots have greatly reduced worker exposure. This was good to hear, as occupational exposure was a concern coming into this project.

### **Katharine Osdoba: ENERGY STAR**

A meeting was held on Nov. 15, 2005 with Katharine Osdoba, an ENERGY STAR representative. The ENERGY STAR program is unique, as it allows consumers to drive market change through selective purchasing. In addition, the federal government has pledged to only purchase ENERGY STAR labeled equipment. In order for manufacturers to be a part of this \$60 billion a year market, they must change their production standards to meet more energy efficient specifications. For this reason, many companies see ENERGY STAR not as a voluntary program, but as a regulation. In order to stay competitive, especially with governmental contracts, companies must sell ENERGY STAR certified products.

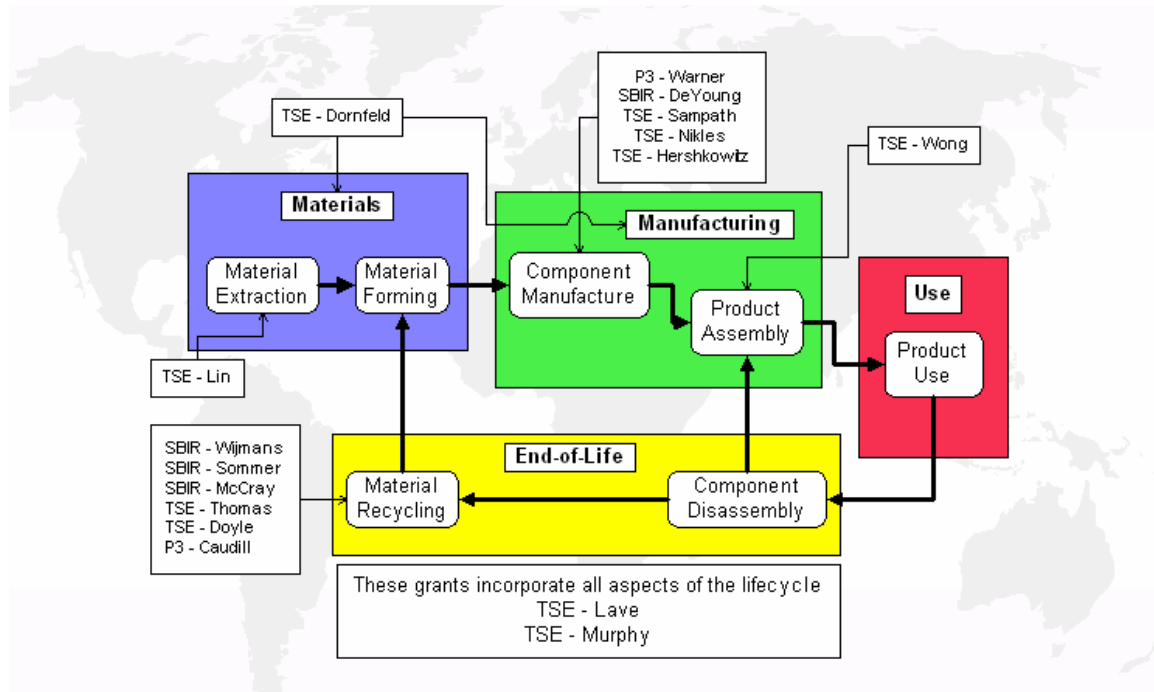
Specifications are developed such that only 25% of specific products can be labeled ENERGY STAR efficient. As electronics become more energy efficient, stricter specifications must be developed to keep this ratio. ENERGY STAR is meant to be a market differentiation tool, but it will not work effectively if the majority of electronics qualify. Ms. Osdoba described how the specification process works. EPA announces that ENERGY STAR is looking to reevaluate its standards on a specific product or product area. After about a year of research, EPA releases new specifications. Manufacturers are typically given around eight months to a year to meet the new requirement before the label becomes active.

A current initiative for consumers, called “Change a Light Challenge”, challenges Americans to change five light bulbs in their homes to ENERGY STAR labeled bulbs. This program has been very successful for several reasons. Replacing five light bulbs is relatively easy and will end up saving the consumer money in the end. In addition, the program is a competition, which can be a good motivator to participate.

Producing energy, using fossil fuels, releases large amounts of harmful greenhouse gasses into the atmosphere. By saving electricity, the ENERGY STAR program prevents some of these releases. Unit shipment and energy consumption data are recorded and the amount of energy saved is calculated. This number can then be equated to an amount of greenhouse gases prevented, which is similar to the quantitative estimation used in this project. ENERGY STAR currently focuses only on the use phase of electronics.

## Award Impacts

The National Center for Environmental Research (NCER) has funded sixteen awards in the electronics sector from the People Prosperity, and the Planet (P3), Technology for a Sustainable Environment (TSE), and Small Business Innovation Research (SBIR) programs. These awards were grouped using the lifecycle of electronics, which can be broken down into four main stages: materials, manufacturing, use, and end-of-life (See Figure 5: NCER Funded Awards and Areas of Impact). Some awards focused on individual steps, such as component manufacture or material recycling, while others covered the entire lifecycle through lifecycle assessments. The impacts of each award on academia, industry, and the environment were then analyzed based on the aspect of the lifecycle they affect.



**Figure 5: NCER Funded Awards and Areas of Impact**

## Materials Stage

The first part in the lifecycle of electronics is the materials stage, which is broken down into extraction and forming. Material extraction involves the mining of metals, capture of elemental gasses, and creation of polymers. These materials are purified and prepared for manufacture in the material forming step.

The only award that focused specifically on the materials stage is Dr. Li Lin's TSE research on a materials selection database. Dr. Lin worked as a design engineer researching service systems, but is currently a professor at the University of New York at Buffalo. From his experience, Dr. Lin realized that the majority of design engineers only focus on the manufacturability and performance of a material, not its effects on the environment. His material selection evaluation tool work will fill this gap between material performance and environmental impacts. The database being developed by Dr. Lin relates materials, emission, and toxicity. He is investigating the toxicity of pollution emitted when using specific materials, based on data provided by Xerox.

Dr. Lin has taught a graduate level course entitled, "Environmentally Conscious Design Manufacturing" for the past three years. It is an advanced research-oriented elective available to students of all majors and averages seven to ten students per year. Dr. Lin worked also with graduate student named Andy Lin. Andy wants a job in the Chinese government where his environmentally friendly research can influence regulations and legislature.

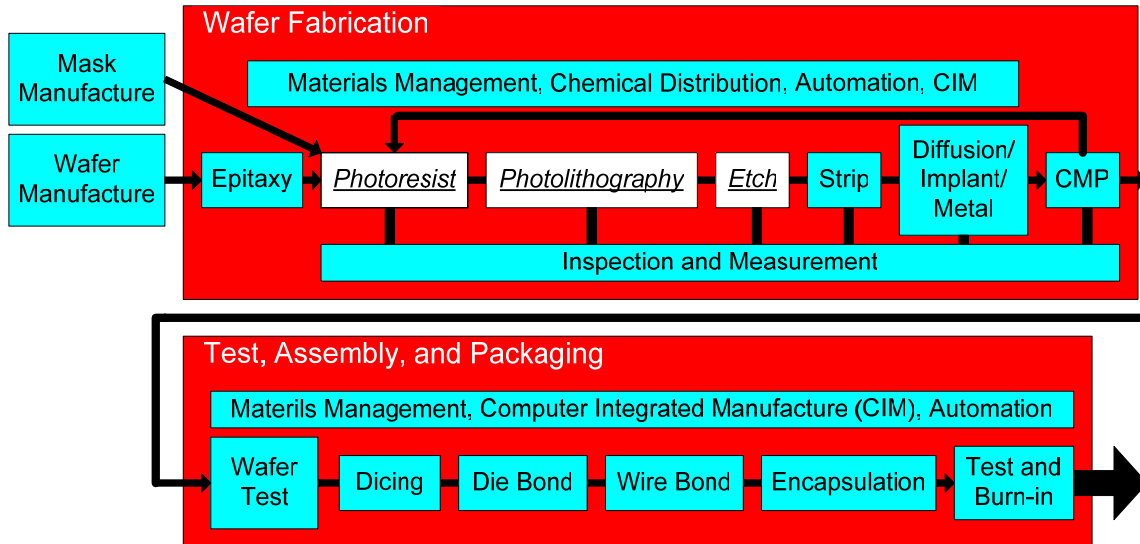
Although his research is not complete, Dr. Lin hopes that the material selection database will be easily implemented by design engineers. It should assist them in considering the end-of-life consequences of using specific materials. Using this tool will



help companies save money by selecting economical and environmentally friendly materials, which reduce costs associated with cleanings and pollution produced.

## Manufacturing Stage

Component manufacture and product assembly make up the manufacturing stage of the lifecycle. Component manufacture involves how individual components are produced, while all the parts are combined to make a final product in the product assembly step. The manufacture of a semiconductor chip is a complex process which can require up to four hundred steps to complete (See Figure 6: The Chip Making Process).



**Figure 6: The Chip Making Process**

The first step for manufacturing a chip is coating a silicon wafer with a layer of silicon dioxide. This is followed by making layers of circuit patterns on the chip through photolithography. This process begins by coating the wafer with a light-sensitive chemical or photoresist. Light is shone through a patterned plate called a mask, which exposes the resist. Parts of the resist “harden” due to this exposure and are not removed by washing chemicals. The remaining photoresist is then washed away. The silicon

dioxide is carved away and then the “hardened” sections are stripped off in the etching process. The photolithography and etching steps may be repeated many times to produce multiple layers of circuit patterns. Certain areas of the chip are then exposed to chemicals that affect its ability to conduct electricity. The entire surface of the chip is electroplated and excess metal is polished off. The chip’s conductive pathways are tested before it is finally packaged. [45]

Etching is an important process in the manufacture of silicon chips and PCB’s and is the focus of two NCER funded awards. A TSE award by Dr. Noah Hershkowitz attempted to replace  $CF_4$  in the etching process, while Dr. W.S. Sampath investigated a unique dry etching process for PCB’s.

Dr. Hershkowitz specializes in plasmas, or charged particle gasses, and has been a professor of engineering physics at the University of Wisconsin for over 24 years. He was approached by one of his graduate students who expressed an interest in using an unconventional approach to conventional plasma etching. The award investigates if it is possible to replace  $CF_4$  in etching, using an alternate process.

Forty percent of the steps in manufacturing a semiconductor involve etching and many conventional processes use hazardous fluorinated gases, such as  $CF_4$ . If carbon and fluorine could be deposited onto the surface of the silicon wafer separately,  $CF_4$  could be replaced in the etching process. Separate gases,  $NF_3$  and  $C_2H_2$  or  $C_2H_4$ , were used to lay down the carbon and fluorine, and a different gas was used to etch the surface.

Despite his best efforts, the research was unsuccessful in achieving its original goal. The fluorine and carbon were successfully deposited on the wafer, but did not have the required selectivity to be etched. Dr. Hershkowitz has greatly increased the

understanding of the etching process as well as the roles of CF<sub>2</sub> and CF<sub>3</sub>. His research has been incorporated into a graduate lecture that is taught once every two or three years, with a class average of 12 students. The student who started this research has since graduated and another student is now working with Dr. Hershkowitz to find an alternative etching agent.

Dr. Sampath is a professor in the Materials Engineering Laboratory at Colorado State University. His research involves using a dry plasma metal deposition process for the manufacture of PCB's. This method utilizes subtractive, rather than additive, techniques to reduce waste. During this process, a thin metalized layer is added to a bare PCB using a unique air to vacuum to air sputtering process. The board can then be drilled, electroplated, and flash etched resulting in a finished PCB.

If successful, Dr. Sampath's research could reduce chemical etch waste by more than 99%. Etching chemical usage is shown in Table 4: Some Environmental Releases from the PCB Industry for 2003. This dry etching process could prevent an upper bound of approximately 198,000 pounds of etching chemicals from being released into the environment. Since an interview couldn't be performed with Dr. Sampath, specific impacts of his research on academia could not be determined.

**Table 4: Some Environmental Releases from the PCB Industry for 2003**

Chemical	Releases* (lbs)	Use	Total US Releases** (lbs)
Hydrofluoric Acid	98,885	Etching Electroplating	110,969
Nitric Acid	52,349	Etching Electroplating	131,583
Sulfuric Acid	49,095	Etching Electroplating Cleaning	133,963
Total	200,329		376,515

\*Scorecard data from semiconductors and related devices (SIC3674) and printed circuit boards (SIC3672)

\*\*Scorecard data: total Electronic & Other Electronic Equipment (SIC36) releases

The process of metal deposition was addressed by Dr. James DeYoung, who is currently the Vice President of the Technology Division of MiCell Technologies Inc. He oversees all of the company's research and development proceedings. Dr. DeYoung received a PhD in chemistry from the University of Texas at Austin where his thesis concentrated on new synthetic methods in organofluorine chemistry.

The semiconductor industry uses many resources, including large quantities of water. Current processes to produce 300 mm wafers can use as much water in one day as a city of 60,000 people will use in a year. Dr. DeYoung studied the use of supercritical carbon dioxide to replace aqueous and organic solvents. Using this alternative would make metal deposition, cleaning, etching, and photolithography dry processes.

The semiconductor industry is always striving to produce smaller chips and passive components. Conventional fluids will no longer be usable by the year 2010 due to the decreasing size of components [46]. Supercritical carbon dioxide does not have the same physical restrictions as water and will be most likely replace it in the future. Using supercritical carbon dioxide would not only reduce resources required, but wastes produced, such as waste water. Supercritical carbon dioxide is also recyclable, which will reduce the costs of buying new materials.

Using supercritical carbon dioxide instead of aqueous and organic solvents has environmental benefits as well. There are 242 FAB's located in the United States. Every FAB uses 11 million liters of ultra pure water (UPW) per day to produce 200 mm wafers. The electronics industry is shifting towards 300 mm wafers, which would require at least an additional 5.5 million liters of UPW. Supercritical carbon dioxide could potentially eliminate this water usage and the resulting wastewater being produced.

Printed Wiring Boards (PCB's) are made of polymer composites. Layers of these composites are laminated together and conductive patterns are added the outside surfaces through photolithography and etching. Holes are drilled in the boards and made conductive through electroplating.

Funded by a P3 Award, Dr. Warner and a team of students developed a cost efficient way to lay down photoresist on PCB's without using organic solvents. Dr. Warner is a professor of green chemistry at the University of Massachusetts at Lowell. He was one of the founders of the thirteen principles of green chemistry and co-authored the green chemistry first book published.

Seventeen graduate students work with Dr. Warner. These students are working on different projects, but they give presentations about their projects and help one another. Once per month each student is required to present their research at a K – 12 school. This allows dissemination of their knowledge to a wide variety of people and helps to develop the articulation needed to clearly explain complex processes.

Although Dr. Warner's work is an important breakthrough, it will take five to seven years for the new technology to be implemented in the manufacture of electronics. The next step for Dr. Warner is to find industrial partners who would be interested in implementing this organic solvent-free photoresist process. Once it is incorporated into the manufacturing process, it will create safer work environments and reduce costs associated with clean up.

By using greener processes such as this, environmental concerns with photolithography could be minimized. This process is less expensive than conventional

methods and there would be no clean up or remediation costs associated with wastes produced.

More than 600 kg of organic solvents are used to in the coating process of the magnetic film in floppy disks per hour. This process releases organic solvent vapors into the atmosphere, many of which are on the EPA's list of 189 air pollutants. Dr. David Nikles' research provided a way to manufacture floppy disks using new acrylate formulations rather than organic solvents. He demonstrated a feasible way to incorporate this into manufacturing processes.

Due to time constraints, an interview with Dr. Nikles was not possible, so the academic impacts of his research could not be determined. If implemented this research would have both environmental and industrial impacts. The biggest environmental impact would be the amount of solvent vapor not being released into the atmosphere. If this research is successful and the technology implemented, 150 metric tons of solvent vapors would not be released into the atmosphere from the coating process of magnetic film strips. Also, once incorporated, this new process will lower manufacturing costs in several ways. These include reducing energy costs associated with drying, solvent recovery, and recycling as well as eliminating the costs associated with complying with the Clean Air Act Amendments, Resource Conservation and Recovery Act, and Toxics Substances Control Act. This award was completed in 2001, but because an interview did not take place it is not known if this process has been implemented in industry..

During the product assembly step, chips and other components are soldered onto a PCB to construct a printed wiring assembly (PWA). The only award that dealt with the product assembly aspect of the manufacturing stage was TSE done by Dr. C.P. Wong.

Dr. Wong is aspiring to find a replacement for lead-solder. He has been a professor at Georgia Tech for nine years and employee of Bell Laboratories for 19 years prior to that. Through his background in researching materials and material processing, Dr. Wong noted the need for a lead-free solder. Many of the so called “lead-free alternatives” have undesired side effects, such as higher melting point that requires more energy to use. Other metal alloy alternatives require the mining of lead to be made. Using his TSE award, Dr. Wong sought to find a suitable electrically conductive adhesive (ECA) which had a low melting point, was reusable in a similar fashion to conventional tin-lead solder, and had similar current density and conductivity to that of traditional solder.

While looking into the existing alternatives such as tin-silver and tin-silver-copper, Dr. Wong found that the melting point for these alternatives to be significantly higher than that of tin-lead. From here, he began investigating ECA’s, which cure at much lower temperatures, but are known to have lower conductivity than traditional solder. He was able to develop repairable resin binders as well as a method of corrosion control while keeping cost at a minimum.

The information obtained from his research is incorporated into an undergraduate and a graduate class, which both have twelve to twenty-five students. Each of these classes is taught yearly. Seven graduate students were funded by this TSE award. Dr. Wong’s continuing research, along with new chemical development has also resulted in major syllabi changes in his courses in the past two years.

Dr. Wong’s research will provide industry with a suitable alternative to tin-lead solder. This stands to eliminate the use of traditional solder almost entirely. The electronics industry uses a total of 2,744 pounds of lead, which is the same weight as a

2002 Honda Civic Si (See Table 5: Lead Usage in the U.S. in 2003). His industrial partners, Intel, TI, and National Semiconductor, and Indium Corp., are leaders in developing ways of effectively using Dr. Wong’s new low cost ECA, while testing its performance. The reduction of lead in electronics waste can prevent ground water contamination, reduce hazards to workers, along with many other environmental benefits.

**Table 5: Lead Usage in the U.S. in 2003**

Rank	SIC	Industrial Sector	Total Releases* (lbs)
3	3672	Printed circuit boards	1,345
7	3679	Electronic Components	835
9	3674	Semiconductors and Related Devices	542
21	3675	Electronic Capacitors	18
30	3671	Electron Tubes	4
		<b>Total:</b>	2,744

\*Scorecard data from Electronic and Other Electric Equipment Sector

## Use Stage

The next stage of the lifecycle is use. Finished electronics products are purchased by consumers or businesses and used. None of the considered awards focused specifically on this area.

## End-Of-Life Stage

The end-of-life stage occurs when a product has become obsolete or broken and is going to be disposed of. Some recycled products can be disassembled and their components reused. Other products are broken down into materials, which can then be recycled. Electronics that are not being recycled can be incinerated, put in landfills, or exported. Dr. Valerie Thomas and Dr. Reggie Caudill based their research on the fact that consumers will utilize convenient, easy to use recycling programs.

Dr. Thomas is a professor at Georgia Institute of Technology in the School of Industrial and Systems Engineering and the School of Public Policy. She specializes in



industrial ecology and researches material and energy use, long term efficiency, and recycling. She found a lack of recycling opportunities on a large scale.

This TSE award proposed attaching electronic tags, such as barcodes, radio frequency identifiers, or global positioning locators to electronics to record disposal data. These tags also contained information directing consumers to online disassembly and recycling instructions. This technology is already being utilized in Europe, so Dr. Thomas is hoping to use this system validate her own.

The TSE award funded two graduate students who aided in Dr. Thomas' research. There have not yet been any curricula changes resulting from this research. Dr. Thomas's tag system has the potential to reduce the solid wasted created from product end-of-life disposal almost entirely. With widespread industrial support this technology could make electronics recycling much easier and more efficient. There would be an initial cost associated with implementing the technology and creating the information references on the Internet.

Dr. Reggie Caudill is a Professor at New Jersey Institute of Technology (NJIT) and a member of National Electronic Product Stewardship Initiative (NEPSI). From his experience in NEPSI and his personal interest in the subject, Dr. Caudill is very knowledgeable about the end-of-life of electronics. Electronics manufacturing steadily increased over the last decade. The technology used in these electronics is constantly changing, so these products are quickly becoming out of date. This is resulting in the large-scale disposal or even exportation of used electronics. It is estimated that in the year 2005, 63 million tons of computer equipment will be taken out of service and 85% will end up in landfills.

In NESPI, Dr. Caudill was part of a 45 person committee which investigated creating a national recovery, reuse, and recycling program for electronics. To look at the problem from a different perspective, Dr. Caudill spoke with a group of senior industrial engineering students from NJIT.

Funded by a P3 Award, Dr. Caudill and his group of students studied a county in New Jersey. They were able to calculate the best locations for recycling facilities, optimal collection for different population densities, and costs of administration, labor, and recycling. The research team successfully identified the conditions for a recycling system, but further funding will be needed to create an infrastructure.

The students involved in the P3 award spread the knowledge they gained from this experience to others in the NJIT community. Dr. Caudill is part of the Industrial Manufacturing Engineering Department of NJIT and focuses on multi-lifecycle engineering, design for the environment, and the applications for reused products. For the past four years, Dr. Caudill has included material from this project into one of the graduate level courses he teaches. This is offered once a year and averages 25 students.

If created, this national system could recycle some of the estimated 53,550,000 tons of computer waste being disposed of in landfills in the 2005. If this infrastructure was adopted by industry, it would also create a significant amount of jobs. This research can have economic benefits, as recycling can produce reusable materials.

Once electronics are collected to be recycled, they need to be sorted. Mr. Edward Sommer and National Recovery Technologies (NRT) Inc., have specialized in sorting materials for recycling since 1981. NRT Inc., headed by Mr. Sommer, has been looking into recycling of electronic waste (e-waste). If this type of waste is left unsorted, it has

minimal value and will usually cost more to recycle it than the worth of the recycled materials. Sorting polymers by type allows them to be recycled and reused in high-value applications, making them very profitable for the waste processor. NRT Inc. has successfully developed a mechanism to sort e-waste, but the infrastructure to implement it is still in development.

If an industry were to adopt this technology, it would prove profitable. It was estimated that by the year 2007, there would be 7 billion tons of plastics from e-wastes available for recycling. When recycled, this plastic is worth \$0.25 - \$1.25 per pound, which makes this a huge market for recyclers. E-waste contains toxic substances, such as lead, beryllium, mercury, cadmium, and brominated flame retardants, which can leech into groundwater if disposed of in a landfill. Implementing this technology would reduce the amount of e-waste piling up in landfills and its effect on the environment.

Another way of recycling is recovering substances used in the manufacturing processes. These substances never see the use phase and are usually disposed of shortly after the product is manufactured. Dr. Scott McCray, Dr. J.G. Wijmans, and Dr. Fiona Doyle all received NCER funding to research the recycling chemicals used during the manufacturing process.

The semiconductor industry has been looking into recycling solvents. During use, solvents are diluted with water or other liquids, decreasing their quality and usefulness. Recycling these solvents, can prevent pollution as well as reduce the cost of purchasing new solvents. Unfortunately, some solvents are hard to recycle using conventional methods, such as distillation, due to azeotropes.

Dr. McCray received his PhD in chemical engineering focusing on membrane separation. He is working for Bendres Research developing a membrane to recycle used solvents. His SBIR award concentrated on isopropyl alcohol (IPA), which is used as a wash in hard drive and computer disk manufacture. A membrane to recycle impure solvents was eventually developed. If this technology is implemented, it has the potential to save a company the cost of disposing impure and buying fresh IPA. In high concentrations, IPA is a neurotoxicant and is known to cause kidney, heart, and skin problems. The implementation of this technology should greatly reduce worker hazards related to computer disk manufacture.

Fluorinated gasses (especially  $C_2F_6$ ) are used in the semiconductor industry to clean chemical vapor disposition (CVD) chambers. Although  $C_2F_6$  is only released in small quantities, it is a potent greenhouse gas with a global warming potential (GWP) of 13,500 and an atmospheric lifetime of at least 10,000 years. A typical semiconductor facility will emit 10,000 to 50,000 lbs of  $C_2F_6$  per year, just from CVD chamber cleaning processes.

An SBIR partnership, between Membrane Technology and Research Inc. and Dr. J.G. Wijmans preformed research to reduce  $C_2F_6$  emissions. Through this partnership, a membrane that could recover 70-80% of  $C_2F_6$  emissions was developed. In 1999, the semiconductor industry moved away from using  $C_2F_6$  in CVD chambers. While this change was beneficial to the environment, it made Dr. Wijmans' technology inapplicable. It is important to note that the research was successful, but the final process was never used in electronics manufacturing.

Dr. Fiona Doyle is a professor at the University of California Berkley and is also interested in reducing the waste from the semiconductor industry. Recycling water, copper, and solutions could prevent millions of tons of waste from being released into the environment.

Using electrodeposition, Dr. Doyle wanted to remove solids from solutions in e-waste streams. She charged a large rotating copper electrode to remove metals from solution. While this was successful, the chemicals used to keep the metals in solution would often slow or prevent the process. She is currently researching a reusable and more effective chelating agent to replace the one used in initial testing.

The preliminary results of Dr. Doyle's research show that this process can have a significant impact on industry. Using it, companies can avoid spending money on the disposal of massive amounts of waste material. This technology can prevent 225 million gallons of solutions from being dumped into the environment per year. The academic impacts of this award were unavailable, as an interview could not be conducted with Dr. Doyle.

## **Lifecycle Analyses**

The three remaining NCER funded awards focus on the lifecycle as a whole. The research takes the role of each stage within a product's life into account in a lifecycle assessment (LCA). LCA's are usually associated with major financial and time investments, which is why industry commonly uses shorter, less comprehensive assessments. Dr. David Dornfeld investigated the environmental impact of semiconductor manufacture. Dr. Lester Lave researched a less expensive and time consuming alternative to traditional lifecycle assessments. Dr. Cynthia Murphy worked

to develop an effective predictive LCA based on inputs rather than reported usage information.

Dr. Dornfeld has been teaching at University of California Berkeley for thirty years and was drawn to green manufacturing technologies through his many contacts in Europe. He found that reducing energy consumption along with minimizing water use and waste production helps the environment and saves industry money. Using TSE funding, he designed a tool which could assess the environmental impacts of semiconductor manufacture and potentially improve the design of related equipment.

The electronics industry understands the value of having such a tool at their disposal and provided Dr. Dornfeld with large amounts of data. This tool makes it easy for industry to be more environmentally conscious when designing and implementing technology. In addition, a mechanical engineering version of the tool can later be developed and used in other industries.

Dr. Lave, a professor at Carnegie Mellon University, found existing LCA's to be too expensive and time consuming. He recognized that LCA's aid industry in making educated choices among materials, designs, manufacturing processes, alternatives for product use, recycling, and disposal. With that in mind he applied for a TSE award with the hopes of developing an input-output assessment that would provide similar results to conventional LCA's but take much less time and money.

To perform his research, Dr. Lave used public government databases to calculate direct and indirect environmental impacts from manufacturing products. He wanted his tool to supply very detailed analysis for any situation that could be presented. By

breaking the subject down into materials, processes, and products; he could provide the user with an accurate and detailed decision making tool.

Dr. Murphy, a professor at the University of Texas at Austin, found that existing LCA's are only as good as the inventory data used to make them. Many companies withhold information from researchers fearing that their profit margins or production numbers will be estimated by competitors. She wanted to develop a predictive, not historical, life cycle analysis.

Through her research, Dr. Murphy found that very toxic and expensive chemicals are not the major cost factors in electronics manufacture, but rather water, energy, and elemental gases are the heavy hitters. She used information provided by her industrial partners, AMD, Motorola, and SEMATECH, to create life cycle inventory modules. These modules can be used to estimate cost and product quality, and it is Dr. Murphy's hope that they can be used to predict and avoid negative results caused by implementing new technologies.

Life cycle assessments are meant to be used as decision making tools. Choosing the most environmentally friendly materials, processes, and disposal methods has a great impact on the environment. If assessments similar to the ones described above are used in the industrial decision making process, they can prevent very large amounts of pollution from being produced. Dr. Murphy and Dr. Dornfeld each funded two graduate students through their respective awards, and both have had changed a class that they are currently teaching. Collectively their research affects approximately fifty students per year. Information on Dr. Lave's academic impacts was not available.

All quantitative data and information about the PI's can be found in either their awards review or interview summary (See Appendix G – PI Case Studies). The impacts of each award on academia, industry, and the environment were established and placed in a table of impacts for quick reference (See Appendix I: Table of Impacts). The individual effects of these NCER funded awards were then totaled and discussed

## ***Discussion***

Consolidating the information gathered from grant reports and interviews should give an overall view of the effects of NCER funded research on academia, the electronics industry, and the environment.

Through PI and graduate student interviews, the effects of NCER's academic grants (TSE and P3) can be seen. Of the principal investigators interviewed, 7 provided quantitative academic impacts of their grants. A total of 8 classes were created or changed due to this research, effecting 402 students. In addition, 39 graduate students were directly funded by these seven grants. On average, a single award created a change in one course, affected 15 students in this course, and funded 5 graduate students. Unfortunately, only 6 awards had publication information, but an impressive 59 publications were written based on these alone. If this ratio holds, about 160 publications should have been written based on the 16 considered awards.

Much of the research funded by NCER directly involves companies as partners. These industrial partners provide testing materials, facilities, industrial data, and even additional funding to research teams. The total number of industrial partners involved in all the research in the electronics sector is difficult to determine due to nondisclosure contracts. Eighteen companies were identified as industrial partners for the 8 awards



with this information. Nine patents were granted as a direct result of the research funded by TSE, SBIR, and P3. Three additional patents have been filed and are still pending approval.

The broad range of NCER funded research could affect thirteen chemicals used and released by electronics manufacture. If implemented, this research could eliminate the use of 970,000 million liters of water per year and release of 14,000,000,000,000 pounds of pollution into the environment per year.

## **Conclusions**

After completing an analysis of National Center for Environmental Research (NCER) funded awards, several conclusions have been developed about their impact on academia, industry, and the environment. These ideas extend the quantitative data given in the previous sections of this project, showing what it means in a social context.

### ***Academia***

Awards funded by NCER have had an extensive effect on academia. The People, Prosperity, and the Planet (P3) and Technology for a Sustainable Environment (TSE) awards produced the major academic impacts, which are: publications, furthering the understanding of various fields of study, course changes, and effects on graduate students.

Publishing work is one of the easiest ways to spread information. While not all research results in a publication, six NCER funded awards did. Dr. Nikles authored sixteen publications, including nine journal articles, based on his TSE research. Doctors Sampath and Doyle each published eight works based on their NCER funded research. The information provided in these types of publications should prove useful to anyone

studying pollution in the electronics sector and could provide a basis for further research in this field.

When conducting research, furthering understanding in a field of study should be a top priority. A small number of NCER funded awards did not succeed in their original objectives, but still resulted in valuable information being learned. For example, TSE research done by Dr. Noah Herskowitz was intended to replace fluorinated gasses in the etching process. His method wasn't completely successful, but a great deal of knowledge was gained about selectivity and the role of fluorinated gasses in etching. Dr. Wijmans found a way to reduce C<sub>2</sub>F<sub>6</sub> emissions from CVD chamber cleanings using recovery membrane technology. Unfortunately this work was never applied because of changes in industry. Dr. Caudill's research proposed a national recycling system for electronics, but it was never implemented due to a lack of funding. While these awards may not have been successful, the knowledge gained from them is very important to their respective fields. According to Dr. John Warner, seventy percent of materials and the corresponding manufacturing processes need fundamental changes to be environmentally friendly. These changes can only be made possibly through continued research in the electronics sector. NCER funded awards themselves have proven very useful and the research being conducted through them could lead to more groundbreaking developments in the future.

The twelve TSE and P3 principal investigators (PI's) studied are all college professors and the material being presented in their classes also has an effect on academia. The majority of these PI's do research in the same field that they teach in. As a result, knowledge gained through their research is being incorporated into the classes they teach.

For example, Dr. Reggie Caudill included information from his P3 research in one of his graduate courses at the New Jersey Institute of Technology. He teaches in the industrial manufacture engineering department, so his research on large scale recycling processes was very applicable. Dr. C. P. Wong is including material from his TSE research on electrically conductive adhesives in both the lectures he gives at the Georgia Tech. The incorporation of NCER funded research into college courses is another way to increase the spread of information. Students in these classes can learn about the most recent work being done in the electronics sector and study real world results that cannot be found in textbooks.

The impressions of TSE and P3 awards in the electronics sector on graduate students were also considered. Only two graduate students were interviewed, but their responses showed how much being a part of this research has meant to them and their careers. Grace Li is currently working on a TSE award with Dr. Wong, exploring electrically conductive adhesives. The research will not be complete until the end of 2006, but Ms Li thinks electrically conductive adhesives will be a very applicable in industry. Since European Union initiatives are banning lead in solder, developing an alternative will be a worldwide effort. With the help of NCER funding, Ms. Li is already a part of this effort and will likely continue work in this field. Andy Lin worked on Dr. Li Lin's TSE award concerning electronics material cost assessments. Mr. Lin received an MS degree in industrial engineering in China, and was recruited to work on this TSE when he returned to the U.S. to get his PhD. Like the U.S. electronics industry, the Chinese electronics industry is showing rapid growth. Mr. Lin hopes to return to China and get a government job where he can incorporate green techniques into current

manufacturing processes in the electronics sector. From conducting PI interviews, it was generally noted that participating in NCER funded research has directly and indirectly affected the career choices of many graduate students. This is a significant impact on academia because these graduate students can bring environmentally friendly mindsets and ideas into teaching or the industrial workforce.

## ***Industry***

The impact of NCER funded awards on industry is difficult to determine, since much of this research is not yet implemented in the electronics sector. However, several effects, such as the implementation of technology in the future, participation of industrial partners in research, issuing of patents, and a gradual change in the attitude of industry, were found.

The majority of NCER funded awards will have a greater impact on the future of the electronics sector. Several disruptive technologies were investigated, which require the failure of current processes. While it may not be feasible or cost effective to implement disruptive methods now, they will be very applicable when conventional processes and materials fail. For example, James DeYoung studied the use of supercritical CO<sub>2</sub> in the metal deposition process. It would not be cost effective to use alternative in current metal deposition processes, when ultra pure water can accomplish the same task. As electronics components get much smaller, water will no longer be usable in many processes. This is when Mr. DeYoung's new process may be implemented.

Two of the considered awards dealt with electronics lifecycle assessments (LCA's). These tools identify wastes produced during specific steps of a product's

lifecycle, which aids in decision making. An LCA being developed by Prof. Cynthia Murphy is using parametric equations as inputs, which makes the tool relatively time and process independent. These attributes are very important in an LCA because the electronics industry is changing and evolving so rapidly. Prof. Murphy's assessment could still be an accurate decision making tool, fifty years from now when all current processes and materials are no longer in use. The alternative materials, processes, and decision making tools being researched by NCER funded awards are new and innovative, but take time to be implemented in industry. It would not be surprising to see a number of these processes being used by the electronics sector in the future.

Much of the research funded by NCER was done with the assistance of industrial partners. These companies provided PI's with data, materials, testing facilities, and even funding and commercialization opportunities. For example, the TSE research done by Dr. Li Lin relied heavily on materials provided by Xerox. While most SBIR research was done in the small business itself, the commercialization of new technologies requires larger companies. So, when Dr. DeYoung's research on new metal deposition techniques is finished, he will need industrial partners to further test and possibly commercialize the process. The fact that large companies, such as Intel, Xerox, SEMATECH, National Semiconductor, and the Indium Corp are willing to provide data, open their facilities to, and even fund this research shows their commitment to developing environmentally friendly alternatives.

Industry is not only assisting in EPA funded research, but performing its own. Large corporations can have entire departments focused on green research and recycling. Unfortunately, green research is not always cost effective or financially possible for small

businesses. The SBIR program funds small businesses in this situation. SBIR is a very unique program, as any patents issued for inventions resulting from funded research belong to the business. From the company's point of view, it is receiving funding for research that could make their manufacturing process more efficient or less resource intensive. Reductions in hazardous material use and production will reduce costs for permits, complying with regulations, and purchasing worker safety equipment. EPA sees this as a company actively investigating environmentally friendly alternatives. The SBIR program has proven beneficial to both industry and EPA.

Research funded by NCER and EPA as a whole have made industry more accepting of green alternatives. In the past, industry was hesitant to work with or share data with EPA due to its enforcement of environmental regulations. This attitude was seen in Motorola, which did not participate in Valarie Thomas' TSE research because it was funded by EPA. A significant change in this attitude has occurred in industry. Companies have realized that using green alternatives reduces costs and can increase productivity. Since cost is a motivator, researching and implementing these technologies makes sense from a business point of view. In addition, EPA sponsored programs and partnerships provide funding for and perform much of the research necessary to do this. Scott Bartos of the Office of Air and Radiation told us how successful the Climate Partnership for the Semiconductor Industry is. Kathy Hart of the Office of Pesticides, Pollution, and Toxics (OPPT) described how her office does research tailored to specific companies to evaluate alternatives. EPA partnerships and industrial research, such as the SBIR program have proven beneficial to both industry and EPA. Ms. Hart felt that companies have become more accepting of environmental friendly technologies over the

ten years she has worked with the electronics sector through OPPT. This is a very significant industrial impact, as the environment cannot benefit from green technology if it is never implemented in industry.

## ***Environment***

NCER funded research in the electronics sector has many immediate and future impacts on the environment. The few awards that have been successful implemented in industry are proving very beneficial to the environment. The vast majority of research, which is either not finished or not implemented, will produce future environmental impacts.

A sustainable environment can be achieved, in part, through reducing the amount of materials being used and implementing efficient recycling techniques. The semiconductor industry is material and energy intensive, but ultra pure water usage will reach a new high with the manufacture of new 300 mm silicon wafers. A facility producing these wafers can use the same amount of water per day, as a city of 60,000 people would use in a year. Research being done by James DeYoung has the potential to replace all this water with much smaller quantities of supercritical CO<sub>2</sub>. The focus of Dr. Fiona Doyle's TSE award was recycling copper from waste solutions produced by semiconductor processing. Separating and reusing valuable materials from waste streams also facilitates sustainable industry.

Air pollution is a becoming a serious problem in the United States. Human health hazards are arising from the smog, acid rain, and the depletion of the ozone layer being caused by this pollution. Three NCER funded grants researched methods to reduce liquid waste and the resulting hazardous vapors being released by the electronics sector.

NAME Nikles developed a successful alternative method to coat floppy discs with magnetic films. This alternative could reduce the one hundred and fifty metric tons of organic solvents produced by conventional coating processes every year. A 99% reduction of chemical etching wastes could be seen by implementing a dry etching process developed by Dr. W. S. Sampath. Dr. Hershkowitz attempted to replace  $CF_4$ , a potent global warming gas, with  $NF_3$  in semiconductor etching processes.

The National Safety Council estimated that 63 million tons computer equipment would become obsolete in the year 2002. Eighty-five percent of these devices, which contain lead, cadmium, and mercury, will end up in landfills (See Caudill, Reggie J. – Appendix G 1). Three NCER funded awards investigated solid waste reduction through green alternatives and recycling. Dr C. P. Wong is developing an alternative for lead in solder, which is found in virtually all electronics. Dr. Valarie Thomas attached electronic tags to electronics products, which direct consumers to online recycling instructions. Radio wave and GPS locators were tested in these tags to provide on disposal data for future LCA's. Once electronics are collected for recycling, they must be sorted, which is the subject of Dr. Edward Sommer's research. He developed a high speed optical sorting system for engineering plastic in electronics. The majority of end-of-life recycling processes only focus on metal recovery, while the plastic casings are simply incinerated or disposed of in landfills.

Understanding the environmental impact of each step of a product's lifecycle is valuable in deciding which materials, manufacturing processes, and recycling methods should be used. Two TSE awards focused on Life Cycle Assessments (LCA's). Dr. Cynthia Murphy developed generic use clusters for silicon chip manufacture, which can



predict and avoid negative results caused by the implementation of new technologies. Dr. Murphy's work should help industry consider trade offs between quality, cost, input material, and environment effects. Lester Lave utilized government databases to create an environmental input-output assessment. His finished assessment produces similar results to conventional LCA's, but with much lower time and cost requirements.

### **Final Remarks**

The problem of pollution in the electronics sector has both technical and social solutions. Fundamental manufacturing changes can have the same impact on the environment as a hundred people turning off their computers when they are not at home. Governments around the world need to work together and incorporate academic, industrial, and societal points of view into their decisions. Research funded by NCER has proven very successful in strengthening the bonds between academia, industry, and government. Without academic research and industrial acceptance, green technology cannot have any significant, large-scale effects on the environment. The common goal is to protect the environment, which is evident in the impacts of NCER funded research.

## Recommendations

The People, Prosperity, and the Planet, Technology for a Sustainable Environment, and Small Business Innovation Research programs have proven successful in academia and in the future of industry and the environment. This project group found several aspects of NCER funded research that could be improved. Specific sections of the electronics sector and the electronics industry as a whole should receive more funding. In addition, EPA should consider enacting regulations on the export of used electronics.

Although electronics make up less than 2% of the United States total municipal solid waste, the electronics manufacturing is growing exponentially (See Appendix F 3 – Lindsay, Clare (Office of Solid Waste)). More funding should be provided for research relevant to the electronics sector. Between 2001 and 2004, NCER received 450 SBIR proposals. Of these, 44 were funded and only one dealt with the electronics sector. The electronics industry is still relatively new, compared to say the automotive industry, but is evolving rapidly. Research has the greatest impact on industries that are still developing and evolving. Therefore, NCER should fund more research in the electronics sector now, while change is still possible.

The awards considered for this project focused on many aspects of the lifecycle of electronics products, but each aspect was not evenly represented. Of the sixteen awards examined in this project, one dealt with materials, six with manufacturing, six with recycling, and three with the entire lifecycle. From a pollution point of view, manufacturing and end-of-life are the biggest concerns, which can be seen in the awards funded. By under-funding research in the other areas of the lifecycle, specifically materials and use, NCER is missing an opportunity to make the entire cycle more

environmentally friendly. For example, developing a green substitute for organic solvents would have a more significant environmental impact than the three NCER funded grants focused on reducing organic solvents in individual manufacturing steps. A single green material development could have a greater environmental effect than multiple funded grants on individual manufacturing steps. Electronics products are being used for shorter and shorter periods of time. A new way to upgrade older products and other research on the use phase of electronics might lead to less being thrown away or burned in the future. No NCER funded grants focused specifically on the use phase of electronics.

There are two main reasons that some areas of the lifecycle are being under funded, either no proposals on these subjects are being submitted or NCER is not funding the ones that are. A funding study should be performed to determine what the reason is. If few proposals are being submitted, maybe research in these areas can be emphasized, possibly through advertisement. The current NCER website also needs improvement. Information on TSE was very difficult to find even after using the site multiple times. The sections on the SBIR and P3 programs were easily located, but were not effectively organized. NCER's website has good content, but needs to be better organized.

After talking to several EPA representatives, this project group developed one recommendation for EPA. There is a problem in the United States with sending old electronics to other countries. These products are being sent overseas to be recycled or reused, but in many cases are just stripped of parts and improperly disposed of. Several countries, including China, are enacting laws prohibiting the import of used electronics. Unfortunately, there are still many developing countries where these used products can

be sent. EPA should consider establishing regulations on the export of used electronics.

If this is too big a step, EPA should at least consider performing an in-depth study on the subject.

## References

1. Environmental Protection Agency. (2005, February). *What is Green Engineering*. Retrieved November 3, 2005 from [http://www.epa.gov/oppt/greenengineering/whats\\_ge.html](http://www.epa.gov/oppt/greenengineering/whats_ge.html)
2. Environmental Protection Agency. (2005, August). *About EPA*. Retrieved November 21, 2005 from <http://www.epa.gov/epahome/aboutepa.htm>
3. Environmental Protection Agency (2005, July). *EPA Organizational Structure*. Retrieved November 21, 2005 from <http://www.epa.gov/epahome/organization.htm>
4. Environmental Protection Agency. (2005, February). *What is Green Engineering*. Retrieved November 3, 2005 from [http://www.epa.gov/oppt/greenengineering/whats\\_ge.html](http://www.epa.gov/oppt/greenengineering/whats_ge.html)
5. Gutowski, Timothy G., et al. *Environmentally Benign Manufacturing*. Baltimore: International Technology Research Institute at Loyola College. 2001 <http://www.wtec.org/loyola/pdf/ebm.pdf> Retrieved on November 12, 2005
6. Cheremisinoff, Nicholas P. *Handbook of Pollution Prevention Practices*. (pp. 373 - 375) New York: Marcel Dekker, Inc., 2001.
7. National Science Foundation. (2002). The 1.7 Kilogram Microchip: Energy and Material Use in the Production of Semiconductor Devices Retrieved on October 26, 2005 from <http://pubs.acs.org/cgi-in/article.cgi/esthag/2002/36/i24/pdf/es025643o.pdf>
8. Cheremisinoff, Nicholas P. *Handbook of Pollution Prevention Practices*. (pp. 373 - 375) New York: Marcel Dekker, Inc., 2001
9. Ibid., (374 - 375)
10. *A New Approach for Reducing Global Warming Emissions from Plasma Etching by Controlling Ion Energy Neutral Flux* presented by Noah Hershkowitz to the EPA. Environmental Protection Agency. (2001). EPA Announces New Toxic Release
11. Inventory reporting Requirements for Lead and Lead Compounds New Rule Effective April 2001 Retrieved on November 3, 2005 from [http://www.epa.gov/tri/lawsandregs/lead/pb\\_fact\\_sheet.pdf](http://www.epa.gov/tri/lawsandregs/lead/pb_fact_sheet.pdf)
12. Environmental Defense (2004) Scorecard. Retrieved November 2 2005, from [http://www.scorecard.org/chemical-profiles/summary.tcl?edf\\_substance\\_id=LCT000](http://www.scorecard.org/chemical-profiles/summary.tcl?edf_substance_id=LCT000)

13. Environmental Defense (2004) Scorecard. Retrieved November 2 2005, from [http://www.scorecard.org/chemical-profiles/rank-industrial-subsectors.tcl?how\\_many=100&type=mass&category=total%5fenv&modifier=na&fips\\_state\\_code=Entire%20United%20States&edf\\_substance\\_id=LCT000&edf\\_chem\\_name=LEAD%20COMPOUNDS&sic\\_2=36&sic\\_desc=Electronic%20%26%20Other%20Electric%20Equipment](http://www.scorecard.org/chemical-profiles/rank-industrial-subsectors.tcl?how_many=100&type=mass&category=total%5fenv&modifier=na&fips_state_code=Entire%20United%20States&edf_substance_id=LCT000&edf_chem_name=LEAD%20COMPOUNDS&sic_2=36&sic_desc=Electronic%20%26%20Other%20Electric%20Equipment)
14. Rubenson, David and Jerry Aroesty. *Hazardous Waste Policy: Unfinished Business and New Challenges*. (pp. 8 - 10) Washington: RAND, 1994.
15. Environmental Protection Agency. *Clean Air Act* Retrieved on November 4, 2005 from <http://www.epa.gov/region5/defs/html/caa.htm>
16. Environmental Protection Agency. *Resource Recovery and Conservation Act*. Retrieved on November 4, 2005 from <http://www.epa.gov/region5/defs/html/rcra.htm>
17. Environmental Protection Agency. (2005, May). *Research Programs*. Retrieved November 3, 2005 from <http://www.epa.gov/ord/htm/researchprograms.htm>
18. Environmental Protection Agency. (2005, June). *P3 Award: A Student Design Competition for Sustainability*. Retrieved September 10, 2005 from <http://es.epa.gov/ncer/p3/>.
19. Caudill, Reggie, et al. (2005, November). *National Electronics Product Reuse and Recycling System*. Retrieved on November 3, 2005 from [http://cfpub.epa.gov/ncer\\_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/7347/report/0](http://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/7347/report/0)
20. Environmental Protection Agency. (2004, May). *Technology for a Sustainable Environment (TSE)*. Retrieved September 10, 2005 from <http://www.epa.gov/gcc/tse.html>.
21. Environmental Protection Agency. (2004, August). *What is Green Chemistry*. Retrieved on November 3, 2005 from [http://www.epa.gov/greenchemistry/whats\\_gc.html](http://www.epa.gov/greenchemistry/whats_gc.html)
22. Hershkovitsk, Noah. (2005, November). *A New Approach for Reducing Global Warming Emissions from Plasma etching by Controlling Ion Energy Neutral Flux*. Retrieved on November 3, 2005 from [http://cfpub.epa.gov/ncer\\_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/6330/report/0](http://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/6330/report/0)
23. Environmental Protection Agency. (2004, May). *Technology for a Sustainable*

- Environment (TSE)*. Retrieved September 10, 2005 from <http://www.epa.gov/gcc/tse.html>.
24. *Examining the Technology for a Sustainable Environment Grant Program* Presented by Eddie Diaz, Melissa Hinton, and Mark Stevenson to Worcester Polytechnic Institute on December 13, 2004
  25. Environmental Protection Agency. (2005, June). *Small Business Innovation Research*. Retrieved September 10, 2005 from <http://es.epa.gov/ncer/sbir/>.
  26. Richards, April. Personal Interview. 1 November 2005.
  27. Environmental Protection Agency. (2005, June). *Small Business Innovation Research*. Retrieved September 10, 2005 from <http://es.epa.gov/ncer/sbir/>.
  28. Richards, April. Personal Interview. 1 November 2005.
  29. Sommer, Edward et al. (2005, November). *Improving the Recyclability of Computer Scrap and Other E-Wastes*. Retrieved on November 3, 2005 from [http://cfpub2.epa.gov/ncer\\_abstracts/index.cfm/fuseaction/display.highlight/abstract/7002](http://cfpub2.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.highlight/abstract/7002).
  30. Environmental Protection Agency. (2005, September). *Partnerships for a Cleaner Future*. Retrieved on September 10, 2005 from <http://www.epa.gov/opptintr/dfe/>.
  31. Environmental Protection Agency. (2003, January). *Computer Display Partnership*. Retrieved on November 3, 2005 from <http://www.epa.gov/opptintr/dfe/projects/computer/index.htm>.
  32. Environmental Protection Agency. (2005, August). *What is ENERGY STAR?*. Retrieved on October 26, 2005 from [http://www.energystar.gov/index.cfm?c=about.ab\\_index](http://www.energystar.gov/index.cfm?c=about.ab_index)
  33. Environmental Protection Agency. (2005, August). *History: ENERGY STAR*. Retrieved on October 26, 2005 from [http://www.energystar.gov/index.cfm?c=about.ab\\_history](http://www.energystar.gov/index.cfm?c=about.ab_history)
  34. Environmental Protection Agency. (2005, August). *Green Initiatives—Electronics*. Retrieved on September 10, 2005 from <http://www.epa.gov/epaoswer/osw/consERVE/priorities/green.htm>
  35. Environmental Protection Agency. (2005, October). *Plug into E-Cycling*. Retrieved on September 12, 2005 from <http://www.epa.gov/epaoswer/osw/consERVE/plugin/index.htm>.
  36. Environmental Protection Agency. (2005, October). *Electronic Product*

- Environmental Assessment Tool*. Retrieved on September 12, 2005 from <http://www.epeat.net/index.htm>.
37. National Journal Group Inc. (2005, February). *Federal Electronics Challenge*. Retrieved on September 12, 2005 from <http://www.federalelectronicchallenge.net/>.
38. Environmental Protection Agency. (2004, June). *PFC Reduction / Climate Partnership for the Semiconductor Industry*. Retrieved on September 10, 2005 from <http://www.epa.gov/highgwp/semiconductor-pfc/index.html>.
39. Environmental Protection Agency. (2005, February). *WasteWise – Membership Listing*. Retrieved November 1, 2005. from <http://www.ergweb.com/wisearch/members.htm>
40. Environmental Protection Agency. (2005, July). *EPA WasteWise*. Retrieved September 6, 2005. from <http://www.epa.gov/wastewise/>.
41. Environmental Protection Agency. (2005, February). *EPA WasteWise – Electronics Industry*. Retrieved September 6, 2005. from <http://www.epa.gov/wastewise/about/id-elect.htm>.
42. United Nations Environment Program, World Health Organization (1998). *Electronics Manufacturing*. In *Pollution Prevention and Abatement Handbook, 1998: Toward Cleaner Production* (pp. 302-306). Washington, D.C.: The World Bank.
43. Environmental Protection Agency. (2005, June). *National Center for Environmental Research*. Retrieved on November 8, 2005 from <http://es.epa.gov/ncer/about/>
44. Berg, Bruce. *Qualitative Research Methods for the Social Sciences*. (pp. 250-260) 5<sup>th</sup> Edition. Boston: Allyn & Bacon, 2004.
45. SEMATECH Inc. *The Semiconductor Manufacturing Process*. (2005) found on December 12, 2005 at <http://www.sematech.org/corporate/news/mfgproc/mfgproc.htm>
46. Intel. *Moore's Law*. (2005) found on December 12, 2005 at <http://www.intel.com/technology/silicon/mooreslaw/>



## Bibliography

*A New Approach for Reducing Global Warming Emissions from Plasma Etching by Controlling Ion Energy Neutral Flux* Presented by Noah Hershkowitz to the Environmental Protection Agency in December 2003

Bartos, Scott. Personal Interview. November 10, 2005

Bauer, Diana. Personal Interview. October 24, 2005

Berg, Bruce. *Qualitative Research Methods for the Social Sciences*. 5<sup>th</sup> Edition. Boston: Allyn & Bacon, 2004.

Camm, Frank, et al. *Implementing Proactive Environmental Management: Lessons Learned from Best Commercial Practice*. RAND 2001.

Caudill, Reggie. Telephone Interview. November 9, 2005

Caudill, Reggie, et al. (2005, November). *National Electronics Product Reuse and Recycling System*. Retrieved on November 3, 2005 from [http://cfpub.epa.gov/ncer\\_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/7347/report/0](http://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/7347/report/0)

Cheremisinoff, Nicholas P. *Handbook of Pollution Prevention Practices*. New York: Marcel Dekker, Inc., 2001.

*Comprehensive Tools to Assess Environmental Impacts of and Improve the Design of Semiconductor Equipment and Processes* Presented by David Dornfeld to the Environmental Protection Agency in October 2003

*Design of a National Electronics Product Reuse and Recycling System* Presented by Reggie J. Caudill to the Environmental Protection Agency in May 2004

*Development of a Membrane – Based System for the Recovery and Reuse of Solvents* Presented by Scott B. McCray to the Environmental Protection Agency in September 1997

*Development of Life Cycle Inventory Modules for Semiconductor Processing* Presented by Cynthia Murphy to the Environmental Protection Agency in April 2000

DeYoung, James. Telephone Interview. November 14, 2005

Dornfeld, David. Telephone Interview. November 9, 2005

- Electrolysis and Ion Exchange for the in-Process Recycling of Copper from Semi-Conductor Processing Solutions* Presented by Fiona M. Doyle to the Environmental Protection Agency in January 2002
- Electronic Tags for Product Environmental Management* Presented by Valerie Thomas to the Environmental Protection Agency in January 2002
- Ellis, Brian. (2000). Environmental Issues in Electronics Manufacturing: a review. *Circuit World*, 26(2), 17-21.
- Environmental Defense (2004) Scorecard. Retrieved November 2 2005, from [http://www.scorecard.org/chemical-profiles/summary.tcl?edf\\_substance\\_id=LCT000](http://www.scorecard.org/chemical-profiles/summary.tcl?edf_substance_id=LCT000)
- Environmental Defense (2004) *Scorecard*. Retrieved October 26, 2005, from [http://www.scorecard.org/chemical-profiles/summary.tcl?edf\\_substance\\_id=7647%2d01%2d0#hazards](http://www.scorecard.org/chemical-profiles/summary.tcl?edf_substance_id=7647%2d01%2d0#hazards)
- Environmental Defense (2004) Scorecard. Retrieved November 2 2005, from <http://www.scorecard.org/env-releases/us-map.tcl>
- Environmental Input-Output Life Cycle Assessment: A Tool to Improve Analysis of Environmental Quality and Sustainability* Presented by Lester B. Lave to the Environmental Protection Agency in October 1998
- Environmental Protection Agency. *Clean Air Act* Retrieved on November 4, 2005 from <http://www.epa.gov/region5/defs/html/caa.htm>
- Environmental Protection Agency. (2003, January). *Computer Display Partnership*. Retrieved on November 3, 2005 from <http://www.epa.gov/opptintr/dfe/projects/computer/index.htm>.
- Environmental Protection Agency. (2005, October). *Electronic Product Environmental Assessment Tool*. Retrieved on September 12, 2005 from <http://www.epeat.net/index.htm>.
- Environmental Protection Agency. (2005, July). *EPA WasteWise*. Retrieved September 6, 2005. from <http://www.epa.gov/wastewise/>.
- Environmental Protection Agency. (2005, February). *EPA WasteWise – Electronics Industry*. Retrieved September 6, 2005. from <http://www.epa.gov/wastewise/about/id-elect.htm>.
- Environmental Protection Agency. (2005, August). *Green Initiatives—Electronics*. Retrieved on September 10, 2005 from <http://www.epa.gov/epaoswer/osw/conserves/priorities/green.htm>

- Environmental Protection Agency. (2005, August). *History: ENERGY STAR*. Retrieved on October 26, 2005 from [http://www.energystar.gov/index.cfm?c=about.ab\\_history](http://www.energystar.gov/index.cfm?c=about.ab_history)
- Environmental Protection Agency. (2005, June). *National Center for Environmental Research*. Retrieved on November 8, 2005 from <http://es.epa.gov/ncer/about/>
- Environmental Protection Agency. (2005, June). *P3 Award: A Student Design Competition for Sustainability*. Retrieved September 10, 2005 from <http://es.epa.gov/ncer/p3/>.
- Environmental Protection Agency. (2005, September). *Partnerships for a Cleaner Future*. Retrieved on September 10, 2005 from <http://www.epa.gov/opptintr/dfe/>.
- Environmental Protection Agency. (2004, June). *PFC Reduction / Climate Partnership for the Semiconductor Industry*. Retrieved on September 10, 2005 from <http://www.epa.gov/highgwp/semiconductor-pfc/index.html>.
- Environmental Protection Agency. (2005, October). *Plug into E-Cycling*. Retrieved on September 12, 2005 from <http://www.epa.gov/epaoswer/osw/consERVE/plugin/index.htm>.
- Environmental Protection Agency. (2005, May). *Research Programs*. Retrieved November 3, 2005 from <http://www.epa.gov/ord/htm/researchprograms.htm>
- Environmental Protection Agency. *Resource Recovery and Conservation Act*. Retrieved on November 4, 2005 from <http://www.epa.gov/region5/defs/html/rcra.htm>
- Environmental Protection Agency. (2005, June). *Small Business Innovation Research*. Retrieved September 10, 2005 from <http://es.epa.gov/ncer/sbir/>.
- Environmental Protection Agency. (2004, May). *Technology for a Sustainable Environment (TSE)*. Retrieved September 10, 2005 from <http://www.epa.gov/gcc/tse.html>.
- Environmental Protection Agency. (2005, February). *WasteWise – Membership Listing*. Retrieved November 1, 2005. from <http://www.ergweb.com/wisearch/members.htm>
- Environmental Protection Agency. (2005, August). *What is ENERGY STAR?*. Retrieved on October 26, 2005 from [http://www.energystar.gov/index.cfm?c=about.ab\\_index](http://www.energystar.gov/index.cfm?c=about.ab_index)

- Environmental Protection Agency. (2004, August). *What is Green Chemistry*. Retrieved on November 3, 2005 from [http://www.epa.gov/greenchemistry/whats\\_gc.html](http://www.epa.gov/greenchemistry/whats_gc.html)
- Environmental Protection Agency. (2005, February). *What is Green Engineering*. Retrieved November 3, 2005 from [http://www.epa.gov/oppt/greenengineering/whats\\_ge.html](http://www.epa.gov/oppt/greenengineering/whats_ge.html)
- Environmentally Benign Lead-Free Electrically Conductive Adhesive for Electronic Packaging Manufacturing Processing* Presented by C. P. Wong to the Environmental Protection Agency in October 2003
- Examining the Technology for a Sustainable Environment Grant Program* Presented by Eddie Diaz, Melissa Hinton, and Mark Stevenson to Worcester Polytechnic Institute on December 13, 2004
- Geibig, Jack. Personal Interview. December 8, 2005
- Gutowski, Timothy G., et al. *Environmentally Benign Manufacturing*. Baltimore: International Technology Research Institute at Loyola College. 2001 <http://www.wtec.org/loyola/pdf/ebm.pdf> Retrieved on November 12, 2005
- Hart, Kathy. Personal Interview. October 30, 2005
- Hershkowitz, Noah. Telephone Interview. November 29, 2005
- Hershkowitz, Noah. (2005, November). *A New Approach for Reducing Global Warming Emissions from Plasma etching by Controlling Ion Energy Neutral Flux*. Retrieved on November 3, 2005 from [http://cfpub.epa.gov/ncer\\_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/6330/report/0](http://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/6330/report/0)
- [http://home.swipnet.se/~w-50674/hifi\\_pics/hifi\\_100pr/qrv01r0\\_overview.jpg](http://home.swipnet.se/~w-50674/hifi_pics/hifi_100pr/qrv01r0_overview.jpg) Retrieved on November 3, 2005
- <http://www.ladyada.net/make/x0xb0x/pcb.jpg> Retrieved on November 3, 2005
- [http://www.squierphotography.com/images/8in\\_wafer.jpg](http://www.squierphotography.com/images/8in_wafer.jpg) Retrieved on November 3, 2005
- Improving the Recyclability of Computer Scrap and Other E-Wastes* Presented by Edward J. Sommer, Jr. to the Environmental Protection Agency in April 2004

- Inventory reporting Requirements for Lead and Lead Compounds New Rule Effective April 2001 Retrieved on November 3, 2005 from [http://www.epa.gov/tri/lawsandregs/lead/pb\\_fact\\_sheet.pdf](http://www.epa.gov/tri/lawsandregs/lead/pb_fact_sheet.pdf)
- Lempert, Robert, et al. *Next Generation Environmental Technologies: Benefits and Barriers*. RAND 2003.
- Li, Grace E. Telephone Interview. November 17, 2005
- Lin, Andy. Telephone Interview. November 16, 2005
- Lin, Li. Telephone Interview. November 17, 2005
- Lindsay, Clare. Personal Interview. October 31, 2005
- Lund, Herbert F., ed. *Industrial Pollution Control Handbook*. New York: McGraw-Hill Book Company, 1971.
- Material Selection in Green Design and Environmental Cost Analysis* Presented by Li Lin to the Environmental Protection Agency in January 2002
- Mazurek, Jan. *Making Microchips: Policy, Globalization, and Economic Restructuring in the Semiconductor Industry*. Cambridge: The MIT Press, 1999.
- McCray, Scott. Telephone Interview. November 14, 2005
- Microstructural, Morphological and Electrical Studies of a Unique Dry Plasma Metal Deposition for Printed Circuit Boards (PCB's)* Presented by W.S. Sampath to the Environmental Protection Agency in September 1997
- Murphy, Cynthia. Telephone Interview. November 7, 2005
- National Science Foundation. (2002). *The 1.7 Kilogram Microchip: Energy and Material Use in the Production of Semiconductor Devices* Retrieved on October 26, 2005 from <http://pubs.acs.org/cgi-bin/article.cgi/esthag/2002/36/i24/pdf/es025643o.pdf>
- National Journal Group Inc. (2005, February). *Federal Electronics Challenge*. Retrieved on September 12, 2005 from <http://www.federalelectronicschallenge.net/>.
- National Science Foundation. (2002). *The 1.7 Kilogram Microchip: Energy and Material Use in the Production of Semiconductor Devices* Retrieved on October 26, 2005 from <http://pubs.acs.org/cgi-in/article.cgi/esthag/2002/36/i24/pdf/es025643o.pdf>

New York State. Department of Environmental Conservation Pollution Prevention Unit. *Environmental Self-Assessment for the Electronics and Computer Industry: A Quick and Easy Checklist of Pollution Prevention Measures for the Electronics and Computer Industry*. October 1999.

Osdoba, Katherine. Personal Interview. November 15, 2005

Pfahl, Bob. Personal Interview. December 9, 2005

*Photocrosslinked Immobilization of Polyelectrolytes for Template Assisted Enzymatic Polymerization of Conjugated Polymers* Presented by John C. Warner to the Environmental Protection Agency in September 2004

*Recovery of Perfluoroethane from Chemical Vapor Deposition Operations in the Semiconductor Industry* Presented by J.G. Wijmans to the Environmental Protection Agency in September 1997

Resetar, Susan A., et al. *Technology Forces at Work: Profiles of Environmental Research and Development at DuPont, Intel, Monsanto, and Xerox*. RAND 1999.

Richards, April. Personal Interview. October 24, 2005

*RoHS/WEEE Directive: Restriction of Hazardous Substances Directives (RoHS)/EU Lead Free Legislation*. 2005. <http://www.pb-free.info/> Retrieved on November 8, 2005

Rubenson, David and Jerry Aroesty. *Hazardous Waste Policy: Unfinished Business and New Challenges*. Washington: RAND, 1994.

*Solventless, Electron Beam-Cured Acrylate Coating Formulations for Flexible Magnetic Media Manufacture* Presented by David Nikles to the Environmental Protection Agency in October 1998

Sommer, Edward. Telephone Interview. November 16, 2005

Sommer, Edward et al. (2005, November). *Improving the Recyclability of Computer Scrap and Other E-Wastes*. Retrieved on November 3, 2005 from [http://cfpub2.epa.gov/ncer\\_abstracts/index.cfm/fuseaction/display.highlight/abstract/7002](http://cfpub2.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.highlight/abstract/7002).

The Microelectronics and Computer Technology Corporation. (1995, July) *Electronics Industry Environmental Roadmap*. Retrieved September 6, 2005 from <http://gdi.ce.cmu.edu/comprec/eier94roadmap1.pdf>.

*TI Semiconductors*. 2005. Texas Instruments Incorporated.  
<http://www.ti.com/corp/docs/press/company/2003/processlarge.gif> Retrieved on  
December 12, 2005

Thomas, Valerie. Telephone Interview. November 29, 2005

United States. The Environmental Protection Agency. *Implementing Cleaner Printed  
Wiring Board Technologies: Surface Finishes*. Washington: EPA, 2000.

United Nations Environment Program, World Health Organization (1998).  
Electronics Manufacturing. In *Pollution Prevention and Abatement Handbook*,  
1998: Toward Cleaner Production (pp. 302-306). Washington, D.C.: The World  
Bank.

Volkes, Kathleen. Personal Interview. October 30, 2005

*Wafer Level Supercritical Carbon Dioxide-Based Metal Deposition for Microelectronic  
Applications* Presented by James P. DeYoung to the Environmental Protection  
Agency in April 2004

Warner, John. Telephone Interview. November 9, 2005

Wong, C. P. Telephone Interview. November 17, 2005

## Appendix A – Environmental Protection Agency (EPA)

In 1970, in response to public demand for cleaner water, air, and land, the White House and Congress created the Environment Protection Agency (EPA). The overall mission of EPA is active protection of the environmental and human health<sup>1</sup>. Its responsibilities include the following: to perform environmental research, create and enforce pollution regulations, financially assist state environmental programs through awards, provide educational programs to increase environmental awareness, and publish information about EPA related activities<sup>2</sup>. In addition, EPA sponsors voluntary programs and partnerships with industry to encourage pollution prevention and energy conservation.

To guarantee EPA accomplishes its duty, a Strategic Plan has been implemented. This plan outlines goals for the next five years and suggests methods for achieving them. It has to be submitted to Congress and the President's Office of Management and Budget as part of a public statement of EPA's strategy. The most recent Strategic Plan was submitted in 2003<sup>3</sup>. It had five main goals: (1) clean air and global climate change, (2) clean and safe water, (3) land preservation and restoration, (4) healthy communities and ecosystems, and (5) compliance and environmental stewardship<sup>4</sup>.

To achieve these goals, EPA has to be well organized (See Figure 7: EPA Organization Chart). The agency is lead by an administrator appointed by the President.

---

<sup>1</sup> Environmental Protection Agency. (August, 2005). *About EPA*.  
<http://www.epa.gov/epahome/aboutepa.htm>

<sup>2</sup> Environmental Protection Agency. (August, 2005). *About EPA*.  
<http://www.epa.gov/epahome/aboutepa.htm>

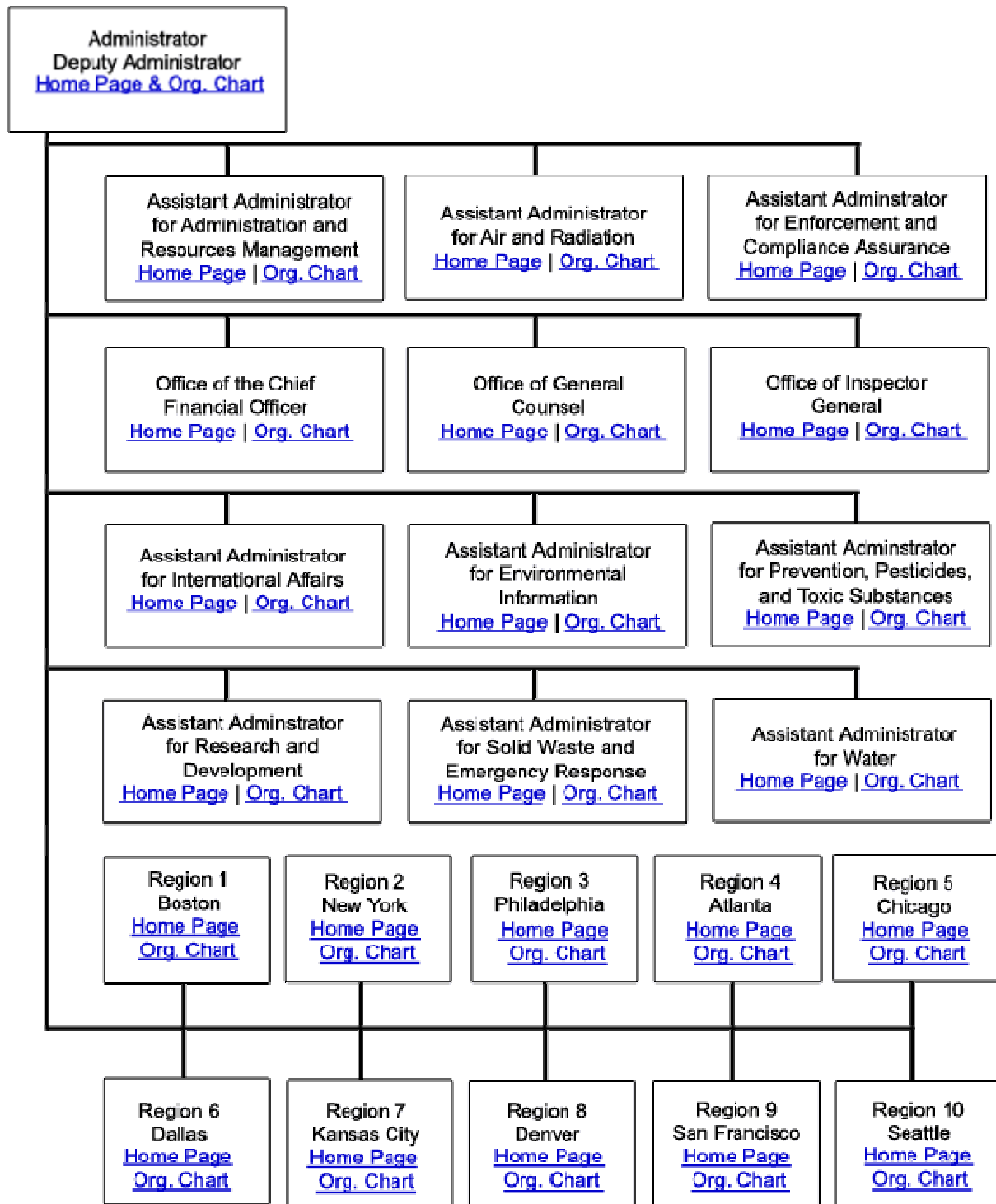
<sup>3</sup> Environmental Protection Agency. (November, 2005). *2003 – 2008 Strategic Plan*.  
<http://www.epa.gov/ocfo/plan/plan.htm>

<sup>4</sup> Environmental Protection Agency. (November, 2005). *FAQ's about EPA's Strategic Plan*.  
<http://www.epa.gov/ocfo/plan/faqs.htm>



It is further broken down into several branches, which focus on different aspects of pollution prevention. Each branch is subdivided to efficiently distribute the workload.

EPA's budget is allotted annually by the Federal Government. It is split into awards, contracts, and department funds over a fiscal year that runs from October to September. Out of the hundreds of programs in which EPA is involved, there are several main initiatives. These include: the P3 Award, Technology for a Sustainable Environment, Small Business Innovative Research, Design for the Environment, ENERGY STAR, Green Initiative Electronics, Climate Partnership for the Semiconductor Industry, and Wastewise. After taking the planned expenditures into account, the EPA's Executive Branch submits a budget to Congress.



**Figure 7: EPA Organization Chart**

Environmental Protection Agency. (December, 2005). *EPA Organizational Structure*.

<http://www.epa.gov/epahome/organization.htm>

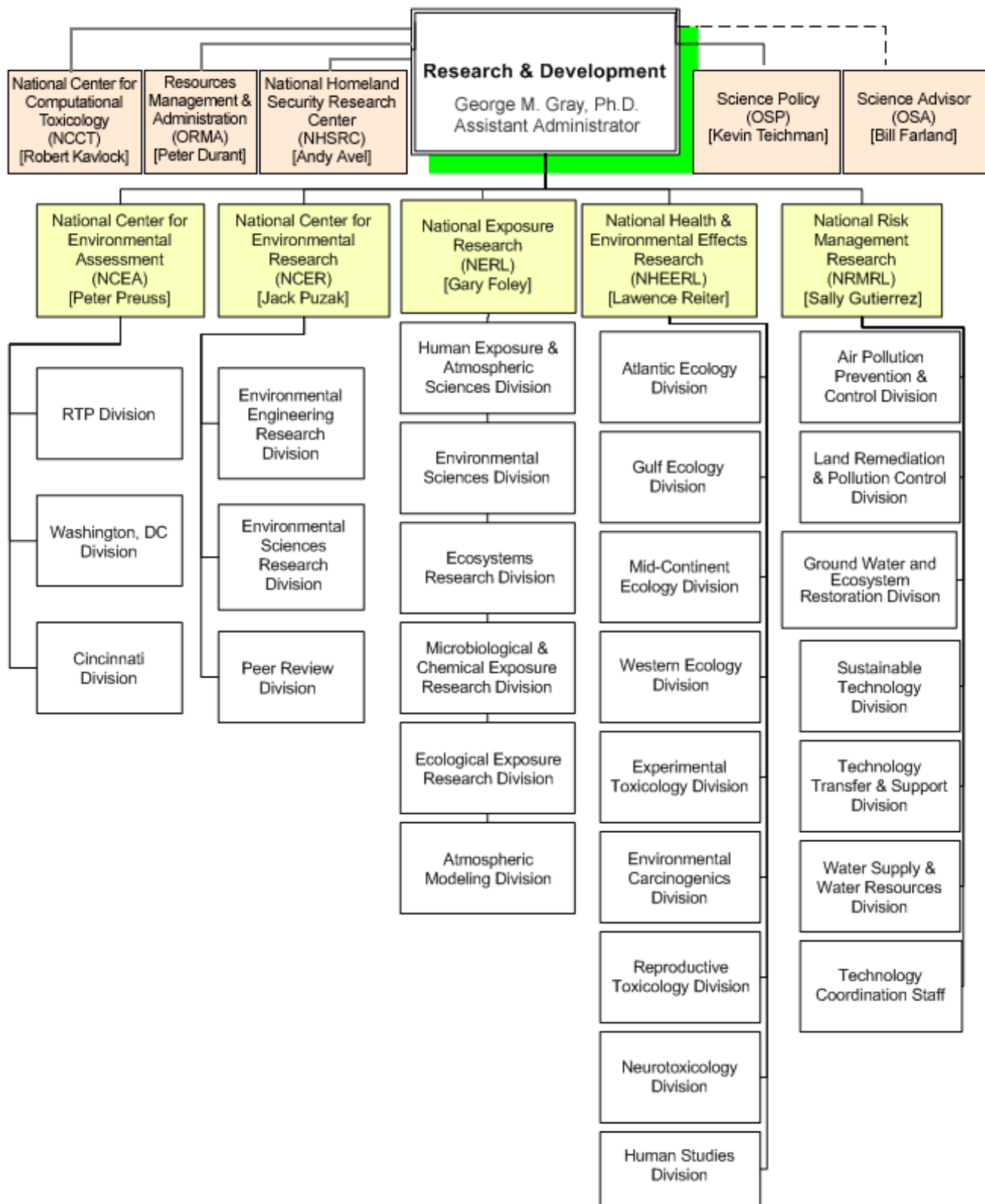
## Appendix B – National Center for Environmental Research (NCER)

The National Center for Environmental Research (NCER) is one of the five research organizations of the Office of Research and Development (See Figure 8: NCER Organization Chart). It is based in Washington, D.C. and employs staff with backgrounds in engineering, communication, information management, and ecological and health sciences. NCER's mission is to support the nation's top scientists in research to improve decision making on environmental issues as well as aid EPA in its goals outlined in the Strategic Plan<sup>1</sup>.

To accomplish its mission, NCER funds programs to aid investigators in research to protect the environment and human health. Its main programs are: People, Prosperity, and the Planet (P3) Award, Small Business Innovation Research (SBIR), and Technology for a Sustainable Environment (TSE). P3 and TSE support academic research, while SBIR provides funding for small business research. Through these programs, NCER hopes to make an environmental difference.

---

<sup>1</sup> Environmental Protection Agency. (June, 2005). *About NCER*. <http://www.epa.gov/ord/htm/aboutord.htm>



**Figure 8: NCER Organization Chart**

Environmental Protection Agency. (December, 2005). *EPA Organizational Structure*.  
<http://www.epa.gov/ord/hm/orgchart.htm>

## Appendix C – Global Warming Potential (GWP)

The strength of a greenhouse gas can be measured by comparing the amount of heat it can absorb to that of another gas. The definition of GWP for a certain gas is the “ratio of heat trapped by one unit mass of the greenhouse gas to that of one unit mass of CO<sub>2</sub> over a specified time period”<sup>1</sup>. Since carbon dioxide (CO<sub>2</sub>) is being used to compare, it has a GWP of 1.

The three main types of high GWP gases are hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF<sub>6</sub>)<sup>2</sup>. Not only do these gases have high GWP’s, but they can remain in the atmosphere for very long periods of time. Table 6: Fluorinated Gases used to Manufacture Semiconductors shows GWP and atmospheric lifetime data for some greenhouse gases used in the semiconductor industry.

**Table 6: Fluorinated Gases used to Manufacture Semiconductors<sup>3</sup>**

Compound	Global Warming Potential (100-year time horizon)	Atmospheric Lifetime (years)
SF <sub>6</sub>	23,900	3,200
CHF <sub>3</sub>	11,700	264
C <sub>2</sub> F <sub>6</sub>	9,200	10,000
c-C <sub>4</sub> F <sub>8</sub>	8,700	3,200
NF <sub>3</sub>	8,000	740
C <sub>3</sub> F <sub>8</sub>	7,000	2,600
CF <sub>4</sub>	6,500	50,000
CO <sub>2</sub>	1	variable

<sup>1</sup> Environmental Protection Agency (June 2005) High Global Warming Potential (GWP) Gasses <http://www.epa.gov/highgwp/scientific.html>

<sup>2</sup> Environmental Protection Agency (June 2005) High Global Warming Potential (GWP) Gasses <http://www.epa.gov/highgwp/scientific.html>

<sup>3</sup> Future FAB International (July 2001) Semiconductor Leadership in Global Climate Protection [http://www.future-fab.com/documents.asp?d\\_ID=1144#](http://www.future-fab.com/documents.asp?d_ID=1144#)

## Appendix D - Online Databases

### Scorecard <sup>1</sup>



Scorecard is an online database founded by Environmental Defense in 1998. It allows easy access to air quality, water quality, and toxic release information.

This data is further broken down into categories, such as location, facility, industrial sector, and pollutant. In addition, the health effects and regulatory coverage of specific pollutants are provided. The main disadvantage of Scorecard is its most recent data is three years old (2002).

### Toxics Release Inventory Program (TRI) <sup>2</sup>

TRI is a public EPA database started in 1987. It was established by the Emergency Planning and Community Right-to-Know Act of 1986 and modified by the Pollution Prevention Act of 1990. The TRI database contains information on toxic releases and other waste management activities. Industry and federal facilities report this data annually to EPA. Many companies are reevaluating their waste management procedures, since pollution production data is being collected and made public. Unfortunately, the most up-to-date TRI data from 2002 and it cannot be sorted by specific industries.

### SIC Codes <sup>3</sup>

Scorecard and TRI organize industry using the U.S. Standardized Industrial Classification (SIC) system. SIC codes represent major groups (2 digits), industry groups (3 digits), and industries (4 digits). For example, SIC36 (electronic and other electric equipment)->SIC367 (electronic components and accessories)-> SIC3672 (PCB's).

---

<sup>1</sup> <http://www.scorecard.org/>

<sup>2</sup> <http://www.epa.gov/triexplorer/>

<sup>3</sup> <http://www.epa.gov/npdes/pubs/app-c.pdf>

## **Appendix E – Interview/Meeting Questionnaires**

### ***Interview Introduction***

Hi, my name is \_\_\_\_\_ and I am working for the Environmental Protection Agency as an intern. I am working on a project determining the impacts of EPA funded awards in the electronics sector. Any information you could provide about your research would be very helpful. Would it be possible to schedule an interview? Here are a few times when I am free (give times), do any of them work for you? Would you like me to e-mail you a list of questions that will be asked? Thank you so much, I look forward to talking with you on (scheduled date).

## ***Principal Investigator TSE/P3 Interview Questionnaire***

Name:

Phone:

E-Mail:

Date Interviewed:

College:

Type of Award

Title of Project:

Hello, this is \_\_\_\_\_, how are you? I will be conducting the interview, while my two group members take notes.

Can you tell us a little bit about how you became interested/involved in this field?\*

1. What research did you perform under P3/TSE?
2. Has your research created any change in:
  - your course syllabus?
  - the school curricula?If so, how long have you taught the lecture and what is the average number of students per class?\*
3. Did you collaborate with any faculty outside your department or institution?
4. Did you receive any additional funding? If so, from whom?
5. What is the potential for this project?
6. Did your work prompt any follow-up research or patents?
7. Did you have any industrial partners while performing your research?
8. If so, what was the extent of their involvement?
9. If not, have any industries learned of your work? Have they implemented it or looked into using it?
  - If so, how are they going to incorporate the research into their processes
  - Have you received any quantitative data?
10. How many students were funded by the award?
11. Are there any graduate students that you would recommend talking to about how this research has affected their careers?
12. Is there anyone else you feel we should contact?
13. What research are you currently working on (if NCER award is finished)?
14. Do you have any additional comments?

We plan on typing up this interview and e-mailing it back to you to make sure your responses were accurately recorded. Can we contact you again if we have any other questions? Thanks for your time. Bye

\*these questions were added during the interview process.



## ***Principal Investigator SBIR Interview Questionnaire***

Name:

Small Business:

Company:

Phone:

E-Mail:

Date Interviewed:

Title of Project:

Hello, this is \_\_\_\_\_, how are you? I will be conducting the interview, while my two group members take notes.

1. What research did you perform under SBIR?
2. Did you receive any additional funding? If so, from whom?
3. What is the potential for this project?
4. Did your work prompt any follow-up research or patents?
5. Did you have any other business or industrial partners while performing your research?
6. If so, what is the extent of their involvement?
7. If not, have any industries learned of your work? Have they implemented it or looked into using it?
  - a. If so, how are they going to incorporate the research into their processes
  - b. Have you received any quantitative data?
8. What research are you currently working on (if NCER award is finished)?
9. Is there anyone else you feel we should contact?
10. Do you have any additional comments?

We plan on typing up this interview and e-mailing it back to you to make sure that your responses were accurately recorded. Can we contact you again if we have any other questions? Thanks for your time. Bye

## ***Graduate Student Interview Questionnaire***

Date Interviewed:

Name of graduate students:

Phone:

E-Mail:

Award PI:

College:

Type of Award:

Title of Project:

Hello, this is \_\_\_\_\_, how are you? I will be conducting the interview, while my two group members take notes.

1. How did you get involved in the P3/TSE research project with Prof. \_\_\_\_\_?
2. Did the project you worked on as a student prompt you to conduct further research in the same or similar area of study?
  - a. If so, what was the new research?
  - b. Has any of your research been published?
3. What research are you working on now?
4. Did your work as a student influence your choice of profession?

We plan on typing up this interview and e-mailing it back to you to make sure that your responses were accurately recorded. Can we contact you again if we have any other questions? Thanks for your time. Bye

## ***EPA Representative Meeting Questionnaire***

Name:

Contact Info:

Contact Info:

Contact Info:

E-Mail:

Date Interviewed:

Organization or Office:

Awards Supported:

1. What types of awards/contracts does your office sponsor or participate in?
2. What is the average award amount?
3. How would someone solicit funding from your office?
4. Has any research been used in an academic setting?
5. Does your office have any industrial partners?
6. If so, what is the extent of their involvement?
7. If not, have any industries learned of work funded by your office?
  - a. How might they implement it or look into using it?
8. Is research funded by your office supported other awards or programs?
9. Has research funded by another office been used in support of your programs?
10. Does your office collaborate with any other organizations outside the EPA?
11. Do you know of any industrial data resulting from research funded by your office?
  - a. Where did it come from?
12. Has your office's work prompted follow-up research or patents?
13. Do you have any additional comments?

We plan on typing up this interview and e-mailing it back to you to make sure that your responses were accurately recorded. Can we contact you again if we have any other questions? Thanks for your time. Bye

## **Appendix F – EPA Representative Meetings**

### ***Appendix F 1 – Bartos, Scott (Office of Atmospheric Programs)***

**Contact Info:** 202-343-9167

**E-Mail:** bartos.scott@epa.gov

**Date Interviewed:** November 9, 2005

**Organization or Office:** Office of Atmospheric Programs

#### ***Background of Office***

The Office of Atmospheric Programs does analytical work on science and policies.

It sponsors three main programs: the Acid Rain, Ozone Layer Protection, and the Climate Protection Programs. Mr. Bartos is a part of the Climate Protection Program, which focuses on the economic and scientific aspects of emission reduction. He is concerned with non CO<sub>2</sub>, high global warming potential (GWP) gases such as methane, PFC's, CFC's, and NO<sub>x</sub>

**Main Program:** Climate Partnership for the Semiconductor Industry

#### ***About the Partnership***

In 1995, EPA developed a voluntary partnership with the semiconductor industry designed to reduce air emissions. After the Montreal Regulatory Protocol for ozone depleting substances was passed, companies in the industry realized that they needed to reevaluate their manufacturing processes. With its knowledge of environmental policies and consequences, EPA helped many of these companies. Twenty-one semiconductor companies are partners in the program and about four to eight use or release high GWP gases.

#### ***What has come from the partnership?***

The goal of the Partnership with the Semiconductor Industry is to reduce gas emissions 10% from their 1995 level by the year 2010. This might not sound like much,

but when one considers the exponential growth of the industry since 1995, it is very large amount. Each company is required to submit an annual report of emissions to EPA, which helps quantify results.

Industry is conducting its own research and developing new technology. For example, it was discovered that chemical vapor deposition (CVD) chambers were being cleaned for too long. This was being done to account for error margins, but wasted cleaning gases and produced unnecessary gas emissions. Industry developed an endpoint detector that could determine when a CVD chamber was clean, reducing the gases used. Industrial research is also being done on abatement control devices and capture membranes.

The chemicals used for cleaning are also improving. Fluorine is an active cleaning agent, but is very corrosive and toxic as a gas. Slightly less toxic fluorinated gases are used in many industrial cleaning processes. One of these gases,  $C_2F_6$ , has a high GWP and can stay in the atmosphere for hundreds of years. From 1995 to present,  $C_2F_6$  has been replaced by  $NF_3$ , which is now common in the semiconductor industry. Cleaning processes using  $NF_3$  over  $C_2F_6$  are shorter, more efficient, and can result in a 99% reduction of green house gas emissions. Mr. Bartos called the widespread use of  $NF_3$  as a replacement for other gases the highlight of the program. These replacements were researched and developed by industry and prove more environmentally friendly than the chemicals being previously used.

Another example of technology developed through industry is an infrared camera that can detect global warming gases. High global warming gases trap certain ultraviolet

rays and release them as thermal energy, which the camera can locate. These cameras are currently being used to find SF<sub>6</sub> leaks, which are otherwise undetectable.

### ***EPA and Industry***

The Partnership with the Semiconductor Industry is an excellent way for companies to get recognized. This partnership has proven very beneficial for both parties and its contract was renegotiated in 2000. Although the original partnership only applied domestic industry, the new contract encouraged EPA to look towards foreign companies as well. This partnership has been so successful that the semiconductor industry uses it as an example when trying to work with other divisions of EPA.

### ***Important Issue***

Mr. Bartos mentioned that many electronics fabrication and assembly factories (FAB's) in the U.S. are closing. Manufacturing is being moved to foundry FAB's overseas, specifically in Asia, where semiconductors can be mass produced. This is being done for economic reasons, not because the companies are trying to move their pollution problem somewhere else. This is an important trend, as it is more difficult to track an industry if it is continually changing locations.

Mr. Bartos also told us about some of the ways industry protects its workers from toxic chemicals. Clean rooms, double walled containers, multiple cleanings, and the use of robots have greatly reduced occupational exposure.

## ***Appendix F 2 – Hart, Kathy (Office of Pollution Prevention)***

**Contact Info:** 202-564-8787

**E-Mail:** hart.kathy@epa.gov

**Date Interviewed:** November 9, 2005

**Organization or Office:** Office of Pollution Prevention

### ***DfE Overview***

This meeting focused mainly on the Design for the Environment (DfE) Partnership. DfE was created by the Pollution Prevention Act of 1990 and is the oldest partnership in EPA (established in 1994). It focuses more on pollution reduction than regulation and works with industry to identify the greatest pollution problems and possible alternatives. Industrial research is usually centered on increasing performance and cost effectiveness. The Office of Pollution Prevention and Toxics (OPPT) uses its expertise to work with industry and promote technologies that are cleaner, more cost-effective, and perform better. DfE started with small businesses, such as dry cleaners and printers, who did not have the time, money, or resources to research environmental alternatives. The DfE program has expanded to other industries and now includes much of the electronics sector.

### ***DfE Approaches***

The DfE program uses many approaches to perform research, including: life-cycle assessments (LCA's), alternatives assessments, formulation improvement, cleaner technologies substitutes assessments (CTSA's), and integrated environmental management systems. Ms. Hart elaborated on several. LCA's take a long time to complete, but show wastes produced through individual steps along a product's lifecycle. This allows industry to locate the largest problem and focus on solving it. Alternatives assessments evaluate "drop in" alternatives that can be implemented without changing an

entire production process. These assessments focus more on toxicity of substances and can be done faster than LCA's.

Formulation improvement is where the OPPT works one on one with a company to research potential alternatives. For example, the OPPT evaluated chemical components in industrial cleaners and suggested alternatives for a number of them. CTSA's are screening level risk assessments for processes like using formaldehyde in the manufacture of printed wiring boards. After taking risks and performance comparisons into account, the CTSA provided useful alternatives.

### ***Involvement with Industry***

The OPPT collaborates with all industries. Companies approach the OPPT for advice on alternatives. Ms. Hart mentioned that through the Restriction of Hazardous Substances, lead solder will soon be banned in the European Union. Companies came to the OPPT for assistance in researching environmentally friendly alternatives. Complying with governmental regulations has associated costs, such as paying for permits and worker safety equipment. In many cases, it is more cost effective for a company to find alternatives to hazardous materials. This is where the OPPT comes in.

### ***Relation of other areas of EPA***

The OPPT does not fund research for developing new technology. They fund research on existing and emerging technology and give advice on possible alternatives. This is most effective when a technology or process is in its infancy and can be more easily altered. Prediction tools, such as analogous chemical tests and other models are commonly used.

Ms. Hart also mentioned how DfE Electronics Partnerships are going to benefit immensely when EPEAT is completed. EPEAT is an environmental assessment tool that



will be helpful in conducting LCA's, such as OPPT's research on CRT versus LCD monitors.

***How would you judge the success of your programs?***

Ms. Hart felt there has been a change in the attitudes of industry over the ten years she has been working in OPPT. Companies have become more accepting of environmental friendly technologies. Many have realized that doing the right thing from an environmental standpoint usually leads to reduced costs. Since cost is a driver to change, reducing or eliminating hazardous materials makes sense.

## ***Appendix F 3 – Lindsay, Clare (Office of Solid Waste)***

**Contact Info:** 703-308-7266

**E-Mail:** lindsay.clare@epa.gov

**Date Interviewed:** October 31, 2005

**Organization or Office:** Office of Solid Waste

Her office has four main focuses:

### ***Plug into e-cycling:*** [www.plugintoecycling.org](http://www.plugintoecycling.org)

Plug into E-cycling encourages manufacturers and retailers to work with the government to start an electronics take back initiative. Some pilot studies include Staples and Office Depot. This program is strictly voluntary, and participation is optional based on meeting the necessary requirements.

### ***EPEAT:*** [www.epeat.net](http://www.epeat.net)

The Electronic Products Environmental Assessment Tool (EPEAT) is a multi-attribute rating system, meant to evaluate the performance of electronic products throughout their lifecycles. EPEAT is an ENERGY STAR type label that will hopefully share the same success. Manufacturers would pay for an EPEAT level of certification and these fees would fund the program. EPA is pushing the government to buy EPEAT products, even though the program is managed independently. EPEAT is currently seeking American National Standards Institute (ANSI) certification.

### ***Federal Electronics Challenge:*** [www.federalelectronicschallenge.net](http://www.federalelectronicschallenge.net)

The Federal Electronics Challenge is a multi-agency effort to convince the federal government to buy green electronics. It is currently supported by the Departments of the Interior, Defense and the Post Office.

### ***Certification System for Electronics Recyclers***

Poorly managed electronics recycling can pose a greater pollution risk than disposal in a properly managed landfill. EPA can regulate waste disposal, but has little

power over recycling. Many electronics are being sent to less developed countries for reuse (Africa) or recycling (South Asia). EPA wants to establish sound practices for electronics recycling and use them to influence industry standards developed from this point forward.

There are many design issues that present research projects. For example, a Design for the Environment award was used to develop a lead free solder. The European Union has undertaken two initiatives, namely Waste Electrical and Electronic Equipment (WEEE) and Restriction of certain Hazardous Substances (RoHS), which both affect the use of lead solder. WEEE requires manufacturers to be responsible for the disposal and recycling of their products. RoHS restricts lead and other hazardous substances commonly used in the manufacture of electronics. By July 2006, European nations will require the removal of all heavy metals from most electronics. In addition, they are pursuing beneficial alternatives and looking for new ways to reduce waste instead of simply shifting the source of pollutants.

The Office of Solid Waste is looking for a total life cycle assessment of electronic devices. This is a challenging task due to the varying materials, techniques, and manufacturing processes being used in the manufacture of electronics. The main focuses of these assessments are televisions and computer monitors, which are made with either cathode ray tubes (CRT's) or flat panel displays (FPD's), due to the large number present in the waste stream. Additionally, little is known about the lifecycles of new of FPD's, such as plasma displays. CRT monitors, along with many smaller devices, have been known to fail the Toxics Characteristics Leaching Procedure (TCLP), which is a

federal hazardous waste test. Trends show that the more steel in a device, the more likely it is to not fail the TCLP.

There is heavy political pressure for recycling and reusing electronic devices. Ms. Lindsay informed us that only 1% of municipal solid waste is electronics. So why is there such a big deal being made about it? Electronics waste is growing fast and it is in the best interest of human health, natural resources, and the environment if we look into ways to manage and recycle it now.

Ms. Lindsay's opinion was that product stewardship is the future of the industry in this area. She defined product stewardship as a process where manufacturers, retailers, and consumers are all responsible for the end-of-life handling of electronics. In a way, it helps them to think about what happens to the product "outside of their gates". In other words, concern for what happens to the product when it is out of their sight. This can be accomplished through lean or green manufacturing, design for reuse, and incentives for recycling.

Ms. Lindsay enlightened us as to some possible definitions for project success. She stated that many times a number of hits on a web site, brochures handed out, or partners in a program will be used to quantitatively evaluate success. It was also mentioned that specific data, for example the number of products recycled in a given program, is more helpful and accurate, but harder to get. Manufacturers involved in these programs report their recycling and usage statistics, which can be used in calculating the amount of green house gas emissions prevented and other valuable quantitative data. Even with these numbers it is difficult to determine if the program is the motivating

factor behind any resulting pollution reduction. It should be considered that the company might make these changes without EPA's help.

Ms. Lindsay named several people who may have additional information relating to our project. These include Bob Tonetti (Export/Recycling), Marilyn Goode (Identifying Hazards), Christina Piper, Zubiar Saleem, and Becky Cuthbertson (the last three economics/risk analysis).

## ***Appendix F 4 – Osdoba, Katharine (ENERGY STAR)***

**Contact Info:** (202)343-9120

**E-Mail:** [osdoba.katherine@epa.gov](mailto:osdoba.katherine@epa.gov)

**Date Interviewed:** November 15, 2005

**Organization or Office:** Product Development: ENERGY STAR

### ***ENERGY STAR Background***

ENERGY STAR is a voluntary program created by EPA that has been active for ten years. It is a labeling system designed to distinguish energy efficient products and enable consumers to drive market change through selective purchasing of these products. While ENERGY STAR labeled products can be slightly more expensive, they are functionally equivalent, energy efficient, and will save money in the long run. The federal government has pledged to only purchase ENERGY STAR labeled equipment. In order for manufacturers to be a part of this \$60 billion a year market, they must alter their production standards to meet more energy efficient specifications.

### ***How ENERGY STAR works***

Currently there are 40 product areas which are eligible for ENERGY STAR certification. Ms. Osdoba focuses on consumer electronics and office equipment, such as telephones, digital to analog television converters, printers, and monitors. The ENERGY STAR office uses “feelers” to find opportunities to initiate change. Representatives attend electronics conferences, talk with manufacturers, do market analyses, and watch consumer trends. ENERGY STAR works with industry, nonprofit organizations, researchers, and international organizations to find the leaders in a given area to set standards by.

Specifications are developed such that only 25% of specific products can be labeled ENERGY STAR efficient. As electronics become more energy efficient, stricter

specifications must be developed to keep this ratio. ENERGY STAR is meant to be a market differentiation tool, but it will not work effectively if the majority of electronics qualify. When developing specifications, points of interest are newer, frequently used products, such as cell phone chargers. These attract attention from ENERGY STAR and begin the process of creating specific energy requirements.

Ms. Osdoba described how this process works. EPA announces that ENERGY STAR is looking to reevaluate its standards on a specific product or product area. After about a year of research, EPA releases new specifications. Manufacturers are typically given around eight months to a year to meet the new requirement before the label becomes active.

### ***Current Projects***

Ms. Osdoba stated that ENERGY STAR is currently looking into standards for computers in active mode. Prior to this point, ENERGY STAR focused only on inactive or passive mode power demands. Power supply efficiencies are being considered and external power supplies were evaluated recently. The use of televisions has also changed, which prompted a reevaluation from ENERGY STAR. Unlike in the past, where televisions were only used for a few hours a day, they are now left on for much longer periods of time. Electronics such as DVD players and “TiVo” systems are always plugged in and may also require the television to be on to record shows. Ms. Osdoba said that EPA hopes to have a new draft specification for televisions for the Consumer Electronics Show in January.

A current initiative for consumers, called “Change a Light Challenge”, challenges Americans to change five light bulbs in their homes to ENERGY STAR labeled bulbs. It is a competition amongst states to see which can save the most energy. Ms. Osdoba said

that competition is a good motivator, which is one reason that this project is so successful. If every American replaced five light bulbs with ENERGY STAR bulbs, one trillion pounds of greenhouse gases would be kept out of the atmosphere per year. This is equivalent to the pollution emitted from 8 million cars.

Ms. Osdoba shared that ENERGY STAR is looking into certifying home heating solutions. It found that the cost differential for an ENERGY STAR label would be too much for a consumer to recoup, so a label will not be implemented as of now.

### ***Publicity***

The ENERGY STAR is very appealing to consumers. Information about it is distributed through campaigns run with advertising firms, news stories, and television media. A good example of this publicity is a recent episode of Oprah, which focused on helping the environment by using ENERGY STAR products. Major retailers, such as Best Buy, Lowe's, Sears, and Home Depot, also encourage consumers to buy ENERGY STAR labeled products.

### ***Related Programs***

Ms. Osdoba briefly mentioned newly developed program called the Electronics Production Environmental Assessment Tool (EPEAT). This is a multi-attribute environmental rating system for electronics. It has adopted ENERGY STAR usage standards as one of its evaluation attributes. Unlike ENERGY STAR, EPEAT has different levels certification, bronze, silver, and gold.

### ***Final Thoughts***

Ms. Osdoba stated that many companies see ENERGY STAR not as a voluntary program, but as a regulation. In order to stay competitive, especially with governmental contracts, companies must sell ENERGY STAR certified products. The program



recently looked at imaging devices and found that industry leaders in energy efficiency wanted higher standards to decrease competition. On the other hand, companies barely meeting standards wanted them lowered. The ENERGY STAR office is currently working with other countries in an effort to increase eligible products. It is also comparing international and domestic production standards.

### ***Environmental Impacts***

Producing energy using fossil fuels releases large amounts of harmful greenhouse gases into the atmosphere. By saving electricity, the ENERGYSTAR program prevents some of these releases. Unit shipment and energy consumption data are recorded and the amount of energy save is calculated. This number can then be equated to an amount of pollution prevented.

## ***Appendix F 5 – Vokes, Kathleen (Office of Pollution Prevention)***

Ms. Vokes is focusing on using an alternatives assessment to provide quick answers concerning the use pentabromodiphenyl ether. This chemical is an industrial concern because it has been detected in the environment, specifically in animals, household dust, and women's breast milk. The European Union and parts of the United States have banned pentabromodiphenyl ether. Investigations are currently underway to determine how this chemical spread through the environment.

### ***How do you know if your office is making a difference?***

Ms. Vokes stated that the questions being asked and approaches taken are factors in the ability to determine success. An example is the OPPT's computer display life-cycle assessment. When Liquid Crystal Displays (LCD's) were first being sold, research showed that they used much less energy than conventional CRT displays. In addition, LCD's take up less space and are more aesthetically pleasing. OPPT correctly predicted that LCD's would overcome CRT's. OPPT research later revealed that the amount of energy required to manufacture an LCD almost offset the energy saved during its use. This and other research was aimed at moving the developing LCD industry towards greener manufacturing techniques.

The fourth phase of this LCA was an improvement assessment of new technology, which was given to industry to consider. This assessment had to take global production into consideration since there are more foreign than domestic LCD manufacturers. It was difficult to get data from these foreign manufacturers. OPPT was able to obtain the necessary data and complete their environmental assessment. Shortly after the work was completed, a statement was issued by Japanese manufacturers claiming that they could

decrease the energy necessary for LCD manufacture by fifty percent within six months. Despite not being mentioned in the statement, OPPT knew it was a big part of this development. It began getting calls from other foreign companies to do similar studies.

Another example is the use of CTSA alternatives. Companies in a specific industry were using either a certain conventional manufacturing process, or a new alternative method. An initial survey showed that only 10% were utilizing this alternative, but two years later this number reached 30% to 35%.

### ***How are quantities measured?***

Some numbers are easy to measure, such as the amount of lead solder used per year or tons of lead emitted. The Government Performance and Results Act (GPRA) was mentioned. This program relates achievements to budget expenditures to get measurable, numerical outcomes.

# **Appendix G – PI Case Studies**

## ***Caudill, Reggie J. – Appendix G 1***

### **Appendix G 1.1: Award Review (P3 SU831815)**

**EPA Contract Number:** SU831815

**Program Type:** P3

**Title:** P3 Design of a National Electronics Product Reuse and Recycling System

**PI:** Reggie J. Caudill

caudill@njit.edu

973-596-5856

**University:** New Jersey Institute of Technology

**Phase:** I

**Project Duration:** September 15, 2004 through September 14, 2005

**Total Budget:** \$9,900

### **Background**

The volume of electronics being produced has increased at a staggering rate over the last decade. Since technology is ever changing, these electronics are quickly becoming out of date. This is leading to the large-scale disposal and even exportation of old electronics to other countries. In 2005, it is estimated that 63 million tons of computer equipment will be taken out of service and 85% will end up in landfills.

The implementation of a recycling system has both social and economic impacts. For society to accept a new recycling system, it would have to be easy to use. In addition, it would have to be inexpensive for both the manufacturers and consumers. Electronics waste needs to be addressed, as landfills are quickly being filled with used electronics products.

### **Objective**

The goal of this research was to create a national electronics recycling program that can redirect garbage from landfills and recycle materials to be used in new products. The initial research will help develop a better understanding of the recycling process then the boundaries associated with implementing the design will be considered.

## **Methods**

Essex County, New Jersey was studied to better understand how to design the infrastructure for an electronics recycling system. The P3 team estimated the amount of e-waste Essex County would produce each year based on the population. This number ended up being around 1.6 million pounds of electronics per year. A per capita e-waste produced estimation was also made. The P3 team tested several collection methods, such as stand alone drop-off sites, a combination of drop-off and demanufacturing sites, and a residential curb-side pick-up. Once the electronics were dropped off, they were visually inspected and sorted.

## **Results**

Overall recycling costs were estimated by dividing the process into three steps: collection, transportation, and processing. By analyzing these steps, the best locations for each facility, labor costs, material handling, and administrative costs could be calculated. The cost to recycle one pound of e-waste was calculated to be \$0.31 (see award report for details). The P3 team found that the 800,000 people in Essex County could be adequately served by three collection sites. Collection options were then researched to determine the most efficient collection type for a specific density of population.

## **Conclusions**

The P3 team did not apply for Phase II funding even though their initial research was successful in the proposed design problem. They included a way to implement their design infrastructure, but felt funding would have been an issue.

## **Appendix G 1.2: Interview**

**Name:** Reggie J. Caudill

**Contact Info:** 973-596-5856

**E-Mail:** caudill@njit.edu

**Date Interviewed:** Wednesday, November 09, 2005

**College:** New Jersey Institute of Technology

**Type of Award:** P3 - SU831815

**Title of Project:** "P3 Design of a National Electronics Product Reuse and Recycling System"

### **Can you tell us a little bit about how you became interested/involved in this field?\***

Mr. Caudill is a member of NEPSI (National Electronic Product Stewardship Initiative), which was developed by EPA to create a national recovery, reuse, and recycling program for used electronics. He was part of a 45 person committee involved in a three year effort to research this problem. About one third of the committee was representatives from major electronics manufacturers, such as Sony, Hewlett Packard, Dell, and Sharp. There were also representatives from various levels of the government, ranging from state to regional. Mr. Caudill helped lead the research on the cost estimates of recycling. From this research, many questions about costs, sources of funding, and feasibility arose.

To get a fresh look at the problem, Mr. Caudill brought in a group of senior industrial engineering students from the New Jersey Institute of Technology. The students had backgrounds in system design and analysis and this P3 coincided with a required senior design project. Mr. Caudill saw this as a great opportunity for them to expand their knowledge about sustainability and recycling.

To aid in the project, a graduate student working at the DEP (Department of Environmental Protection) was added on to the team. He was able to provide information on policy and regulatory compliances. The P3 research team was well rounded and

possessed a wide range of perspectives, including academic, industrial, and environmental points of view.

**1. What research did you perform under P3/TSE?**

The goal of the project was to develop a national recycling system, using the one in Seattle, Washington as an example. The students researched the best ways for New Jersey to implement this type of recycling program. Curbside pick up of old electronics and dedicated drop-off facilities were considered. The industrial, environmental, and economic impacts of a national recycling program were also considered.

**2. Has your research created any change in:**

- your course syllabus?
- the school curricula?

If so, how long have you taught the lecture and what is the average number of students per class?\*

Mr. Caudill is part of the Industrial Manufacturing Engineering Department and focuses on multi-lifecycle engineering, design for the environment, and applications of reused products. The research done under P3 has indirectly affected the student body, since a larger portion of students are now aware of this problem and the ways in which the research team attempted to address it. For the past four years, Mr. Caudill has taught a graduate class with material from this project imbedded in it. This class is offered once a year and averages 25 students.

**3. Did you collaborate with any faculty outside your department or institution?**

Mr. Caudill worked with two faculty members from the New Jersey Institute of Technology's graduate program in environmental policy studies. Maurie Cohen, who focused on sustainability and Daniel Watts, who focused on environmental research

both aided in completing the project. A few others helped, but played minor roles in the P3.

**4. Did you receive any additional funding? If so, from whom?**

No

**5. What is the potential for this project?**

This research could result in a consistent national method for recycling electronics.

**6. Did your work prompt any follow-up research or patents?**

NEPSI is still looking into it. There are still disagreements as to what the funding mechanism will be. Some want to internalize recycling, so an additional recycling fee would be charged on electronics products. Others think that the fee should be external, so the consumer can see what it is being used for. A thorough economic assessment still needs to be done.

**7. Did you have any industrial partners while performing your research?**

Mr. Caudill has had many industrial partners, but none were directly involved in this P3 project.

**8. If so, what was the extent of their involvement?**

Many saw the outcomes of the research through NEPSI, but did not contribute directly.

**9. If not, have any industries learned of your work? Have they implemented it or looked into using it?**

- If so, how are they going to incorporate the research into their processes
- Have you received any quantitative data?

As seen above (number 7 and 8)



**10. How many students were funded by the award?**

A total of seven students were funded by this research.

**11. Are there any graduate students that you would recommend talking to about how this research has affected their careers?**

No. All the seniors that worked on the project have graduated and Mr. Caudill was unsure if they can be reached. He did not feel that this research impacted their career choices, but stressed what a great experience this was for them. Mr. Caudill was uncertain of the contact information for the graduate student that was involved.

**12. Is there anyone else you feel we should contact?**

No

**13. What research are you currently working on (if NCER award is finished)?**

Mr. Caudill is still working with NEPSI and is trying to perform an economical and environmental assessment of a national recycling program.

**14. Do you have any additional comments?**

No

**We plan on typing up this interview and e-mailing it back to you to make sure your responses were accurately recorded. Can we contact you again if we have any other questions? Thanks for your time. Bye**

Yes

## ***DeYoung, James (MiCell) – Appendix G 2***

### **Appendix G 2.1: Award Review (SBIR EPD05052)**

**EPA Contract Number:** EP-D-05-052

**Program Type:** SBIR

**Title:** Wafer Level Supercritical Carbon Dioxide-Based Metal Deposition for Microelectronic Applications

**PI:** DeYoung, James P. – Director of R&D

**Email:** jdeyoung@micell.com

**Small Business:** MiCell Technologies, Inc.

**Phone:** (919) 313-2108

**Phase:** II

**Project Duration:** April 1, 2005 through June 30, 2006

**Total Budget:** \$225,000

### **Background**

Since 1997, much of the electronics industry has moved away from using aluminum alloys for electroplating. Copper electroplating is being used more, but it produces two types of waste: spent copper sulfate plating baths and rinse water from wafer-rinsing operations. The proposed plan of MiCell Technologies, Inc. is to develop a means to dispose of copper and copper barrier materials. This process would replace copper electroplating, specifically in circuit board manufacture. There are large quantities of aqueous wastes, which contain copper and other hazardous chemicals, being produced from the electroplating process that need to be treated. The proposed process uses an environmentally safe solvent, supercritical carbon-dioxide, which not only transports a metal precursor to the semiconducting wafer substrate, but provides control of the metal deposition process. This generates superior films and electrical interconnects.

MiCell Technologies, Inc. successfully completed Phase I of its SBIR, which determined the operating variables in the liquid and supercritical carbon dioxide surface deposition processes. Phase I also determined if this technology could be used for the

deposition of copper and copper barrier materials and if it can prevent metal intercalation. The research shows that it can be used for deposition, but preventing metal intercalation is still an unresolved problem.

## **Objective**

The objectives of Phase II are to design a full size wafer tool that is capable of metal deposition, using the technology developed in Phase I. Other candidate barrier layer materials that can be deposited from the liquid or supercritical carbon dioxide also need to be developed.

## **Methods**

The proposed solvent (CO<sub>2</sub>) will contain the precursor and immerse the wafer, which is heated while a reactant is added. A metal film is left on the wafer surface, after a reaction occurs between the metal precursor and the added reactant. The low surface tension and viscosity of the carbon dioxide allows the precursor to penetrate narrow gaps in the substrate. Once the conversion of the metal precursor occurs, a solid metallic layer remains on the surface, which forms the interconnect or barrier layer.

## **Expected Results**

The use of supercritical carbon dioxide would make this a completely dry process and result in a significant reduction of wastewater. This project is one part in approach to replace all aqueous and organic solvents in microelectronics production. It is estimated that a large wafer FAB can use up to 11 million liters of ultra pure water per day when producing 200 mm wafers. This water usage is expected to increase by 1.5 times when FAB's begin to produce new 300 mm wafers. To put this in perspective, when manufacturing 300 mm wafers, a large FAB will use the same amount of water in a day as a city of 60,000 people would use in a year.

## **Appendix G 2.1: Interview**

**Name:** James DeYoung

**Contact Info:** 919-313-2108

**E-Mail:** jdeyoung@micell.com

**Date Interviewed:** Monday, November 14, 2005

**Company:** MiCell

**Type of Award:** SBIR (EPD05052)

**Title of Project:** “Wafer Level Supercritical Carbon Dioxide-Based Metal Deposition for Microelectronic Applications”

### **Can you tell us a little bit about how you became interested/involved in this field?\***

Mr. DeYoung is currently the vice president of technologies for MiCell, an electronics manufacturing company founded in 1997. MiCell focuses on industrial uses for supercritical CO<sub>2</sub> and conducts research on early stage technology. Once the background research is complete, MiCell finds other companies to continue the project as a joint development. Through these team efforts, new products and technologies can be commercialized. MiCell licenses out patented technologies to large companies and collects royalties on them.

#### **1. What research did you perform under SBIR?**

It takes approximately 400 steps to manufacture a microprocessor. MiCell is concerned with the 100 steps that involve metal deposition. Metal deposition is the addition of insulation or metal layers or removal of material done through etching and other processes. Supercritical CO<sub>2</sub> can be used to deposit a metal precursor on a wafer, allowing for a superior electrical interconnects. Phase I involved testing supercritical CO<sub>2</sub> on a small scale. Developing a large scale tool that would use it is the focus of phase II.

**2. Did you receive any additional funding? If so, from whom?**

Yes, but this information is private. Most additional funding comes from venture capital investments from New York.

**3. What is the potential for this project?**

This is a disruptive technology, meaning that it is not an alteration of current technology. In order for it to be implemented, an existing process must fail. Current trends in manufacturing show that conventional fluids will no longer meet the needs of production by the year 2010. This is calculated using nodes that determine the minimum feature size of transistors. There are currently 1,000,000,000 transistors on a microchip. Supercritical CO<sub>2</sub> does not have the physical restrictions of other liquids and will be needed as these transistors continue to decrease in size.

Using supercritical CO<sub>2</sub> has many environmental benefits as well. Conventional manufacturing methods require 30,000 gallons of water to make one chip. Using this new technology, water used and wastewater released are greatly reduced. In addition, supercritical CO<sub>2</sub> is recyclable, so it can significantly reduce costs.

**4. Did your work prompt any follow-up research or patents?**

Yes, some patents were issued before work began and others are processing now. MiCell's work with lithography goes hand in hand with this SBIR. MiCell is working with Intel to take advantage of CO<sub>2</sub> in lithography.

**5. Did you have any other business or industrial partners while performing your research?**

There are no existing partners as far as research is concerned. MiCell is working on the manufacturing tool with Semitool, which is an original equipment manufacturer (OEM).

**6. If so, what is the extent of their involvement?**

N/A

**7. If not, have any industries learned of your work? Have they implemented it or looked into using it?**

- (if the researchers know: how are they going to begin to incorporate the research into their process)
- If so, have they given you any quantitative data?

Mr. DeYoung and other company representatives attend many industrial conferences and advertise their research through publications. According to Mr. DeYoung, several large companies have shown interest in this technology. Research of this type is usually three to six years ahead of the commercialization curve, so all the companies understand that this technology won't be applicable until around the year 2010.

**8. What research are you currently working on (if NCER award is finished)?**

The SBIR research is currently in progress and the tool should be manufactured by the first of the year (2006).

**9. Is there anyone else you feel we should contact?**

There is a professor at the University of Massachusetts, Jim Watkins, who owns the preliminary patents in the field of super or sub critical CO<sub>2</sub>. He also has experience in the field through his work with Novellus, an OEM.

**10. Do you have any additional comments?**

No

**We plan on typing up this interview and e-mailing it back to you to make sure that your responses were accurately recorded. Can we contact you again if we have any other questions? Thanks for your time. Bye**

Yes

## ***Dornfeld, David – Appendix G 3***

### **Appendix G 3.1: Award Review (TSE R831456)**

**EPA Contract Number:** RD831456

**Program Type:** TSE

**Title:** Comprehensive Tools to Assess Environmental Impacts of and  
Improve the Design of Semiconductor Equipment and Processes

**PI:** Dornfeld, David A.

**Phone:** 510-642-0906

**Email:** [dornfeld@me.berkeley.edu](mailto:dornfeld@me.berkeley.edu)

**University:** University of California - Berkeley

**EPA Contact (PO):** Julie Zimmerman, PhD

**Project Duration:** 10/14/2003 – 10/15/2006

**Total Budget:** \$324,970

**Graduate Students:** Comprehensive list given

### **Background**

The electronics industry has shown rapid growth in recent years. It requires large amounts of water, chemicals, materials, and energy, but releases pollution and hazardous wastes. In addition, health questions associated with semiconductor manufacture are growing in importance. In order to develop an accurate environmental impact tool, one must understand potential effects at different manufacturing stages:

- Level I Design: maximum flexibility for changes in device or system design
- Level II Process Development: limited design flexibility, but small changes in production processes and layouts can be made
- Level III Process or System Troubleshooting: no design flexibility, limited layout changes, but operation of elements can be modified
- Level IV Packaging/Assembly: no design or production modifications

Previous work has been done in this area, but no comprehensive system has been developed. Some current tools are based on databases, which can be incomplete and restrictive. Others do not consider environmental effects at all. There is no comprehensive Life Cycle Assessment (LCA) that can take the manufacturing process, environmental effects, and the multitude of remaining changing variables into account.



## **Objectives**

The goal of this project is to make a tool to assess the impacts of semiconductor manufacture. “The tool aims to be comprehensive in terms of (i) scope – by considering upstream life cycle impacts and facilitating integration into downstream environmental assessments and (ii) metrics – by supporting a wide range of local and global environmental and health metrics”. It will include all four manufacturing stages, and address both industrial and academic needs

## **Methods**

First, a library of equipment centric environmental process modules must be built. This includes libraries of equipment platforms, facility infrastructures, and recipes for individual process steps. Bottom up and other methods will be incorporated to account for production inputs. The health effects of this waste will also be considered, but they must first be quantified. They will be characterized by acute toxicity, system toxicity, developmental/reproductive toxicity, carcinogenicity, physical hazards, and standards and regulations. Specific chemicals are given scores in each category and the numbers are plotted in a “Hazard Profile”. Indirect and community health costs will be also accounted for. Industrial chemicals are changing very frequently, making it difficult to perform proper toxicity tests. In the future, a fast, low cost testing method should be in place.

## **Expected Results**

Information extracted from this tool will be given to groups of designers, who can then integrate environmental issues more into semiconductor design. The results will be used to inform regulators and industry in environmental decision making. Predictive and downstream analysis can also be done.

## **Appendix G 3.2: Interview**

**Name:** David Dornfeld

**Contact Info:** (510) 642-0906

**E-Mail:** dornfeld@me.berkeley.edu

**Date Interviewed:** November 9, 2005

**College:** University of California Berkeley

**Type of Award:** TSE

**Title of Project:** “Comprehensive Tools to Assess Environmental Impacts of and Improve the Design of Semiconductor Equipment and Processes”

### **Can you tell us a little bit about how you became interested/involved in this field?\***

Dr. Dornfeld received his PhD in manufacturing engineering from the University of Wisconsin. He has been teaching mechanical engineering courses for the past 30 years at the University of California Berkeley. Dr. Dornfeld has many contacts in Europe and is interested in the green manufacturing technologies that are developing there. He is still concerned with this subject and is trying to develop tools with a focus on minimizing water use, energy consumption, and waste production. He pointed out that reducing the hazardous materials used and wastes produced is very cost effective, making it desirable for industry.

#### **1. What research did you perform under P3/TSE?**

Dr. Dornfeld is working to develop a tool to assess environmental impacts of semiconductor manufacture and potentially improve the design of related equipment. There is a large demand for such a tool from industry, so it has been relatively easy for him to gather data.

**2. Has your research created any change in:**

- your course syllabus?
- the school curricula?

If so, how long have you taught the lecture and what is the average number of students per class?\*

Dr. Dornfeld teaches classes in semiconductor manufacturing. For the last three years he has been teaching a class on management of technology for the environment. This is a joint class involving business and management. He uses examples of his research to relate his teachings to real life. The class averages 20 students per year.

**3. Did you collaborate with any faculty outside your department or institution?**

Yes, especially when designing the lecture he was going to teach. Dr. Dornfeld collaborated with both the school of business and engineering department to design this class. If all goes well, it will be implemented at the undergraduate level as a course on sustainability.

**4. Did you receive any additional funding? If so, from whom?**

About \$25,000 per year from Applied Materials and a one time amount of \$10,000 from Ford. He is looking into funding from the Lawrence Berkeley National Laboratory for continued research. Dr. Dornfeld is also waiting for the Department of Energy to call for research proposals.

**5. What is the potential for this project?**

This tool could allow industry to be more environmentally conscious when designing and implementing technology. A mechanical engineering version of the tool can be developed and used in different industries.

**6. Did your work prompt any follow-up research or patents?**

It is not clear if the final software is going to be patentable. The tool will most likely be licensed to companies from the university.

**7. Did you have any industrial partners while performing your research?**

Applied Materials and Ford

**8. If so, what was the extent of their involvement?**

These companies provide data to the research team that would otherwise be inaccessible.

**9. If not, have any industries learned of your work? Have they implemented it or looked into using it?**

- If so, how are they going to incorporate the research into their processes
- Have you received any quantitative data?

**10. How many students were funded by the award?**

2

**11. Are there any graduate students that you would recommend talking to about how this research has affected their careers?**

At least three. Dr. Dornfeld supplied names and contact information through email.

**12. Is there anyone else you feel we should contact?**

Dr. Dornfeld mentioned a possible contact in the Ford Motor Company.

**13. What research are you currently working on (if NCER award is finished)?**

This TSE is still in progress.

**14. Do you have any additional comments?**

If possible, Dr. Dornfeld would like a copy of our results.

**We plan on typing up this interview and e-mailing it back to you to make sure your responses were accurately recorded. Can we contact you again if we have any other questions? Thanks for your time. Bye**

Yes

## ***Doyle, Fiona M. – Appendix G 4***

### **Appendix G 4.1: Award Review (TSE R829627)**

**EPA Contract Number:** R829627

**Program Type:** TSE

**Title:** Electrolysis and Ion Exchange for the in-Process Recycling of  
Copper from Semi-Conductor Processing Solutions

**PI:** Fiona M. Doyle

**Phone:** (510)642-2846

**Email:** [fiona@socrates.berkeley.edu](mailto:fiona@socrates.berkeley.edu)

**University:** California Berkley University

**EPA Contact (PO):** Nora Savage

**Project Duration:** 1/1/2002 – 4/30/2005

**Total Budget:** \$325,000

**Graduate Students:** None listed

### **Background**

The ability to recycle copper, water, and solutions in electronics manufacturing could prevent millions of tons of waste from being introduced into the environment. Copper solutions are being used more frequently in industry because copper metallization displaces aluminum. Electrolysis and ion exchange have both proven useful in the removal of copper from waste streams. These separations and removals need to be almost 100% efficient for waste to be released into the environment without effect. Any reagents used in this effort should also be recyclable if possible.

### **Objectives**

Dr. Doyle wanted to understand the electrodeposition of copper onto extended area electrodes. She also wanted to investigate the adsorption or desorption of copper into ion exchange resins with a high affinity for copper.

### **Methods**

Dr. Doyle wanted to perform laboratory scale electrochemical investigations using a rotating copper electrode. This would allow her to determine the kinetic parameters and the nature of the electrodeposit for the solutions of interest. These tests

also identified any side-reactions, and allowed the determination of mass-transfer parameters that will influence the future design of commercial cells. She applied extended surface area electrodes to representative industry waste solutions. Electrode area, current density, electrolyte flow rate, current efficiency, and the ultimate copper concentration were also tested. She performed a measurement of adsorption and desorption of isotherms for metals on chelating resins with a strong affinity for copper. Dr. Doyle could then develop a model for uptake and selectivity of metals onto resins to make commercial development of ion exchange units possible.

## **Results**

Dr. Doyle found that it is possible to use an extended area electrode to remove copper from waste flows. While it is possible, some chemicals and solutions used in industry can prevent or slow the progress of this procedure. A fixed distance electrode was developed to ensure constant cell voltage while copper deposition was taking place. There is currently an investigation into a more effective and reusable chelating agent than the one used in tests.

## **Other References**

Ding R, Evans JW, Doyle FM. *An investigation of the electrodeposition of copper relevant to the removal of dissolved copper from semiconductor industry waste streams*. Presented at the 203rd Meeting of the Electrochemical Society, Paris, France, April 28-30, 2003.

Ding R, Evans JW, Doyle FM. *Electrodeposition as a means of processing semiconductor industry waste streams containing copper*. To be presented at The Minerals, Metals, and Materials (TMS) Annual Meeting, Charlotte, SC, March 14-18, 2004.

- Ding R, Ewing W, Doyle FM, Evans JW. *In-process recycling of copper from semiconductor processing solutions*. Presented at the Annual Meeting of the American Institute of Chemical Engineers, Indianapolis, IN, November 2002.
- Ewing W, Doyle FM. *Probing the copper-selective bis(pyridylmethyl) amine functional group*. Presented at the Annual Meeting and Exhibit of the Society for Mining, Metallurgy, and Exploration, Cincinnati, OH, February 24-26, 2003.
- Ewing W, Darmawan F, Doyle FM, Evans JW. *Selection of ion-exchange resins suitable for removing copper from aqueous wastes generated during semiconductor processing operations*. To be presented at The Minerals, Metals, and Materials Society (TMS) Annual Meeting, Charlotte, SC, March 14-18, 2004.
- Ewing W, Evans JW, Doyle FM. *The effect of plating additives on the recovery of copper from dilute aqueous solutions using chelating resins*. Young CA, Alfantazi AM, Anderson CG, Dreisinger DB, Harris B, James A, eds. Presented at the 5th International Symposium on Hydrometallurgy, Vancouver, British Columbia, Canada, August 24-27, 2003.
- Evans JW, Ding R, Neugebauer A, Doyle FM, Jiricny V. *Copper electrodeposition onto extended surface area electrodes and the treatment of copper-containing waste streams*. Proceedings of Metal Separation Technologies III—Professor Holappa Honorary Symposium, Copper Mountain, CO, June 20-24, 2004.
- Ewing W, Evans JW, Doyle FM. *The effect of plating additives on the recovery of copper from dilute aqueous solutions using chelating resins*. In: Young CA, Alfantazi AM, Anderson CG, James A, Dreisinger DB, Harris B, eds. Hydrometallurgy 2003, Proceedings of the 5th International Symposium. Warrendale, PA: The Minerals, Metals and Materials Society, 2003, pp. 753-762.



## ***Hershkowitz, Noah – Appendix G 5***

### **Appendix G 5.1: Award Review (TSE R831459)**

**EPA Contract Number:** RD83145901

**Program Type:** TSE

**Title:** A New Approach for Reducing Global Warming Emissions  
from Plasma Etching by Controlling Ion Energy Neutral Flux

**PI:** Hershkowitz, Noah

**Phone:** 608-263-4970

**Email:** [hershkowitz@engr.wisc.edu](mailto:hershkowitz@engr.wisc.edu)

**University:** University of Wisconsin-Madison

**EPA Contact (PO):** Julie Zimmerman, PhD

**Project Duration:** 12/01/2003 – 11/30/2006

**Total Budget:** \$324,820

**Graduate Students:** Cary Forest, Drew Bailey, Steve Meassik, John Menard, and others

### **Background**

Semiconductor manufacture is a major source of global warming gases. Currently CO<sub>2</sub> is the most prevalent greenhouse gas in the atmosphere, but high global warming potential (GWP) gases, such as CF<sub>4</sub>, may become comparable. CF<sub>4</sub> has a GWP of 5700 compared to 1 for CO<sub>2</sub> and an atmospheric lifetime of 500-50,000 years compared to 50-200 for CO<sub>2</sub>. CF<sub>4</sub> is currently being used in semiconductor etching plasmas. Transition from wet chemical to dry plasma etching has reduced waste products, but this process still produces perfluorocarbons (PFC's) and hydrofluorocarbons HFC's. Annual PFC and HFC emissions from the U.S. semiconductor industry are about 3 million metric tons of carbon equivalent, 15 to 20 percent from patterned dielectrics etching.

Prof. Hershkowitz is currently the director of the Center of Plasma-Aided Manufacturing (C-PAM).

### **Objectives**

The goal of this research is “to explore the use of new and more environmentally friendly plasma and control processes for semiconductor fabrication”.

## **Approach**

NF<sub>3</sub> was substituted for CF<sub>4</sub> in etching plasma. Interactions between the plasma and the surface of the product were also altered using through an understanding of Ion Energy Distribution Functions (IEDFs). The combination of these changes allowed a semiconductor to be etched without using CF<sub>4</sub> plasma.

## **Expected Results**

Preliminary results show NF<sub>3</sub> and acetylene plasmas produce 1/7 the amount of CF<sub>4</sub> that would be produced using traditional CF<sub>4</sub> plasmas. This process could potentially reduce PFC emissions by at least a factor of 7 for Magnetically Enhanced Reactive Ion Etching (MERIE) tools. This research was specific to high density plasma tools so an additional 5 times PFC reduction is expected in lower pressure tools. Semiconductor device and etch tool manufacturers will be contacted to use this method, if it meets industrial standards.

## **Conclusions**

This technology can significantly reduce fluorocarbon releases from the semiconductor fabrication process. These emissions are very harmful to the environment, so this new etching processes has important environmental implications. If the final process is successful, funding may be continued by industry. Further impacts include the effects of graduate students on industry and in the field of plasma science.

## **Appendix G 5.2: Interview**

**Name:** Noah Hershkowitz

**Contact Info:** 608-263-4970

**E-Mail:** [hershkowitz@engr.wisc.edu](mailto:hershkowitz@engr.wisc.edu)

**Date Interviewed:** November 29, 2005

**College:** University of Wisconsin-Madison

**Type of Award:** TSE

**Title of Project:** “A New Approach for Reducing Global Warming Emissions from Plasma Etching by Controlling Ion Energy Neutral Flux”

### **Can you tell us a little bit about how you became interested/involved in this field?\***

Dr. Hershkowitz has been a professor at the University of Wisconsin for over 24 years in the field of engineering physics. Before that, he taught at the University of Iowa for 14 years. Dr. Hershkowitz specializes in plasmas, or charged particle gasses, and their applications.

#### **1. What research did you perform under P3/TSE?**

One of Dr. Hershkowitz’s students came up with the idea to use an unconventional approach to conventional plasma etching, which is used to produce semiconductors. Forty percent of the steps required to manufacture a semiconductor use plasma and half of these steps involve etching. Dr. Hershkowitz’s research focused on replacing  $\text{CF}_4$ , a strong greenhouse gas, in the plasma etching process. During semiconductor manufacture, carbon and fluorine are applied to a silicon wafer, forming a film on the surface. This is usually done with a fluorinated gas, such as  $\text{CF}_4$ . This film is around five nanometers thick and provides a surface for the etching.

Dr. Hershkowitz attempted to replace  $\text{CF}_4$  in the film deposition process with  $\text{NF}_3$  and either  $\text{C}_2\text{H}_2$  (acetylene) or  $\text{C}_2\text{H}_4$  (ethylene). This method provided carbon and fluorine for the film without using  $\text{CF}_4$ . A layer of  $\text{Si}_3\text{N}_4$  would be applied under this

film to limit the depth of the reaction. The point is to etch the film, but stop at the layer underneath. Unfortunately, this could not be done. It was found that a fluorinated gas was necessary for the process to etch only the film. While then film itself could be etched, the process did not have the selectivity to be completely successful.

This process increased the understanding of the etching process as well as the roles of  $CF_3$  or  $CF_2$  in it. Without these fluorinated gasses, etching can be done, but there will be selectivity issues.

**2. Has your research created any change in:**

- your course syllabus?
- the school curricula?

If so, how long have you taught the lecture and what is the average number of students per class?\*

This research has not changed any classes directly. It will be incorporated in a graduate level lecture on plasma processing techniques taught by Dr. Hershkowitz. This class is taught once every two to three years and averages 12 students.

**3. Did you collaborate with any faculty outside your department or institution?**

Did not ask

**4. Did you receive any additional funding? If so, from whom?**

No

**5. What is the potential for this project?**

This research has potential to reduce CFC emissions into the atmosphere by eliminating the use of  $CF_4$  in the plasma etching process.

**6. Did your work prompt any follow-up research or patents?**

The research did prompt follow ups. Dr. Hershkowitz learned a great deal about the etching process and is currently trying to fix the selectivity issues in his process.

**7. Did you have any industrial partners while performing your research?**

No

**8. If so, what was the extent of their involvement?**

N/A

**9. If not, have any industries learned of your work? Have they implemented it or looked into using it?**

- If so, how are they going to incorporate the research into their processes
- Have you received any quantitative data?

The research is new and being extensively studied. It is not yet ready for industry.

**10. How many students were funded by the award?**

2

**11. Are there any graduate students that you would recommend talking to about how this research has affected their careers?**

No, the student who developed the idea for this project is now working for Intel in a different area. Dr. Hershkowitz explained that she is very hard on herself and would only tell us that her research failed.

**12. Is there anyone else you feel we should contact?**

No.

**13. What research are you currently working on (if NCER award is finished)?**

The project is still in term.

**14. Do you have any additional comments?**

No

**We plan on typing up this interview and e-mailing it back to you to make sure your responses were accurately recorded. Can we contact you again if we have any other questions? Thanks for your time. Bye**

Yes

## ***Lave, Lester B. – Appendix G 6***

### **Appendix G 6.1: Award Review (TSE R826740)**

**EPA Contract Number:** R826740

**Program Type:** TSE

**Title:** Environmental Input-Output Life Cycle Assessment: A Tool to Improve Analysis of Environmental Quality and Sustainability

**PI:** Lave, Lester B.

**Phone:** (412)268-8837

**Email:** [ll01@andrew.cmu.edu](mailto:ll01@andrew.cmu.edu)

**University:** Carnegie Mellon University

**EPA Contact (PO):** Barbara Karn

**Project Duration:** 10/1/1998 – 9/30/2001

**Total Budget:** \$290,000

**Graduate Students:** None listed

### **Background**

Life cycle assessments (LCA's) assist in making educated choices for product materials, design, manufacturing processes, recycling, and disposal. LCA's are designed to sum up the environmental discharges at each stage of a product's life. Conventional LCA's are said to be unreliable because they must take constantly changing materials and manufacturing processes into account. These assessments are also limited to a single industry and do not take the dependence of industry into account.

### **Objectives**

Dr. Lave sought develop a new environmental input-output assessment (EIO-LCA), which should decrease cost and time factors associated with normal life cycle assessments. Public, government compiled databases will be used to calculate both the direct and indirect environmental implications of producing commodities. EIO-LCA's can only be used in conjunction with one of the 500 sectors of the U.S. economy recognized by the Department of Commerce. Dr. Lave's project should remove this

restriction. The ultimate goal is to be able to evaluate materials, processes and products as well as what has previously been established.

## **Methods**

Dr. Lave accomplished his research through six steps. First, he modified existing EIO-LCA's to take materials, processes, and products into account, as an extension of previous models. He developed a method to break down the 500 industrial sectors into materials, processes, and products. An edit capability to perform "what if" calculations was also developed to change environmental discharges and production functions. The EIO-LCA government database was updated and extended using the most recent Department of Commerce and EPA discharge data. Dr. Lave then improved the existing database's coverage. A World Wide Web site to allow other analysts and the EPA access was created. He collected data access patterns and finally developed interactive user manual for EIO-LCA.

## **Results**

Dr. Lave successfully completed his research and now there is a web hosted EIO-LCA ([www.eiolca.net](http://www.eiolca.net)). The site was visited over 30,000 times from over 40 different countries in just one year. Most of the online traffic was from the United States, but 15% was international. The majority of these visits (90%) were from \*.edu addresses, while 4% were from households, and 3% were from governments and nonprofit organizations.



## ***Lin, Li – Appendix G 7***

### **Appendix G 7.1: Award Review (TSE R829598)**

**EPA Contract Number:** R829598

**Program Type:** TSE

**Title:** Material Selection in Green Design and Environmental Cost Analysis

**PI:** Lin, Li

**Phone:** (716)645-2357 ext. 2119

**Email:** [lilin@eng.buffalo.edu](mailto:lilin@eng.buffalo.edu)

**University:** University of New York at Buffalo

**EPA Contact (PO):** Barbara Karn

**Project Duration:** 1/1/2002 – 12/31/2005

**Total Budget:** \$325,000

**Graduate Students:** None listed

### **Background**

The main problem facing environmentally conscious manufacturing is the lack of a methodology for evaluating product design. Solving environmental problems after they have occurred has proven expensive and ineffective. Prevention is the most effective way to prevent adverse impacts to the environment.

### **Objectives**

Designing green products from materials to end-of-life is the focus of this project. It is attempting to fill the research gap in design evaluation of a given product's environmental impact. There will first be an evaluation of a product's end-of-life environmental impact, which will lead to the development of a methodology for material selection. An analysis of the environmental cost in green design will also be conducted by considering the cost to the manufacturer and society and evaluating the significance of product recovery options.

Lastly, in collaboration Xerox, a multidisciplinary industrial study will be conducted applying the methodology to ensure validity and applicability to future developments.

## **Methods**

Dr. Lin will develop a methodology for material selection then analyze the environmental cost. A multidisciplinary industrial study will also be conducted.

## **Expected Results**

This project can make material selection easier for the design engineers and make finding green replacements possible as well. It will provide a relational database for materials, emission, and toxicity.

## **Appendix G 7.2: Interview**

### **TSE Interview**

**Name:** Li Lin

**Contact Info:** 716-689-7606

**E-Mail:** lilin@eng.buffalo.edu

**Date Interviewed:** November 17, 2005

**College:** State University of New York at Buffalo

**Type of Award:** TSE

**Title of Project:** “Material Selection in Green Design and Environmental Cost Analysis”

### **Can you tell us a little bit about how you became interested/involved in this field?\***

Professor Lin did research in manufacturing service systems for many years. He became interested in green design when environmental issues arose on the United States-Mexican border. Companies began putting their facilities on the Mexican side of the boarder and stopped meeting EPA regulations. Professor Lin got his degree in industrial engineering, so he was interested in the reduction of pollution in the design process.

#### **1. What research did you perform under P3/TSE?**

Professor Lin’s TSE research is occurring on two levels. The first is a detailed level that focuses more on the toxicity than the quantity of pollution. The second is a higher level that concentrates on the social and economic aspects of the industry. Professor Lin feels that his research will have bigger industrial and social impacts if he includes both environmental and economic incentives.

**2. Has your research created any change in:**

- your course syllabus?
- the school curricula?

If so, how long have you taught the lecture and what is the average number of students per class?\*

Yes, Professor Lin has been teaching a graduate level course entitled, “Environmentally Conscious Design Manufacturing” for three years. It is an advanced research oriented elective that usually has between 7 – 10 students per year. Many industrial engineers and other majors are taking this class, but Professor Lin hopes to have more social science and law students enrolled next year.

**3. Did you collaborate with any faculty outside your department or institution?**

Yes, Professor Lin collaborated with other professors in the environmental engineering, social science, and management departments.

**4. Did you receive any additional funding? If so, from whom?**

No

**5. What is the potential for this project?**

Professor Lin hopes that his methods will be used by design engineers when they are making material selection decisions. He knows that most engineers are focused on the function of the product, how easily it can be manufactured, maintained, and its end-of-life. Using Prof. Lin’s research, they can focus on the environmental implications of material selection as well. He wants design engineers to be concerned with a product from cradle-to-grave, or cradle-to-reincarnation.

**6. Did your work prompt any follow-up research or patents?**

The research is still in progress and probably won’t receive any patents because it is design based.

**7. Did you have any industrial partners while performing your research?**

Yes, Xerox

**8. If so, what was the extent of their involvement?**

Xerox has been in a support role for Professor Lin's research. He feels that it is a good partner because it is a forerunner in environmental design and assembly. Xerox contributed data to help Professor Lin in his research. Additionally, he could submit a paper to the company, to be looked over before publication. Dr. Lin stated that Xerox is one of few companies that have a dedicated environmental and human safety department.

**9. If not, have any industries learned of your work? Have they implemented it or looked into using it?**

- If so, how are they going to incorporate the research into their processes
- Have you received any quantitative data?

No, this project is not yet complete.

**10. How many students were funded by the award?**

2

**11. Are there any graduate students that you would recommend talking to about how this research has affected their careers?**

Yes, Andy Lin.

**12. Is there anyone else you feel we should contact?**

No.

**13. What research are you currently working on (if NCER award is finished)?**

The award research is not complete

**14. Do you have any additional comments?**

No

**We plan on typing up this interview and e-mailing it back to you to make sure your responses were accurately recorded. Can we contact you again if we have any other questions? Thanks for your time. Bye**

Yes

## ***McCray, Scott B. (Bendres Research) – Appendix G 8***

### **Appendix G 8.1: Award Review (SBIR 68D70053)**

**EPA Contract Number:** 68D70053

**Program Type:** SBIR

**Title:** Development of a Membrane – Based System for the Recovery and Reuse of Solvents

**PI:** McCray, Scott

**Small Business:** Bend Research, Inc.

**Email:** info@bendres.com

**Phone:** (541) 382-4100

**Project Duration:** 9/5/1997 – 7/5/1999

**Phase:** Completed Phase II

**Total Budget:** \$225,000

#### **Background**

By recycling solvents, industry can prevent pollution and minimize the cost of purchasing new solvents and disposing of hazardous wastes. The problem is that some solvents are hard to recycle because of azeotropes, which cannot be separated using conventional methods, such as distillation. The feasibility of developing a cost-effective membrane system for the recovery and reuse of industrial solvents was demonstrated in Phase I. Pure isopropyl alcohol (IPA) was successfully produced when water, metal ion, and particulate levels were reduced to levels below those required for microelectronics applications. This recycling process could provide cost and performance advantages over competing processes for IPA recycling.

#### **Objectives**

The goal of Bend Research Inc. was to produce a membrane that is able to separate and recover industrial solvents, specifically IPA.

#### **Methods**

Phase II incorporated hollow-fiber modules and improved fibers, which had been coated with the high performance membrane developed in Phase I. The fibers were

successfully developed solvent-resistant hollow fiber supports from PBI that were shown to have a hydrolytically stable lifetime.

The PBI fibers were coated with the membrane from Phase I, which resulted in composite membranes with high water permeability and high selectivity for water over IPA. The final objective was to test this system on a waste stream from a microelectronics production line that contained organic solvents such as IAP.

## **Results**

Bend Research Inc. did produce a recovered solvent stream that could be reused. Several of these large scale modules were sent to a microelectronics company for use in existing IAP recycling operations.

The research was very successful and commercialization began once Phase II was completed. During Phase II, Bend Research, Inc. completed negotiations with Cascade Separations, Inc and received \$600,000 for the continuation of their work related to this system. Cascade is an engineering, systems-manufacturing, and marketing company.



## **Appendix G 8.2: Interview**

**Name:** Scott McCray

**Contact Info:** 541-382-4100

**E-Mail:** mccray@bendres.com

**Date Interviewed:** Monday, November 14, 2005

**Company:** Bendres

**Type of Award:** SBIR (68D70053)

**Title of Project:** “Development of a Membrane – Based System for the Recovery and Reuse of Solvents”

### **Can you tell us a little bit about how you became interested/involved in this field?\***

Dr. McCray started this project in 1997. He got his PhD in Chemical Engineering focusing on membrane separation. His educational background led him into a similar career field.

#### **1. What research did you perform under SBIR?**

During use, solvents are diluted with water or other liquids, decreasing their quality and usefulness. Dr. McCray developed a process to filter these “dirty” solvents using membranes. His research focused on isopropyl alcohol (IPA), which is used as a wash in hard drive and computer disk manufacture. Dirty IPA can be cleaned and reused using this membrane technology.

#### **2. Did you receive any additional funding? If so, from whom?**

Yes. Private investments were used to create a spin-off company. This company funded further research and planned on commercializing this technology.

**3. What is the potential for this project?**

This technology allows solvents used in electronics manufacturing to be recycled. Previously, used solvents were too impure to be used again, but using this new method, they can be separated and recycled. If implemented, this method has the potential to save a company the cost of disposing of spent and buying fresh IPA. While the spin-off company has since gone out of business, the technology still has applications in industry.

**4. Did your work prompt any follow-up research or patents?**

Yes, two patents were granted to the technology developed through this research. All the research Mr. McCray's current company does is related, so the work done under this award has indirectly led to developments in other membrane-related research programs.

**5. Did you have any other business or industrial partners while performing your research?**

The research had no partners while in progress, but upon completion partnered with a privately started company.

**6. If so, what is the extent of their involvement?**

The company continued funding and planned to commercialize the technology

**7. If not, have any industries learned of your work? Have they implemented it or looked into using it?**

- If so, how are they going to incorporate the research into their processes
- Have you received any quantitative data?

While the spin-off company has since gone out of business, this work is still applicable. Unfortunately, Bendres has since changed direction and this is not one of

their top priorities. There are currently no companies actively marketing this technology.

**8. What research are you currently working on (if NCER award is finished)?**

None that is involved with or focused on the electronics sector

**9. Is there anyone else you feel we should contact?**

No

**10. Do you have any additional comments?**

Recalling information from research conducted five years ago is difficult and requires a more in-depth review of the award.

**We plan on typing up this interview and e-mailing it back to you to make sure that your responses were accurately recorded. Can we contact you again if we have any other questions? Thanks for your time. Bye**

Yes

## ***Murphy, Cynthia F. – Appendix G 9***

### **Appendix G 9.1: Award Review (TSE R828208)**

**EPA Contract Number:** R828208

**Program Type:** TSE

**Title:** Development of Life Cycle Inventory Modules for Semiconductor Processing

**PI:** Murphy, Cynthia F.

**Phone:** 512-475-6259

**Email:** [cfmurphy@mail.utexas.edu](mailto:cfmurphy@mail.utexas.edu)

**University:** University of Texas at Austin

**EPA Contact (PO):** Barbara Karn

**Project Duration:** 4/01/2000 – 3/31/2003

**Total Budget:** \$325,000

**Graduate Students:** Comprehensive list given

### **Background**

There is a growing interest in Life Cycle Assessments (LCA's), but they have been criticized as being too complicated and cost intensive. Environmental impacts are generally, qualitatively understood, but few means of quantitative study can be employed. The Semiconductor Industry Association (SIA) has developed several environment, safety, and health (ESH) categories:

- Qualification of new chemicals
- Reduction in PFC emissions
- Reduction in energy and water usage
- Integration of ESH impact and analysis capability
- Chemical management, natural resource use reduction, worker protection, and design tools

### **Objectives**

The goal of this research was “to develop generic, use cluster, life cycle inventory (LCI) modules for activities performed during the manufacture of integrated circuits (ICs)”. It was meant to help establish more accurate standards and promote predictive, not historical, life cycle analyses.

## **Methods**

Environmental metrics, which are associated with environmental goals, were standardized. Predictive parametric data modules linked the environmental metrics to a product design or function. This information was reformatted to ease communication along the supply chain.

Motorola and SEMATECH (both in Austin, TX) agreed to share data. This data was analyzed and applied to all aspects of industry. Use clusters and LCI modules were created, populated with real data, and validated in a manufacturing setting. Cost and product quality were also included in the LCI. Specific modules were selected, implemented, and the results will be shared with industrial representatives.

This research used generic modules, which have several advantages. The data is not process specific, so it is relatively independent of time. This means that generic modules will not become obsolete as technology advances. These modules also promote standardization and are not specific to a certain company. Because of this, they are less likely to contain confidential industrial information.

## **Results**

Generic LCI modules will be spread through the semiconductor industry by SEMATECH. This should create better communication through the supply chain to the customer. In addition, manufacturers will not be required to perform individual tests for each customer.

## **Conclusions**

If adopted, impact assessments can be used to predict and avoid negative results caused by new technologies. This should help industry consider trade offs between quality, cost, input material, and environment effects.

## **Appendix G 9.2: Interview**

**Name:** Cynthia Murphy

**Contact Info:** 512-475-6259

**E-Mail:** cfmurphy@mail.utexas.edu

**Date Interviewed:** Monday, November 07, 2005

**College:** University of Texas at Austin

**Type of Award:** TSE (R828208)

**Title of Project:** “Development of Life Cycle Inventory Modules for Semiconductor Processing”

### **1. What research did you perform under P3/TSE?**

Ms. Murphy attempted to develop a lifecycle assessment (LCA) for electronic products. Past work focused more on impact evaluations, but it is now widely accepted that an LCA is only as good as its inventory data. Ms. Murphy found that many industries, such as the semiconductor industry, protect their input and production numbers. This is done to eliminate the possibility of others estimating a company’s productivity or profit margins. Standard chemicals were also assumed in many LCA’s, when purified specialty chemicals were in fact being used. PCB’s pose additional problems, as the size and number of layers had to be accounted for. Differences between the numbers used and actual industrial data made many LCA’s inaccurate. As a result, general and inexact numbers such as amount of energy required to produce one chip were being used. Industries are having trouble collecting valid data due to time and money constraints and the fact that the lifecycle of an electronics product may only last 18 to 24 months.

Ms. Murphy wanted to develop parameters to predict energy and material requirements based on a final product. Originally, the most expensive and toxic chemicals, like photoresists, were focused on. These “sexy chemicals” were thought to be the main problem, but in reality they were not the biggest cost factor and

relatively small amounts were actually used compared to other inputs. Eric Williams et al. wrote a paper stating that energy, water, and elemental gases are the main environmental concerns, as they are used in very large amounts. Parameters to predict the usage of these inputs are needed to assess environmental impacts and industrial spending priorities.

**2. Has your research created any change in:**

- your course syllabus?
- the school curricula?

There is one lecture based on this research. It is meant to impress upon students the idea that even if a product is small, the inputs required to manufacture it may not be. Students are also encouraged to estimate, if they do not have all necessary data. A good estimate now is more useful than exact numbers years later.

**3. Did you collaborate with any faculty outside your department or institution?**

No

**4. Did you receive any additional funding? If so, from whom?**

No

**5. What is the potential for this project?**

Ms. Murphy mentioned that smaller scale processes require more materials and energy to avoid contamination. As chips get smaller, greater amounts of materials are being used. Industry is justifying this by saying that chip functionality is increasing exponentially, while materials required are increasing only linearly, but this functionality must be objectively defined.

Better ways of quantifying LCA data, such as the effects of a temperature change on an existing process, will be very useful. Relationships, not absolute values will be used, so the data will be time and process independent.

**6. Did your work prompt any follow-up research or patents?**

Ms. Murphy knows of no patents that have resulted from this research. She did apply to receive additional funding from the EPA, but the proposal was turned down. Her project is being continued by two students at MIT, who are establishing general rules for manufacturing processes and the corresponding environmental loads.

**7. Did you have any industrial partners while performing your research?**

Motorola, SEMATECH and AMD

**8. If so, what was the extent of their involvement?**

After realizing EPA's involvement in the project, Motorola officially backed out, but ended up providing some numerical data. SEMATECH and AMD allowed data collection in their facilities.

**9. If not, have any industries learned of your work? Have they implemented it or looked into using it?**

- If so, how are they going to incorporate the research into their processes
- Have you received any quantitative data?

Most of the benefit of her work has been indirect. It showed that industry should be more concerned with water, energy and elemental gases than specialty chemicals. Fortunately, these inputs are more easily cost assessed and managed.

**10. How many students were funded by the award?**

2



**11. Are there any graduate students that you would recommend talking to about how this research has affected their careers?**

One is away in France right now and the other had a bad experience on the project.

**12. Is there anyone else you feel we should contact?**

Jean Phillippe, from SEMATECH, who is currently working for Michelin Tire.

**13. What research are you currently working on (if NCER award is finished)?**

IEEE Electronics and the Environment is her current research focus. This group is trying to apply expertise already available in the electronics sector to new sciences, such as nanotechnology and alternative energy sources. She is currently receiving funding for air quality research and curricula development.

**14. Do you have any additional comments?**

The International Symposium on Electronics and the Environment is November 28 to December 1, 2005. Ms. Murphy is a program chair and has been a part of the conference since its inception. Last year's conference had the largest attendance so far, and the upcoming symposium looks to surpass that. There are many foreign presenters and abstracts being submitted. About one third of these abstracts are foreign, which displays a global interest on the subject.

Much of the focus will be on European Union directives, such as Waste from Electric and Electronic Equipment (WEEE) and Restriction of Hazardous Substances (RoHS). These policies place strict limitations on manufacturing, specifically lead in solder, bromated flame retardants, and hexavalent chromium will no longer be allowed in manufactured materials. Electronics companies in the U.S. are also trying to comply with these directives, as to avoid having separate manufacturing lines in the U.S. and Europe.

The conference attracts many specialists in environmental fields and gives them a chance to make a difference. Ms. Murphy emphasized that while this research is focused on electronics, it may be applicable to other manufacturing sectors. In addition, more policy and economics representatives have taken an interest in this type of environmental research. Historically, sessions have been on LCA's and design for the environment, but this year there are exciting new sessions on subjects such as fuel cells and nanotechnology.

**We plan on typing up this interview and e-mailing it back to you to make sure your responses were accurately recorded. Can we contact you again if we have any other questions? Thanks for your time. Bye**

Sure. If there are easy questions, e-mail is fine.

## ***Nikles, David – Appendix G 10***

### **Appendix G 10.1: Award Review (TSE R826728)**

**EPA Contract Number:** R826728

**Program Type:** TSE

**Title:** Solventless, Electron Beam-Cured Acrylate Coating Formulations for Flexible  
Magnetic Media Manufacture

**PI:** David Nikles

**Email:** dnikles@mint.ua.edu

**Unversity:** University of Alabama

**EPA Contact:** April Richards

**Project Duration:** 10/ 1/1998 – 9/30/2001

**Total Budget:** \$285,000

### **Background**

More than 600 kg of organic solvents are used per hour in the coating process of magnetic film in floppy disks. This has the potential of releasing 150 metric tons of solvent vapors into the environment per year. Most of these organic solvents are on the EPA's list of 189 air pollutants. Developing a new tape and floppy disk manufacturing process without the use of organic solvents would be cost effective and reduce the amount of air pollution emitted.

### **Objectives**

The goal of this project was to develop a solventless coating process for the magnetic film in floppy disks.

### **Methods**

A liquid acrylate monomer was used instead of an organic solvent to disperse the magnetic pigments and dissolve any other components. The acrylate polymerizes once an electron beam is shone onto it, causing it to become a solid binder. This binder has the required mechanical properties, so the first task is to identify the binder materials package that enables a solventless coating process. The researchers used a magnetic tape manufacturing process assuming that any results could be implemented in floppy disk

manufacture. The most challenging problem was to solve dispersion on the rheology of the dispersions

## **Results**

This research provided a way to manufacture floppy disks using acrylate formulations instead of organic solvents. It also demonstrated a way to incorporate this into current manufacturing processes. Through a series of very complicated steps (laid out in the award report), he was able to produce fully pigmented, solventless acrylate formulations, which provided a film thickness of 1 micron or less. Once incorporated in industry, the new process will lower manufacturing costs in several ways. It will eliminate energy costs associated with drying, solvent recovery, and solvent recycling. This research should also get rid of the costs associated with complying with the Clean Air Act Amendments, Resource Conservation and Recovery Act, and Toxics Substances Control Act. The new tape will allow the industry to remain competitive, especially with growing markets for back-up storage for servers and electronic libraries.

## ***Sampath, W. S. – Appendix G 11***

### **Appendix G 11.1: Award Review (TSE R826119)**

**EPA Contract Number:** RD26119010

**Program Type:** TSE

**Title:** Microstructural, Morphological and Electrical Studies of a  
Unique Dry Plasma Metal Deposition for Printed Circuit Boards (PCB's)

**PI:** Sampath, W.S.

**Phone:** 970-491-8411

**Email:** sampath@engr.colost.edu

**University:** Colorado State University

**EPA Contact (PO):** Deborah Hanlon

**Project Duration:** 10/01/1997 – 9/30/2000

**Total Budget:** \$200,001

**Graduate Students:** Robert Enzenroth and others

### **Background**

The PCB industry is very large and resource intensive. Spent solvents, sludges, and wastewater containing metals are the main wastes produced by PCB manufacture. The industry is looking into using plasma for etching, due to environmental concerns with conventional processes. This is important research, as complying with environmental regulations can cost millions of dollars.

### **Objectives**

The goal of this project was “to conduct basic research for applying dry plasma metal film deposition to PCB manufacturing”. This process should reduce or eliminate liquid waste and reduce solid waste in the PCB manufacture process.

### **Methods**

This method utilizes subtractive techniques, rather than additive processes to reduce waste. A thin metalized layer was added to the bare PCB, which provided a conductive path. This was done using a unique air to vacuum to air sputtering process. The board was then drilled, electroplated, and flash etched.

## **Results**

“When deposited on a plasma cleaned or abraded interlayer, the sputtered film is adherent and survives the PCB manufacturing process”. Electroplating was done in local PCB shops, but there were adherence problems between the copper and nickel.

## **Conclusions**

If this process is successful, it “could reduce chemical etch waste by more than 99%”. Electroplating research is required to obtain an industrial grade product.

**Sommer Jr., Edward J. (National Recovery Institute Inc.)  
– Appendix G 12**

**Appendix G 12.1: Award Review (SBIR EPD04058)**

**EPA Contract Number:** EP-D-04-058

**Program Type:** SBIR

**Title:** Improving the Recyclability of Computer Scrap and Other E-Wastes.

**PI:** Ed J. Sommer, Jr.

**Small Business:** National Recovery Technologies, Inc. (NRT)

**Email:** ejsommer@nrt-inc.com

**Phone:** (615) 734-6410

**Project Duration:** April 1, 2004 through June 30, 2005

**Phase:** II

**Total Budget:** \$225,000

**Background**

Electronic waste (e-waste) is one of the most rapidly growing problems facing the world today. There is much to be gained through recycling electronics, as many of them are made of valuable engineered plastics. However, if these plastics are left unsorted, they have minimal value and usually cost more to recycle than the worth of the recycled material. Sorting polymers by type allows them to be reused in high-value applications, making them very profitable to waste processors. Current sorting technologies are slow and inefficient, which lead to low recycling rates. Through Phase I, NRT demonstrated that high-speed spectroscopic sorting technology could be developed.

**Objectives**

Design an e-waste processing facility, which will be used to test a prototype electronic waste sorting system and complete the development of Phase I technology.

**Methods**

NRT evaluated adapting the near-infrared (NIR) sorting system that it uses to sort packing plastics to electronics in Phase I. NRT feels that spectroscopic techniques can be

utilized to sort electronics. A complex description of how this works is included in the award report.

## **Results**

NRT successfully produced a recycling system for e-waste. It is currently in the final stages of development.



## **Appendix G 12.2: Interview**

**Name:** Edward Sommer

**Contact Info:** (615) 734-6400

**E-Mail:** ejsommer@nrt-inc.com

**Date Interviewed:** Wednesday, November 16, 2005

**Company:** National Recovery Technology Inc. (NRT)

**Type of Award:** SBIR (EPD04058)

**Title of Project:** Improving the Recyclability of Computer Scrap and Other E-Wastes

### **Can you tell us a little bit about how you became interested/involved in this field?\***

National Recycling Technologies (NRT) produces sorting equipment worldwide, specifically for plastics. High speed NRT machines sort plastics by characteristics, like color or polymer. Through effective sorting, plastics can be recycled and used again in other applications. NRT generally deals with packaging plastics, such as soda bottles, which are meant to be used only once. It has since shifted focus to electronics plastics, which are meant to be used more than once. Unfortunately, most electronics recycling programs only focus on metal, while plastics are either burned or put into landfills. NRT's goal was to find a way to sort electronic plastics so they can be recycled.

#### **1. What research did you perform under SBIR?**

Mr. Sommer's company developed an electro-optical device to sort electronics plastics by polymer. Additives, such as fillers, were also taken into account.

#### **2. Did you receive any additional funding? If so, from whom?**

Not yet. Mr. Sommer said that NRT is negotiating with several companies for additional funding.

**3. What is the potential for this project?**

This project has tremendous potential. It allows for a way to recycle and reuse more of the materials in electronic products. These plastics are very valuable, but not many companies recycle them. Sorting devices like these can be incorporated in existing electronics waste processing systems to sort plastics. The required infrastructure is not currently set up, but may be in the future.

**4. Did your work prompt any follow-up research or patents?**

Yes. As in any high tech machine, problems and glitches arose and required additional research to fix. Further research needs to be done to industrialize the device. A recycling factory is a completely different environment than a laboratory. A finished product would need to be able to deal with the dust, dirt, and movement associated with an industrial setting. There is a good possibility of patents being issued once the research is complete.

**5. Did you have any other business or industrial partners while performing your research?**

There are industrial partners, but they wish to remain private as of now.

**6. If so, what is the extent of their involvement?**

N/A

**7. If not, have any industries learned of your work? Have they implemented it or looked into using it?**

- If so, how are they going to incorporate the research into their processes
- Have you received any quantitative data?

Industries have learned of NRT's work and are actively pursuing partnerships with them. The electronics industry is responsible for billions of pounds of plastic waste which is being burnt or put into landfills. This plastic can range from \$0.25 to \$1.25 per pound. Some electronics waste management facilities are hand sorting plastics but this is time consuming and can be inaccurate. Industrial desire is there, but the infrastructure is not.

**8. What research are you currently working on (if NCER award is finished)?**

The award research is still in progress.

**9. Is there anyone else you feel we should contact?**

No

**10. Do you have any additional comments?**

**We plan on typing up this interview and e-mailing it back to you to make sure that your responses were accurately recorded. Can we contact you again if we have any other questions? Thanks for your time. Bye**

Yes

## ***Thomas, Valerie – Appendix G 13***

### **Appendix G 13.1: Award Review (TSE R829585)**

**EPA Contract Number:** RD829585

**Program Type:** TSE

**Title:** Electronic Tags for Product Environmental Management

**PI:** Valerie Thomas

**Phone:** (602)258-4665

**Email:** [vmthomas@princeton.edu](mailto:vmthomas@princeton.edu)

**University:** Princeton University

**EPA Contact (PO):** Barbara Karn

**Project Duration:** 1/1/2002 – 12/31/2005

**Total Budget:** \$340,000

**Graduate Students:** None listed

### **Background**

There is a lack of recycling opportunities for consumer products. Only a small number of products, such as lead acid batteries, automobiles, newspapers, aluminum and glass beverage containers, steel cans, and some plastic packaging have successful recycling programs. The use of information technology can make product recycling and lifecycle management easier and less expensive.

### **Objectives**

Dr Thomas's goal was to develop a system of tags for electronic devices. These tags were meant to facilitate recycling and reuse, along with providing data for lifecycle assessments. As a research tool, these tags could provide product distribution, consumption, use, and disposal statistics. Recycling and improper disposal numbers can also be compared. Very low cost tags will be flexible and printable.

### **Methods**

Dr. Thomas evaluated the tag and product compatibility to ensure that the tag would not interfere with the device and the device with the tag. She tried to monitor recycling electronically to track the device. The physical limits of the tags and readers

were then evaluated in complex environments. Field tests were done to determine the range of tag detection and which motoring methods proved the most accurate and efficient.

## **Results**

The research found that product bar codes are a commercially cost effective and simple way to manage waste and recycling operations. Identifying the contents of a waste bin using Radio Frequency Identification (RFID) tags works when the detectors are installed on the bin itself. Unfortunately, this method was found not to be commercially feasible. If the detector is placed on the garbage truck, however, the system becomes much more cost effective and can increase truck routing efficiency.

## **Conclusions**

Barcodes are already being used to enhance reuse, but standard bar codes are limited to products such as books, cell phones, and packaged goods. RFID tags are being used on trash bins in Europe to make waste collection more efficient and provide incentives for recycling. Both RFID and GPS could be used for recycling research and for destination verification of recycled materials.

## **Other References**

*Toward Trash that Thinks* in Journal of Industrial Ecology

*Product Self-Management: Evolution in Recycling and Reuse* in Environmental Science and Technology

*Towards Intelligent Recycling: A Proposal to Link Bar Codes to Recycling Info.* in Science Direct

## **Appendix G 13.2: Interview**

**Name:** Valerie Thomas

**Contact Info:** (404) 385-7254

**E-Mail:** [valerie.thomas@isye.gatech.edu](mailto:valerie.thomas@isye.gatech.edu)

**Date Interviewed:** November 29, 2005

**College:** Georgia Institute of Technology

**Type of Award:** TSE

**Title of Project:** “Electronic Tags for Produce Lifecycle Management”

### **Can you tell us a little bit about how you became interested/involved in this field?\***

Dr. Thomas is currently an Associate Professor at Georgia Institute of Technology in the School of Industrial and Systems Engineering and School of Public Policy. She works in industrial ecology, which considers using material, energy, and recycling more efficiently in the long-term. Dr. Thomas found that recycling is very limited and people are going to need “help” to expand it. The goal of this research was to develop a way for a product to help its owner recycle it. Dr. Thomas wanted to attach information technology to electronics products. Barcodes are a good example of this, as they are used by manufacturers and retailers. She wanted to continue this connection to the consumer.

#### **1. What research did you perform under P3/TSE?**

Dr. Thomas started by gathering information about incorporating technology into waste management practices. Radio Frequency Identification (RFID) tags were considered, since manufacturers were already looking into implementing them to manage products. Dr. Thomas thought she could “piggy back” this idea and add environmental benefits.

Dr. Thomas felt that this research could help consumers recycle more electronics products. The barcodes added to the electronics products corresponded to online

dismantling and recycling instructions. When a product was ready to be recycled, instructions could be found and it could be properly disposed.

She found that products could be tracked after disposal using GPS Technology. This method is not completely successful, as metal in trash interferes with the GPS signal. In addition, GPS locators are very expensive. Dr. Thomas also attempted to track products using radio transmitters, but found that the range was too short for them to be practical.

**2. Has your research created any change in:**

- your course syllabus?
- the school curricula?

If so, how long have you taught the lecture and what is the average number of students per class?\*

No, not yet.

**3. Did you collaborate with any faculty outside your department or institution?**

Dr. Thomas is collaborating with faculty in the School of Management at Georgia Tech.

**4. Did you receive any additional funding? If so, from whom?**

Yes, Dr. Thomas received start-up funds from Georgia Tech.

**5. What is the potential for this project?**

Waste management techniques can efficiently route trucks for pickup, if they know what kinds of products a household is disposing of. Dr. Thomas felt that a tracking device to monitor this would help immensely. Consumers would recycle more, if there was an easy and convenient way to do so.

**6. Did your work prompt any follow-up research or patents?**

Yes, Dr. Thomas is doing follow up research (See Number 13).

She did not receive any patents for this research, but Motorola did make an intellectual property disclosure. An Austrian company, Ecotronics, is using similar cell phone recycling methods

**7. Did you have any industrial partners while performing your research?**

Yes, Dr. Thomas had several industrial partners. Motorola contributed data in the area of cell phone recycling. A German company, Mobile Automation (MOBA), was involved in waste disposal logistics. Oxloc, located in Oxford, England made the GPS locators.

**8. If so, what was the extent of their involvement?**

See number 7

**9. If not, have any industries learned of your work? Have they implemented it or looked into using it?**

- If so, how are they going to incorporate the research into their processes
- Have you received any quantitative data?

N/A

**10. How many students were funded by the award?**

2

**11. Are there any graduate students that you would recommend talking to about how this research has affected their careers?**

Yes, Dr. Thomas recommended Audrey Lee, who completed her PhD at Princeton in Electrical Engineering and Steven Saar, who is currently working at Intel.

Audrey Lee: [jalee@princeton.edu](mailto:jalee@princeton.edu)

Steven Saar: [ssaar@alumni.princeton.edu](mailto:ssaar@alumni.princeton.edu)

**12. Is there anyone else you feel we should contact?**

No



**13. What research are you currently working on (if NCER award is finished)?**

Dr. Thomas is currently working on a follow up project at Georgia Tech. Oxloc has made improvements to GPS locators, which will be used for further research. Dr. Thomas is also collaborating with Claudia Binder, a Swiss researcher at ETH Zurich. They will look at the benefits of using RFID for waste management in Switzerland and the US.

Ideally, Dr. Thomas would like her research to be included in policy options or proposals and maybe even be used by EPA. She knows that more work needs to be done to explore what is feasible and cost effective for recycling in the short-term.

**14. Do you have any additional comments?**

Dr. Thomas feels that we should apply her research to specific things. For example, if the state of Georgia recycled x pounds of used electronics, it would impact the environment this way and industry this way. Dr. Thomas would also like a copy of our report.

**We plan on typing up this interview and e-mailing it back to you to make sure your responses were accurately recorded. Can we contact you again if we have any other questions? Thanks for your time. Bye**

## **Warner, John C. – Appendix G 14**

### **Appendix G 14.1: Award Review (P3 SU831894)**

**EPA Contract Number:** SU 831894

**Program Type:** P3

**Title:** Photocrosslinked Immobilization of Polyelectrolytes for Template Assisted Enzymatic Polymerization of Conjugated Polymers

**PI:** John C. Warner  
john\_warner@uml.edu  
(978) 934-4543

**University:** University of Massachusetts Lowell

**Phase:** I

**Project Duration:** September 30, 2004 through May 30, 2005

**Total Budget:** \$10,000

### **Background**

Electronic products rapidly become out of date and in many cases, are not properly disposed of. As a result, millions of tons of toxic waste are generated by the electronics industry every year. New environmentally friendly manufacturing processes are being researched around the globe. These new technologies will provide new jobs, decrease shipping costs, and provide extraordinary environmental benefits.

### **Objective**

The goal of this project was to develop an environmentally friendly way to pattern substrates with conductive polymers. It was the aim of this project group to synthesize intrinsically conductive polymer films of a conjugated polymer on a photoelectrolyte template that is immobilized on a substrate through photocrosslinking.

### **Methods**

The electrical properties of conjugated polymers can be manipulated, changing their physical and chemical properties and making them possible alternatives for metals and semiconductors. Quantitative assessments of the effects of polymer molecular weight and composition of small molecules onto the polymer surface were done. The similarity of vinylbenzylthymine to conventional substances was also tested.

## **Results**

In the first stage, the research group found that they could control the properties of the films. In stage two, it was demonstrated that conductive polyaniline could be synthesized using photocrosslinking.

## **Conclusions**

The project goals were accomplished and the research was successful. By using green processes such as this, human and environmental concerns can be minimized. If applied this process would be more affordable than the conventional methods, and would not require the same clean up and remediation costs.

## **Appendix G 14.2: Interview**

**Name:** John C. Warner

**Contact Info:** (978) 934-4543

**E-Mail:** john\_warne@uml.ed

**Date Interviewed:** November 9, 2005

**College:** University of Massachusetts Lowell

**Type of Award:** P3

**Title of Project:** “Photocrosslinked Immobilization of Polyelectrolytes for Template Assisted Enzymatic Polymerization of Conjugated Polymers”

### **Can you tell us a little bit about how you became interested/involved in this field?\***

After graduating college, Prof. John Warner worked for Polaroid as an industry professional. He later helped create the twelve rules of green chemistry and was the co-author of the first green chemistry book. In 1996 he received a TSE award and is familiar with working with EPA.

#### **1. What research did you perform under P3/TSE?**

Prof Warner’s students worked on two separate P3 projects. Since both the projects were focused on chemistry, not engineering, they stood out against the rest of the P3 projects. Unlike the engineering projects, this chemistry based research was “removed from the product”. In other words, chemistry is used to make the materials used in industry by engineers. The projects he oversaw were designed to develop practical industrial solutions. He also mentioned that working with industrial partners early on in the development of these technologies can assist their implementation.

The first project developed a cost efficient way to lay down photoresist on printed circuit boards (PCB’s) without using organic solvents. He looked to nature, specifically skin cells, and mimicked the way two plus two naturalization occurs. In nature, this process results in skin cancer, but when added to polymers it makes them soluble. When light was shined onto a piece, through this substance, a polymer

pattern was left behind. After this pattern set, the PCB was dipped into an enzyme bath. The enzyme adhered to the polymer creating a conductive pattern on the PCB. This process requires no organic solvents or other toxic materials. The group successfully demonstrated this process on small and large scales. This is an important breakthrough, but may take five to seven years for it to be used in industry.

Prof. Warner's second project developed a method of using organic molecules and proteins in the production of metal oxide semiconductors. The project compared metal oxide semiconductors, to bones. They are both structured the same way, but semiconductors require much higher temperatures, up to 500°C, to form. Using Prof. Warner's research, a semiconductor can be made at room temperature, saving large amounts of energy. While testing was successful, this method must undergo further testing and is not a drop in replacement for current processes. Similar techniques have been used to remove toxins from drinking water. Both of these projects look to nature as a teacher on how to make materials.

**2. Has your research created any change in:**

- your course syllabus?
- the school curricula?

If so, how long have you taught the lecture and what is the average number of students per class?\*

Prof. Warner oversees seventeen graduate students. He believes that research and teaching are one and the same. His students' research is integrated into his class through weekly presentations and occasional test questions on it. Each student is required to go to a K – 12 school and give a monthly talk about their research.

**3. Did you collaborate with any faculty outside your department or institution?**

Yes, quite a bit

**4. Did you receive any additional funding? If so, from whom?**

Prof. Warner indirectly received additional funding towards his projects. All of his projects focus on green chemistry, so the funding he receives goes towards the same goals. He disperses the funds where needed.

**5. What is the potential for this project?**

The first project had the potential replace organic solvents with less toxic substances in PCB manufacture. This could create safer work environments and reduce both hazardous waste emissions and cleanup related to conventional processes.

The second project has the potential to considerably reduce energy inputs in semiconductor manufacture. Other applications include water purification in third world countries.

**6. Did your work prompt any follow-up research or patents?**

No patents were filed by the actual research. Some were filed on the background principles and ideas of this research before the P3 began.

**7. Did you have any industrial partners while performing your research?**

No.

**8. If so, what was the extent of their involvement?**

N/A

**9. If not, have any industries learned of your work? Have they implemented it or looked into using it?**

- If so, how are they going to incorporate the research into their processes
- Have you received any quantitative data?

While the students were very successful in accomplishing their goals, industry is not ready to implement this research quite yet. The next step is to find industrial partners, who can assess the feasibility of incorporating it into the manufacturing process. Prof. Warner feels that ten percent of existing materials can be replaced with benign alternatives now. Thirty percent could be replaced if industrial processes themselves changed. In his view, seventy percent of materials and the corresponding manufacturing processes need fundamental changes to be environmentally friendly. His work focuses on these fundamental material changes.

**10. How many students were funded by the award?**

17

These students were all aware of other research being conducted and weekly progress reports were required. They also helped each other, for example ten students took a weekend to assist one of their classmates with a project.

**11. Are there any graduate students that you would recommend talking to about how this research has affected their careers?**

If we have specific questions, Mr. Warner said he would be happy to set us up with a graduate student to answer them.

**12. Is there anyone else you feel we should contact?**

Graduate students can be consulted if there are any further questions.

**13. What research are you currently working on (if NCER award is finished)?**

Prof. Warner is currently researching the use of enzymes to reverse the crosslinking process. Certain substances become solid when ultraviolet light is shined on them. A specific enzyme is the only way to reverse this process. If a product was made from this substance, the substance itself could be easily removed and recycled using an enzyme.

The first enzyme used was found in E-coli, but it proved thermally unstable. Microbes from the ocean, similar to E-coli, are now being considered. This type of research may lead to very effective reuse and recycling methods that do not produce hazardous waste.

**14. Do you have any additional comments?**

No

**We plan on typing up this interview and e-mailing it back to you to make sure your responses were accurately recorded. Can we contact you again if we have any other questions? Thanks for your time. Bye**

Yes



## ***Wijmans, J. G. (Membrane Technology and Research Inc.) – Appendix G 15***

### **Appendix G 15.1: Award Review (SBIR 68D70051)**

**EPA Contract Number:** 68D70051

**Program Type:** SBIR

**Title:** Recovery of Perfluoroethane from Chemical Vapor Deposition Operations in the Semiconductor Industry

**PI:** Dr. J.G. Wijmans

**Email:** [wijmans@mtrinc.com](mailto:wijmans@mtrinc.com)

**Small Business:** Membrane Technology and Research, Inc. (MTR)

**Phone:** (650) 328-2228

**EPA Contact:** Mr. Marshall Dick

**Project Duration:** 9/ 5/1997 – 9/5/1999

**Phase:** Completed Phase II

**Total Budget:** \$225,000

### **Background**

Perfluorocarbons, specifically  $C_2F_6$  are used in the semiconductor industry for cleaning chemical vapor deposition (CVD) chambers. While this gas is released only in small quantities, it is a very powerful greenhouse gas.  $C_2F_6$  has an atmospheric lifetime of at least 10,000 years and a global warming potential (GWP) 13,500 times that of carbon dioxide. A typical semiconductor facility will release 10,000 to 50,000 lbs of  $C_2F_6$  into the atmosphere per year from CVD chamber cleaning. In the early 1990's EPA formed a voluntary partnership with the semiconductor industry to reduce  $C_2F_6$  other greenhouse gas emissions.

MTR proposed that emissions could be reduced by reusing and recycling  $C_2F_6$  gas through membrane separation. Phase I research showed how membranes can be used to concentrate  $C_2F_6$  and other PFCs. The concentrated gas is recovered through a condensation step. In Phase II, MTR wanted to build a demonstration system, which could be used at a semiconductor company. A company that focuses on the development and commercialization of semiconductor equipment will host the testing.

## **Objectives**

To develop an innovative membrane separation process to recover at least 95% of the  $C_2F_6$  used in CVD chamber cleanings.

## **Methods**

Two subsystems would be applied: a nitrogen/ $C_2F_6$  separation system and a  $C_2F_6$  liquefaction system. The separation system should increase the  $C_2F_6$  concentration in the off-gas, while the liquefaction system would recover the  $C_2F_6$  as a liquid. This can only occur if the concentration levels reach the desired levels for condensation (70 – 80%).

A membrane material with high nitrogen permeabilities and nitrogen/ $C_2F_6$  selectivities was identified. The most applicable membrane materials would be scaled up and tested. An analysis of the recovery process would be performed.

## **Results**

Eight potential membranes demonstrated high nitrogen permeabilities and were tested. Two of these met the necessary performance objective of showing high nitrogen/ $C_2F_6$  selectivities. Several problems occurred since the low permeability of the membrane caused the module separation to be very susceptible to imperfections in both the membrane and module. Strong flow distribution in the feed channels is imperative since this application required the module to operate at a high stage-cut. Once these issues were resolved, an effective selectivity was achieved at stage-cuts of over 90%.

## **Conclusions**

An economic analysis was done, which showed that  $C_2F_6$  recovery is economically feasible and can reduce hazardous emissions. Unfortunately in 1999, the electronics industry moved away from using  $C_2F_6$  in CVD chambers, therefore, this research became inapplicable and the planned scale-up testing did not take place. This

work was successful in developing a high-performance thin-film composite membrane to separate and recover  $C_2F_6$ .

## **Wong, C. P. – Appendix G 16**

### **Appendix G 16.1: Award Review (TSE R831489)**

**EPA Contract Number:** R831489

**Program Type:** TSE

**Title:** Environmentally Benign Lead-Free Electrically Conductive Adhesive for  
Electronic Packaging Manufacturing Processing

**PI:** C. P. Wong

**Phone:** (404) 894-8391

**Email:** [cp.wong@mse.gatech.edu](mailto:cp.wong@mse.gatech.edu)

**University:** Georgia Technology Research Corp.

**EPA Contact (PO):** Diana Bauer

**Project Duration:** 12/22/2003 – 12/21/2006

**Total Budget:** \$345,000

**Graduate Students:** None listed

### **Background**

The increasing use of tin-lead solders in electronics manufacturing is a serious environmental concern. Lead is one of the top 17 chemicals that pose the greatest threat to human health and the environment. Most metal replacements to tin-lead solder have higher melting points and cost more to manufacture. In addition, many of these replacements are mined with lead, partially defeating the purpose of moving away from the tin-lead solder.

### **Objectives**

Dr. Wong wants to develop a low cost electrically conductive adhesives (ECA's) to replace lead solder.

### **Methods**

Research was done on the corrosion behavior of ECA joints on various metals, and the correlation between corrosion behavior and electrochemical potentials on various metal surfaces. Dr. Wong developed a mechanism of corrosion control by cathode protection and assessed the role of sacrificial anode materials in the joints. He found reworkable and repairable resin binders in ECA's to reduce PCB and IC waste. This

should aid in understanding the thermomechanical failure of ECA joints. The performance of these ECA's can then be improved with conductive particles. Estimations for further energy savings can be calculated using variable frequency microwave curing.

## **Results**

Dr. Wong was successful in all areas of his research so far. His work produced an ECA, which is similar to tin-lead solder.

## **Conclusions**

Industry could adopt this technology for several applications, including chip mounting. Before this technology is more widely accepted, problems with low current density must be solved.

## **Appendix G 16.2: Interview**

**Name:** C.P. Wong

**Contact Info:** (404) 894-8391

**E-Mail:** [cp.wong@mse.gatech.edu](mailto:cp.wong@mse.gatech.edu)

**Date Interviewed:** November 17, 2005

**College:** Georgia Tech

**Type of Award:** TSE

**Title of Project:** “Development of Life Cycle Inventory Modules for Semiconductor Processing”

### **Can you tell us a little bit about how you became interested/involved in this field?\***

Dr. Wong worked for Bell Labs for 19 years in the field of telecommunication materials where he was elected an AT&T Bell Labs Fellow. In 1996, he became a professor at Georgia Tech and began conducting research on the material and processing of microelectronics through the National Science Foundation (NSF). He is currently a Regents’ Professor and the Charles Smithgall Institute Endowed Chair at the School of Materials Science and Engineering at Georgia Tech. Dr. Wong became interested in alternatives for microchip interconnects eight years ago.

#### **1. What research did you perform under P3/TSE?**

Dr. Wong is working on an alternative for lead solder, such as lead-free alloys and electrically conductive adhesives (ECA’s). Lead-free alloys, such as tin-silver or tin-silver-copper melt at higher temperatures than conventional lead solder. This not only requires more energy to use, but puts the components under higher thermal stresses. Tin-lead solder melts at approximately 183°C, but reflows at 230°C, while lead-free alloys melt at 217-221°C and reflow at 260°C. The ECA’s that Dr. Wong has been researching cure at 150°C.

**2. Has your research created any change in:**

- your course syllabus?
- the school curricula?

If so, how long have you taught the lecture and what is the average number of students per class?\*

Yes, for the past eight years Dr. Wong's research has been incorporated into his lectures. One is an undergraduate class entitled, "Material Design" and the other is a graduate level course on material use and the environment. These classes average about 12-25 students per year. The course syllabi of these lectures have changed in the past two years as more environmentally friendly materials have become available.

**3. Did you collaborate with any faculty outside your department or institution?**

Yes

**4. Did you receive any additional funding? If so, from whom?**

Yes. Funding was provided from the EPA, NSF, DOD, NASA, Intel, TI, National Semiconductor, Indium Corporation, and others.

**5. What is the potential for this project?**

This research has the potential to greatly reduce or eliminate lead from soldering processes.

**6. Did your work prompt any follow-up research or patents?**

Since the award is still in term, there has been no follow up research other than fixing problems that have arisen. Dr. Wong has received one patent, filed for an additional three, and expects more to come once his research is complete.

**7. Did you have any industrial partners while performing your research?**

Yes, Intel, TI, and National Semiconductor, Indium Corp.

**8. If so, what was the extent of their involvement?**

These companies allow Dr. Wong to use their facilities for testing, gave him materials to experiment with, and provided data helpful to his research.

**9. If not, have any industries learned of your work? Have they implemented it or looked into using it?**

- If so, how are they going to incorporate the research into their processes
- Have you received any quantitative data?

Yes, once it is complete, this research is going to be very applicable in industry.

Much of the industry is familiar with his work because ten magazines have published his results.

**10. How many students were funded by the award?**

7 students

**11. Are there any graduate students that you would recommend talking to about how this research has affected their careers?**

Yes, Grace Li. He provided her phone number

**12. Is there anyone else you feel we should contact?**

No

**13. What research are you currently working on (if NCER award is finished)?**

The research is not yet finished.

**14. Do you have any additional comments?**

Dr. Wong wanted us to contact him if we had any further questions. He also wanted to extend thanks to EPA for its funding. He feels funding of this nature has a great impact on educational training, student growth, and publicizing research.



**We plan on typing up this interview and e-mailing it back to you to make sure your responses were accurately recorded. Can we contact you again if we have any other questions? Thanks for your time. Bye**

Yes

# Appendix H: Graduate Student Interviews

## ***Li, Grace – Appendix H 1***

**Date Interviewed:** November 17, 2005

**Name of Graduate Student:** Grace Yi Li

**Contact Info:** (404) 894-8465

**E-Mail:** gtg973i@mail.gatech.edu

**Name of PI whom they worked with:** C.P. Wong

**College:** Georgia Tech

**Type of Award:** TSE

**Title of Project:** “Development of Life Cycle Inventory Modules for Semiconductor Processing”

### **1. How did you get involved in the P3/TSE research project with Prof. Wong?**

Grace Li is a third year PhD student. She joined Prof. Wong’s research group about two and half years ago and has been doing extensive research for the project ever since.

### **2. Did the project you worked on as a student prompt you to conduct further research in the same or similar area of study?**

- a. If so, what was the new research?
- b. Has any of your research been published?

N/A

### **3. What research are you working on now?**

Ms. Li is still doing research on this project only. She feels that it is going to be very applicable to the world in a few years, especially with the regulations the European Union is passing. She believes that developing a lead-free solder is going to be a worldwide effort. Electronic conductive adhesives (ECA’s) still have some problems, such as reliability, lower conductivity, and decreased current density. None the less, Ms. Li thinks that ECA’s will be the future of lead free solder.

**4. Did your work as a student influence your choice of profession?**

Yes, Ms. Li enjoys this work and sees a place for this technology in the future of industry. She hopes that being environmentally conscious will be part of her career.

**We plan on typing up this interview and e-mailing it back to you to make sure that your responses were accurately recorded. Can we contact you again if we have any other questions? Thanks for your time. Bye**

## ***Lin, Andy – Appendix H 2***

**Name of graduate students:** Andy Lin

**Contact Info:** 716-645-5033

**E-Mail:** flin4@eng.buffalo.edu

**Name of PI whom they worked with:** Li Lin

**College:** University of Buffalo

**Type of Award:** TSE

**Title of Project:** Material Selection in Green Design and Environmental Cost Analysis

### **1. How did you get involved in the P3/TSE research project with Prof. Lin?**

Mr. Lin has a MS degree in industrial engineering in China, and his thesis is about green computer aided process planning. He worked in industry for five years as a design engineer, which gave him a good background in material selection. When he came to the United States to get his PhD, he was recruited to work on this TSE by Dr. Lin. The research involved the environmental impacts of using different materials, which is similar to Mr. Lin's background.

### **2. Did the project you worked on as a student prompt you to conduct further research in the same or similar area of study?**

- a. If so, what was the new research?
- b. Has any of your research been published?

This research did not prompt Mr. Lin into any further research. His paper, "The Discussion of State of the Art Research on Environmentally Conscious Material Selection Methodology" was published in the Journal of Sustainable Design. He also gave a speech on environmentally conscious material selection methodologies for the reduction of product's toxic impact at the 2nd International Conference on Green and Sustainable Chemistry and 9th Annual Green Chemistry and Engineering Conference.

### **3. What research are you working on now?**

Mr. Lin is approaching graduation and is not conducting any research. He is currently writing dissertations and preparing for his final exams.

**4. Has your work as a student influence your choice of profession?**

Mr. Lin is aspiring to get a governmental or industrial job in China. China has a high rate of industrial growth and is trying to assess the impact of this development on the environment. Mr. Lin's focus is including green techniques into design and manufacturing processes.

**We plan on typing up this interview and e-mailing it back to you to make sure that your responses were accurately recorded. Can we contact you again if we have any other questions? Thanks for your time. Bye**

## Appendix I: Table of Impacts

Program	Principle Investigator (PI)	Small Business or University	Who is Affected	Completed	Impacts/Outcomes
P3	Reggie Caudill	New Jersey Institute of Technology	Recycling Industries	Yes	This research could potentially result in a consistent national method for recycling electronics. This method would be economically feasible and environmentally friendly.
SBIR	James DeYoung	MiCell Technologies, Inc.	Semiconductor Industry	No	Looking to the future to use CO <sub>2</sub> when the current technology is obsolete. CO <sub>2</sub> is a dry process and using it will save a lot of money in water consumption and cleaning. It is estimated that a large wafer FAB can use up to 11 million liters of ultra pure water per day when producing 200 mm wafers. This is expected to increase by 1.5 times when producing new 300 mm wafers. To put this in perspective, when making a 300 mm wafer, a large FAB is using as much water as a city of 60,000 people.

TSE	David Dornfeld	University of California at Berkley	Semiconductor Industry/Academics	No	<p><u>Industry</u>: will use this tool to assess the environmental impact of implementing new technology and become a part of the decision making process of industry and regulators.</p> <p><u>Academics</u>: Dr. Dornfeld teaches classes in semiconductor manufacturing. For the last three years he has been teaching a class on management of technology for the environment. This is a joint class involving business and management. He uses examples of his research to relate his teachings to real life. The class averages 20 students per year.</p>
TSE	Fiona M. Doyle	University of California at Berkley	Semiconductor Manufacturers	Yes	The research studied the effects of copper when present in semiconductor wastes. This grant hopes to create a foundation for development of commercial processes that can recycle both copper and water within a semiconductor fabrication plant.
TSE	Noah Hershkowitz	University of Wisconsin-Madison	Semiconductor Industry	No	This grant proposes substituting SF3 for CF4 in the etching process. CF4 has Global Warming Potential (GWP) of 5700 compared to 1 for CO2 and an atmospheric lifetime of 500-50,000 years compared to 50-200 for CO2. If this process is successful, it could reduce PFC (CF4) emissions by a factor of 7. Annual PFC and HPC emissions from the U.S. semiconductor industry are about 3 million metric tons of carbon equivalent, 15 to 20 percent from patterned dielectrics etching

TSE	Lester Lave	Carnegie Mellon University	Industry that use LCA (especially for environmental uses)	Yes	This research will provide the first LCA tool that is sufficiently cheap, quick, and reliable to be used generally. LCA information is crucial to informing public policy and private decisions regarding choices among competing materials, processes, products, use patterns, and end of life alternatives. It will be easily accessible through the internet.
TSE	Li Lin	State University of New York at Buffalo	Design Engineers	No	Creating a database of materials used in manufacturing (not limited to semiconductor industry) that includes the environmental impacts of each material if used. Using the relational database for materials, emission and toxicity, it provides invaluable decision support to design engineers in evaluating a product's environmental impact by minimizing its adverse effects to human health.
SBIR	Scott McCray	Bend Research, Inc.	Users of Isopropyl Alcohol and other solvents	Yes	Cost efficient way to recycle solvent – using the recycling would cost \$3.75/kg of dry IPA, where buying dehydrated IPA would cost \$4.00/kg. This would take 6.3 months to see a payback period after implementing this technology (see page 30 in grant write up).



TSE	Cynthia Murphy	University of Texas at Austin	Semiconductor Industry	Yes	<p><u>Industry</u>: If adopted, impact assessments can be used to predict and avoid negative results caused by new technologies. This is good for industry because they will be able to way the results of something before spending the money to implement it.</p> <p><u>Academics</u>: In the classroom (which we need to find out the size/years being taught), Ms. Murphy stresses that just because something is small does not mean that the materials to create it were small.</p>
TSE	David Nikles	University of Alabama	Floppy Disk Manufacturers	Yes	A magnetic tape coating line can release more than 150 metric tons of solvent vapors into the environment per year. This solventless manufacturing process will reduce the emissions to zero.
TSE	W.S. Sampath	Colorado State University	Printed Circuit Board Manufacturers	Yes	This grant's research has the potential to reduce chemical etching waste by more than 99%.
SBIR	Edward Sommer	National Recovery Technologies, Inc.	Recycling/Manufacturers	Yes	From the NCER website, this grant has estimated that there will be almost 7 billion tons of plastics from e-waste available for recycling by the year 2007, representing a potential market value of almost \$3.6 billion to the recycler.
TSE	Valerie Thomas	Princeton University	Recyclers	No	The research under this grant, proposes using bar codes to facilitate the reuse and recycle of electronics. As far as a research tool these bar codes could provide product distribution data, consumption, use, and disposal statistics, along with recycling compared to improper disposal numbers.

P3	John Warner	University of Massachusetts at Lowell	Printed Circuit Board Manufacturers	Yes	The research done under this grant had the potential to replace using organic solvents with less toxic substances. This could create safer work environments and reduce both hazardous waste emissions and cleanup related to conventional processes.
SBIR	J.G. Wijmans	Membrane Technology and Research, Inc.	Semiconductor Industry	Yes	In 1997 when this grant was awarded, C <sub>2</sub> F <sub>6</sub> emissions from the CVD chamber were very high. This grant proposed a membrane that would recover the C <sub>2</sub> F <sub>6</sub> . In 1999, the industry moved away from using C <sub>2</sub> F <sub>6</sub> , so this is inapplicable. It would have recovered 70-80% of the 10,000 – 50,000 pounds of C <sub>2</sub> F <sub>6</sub> emitted per year by a typical semiconductor facility.
TSE	C. P. Wong	Georgia Institute of Technology	Electronic Packaging Manufacture	No	This grant would reduce or eliminate lead by using lead-free solders or electrically conductive adhesives (ECA). Total replacement of tin-lead solder has the potential of reducing the US lead consumption by as much as 10% in short term. In addition, using ECAs instead of alloy solders decreases the reflow temperature by more than 60% in electronic packaging manufacturing. This represents a significant energy saving for the electronics industry, which will have a positive impact on the environment.