Full Cost Accounting Case Study: Semiconductor Fabrication Facility

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Introduction

Environmental management systems are becoming essential tools for maintaining environmentally responsible production and maintaining a competitive edge in waste management and efficiency. Full cost accounting is a valuable element within environmental management, and this case study investigates a semiconductor facility's current environmental management system and potential full cost accounting applications. The facility's main environmental issues are concentrated in chemical accounting, environmental performance measurements, community perception and accurate cost evaluations. Environmental performance over time is difficult to characterize because of changing production volumes, products, technologies and manufacturing equipment.

Facility Background

In October 1998, representatives from Carnegie Mellon's Green Design Initiative visited a semiconductor fabrication facility to investigate their operations and environmental management system. The facility manufactures a variety of semiconductors, memory and logic chips, each of which have their own individual manufacturing recipe of specific processing steps. Current operations include waste management tracking, chemical accounting and foundations for detailed full cost accounting. While the facility has a detailed environmental management system in place, the environmental managers are concerned with several additional issues such as environmental assessments of manufacturing, community perception of industrial wastes and uncertain production costs for each chip. Government and corporate book keeping requirements for the facility currently consume a significant amount of time.

Industrial Waste

With approximately 44,000 pounds of chemical input per day, the facility has the potential to have a variety of impacts to its local environment. However, the facility has developed an extensive waste management and recycling system on site to minimize the potential impacts of their manufacturing on the environment. Each day, approximately 1000 pounds of waste are directly released into a nearby river and 200 pounds of chemicals are released to the air. On-site recycling accounts for 7,000 pounds of waste each day. However, the on-site wastewater treatment system processes the majority of the waste by treating approximately 36,500 pounds per day. The waste water treatment system discharges into the local river with contaminants 81% below permit levels. An accurate chemical mass balance (Error: +-3%) helped determine actual disposal costs, motivated the corporation to make the investment in the treatment system, and eliminated use of publicly owned treatment works. By processing waste on site, the facility reduces the risk of off site accidents which pose potential environmental and public relations problems. Although this extensive wastewater treatment system required a significant initial investment, the facility now spends only $500,000 in waste treatment and disposal annually.

Existing Chemical Accounting

The facility has a very thorough chemical management system in place. The system is used to manage the inventory of chemicals, determine which chemicals are appropriate for use on-site and assist in Toxics Release Inventory (TRI) reporting. Chemical waste tracking includes measurements of consumed pounds, volume reduction, toxicity reduction, and overall usage reduction. This program also indicated that even when the wafer size was doubled, chemical usage was still reduced.

The chemical management system requires careful review of all new chemicals in addition to materials safety data sheets (MSDS). Other required data includes safety, medical, air quality, waste treatment, hazardous waste and spill engineering reviews of chemicals. If a chemical passes all the reviews, it may be used in the manufacturing facility. A detailed mass balance of each chemical is kept to accurately track usage. These data are used for the annual TRI report.

Community right to know initiatives and TRI websites motivate the facility to reduce the chemical usage per product output. Since their 1988 debut TRI report, the facility has been more conscientious about chemical releases. Their actual TRI report for the EPA takes approximately 4-5 months of one person's time to compile the necessary data; the overall mass balance calculations appear to be the major time requirement. The facility now uses TRI data to heighten their awareness of chemical usage and to track their own emissions reduction progress.

Public perception of their reported TRI data is also a major concern for the facility. Web-based public right to know informants such as "Scorecard" (www.scorecard.com) provide easy access to facility specific TRI data. However, these data do not show trends over time, actual emissions relative to regulated maximum emissions, toxicity assessments with adequate explanations or breakdowns by releases and transfers. To better determine what TRI data indicate, an analysis of the facility's data was performed on all reported chemicals (See Appendix A: TRI Evaluation). TRI mass release data trends indicate that total releases to the environment have increased over the 1988-1995 reporting period, while air releases have decreased.

To enhance the analysis, a weighting scheme was applied to the mass release data. This scheme, the Carnegie Mellon University Equivalent Toxicity (CMU-ET)[1], applies a toxicity weighting based on Threshold Limit Values. The resulting relative toxicities of mass releases are expressed in equivalent pounds which can be compared from chemical to chemical. Weighting the facilities mass release data by relative toxicity shows that both the toxicity of total releases and air releases has decreased. Even though not all the mass release are decreasing, the toxicity trends are decreasing which is encouraging from an environmental perspective. However, communicating relative toxicity trends to the public is difficult. Therefore, strong public relations are important to maintaining the facility's good reputation in the community.

Facility and Industry Chemical Performance

To expand the TRI evaluation, a more refined analysis of the facility's TRI data was performed and compared to the total semiconductor industry (SIC 2674). Over the 1988-1995 period, the facility has a set of only three chemicals consistent from year to year. These chemicals (referred to as "core chemicals") are hydrogen fluoride, nitric acid and

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[1] Horvath, A; Hendrickson, CT; Lave, LB; McMichael, FC; Wu, T-S. "Toxic Emissions Indices for Green Design and Inventory." Environmental Science and Technology. Vol. 29, no. 2, pp. 86A-90A, 1995.

phosphoric acid. All three chemicals are used as wet etching agents in the semiconductor industry.

The core chemical analysis of the facility (See Appendix B: Core Chemical Facility Analysis) showed that the air releases were equal to the total releases for all eight years and no core chemicals were transferred off site. The semiconductor industry's data set for the chemicals shows varying air releases, total releases and transfers (See Appendix C: Semiconductor Industry TRI Analysis). Both the facility's and the industry's TRI reports fluctuate over the 1988-1995 time period with mass release numbers and CMU-ET equivalent pounds. The overall CMU-ET toxicity trends of both industry and the facility follow the same trends of their respective mass release numbers, indicating the overall ratios of the core chemicals remain the same over the eight year period. Interestingly, the inflection points in the trends are similar between industry and the facility for air releases and total releases (See Appendix D: Facility v. Industry TRI Trends). This is perhaps indicating that technologies and respective usage of core chemicals are related industry wide. There may be a correlation with the overall production or demands for semiconductors from year to year. Although the graphs are not identical, similarities in the overall curve do provide a case for a relationship between industry and facility usage of the core chemicals. However, the levels of core chemical usage are different. The facility's relative usage of core chemicals increases to an index above one, while the whole industry's usage decreases to an index below one. This evaluation indicates a similar usage patterns of core chemicals (overall trends) and differences in the relative usage levels of the core chemicals (index trends).

Potential Full Cost Accounting Applications

Full cost accounting would be a valuable tool for isolating environmental impacts and costs of manufacturing processes. The facility uses approximately 200-400 individual operations to produce a variety of chips. More detailed cost accounting within such a complex manufacturing facility could indicate operations with high overhead costs. Efficient management of these overheads could lead to substantial and immediate savings as over 1000 chips are introduced to the line each day.

The facility has a Value Added Operations Output (VAOO) model which helps to determine the material inputs and machine costs (including maintenance and floor space) of each fabrication step for each wafer. It does not include testing or verification steps which are not considered "value-added" processes. The VAOO model accounts for each automated tool or machine's operation in the manufacturing facility. This model is the potential foundation for a detailed full cost accounting system. Currently waste treatment and energy costs are still allocated to plant overhead costs, not to machines or VAOO. From a cost accounting perspective, it would be beneficial to expand the VAOO model to include:

- Machine cycle times
- Energy consumption for the cycle times
- Waste measurements and treatment costs
- Labor costs associated with each machine.

The inclusion of such information could better indicate where the process' time sinks are and where operations should be improved to make more efficient use of time and resources. This activity based accounting system can be justified by decreased cycle time and increased productivity and environmental safety. Furthermore, the system would help in estimating the actual cost of a chip by summing the prices of its VAOO items in its "recipe."

Additional savings can be found in several places. Currently, facility chemical use savings are only calculated by materials and chemicals not including labor savings. This leaves out the additional savings from handling time and reduced risk in the facility. Also, initial testing of wafers is done half way through the 90 day manufacturing period. If the facility experimented with various testing times earlier in manufacturing, they could isolate particular steps which tend to cause defects in a wafer. Finally, by having a better understanding of the overall manufacturing process, they can identify problematic areas, time sinks, and excess waste to improve the efficiency of the facility as a whole.

Challenges for Efficient Full Cost Accounting

Developing and maintaining an efficient and reliable full cost accounting system in the semiconductor facility is a challenging endeavor. Product inventory is difficult to track in a large facility with a 90 day production period. Specific product batches can be small, and tracking from value added step to step would have to be detailed and well documented. Also, overall production is sometimes estimated by revenues for a certain time period. However, there is a lag time with this type of data reporting which results in challenges for correlation of data sets. Staff knowledge and awareness of accurate and timely reporting can contribute to the success of a full cost accounting system. To maximize the environmental management system's potential, it is important to educate employees on how the system works and what it is trying to accomplish. Education should include specific information on data requirements, reporting systems and analysis. In a complex semiconductor facility, an exceptional number of variables can effect a full cost accounting analysis. Consistency in reporting these variables is key to error detection and meaningful correlation between data sets.

A full cost accounting system will not overcome all manufacturing challenges. It is important to note that this semiconductor facility includes a wide variety of over 200-400 value added operations, depending on the product. Therefore, it is not possible to maintain a clear, straight line process for each wafer introduced to the line. In addition to full cost accounting measurements, this complex system poses significant scheduling mathematics problems.

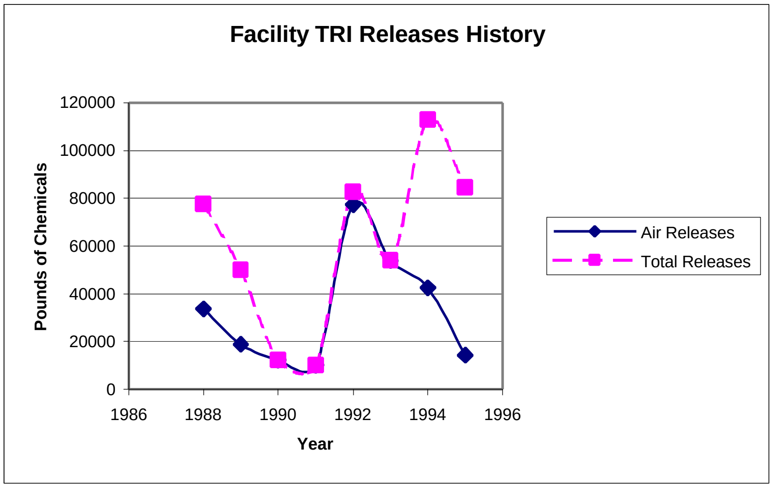
Conclusions

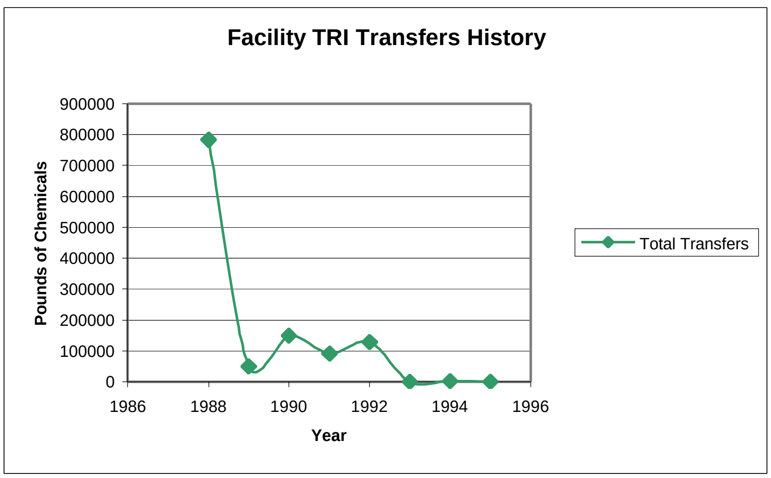
We focused on four main environmental issues: chemical accounting, cost evaluations, environmental performance measurements and community perception. The facility's current environmental management system is able to accurately report current chemical usage as indicated by a chemical mass balance. While the current manufacturing system works and is profitable, a more detailed cost analysis of the system would reveal potential savings. The foundations of detailed cost accounting analyses are evident in the Value Added Operation Output (VAOO) model. If resources could be allocated to developing the VAOO model, plant efficiency could be increased thus improving the bottom line for business purposes. The additional efficiency would also require less materials and energy, thereby reducing the environmental impacts of the semiconductor fabrication.

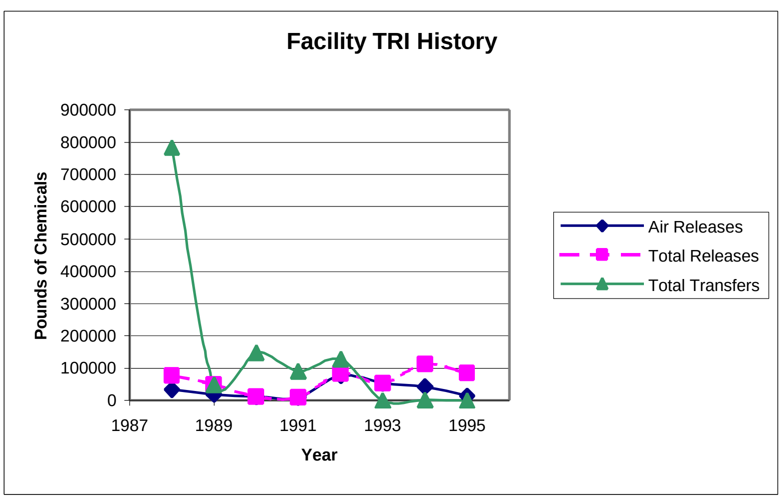
Major challenges will still exist in environmental performance measurements and community perception. Reliable environmental performance measurements are difficult to develop because data sets are compiled at different times and data analyses are not consistent enough to detect correlation. Community perception of the facility should be monitored, and corporate environmental reports, including facility versus industry comparisons, should be readily available for the public. This will assure that public has a complete picture of the facility's environmental performance.

Appendix A: TRI Evaluation

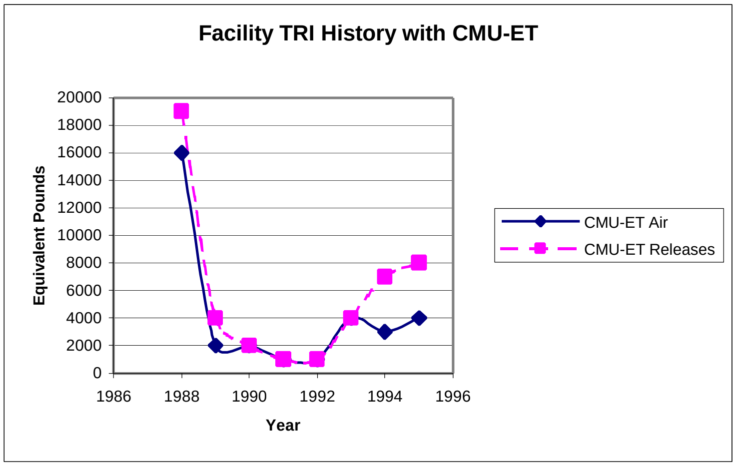
TRI Mass Release Trends

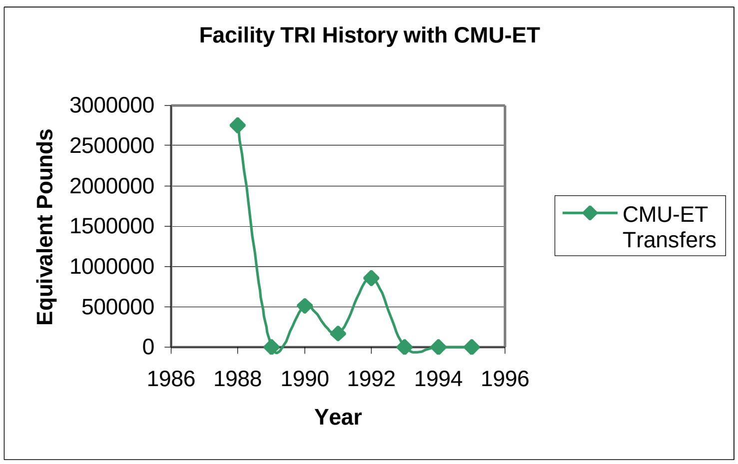


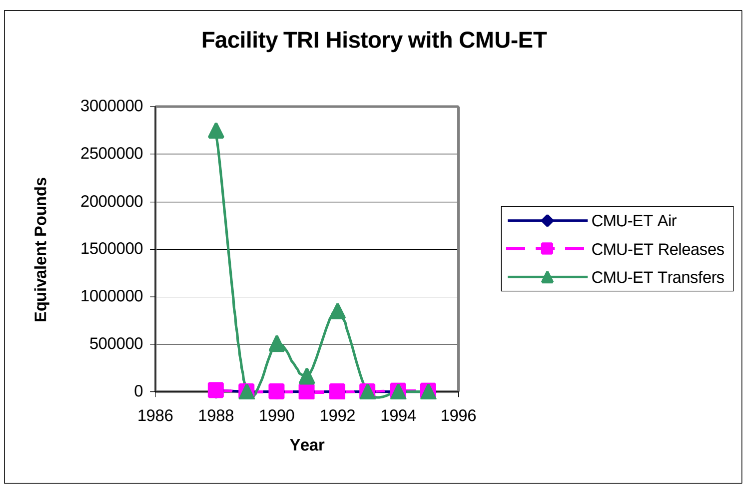




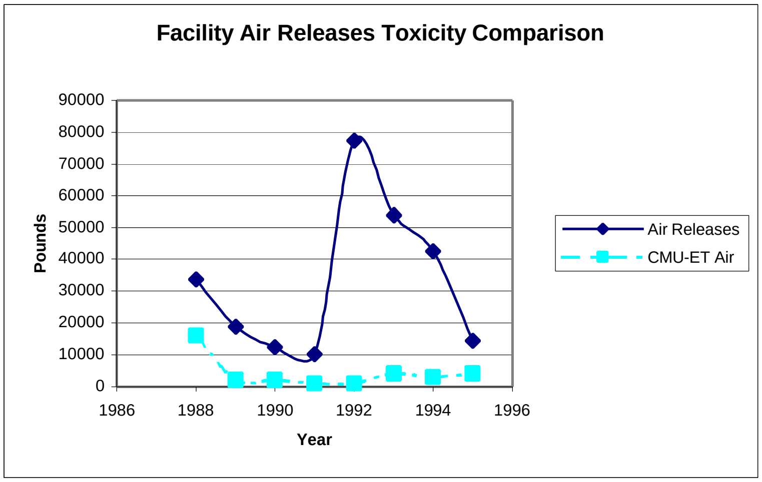
TRI Data Trends applied to the CMU-ET with Equivalent Pounds

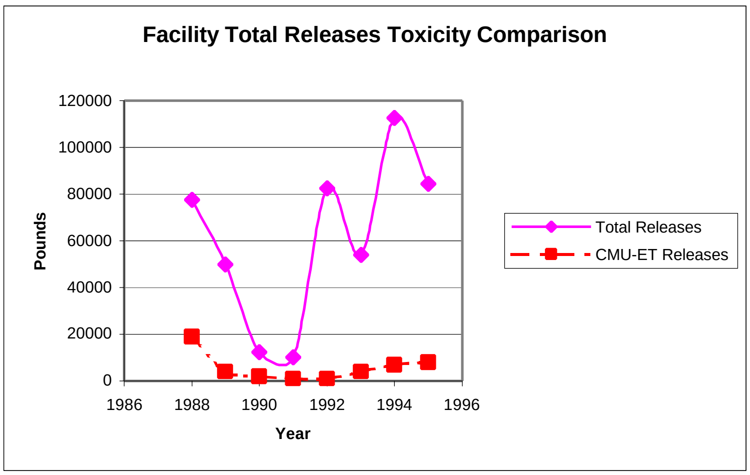


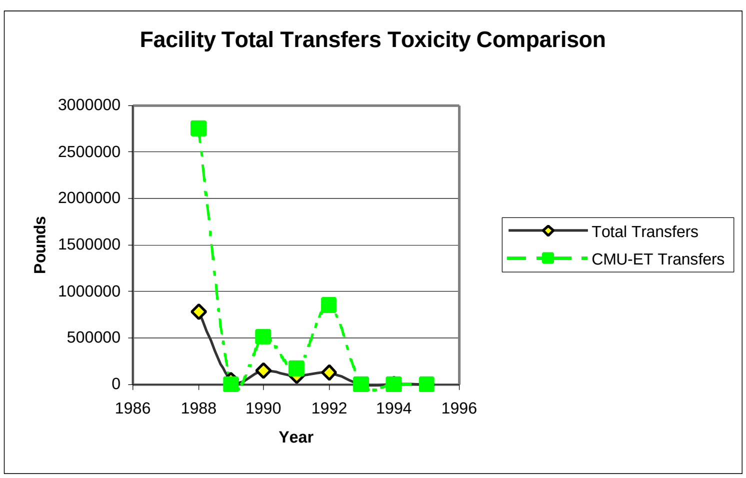




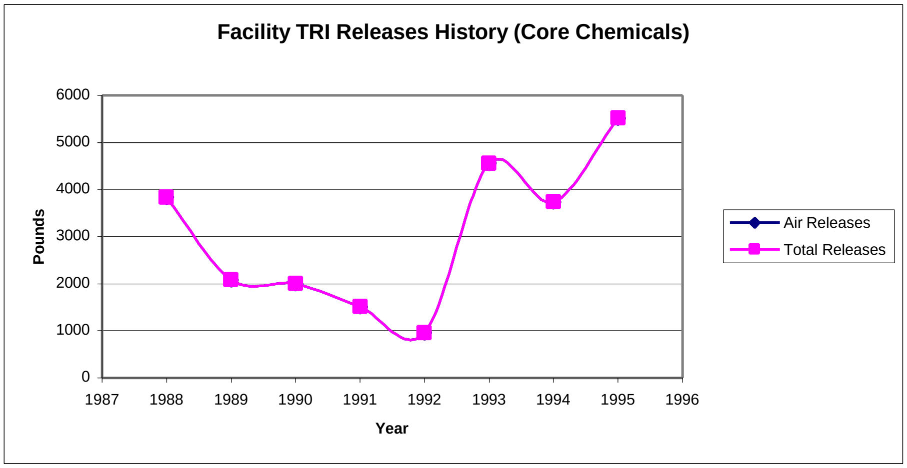
TRI Mass Release Data Trends compared to CMU-ET Equivalent Pound Trends

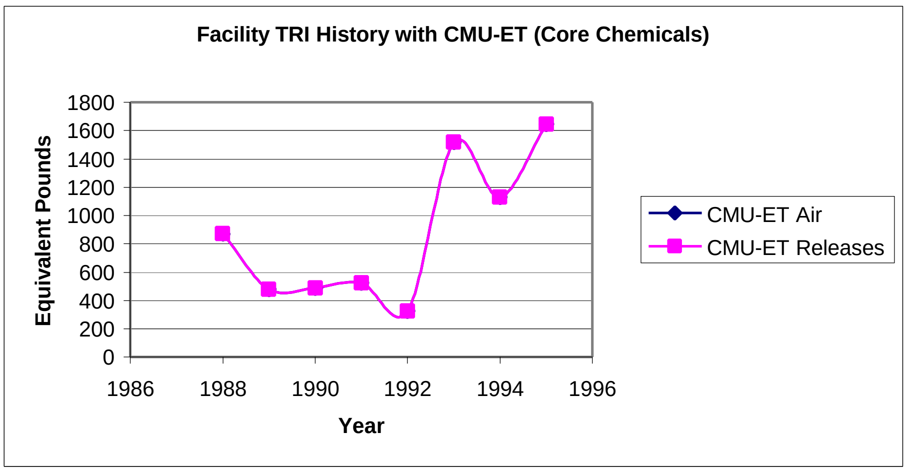


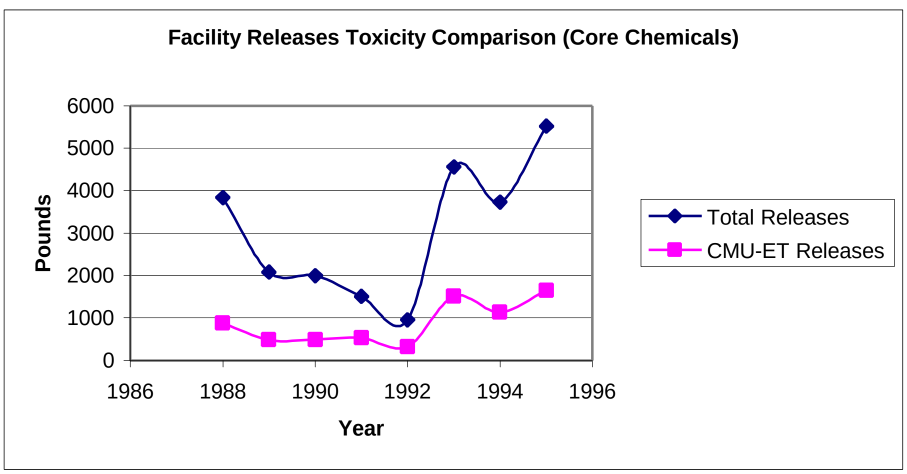




Appendix B: Facility Core Chemicals TRI Analysis

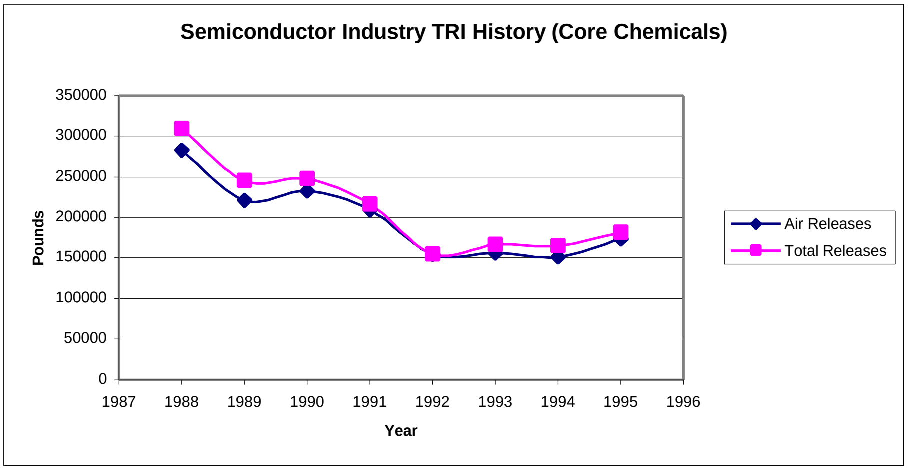


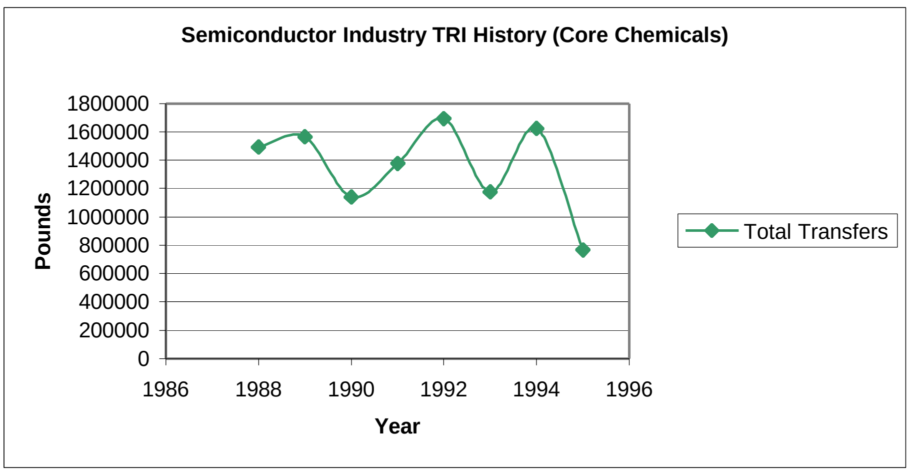


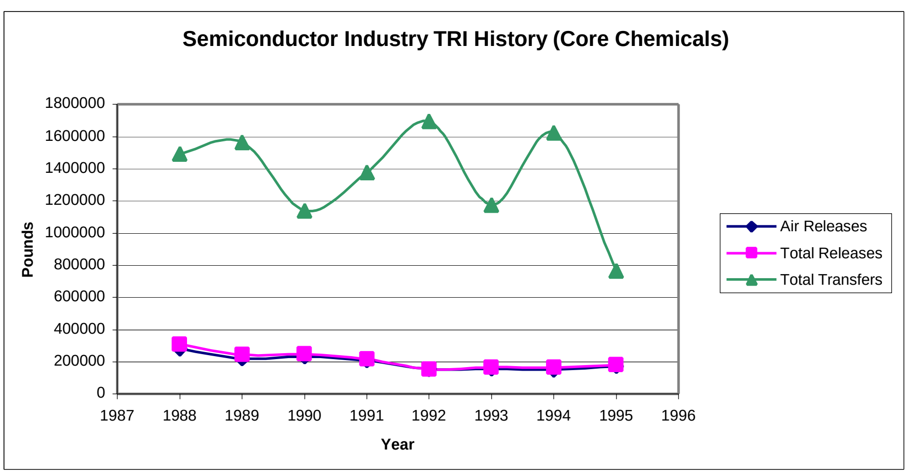


Appendix C: Semiconductor Industry TRI Analysis

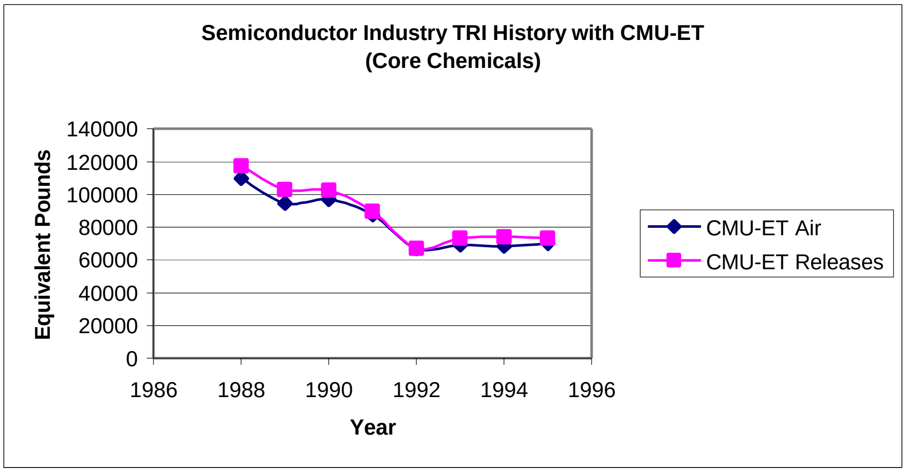
Mass Release Data Trends

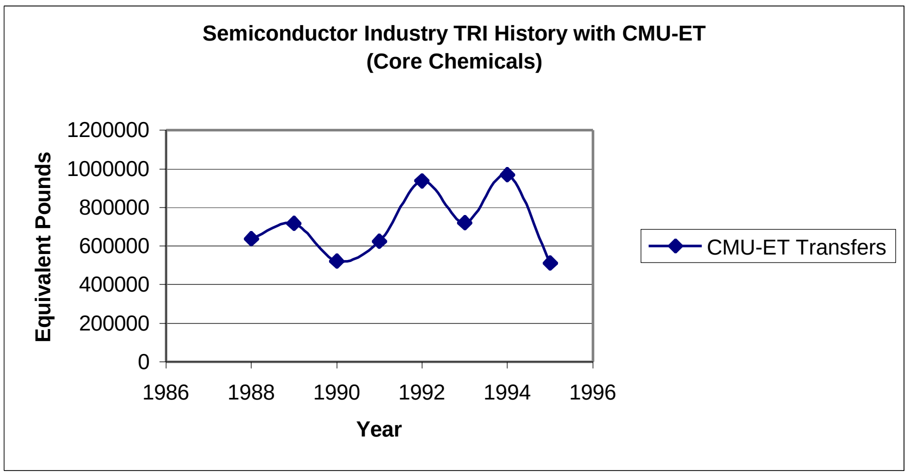




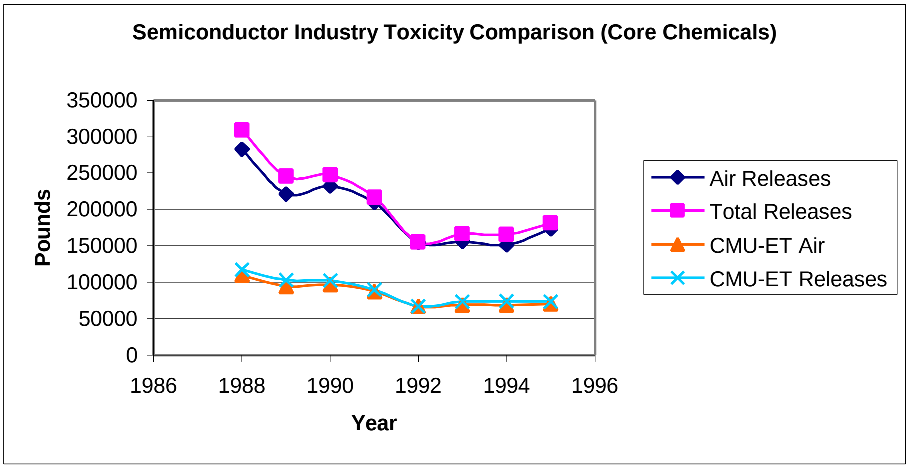


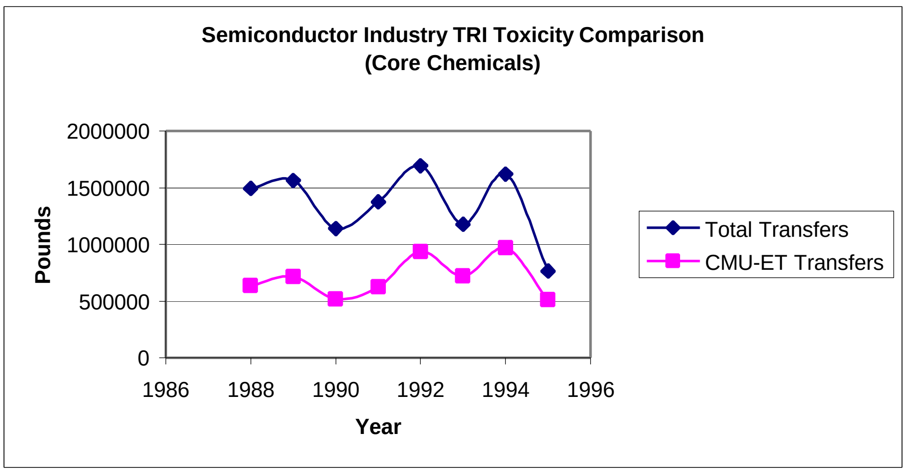
TRI Data Trends applied to the CMU-ET with Equivalent Pounds





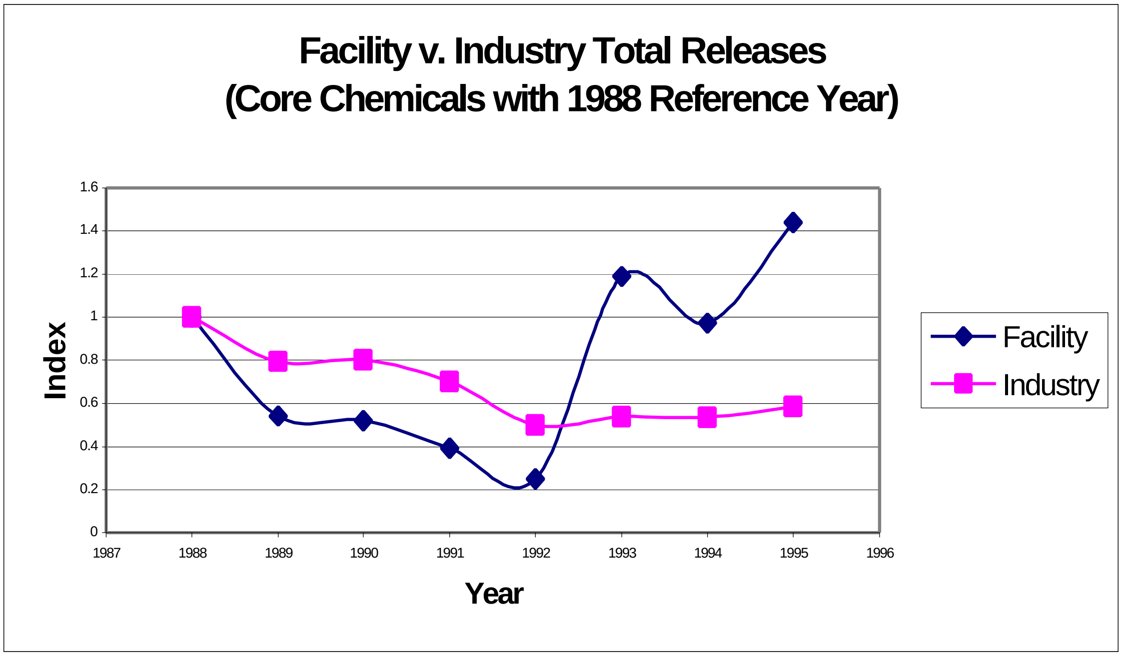
TRI Mass Release Data Trends compared to CMU-ET Equivalent Pound Trends





Appendix D: Facility v. Industry TRI Trends

Mass Release Data Comparison



CMU-ET Data Comparison