Project S116 Water Conservation
1994 Final Report

Technology Transfer 95042789A-ENG

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Abstract: This report provides and interprets the results of the assessment phase of the S116 water conservation project. It consists of the development, execution, and evaluation of a U.S.-based member company survey on water conservation and the development of an ultrapure water (UPW) cost model. The evaluation of survey data is limited to the interpretation of the survey responses; no attempt was made to perform a statistical analysis because of the limited sample. The status, issues, and opportunities in reclamation, recycle, and source reduction are discussed and recommendations are made. The data is presented in frequency and pareto charts for benchmarking purposes. The format, assumptions, and report capablities of the UPW cost model are discussed.

Keywords: Ultrapure Water, Cost Modeling, Facilities, Waste Treatment , Process Optimization, Cost of Ownership, Water Use Reduction

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I would also like to thank all the member company representatives for their time, patience, and perserverence in completing the survey.

1 EXECUTIVE SUMMARY

1.1 Introduction

This document is the final report of the 1994 water conservation project (S116) to assess the current status of water conservation in the semiconductor industry and determine future requirements. U.S.-based member companies were surveyed to determine regional and regulatory trends and establish the benefits, risks, and costs of water conservation. In addition, the project developed standard terminology and metrics including an Excel-based cost of ownership (COO) model for ultrapure water (UPW) systems.

1.2 Industry Survey

The industry survey assessed three key areas of water conservation: reclamation, recycle, and source reduction. Results indicated a high level of industry interest in water conservation with roadmap and cross functional team development at the division and corporate level and extensive activity in assessment and pilot projects at the site level.

Reclaiming utility and process wastewater for use in alternate applications (cooling towers, scrubbers, landscape) is widely practiced with recovery of 5 to 10% of the total water consumed by the facility. Reclamation opportunities are directly related to the facility location and the source water quality. Because the majority of the facility water usage (~70%) is associated with the wafer fabrication facility, greater reductions are possible with process water recycle and process optimization strategies.

Recycling process wastewater back to the UPW system has been implemented in 40% of the surveyed facilities, with recovery levels ranging from 30 to 70%. The systems are capable of producing high purity water with a return on investment (ROI) of four years or less. Although quality control and employee awareness programs have significantly improved system reliability, the systems are subject to infrequent but potentially catastrophic contamination. Opportunities exist for improved system design and purification components to maximize recovery and minimize risk with a critical need for online sensor technology to provide real-time detection of specific organic contaminants.

Industry activity in source reduction includes the optimization of both utility and wafer fabrication processes to reduce water consumption. Process optimization will increase as opportunities are identified by site assessment activities. However, changes in the fabrication process will be limited by the lack of comprehensive process characterization to determine the UPW volume and purity required by the the wafer rinse processes.

1.3 UPW Cost Model

The UPW COO model analyzes the total cost of acquiring, maintaining, and operating the UPW supply and distribution systems to estimate the cost in dollars per gallon to supply UPW to the wafer fabrication facility. The model evaluates the cost effect of various production and disposal options including reclaim and recycle. The cost model uses Excel 5.0 workbook and provides the user with the option of conducting a detailed or general cost analysis. It does not consider UPW system interaction to process tools, UPW purity level, or system capacity factors and assumes that the system is composed of a maximum of ten subsystems. The model uses input data on capital costs, operation costs, flowrate, and system maintenance and availability data to determine the value of the water produced by the individual subsystems as well as the total system cost. This feature is critical for the cost evaluation of various reclaim and recycle options.

2 INTRODUCTION

2.1 Industry Background

Recently, the domestic semiconductor industry has received widespread public attention as a major consumer of local water and wastewater services. This is due in part to the increasing number of semiconductor companies that are choosing to locate or expand facilities in the semiarid regions. Simultaneously, the total amount of water consumed in the wafer fabrication process is increasing. As processes are converted to accommodate larger wafers and smaller geometries, the water consumption rate is expected to increase. Additionally, the semiconductor industry anticipates increased water and wastewater fees and locally mandated water conservation. The overall result is an increase in wafer processing COO.

A proactive strategy for water conservation is crucial to satisfy future processing requirements in an environmentally conscious manner. An integrated strategy of water conservation including reclamation, recycle, and source reduction is necessary to significantly reduce water consumption.

Although current conditions have generated a high level of industry awareness and interest, limited information is available on the current level of water consumption and implementation of conservation strategies in the industry. In addition, communication on the issue is hampered by the lack of standard terminology and metrics for UPW and water conservation. This project was initiated in February 1994 to promote an industry dialogue on water conservation, to assess the current position, and to determine the future requirements of the semiconductor industry.

2.2 Project Development

The biannual SEMATECH Ultrapure Water Advisory meeting (February ‘94) and the SEMATECH/Semiconductor Safety Association (SSA) International Water Conservation forum (March ‘94) were used to establish the objectives, approach, and scope for the project identified in Section 2.2.1 and 2.2.2.

2.2.1 Objectives

Objectives included the following:

- Assess the current status of water conservation in the semiconductor industry, provide member companies with a benchmark, and determine the need for further research and development in the area
- Establish standard terminology and metrics for characterization of the cost and consumption of UPW in the semiconductor industry
- Provide an assessment of the benefits and risks of current water recycle purification systems
- Identify existing programs at universities and national laboratories with research and development activity in semiconductor water conservation

2.2.2 Scope and Approach

The scope of the project was limited to the assessment of the domestic semiconductor industry and the development of standard terms and metrics for the evaluation of water consumption and conservation. The scope of the project did not include assessment of foreign companies/sites or non-member companies. Although not within the scope of this project, it is recognized that the foreign semiconductor community maintains a considerable level of expertise in the area. Information from open forums and industry journals was considered during the development of the project.

The following approach was taken to complete the industry objectives:

- A survey of the domestic semiconductor industry was conducted to assess the current state of the industry and provide a benchmark for members. In addition, the survey would identify areas of opportunity for further research and development and establish a dialogue with universities and national laboratories active in the area. The survey scope was limited to domestic member company semiconductor sites.
- A computer-based cost model was developed to provide a standard method for determining the capital and operating costs for an UPW system. The model includes recycle and reclaim subsystems and allow customization for site-specific conditions and report costs in dollars per gallon. The model is based on the existing SEMATECH COO model. A set of standard terminology and metrics was developed and validated by the Project Technical Advisory Board (PTAB.)

3 INDUSTRY ASSESSMENT

3.1 Survey Development

The survey was developed to assess regional and regulatory trends; establish the benefits, risks, and costs of water conservation strategies; and identify key success factors. The survey was designed to consider industry activities in source reduction, water recycle, and reclamation with reference to facility indicators such as site location, facility size, and product. The survey was divided into the following four sections with each section comprised of approximately 25 questions.

3.1.1 Water Conservation

The Water Conservation section was designed to determine industry philosophy and current/future practices impacting water consumption, to include

- Corporate philosophy and commitment
- Future UPW and wafer processing trends
- Timeline for implementation of water conservation strategies

3.1.2 Facility

The facility section was designed to provide information on the location, facility, and product of the survey site. The information will be used to identify regional trends and relationships between water consumption rates and site indicators. It includes

- Regional information (e.g., weather conditions, utility rates, and local regulations). Respondents were asked to validate weather and utility information compiled in the SEMATECH Future Factory Design Facility Report: Roadmaps and Reports, Technology Transfer #93031528A-XFR.
- Facility information (e.g., size, design, and capacity specifications)
- Product information (e.g., wafer size, device structure, general process, and tool practices)

3.1.3 Water Reclaim

The water reclaim section was designed to determine current state of implementation, system design/operation strategies, recovery rates, and benefits/risks associated with recovery of water for use in an alternative process:

- Motivating factors
- System components, operating cost, percent recovery

3.1.4 Water Recycle

The water recycle section was designed to determine current state of implementation, system design/operation strategies, recovery rates, and the benefits/ risks associated with recovery of water for use in the original process:

- Motivating factors
- System components, operating cost, percent recovery
- Control strategies, sensors, protocol

3.2 Survey Execution

A person-to-person interview was conducted at all member companies with respondents from facilities and environmental and/or wafer processing organizations from 18 domestic member company sites. The sites were evenly distributed among the South, Northwest, Northeast and Rocky Mountain regions. The survey evaluated both small and large wafer fabrication facilities ranging from 8K–100K square feet of manufacturing area. The survey included sites producing device structures from 1.5 µm-0.35 µm in 5” to 8” (150–200 mm) wafer fabrication facilities. All data was collected and evaluated with respect to the confidentiality of the individual respondent’s site.

3.3 Survey Results

Because the survey sites were not selected in a purely random method and the number of sites surveyed is relatively small, a comprehensive statistical evaluation is not appropriate. The survey results and subsequent evaluation are interpretive rather than analytical. Conclusions drawn from this dataset evaluation are limited to the survey population and cannot be considered predictive of the industry as a whole. The dataset can provide instructive information on the frequency and relationships found within the survey sample and should prove useful in determining status and identifying areas of opportunity for water conservation in the semiconductor industry. The distribution of data was calculated and presented with standard frequency tables and Pareto charts for use in benchmarking. The complete set of frequency data tables and graphs and responses from 60 of the original 100 survey questions are presented in Appendix A. Further analysis was conducted using cross-tabulation tables to compare the specific dataset discussed in the appropriate section. The average response rate for the question set of 100 questions was 70%. A slightly lower response rate was noted on questions that addressed product indicators (e.g., wafer starts, device structures, and recycle system specifications).

3.3.1 Water Conservation

In our effort to reduce costs, conserve resources, and be good environmental stewards, industry has developed a great interest in and awareness of water conservation. Of the respondents, 90% indicated a high level of management commitment to achieving their water conservation goals. Although some companies have been active in various aspects of water conservation for the last decade, until recently few had adopted a commitment to water conservation as an integrated corporate philosophy. The majority of the sites surveyed are in the initial implementation stage of a comprehensive water conservation program that encompasses source reduction, water reclamation, and recycle. This initial stage is characterized by a high level of activity in planning, team development, and the assessment of existing operations. Over 70% of those surveyed indicated that water usage was documented throughout their facility, including the wafer fabrication area.

The assessment has resulted in changes to the operation and maintenance of UPW and utility systems to reduce water consumption. These changes include modification of regeneration and maintenance procedures, reclamation of high purity sample and instrumentation effluent, and increased efficiency of the reverse osmosis (RO) filtration systems. Of the sites surveyed, 80% have modified the process tool to reduce water consumption. Generally, this resulted in a 5 to 10% reduction in water consumption. These changes include implementation of automatic controls; reuse of overflow from quick dump rinsers (QDR) and flow restrictors, and reduced the idle mode flowrate. Although 20% of the respondents indicated that the implementation of the hot UPW rinse processes had reduced water consumption by 5 to 15%, less than 30% of the sites affected process changes to reduce water consumption. The relatively low rate of process change is due to the risk associated with changing process variables and the limited information on the quality impact of standard rinse process specifications. Further characterization of the rinse process and quality are critical to the implementation of water reduction measures at the tool and process level.

3.3.2 Facility

The regional location and source water quality of a facility has a direct impact on the water conservation opportunities available. Facilities located in arid and semiarid regions generally have greater cooling capacity and increased opportunities for reclaiming water. In addition, the source water quality can be a limiting factor in the application of reclaimed water.

There is a significant degree of variation in water/wastewater rates among the geographical regions, with municipal water rates ranging from $0.50/Kgal in the Western region to $2.44/Kgal in the Southern region. Municipal wastewater rates were higher on average than water rates and ranged from $0.60/Kgal in the Southwest to $3.58/Kgal in the South. Figure 1 illustrates the approximate water and wastewater rates for the regions included in the survey. The rate structure appears to be independent of a region's annual rainfall.

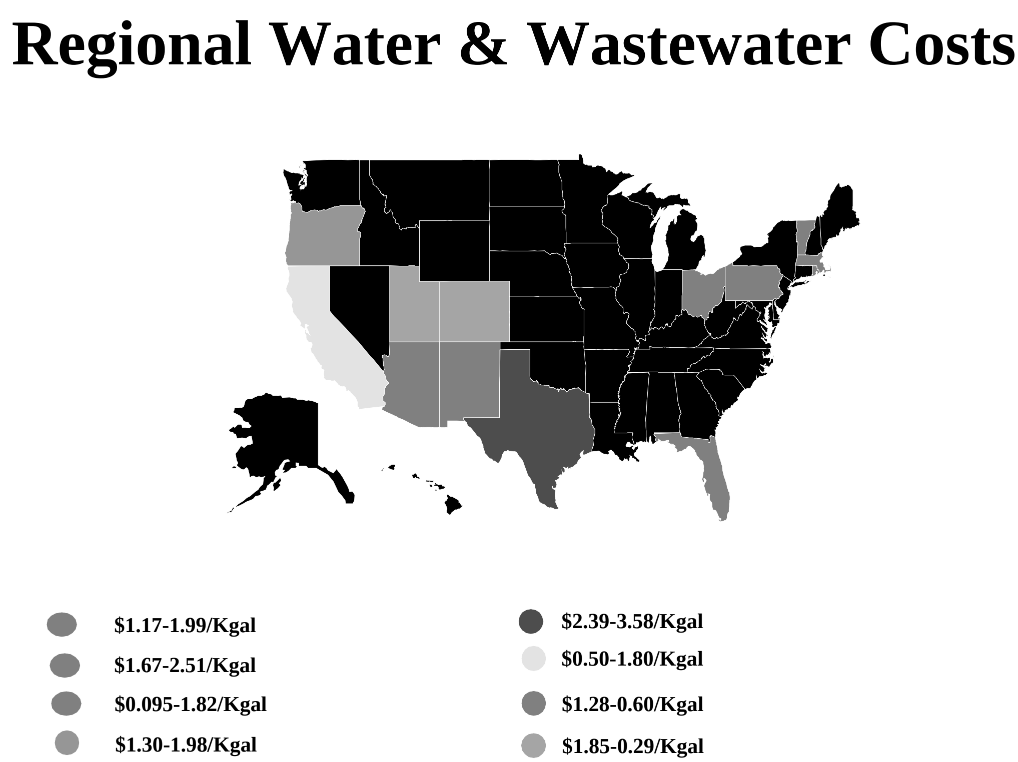
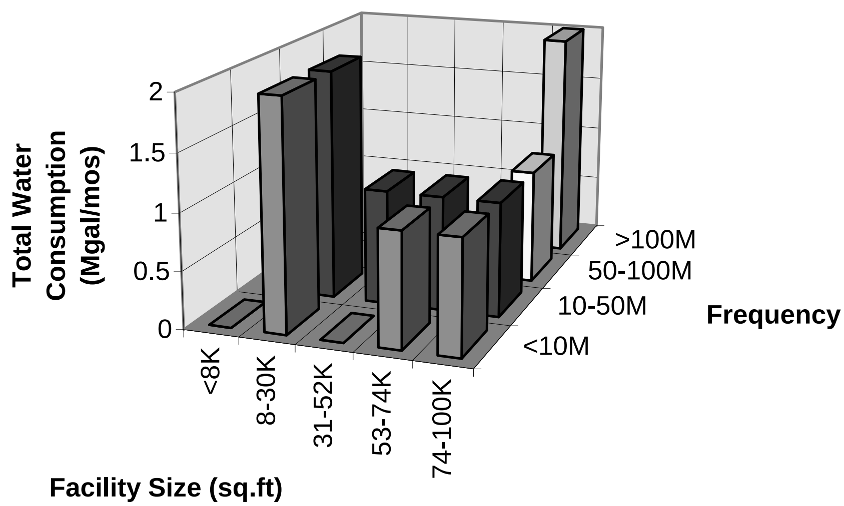


Figure 1 Regional Water and Wastewater Costs

Approximately 40% of the sites surveyed did not discharge to the publicly-owned treatment works (POTW); these sites pre-treat the wastewater effluent on site for direct discharge to public waterways or for irrigation. The wastewater permitting process and POTW capacity appears to have a greater impact on water consumption than either water or wastewater rates. Sites considering expansion of existing facilities and increased levels of wastewater discharge often encounter costly permit upgrades and local POTW's with limited capacities. Facilities must limit the discharge volume through reclaiming/recycling or subsidizing the expansion of the POTW to treat the increased volume of discharge.

Currently, regulatory conditions do not appear to impact water consumption or discharge. However, some facilities were required to reclaim contaminated groundwater as a provision of their water/wastewater permits. A majority of the sites surveyed anticipate an increase in regulatory conditions within the next 5 years. Regulatory changes are expected to require greater documentation of water consumption and discharge and incentives for the reduction of water consumption.

The size of the manufacturing facilities surveyed were evenly distributed from 8K–100K square feet of wafer fab with a slightly higher number in the 74–100K range. The average facility consumes between 10 and 50 million gallons of water every month, with some facilities consuming more than 100 Mgal/month. Figure 2 depicts the comparison of total water consumption and facility size.



Total Water Consumption (Mgal/month)	Facility Size (sq. ft.)				
	<8K	**8–30K**	**31–52K**	**53–74K**	**74–100K**
<10 Mgal	0	2	0	1	1
10-50 Mgal		2	1	1	1
50-100 Mgal					1
> 100 Mgal					2

Figure 2 Comparison of Total Site Water Consumption and Facility Size

The two facilities that use more than 100 Mgal of water per month were in the 74–100K ft. cleanroom size range. However, three additional facilities in that size range were evenly distributed in the less than 10–100 Mgal/month range. Therefore, it would appear that size alone is not an indicator of total water consumption. Respondents expect the water consumption to increase from 10 to 20% over the next 5 years because of wafer fab expansion and projected increases in wafer throughput.

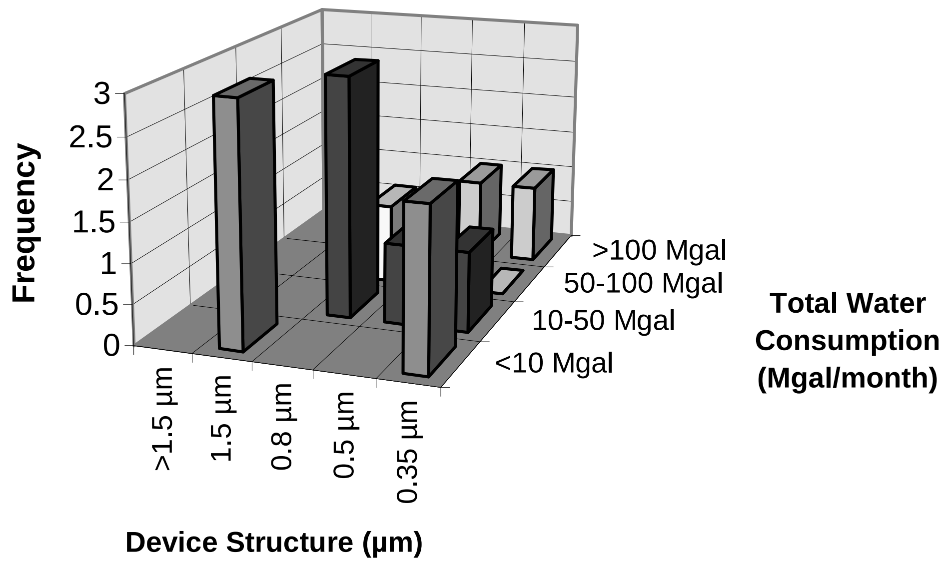
Ninety percent of the facilities use surface water or a surface/well combination as the primary source of water for the manufacturing facility. The supplied water source is considered occasionally variable in quality because of seasonal changes and an inconsistent mixture of surface and well water. Although communication has increased between the industrial facility user and the municipal supplier, it has not resulted in a greater level of control over these variations.

The average UPW system has a distribution capacity of 500 gallons per minute (gpm) to the manufacturing facility. The average cost for production of UPW is 1.4 cents per gallon. This figure generally includes source acquisition, wastewater discharge, electricity, labor, and expendibles with newer facilities including capital depreciation.

The majority of the facilities interviewed were producing 0.5 µm and 0.35 µm devices on 150–200 mm wafers. Figure 3 compares total water consumption and device structure. Two facilities where 0.35 µm structures are produced are located in the lowest water consumption category of less than 10 Mgal water consumed per month, the remaining 0.35 µm and 0.5 µm facilities are distributed throughout the 10 Mgal to more than 100 Mgal water consumption categories. More complex device structures will no doubt require an increased number of process steps, and a greater number of rinses will require a greater volume of water to produce. Because more than one device structure is produced at a given site, it is impossible to assess the impact on total water consumption. Detailed data (beyond the scope of this project) on the consumption per wafer start for 1.0, 0.5, and 0.35 would be required to establish the relationship.

Wet decks with quick dump rinsers are the predominant cleaning technology for 50% of the sites; the remaining 50% are split evenly between spray processors and wet decks with cascade rinsers. Dilute cleaning technologies are currently under evaluation by most facilities and are expected to reduce rinse water consumption significantly. However, exact reductions have not been determined at this time. Only 20% of the sites surveyed expect a significant increase in the use of dry cleaning technologies within the next 5 years.

Product indicators (e.g., facility size, wafer size, device technology, and wafer starts) are expected to have a significant impact on the total water consumption rate. However, comparisons of these datasets with the total water and UPW consumption level did not reveal any consistent trends. It does not appear that any one factor has a significant impact on the water consumption of a facility surveyed as measured by the data collected. Due to the categorical nature of the survey, it was not possible to convert UPW/total water consumed volume data to a more significant volume/wafer start metric. An algorithm incorporating recycle, reclaim, and process indicators is necessary to characterize the water consumption of a facility. An industry standard of this complexity does not currently exist, although several survey sites indicated work in this area. The development of a standard metric will facilitate a greater understanding of water consumption in a facility and allow the establishment of a baseline to measure the impact of water conservation strategies. However, meaningful comparisons of water consumption across the industry will require knowledge of the individual values used in the metric algorithm.



Total Water Consumption (Mgal/month)	Device Structure				
	> 1.5 µm	**1.5 µm**	**0.8 µm**	**0.5 µm**	**0.35 µm**
<10 Mgal		3			2
10-50 Mgal			3	1	1
50-100 Mgal			1		0
> 100 Mgal				1	1

Figure 3 Total Site Water Consumption and Device Structure

3.3.3 Reclaim

Reclamation is defined as the recovery of water for use in an alternative process. Of the sites surveyed, 70% reclaim process wastewater, DI regeneration, and RO reject water for use as the source water for cooling towers, scrubbers, and landscape irrigation. The average recovery rate achieved with reclamation is 5–10% of the total site water consumption. Cost savings are realized from the source and discharge savings and in some cases a reduction in the amount of pretreatment chemicals required for the reclaim application. These reclaim applications are relatively low risk when compared to recycling and are generally implemented using internal personnel with relatively low capital investment (< $250K) and a return on investment (ROI) of less than one year. Sites currently reclaiming indicated the system required less than 8 hours per week to operate and maintain.

The opportunities for reclamation are dictated by the site location, subsequent cooling requirements, and source water quality. The amount of water available for reclamation (process, ion exchange regeneration, and RO reject) often far exceeds the capacity of the available applications (cooling tower, scrubbers, etc.). Arid regions requiring higher cooling capacity will realize greater total water consumption with reclaim than facilities in more temperate climates. The quality of the source water also impacts the utilization of RO reject for reclaim applications; areas with high total dissolve solids (TDS) and silica may require additional pretreatment for cooling tower or scrubber use and prohibit its use for landscape irrigation. On average, 70% of the total site water consumption is attributed to the production and consumption of UPW; therefore, only 30% of the total water consumed can be replaced with reclaimed water.

3.3.4 Recycle

Recycle is defined as the recovery of water for use in the original process. Of the sites surveyed, 39% recycle process wastewater. Figure 4 depicts the primary motivational factors for implementation of recycle including increased capacity requirements, cost, and efficiency.

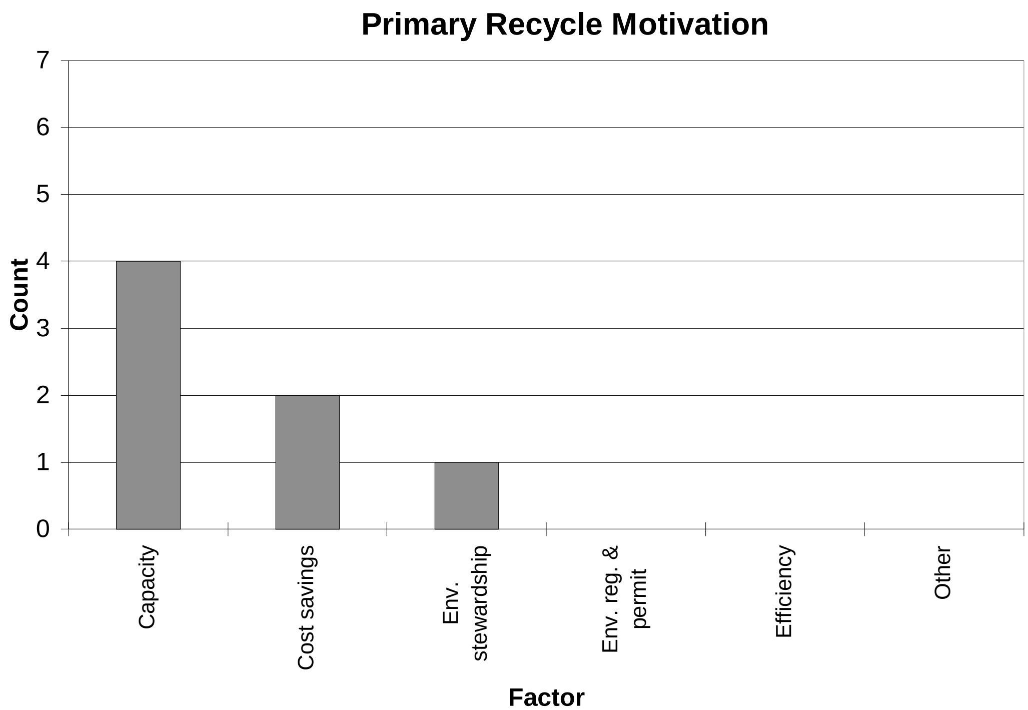
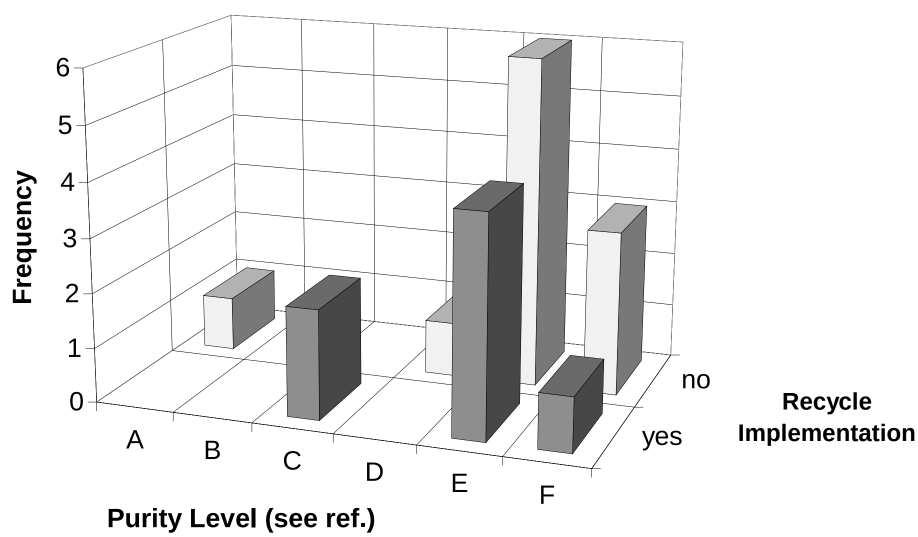


Figure 4 Recycle Motivation Factors

Risk to the product was the primary reason given by respondents who do not currently recycle. Failure at past attempts to recycle and an insufficient ROI were also cited. Several respondents indicated recycle had been practiced at the facility in the past but that the installed systems were vulnerable to contamination from the fabrication facility. These systems were removed after the introduction of high levels of chemical (usually organic in nature) resulted in shutdown of the UPW system and product loss. The introduction of high levels of chemical were caused by the improper disposal of chemicals in wet deck rinse tanks, the accidental connection of industrial waste and cooling water piping into the recycle system, and the connection of nonspecified tools or processes.

Of the recycle systems, 60% have been in operation for 8 years or longer; 40% have been in operation for less than 2 years. The majority of the recycle systems were implemented as new systems rather than modifications to an existing system. These facilities indicated a general satisfaction with the current recycle system and cited quality control and employee awareness as key success factors. Of the systems, 57% produce supply water quality in the "E" category of the water quality specifications table in Figure 5, 29% produce supply water quality in the "C" category, and 14% in the "F" category. Half of the recycle systems recover ~70% of the UPW consumed in the manufacturing process; the remaining half recover ~30%. The UPW recovery rates translate to ~49% and ~21% respectively for total site water consumption.



Recycle	Quality Level					
	A	B	C	D	E	F
Yes			2		4	1
No	1			1	6	3

Figure 5 UPW Quality Level versus Recycle

The range of recovery rates noted previously is due largely to the collection strategies and recycle system design. The majority of the recycle systems segregate the process wastewater from the industrial waste stream and combine the segregated waste streams from select processes in the fabrication area. Of the recycle systems, 30% collect pre-diffusion process waste; 30% collect a combination of pre-diffusion/pre-gate; and the remaining 40% collect from pre-diffusion/gate/silicide/metal, resist strip, and post planar.

Of the systems, 88% use a combination of internal and external tool controls to segregate the process waste. Internal controls consist primarily of timing controls set to divert to the recycle system at a specified rinse cycle; 85% of the systems divert to the recycle system at the second rinse cycle.

The recycle systems have additional external controls that consist of a combination of total oxidizable carbon (TOC) and resistivity meters to evaluate the quality of the process effluent. The combination of TOC/resistivity is used in 68% of the recycle systems; the remaining systems use resistivity alone or pH sensors for quality evaluation. The setpoints to divert range from 100Kohms to 500 KΩ resistivity and 100 ppb to 500 ppb TOC. The resistivity measurement is made with in situ electrodes characterizing the electrical activity based on a Na+ reference standard, the measurement is online with a response time of one second. Total oxidizable carbon is typically measured with an instrument employing a conductivity cell to measure the CO_2 resulting from the oxidation of organics by a catalytic UV reactor. The method, considered a standard for UPW, requires a sample delay time (1–10 minutes) for oxidation of organics and has limited ability to characterize organics by general type.

It is important to note that there are numerous organic compounds with many oxidation reaction rates. The technique cannot speciate and may not oxidize all compounds to CO_2. Specific compounds are not sufficiently oxidized to impact TOC measurement while certain compounds may cause interferences and extended oxidation times. All respondents expressed a need for faster response times and speciation capability. The ability to detect key potential contaminants introduced into the recycle system is critical to decrease the risk of UPW system contamination and product loss. The respondents indicated that organic compounds like acetone, IPA, and surfactants pose the greatest risk to the UPW/recycle system and the wafer manufacturing process.

The majority of the recycle systems are constructed with poly vinylchloride (PVC) piping. A small percentage are constructed with poly vinyldifluoride (PVDF). The PVC systems have performed satisfactorily with no impact (after an initial rinse-up period) on the process wastewater purity. PVC systems are not compatible with the use of oxidative sterilizing agents such as O_3. All of the recycle systems surveyed incorporate at least one holding tank in their system design; 25% of the systems had two or three holding tanks. The holding tanks function as a reservoir to stabilize flow and pressure and provide a time delay to allow evaluation of TOC levels in the process wastewater. The combination of metrology, holding tank, and a diversion valve creates a feedback loop for detection and diversion of unacceptable process wastewater. The primary drawback to the use of storage tanks is the space requirement for tank placement. The tank size may become prohibitive in larger UPW/recycle systems. The majority of the recycle systems include a combination of activated carbon, ion exchange, microfiltration, and UV for purification. After purification in the recycle system, the effluent is introduced into the UPW system. Fifty percent of the systems introduce the purified recycle water into the post-RO storage tank, 25% to the DI tank, and 25% to the source water tank.

All respondents indicated an ROI for the recycle system of 4 years or less; 70% indicated system ROI of 2 years or less. Because of the relatively high risk and cost of recycle systems, the systems are generally implemented using both internal personnel and external OEM and external engineering and design consultants. The operation and maintenance of these systems generally required less than 8 hours of labor per week.

3.4 Research and Development

A dialogue was established with several university and national laboratory organizations with active programs in water conservation. Activities include recycle process development, recycle sensor technology development, and rinse process optimization.

The recycle design and purification activities at the University of Arizona focused on the chemical characterization of process wastewater and the development of purification technologies to maximize the recovery of process wastewater in a cost effective manner. The program objectives include developing a simulation modeling tool to assess and optimize recycle purification systems and developing new purification technologies to remove recalcitrant compounds in process water recycle systems. The program is an extension of an established research program in UPW purification.

Two research and development programs in process rinse optimization are in progress. A Sandia National Laboratories' program in wet processing focuses on the optimization on the Santa Clara Plastics' wetdeck for enhanced rinse process and reduced water consumption. Recent program advancements in tool design have resulted in significant reductions in water consumption at the process tool level. Opportunities exist for continued process tool improvements to further advance performance. Numerical modeling of a typical rinse tank predicted that most of the water passed around the wafer stack rather than through it, implying that the convective removal of contaminants was being performed inefficiently. Experimental results confirm these model predictions. Patents have been filed on designs that produce more favorable flow patterns. Sandia's next task will be to validate these patent concepts.

The Stanford University program under Dr. Robert Helms focuses on the optimization of wafer processes and various process tools to characterize the rinse process and reduce water consumption. The first year research tasks include the benchmark of current best practices in wafer rinsing, modeling experiments to simulate rinse performance, and the development of in situ electrochemical sensors to advance characterization of the process. Work is in progress on simple physical models for diffusion and convection in overflow processes, with some initial data on hydrofluoric acid (HF) and post-sulfuric rinse processes. This data indicates that removal of surface contaminants depends initially on diffusion through a boundary layer before convective flow carries the contaminants away; therefore, low water flow makes sense during the initial diffusion dominated period. The industry assessment on water reduction for diffusion of wet tools will include wafer size, lot size, types of rinses, flow rates, typical water consumption, and availability of sensors. Electrochemical sensor development is focusing on the development of the technology for heavy metals and hydrogen peroxide.

Sandia National Laboratories has initiated a task to address the need for sensors in process water recycle systems. The task begins with a comprehensive assessment of sensor availability and development. One goal of this survey is to identify major gaps in meeting present and future sensor needs so that project resources can be concentrated on the high priority requirements. A second objective is to identify little known but potentially applicable research and development activity that could accelerate the availability of useful sensors to the UPW community. Based on the findings of this assessment, the conclusions of the S116 survey report, and a lab bench survey of the performance of three known sensor types (quartz crystal microbalance, surface acoustic wave, and optical fiber), a specific sensor will be selected for development/testing in the Sandia Microelectronic Development Lab.

A separate university program under Dr. Srini Ragahavan at the University of Arizona is investigating both the integrity and feasibility of the electrochemical quartz crystal microbalance technology for TOC analysis and organic speciation.

3.5 Summary

Water conservation in the semiconductor industry encompasses reclamation, process water recycle, and source reduction strategies. The interest and activity level within the sites surveyed is high. Water conservation has a high level of commitment illustrated by the large number of corporate water conservation teams, roadmaps, and the number of assessment activities and pilot projects in progress.

The survey indicates wastewater reclamation is extensively practiced and resulted in a modest 5–10% reduction in total site water consumption for most facilities. However, greater reduction levels may be possible in regions that require additional cooling capacity. Process wastewater recycling using closed loop recovery systems, demonstrated in 40% of the sites surveyed, recovered from 30–70% recovery of the water used for processing. The current systems are capable of providing a high purity product at an ROI of less than 4 years with relatively low operating and maintenance requirements. Risks have been substantially reduced by limiting the fabrication tools and processes connected to the recycle system, improving recycle system design, and increasing the commitment level and awareness of fab employees. Unfortunately, these systems are still susceptible to the devastating and inadvertent introduction of chemicals into the recycle system. The human error element highlights the need for sensor technology to quickly detect key organic contaminants. Site assessment programs are instrumental in identifying source reduction opportunities throughout the facility. Moderate reductions are expected in the utility process consumption level. Source reduction at the process tool has the potential to substantially reduce water consumption. Source reduction has been implemented by only 40% of the sites surveyed because the industry lacks comprehensive information on the required purity and flowrates for optimal rinse processing and product reliability.

Research and development is underway at a number of universities and laboratories to address needs in the area of sensor technology, recycle system design, and rinse process optimization. However, most of these programs are still in the initial stages and may require 1 to 2 years to provide solutions to the industry's critical needs.

4 ULTRAPURE WATER COST MODEL

4.1 Objective

The SEMATECH UPW COO model was developed to analyze the total cost of acquiring, maintaining, and operating the UPW supply and distribution system. The purpose of the UPW COO model is to estimate the costs of generating a gallon of UPW supplied to the fab. It can be used to perform cost comparisons to evaluate various options for production, recycle, and reclaim of UPW. The UPW COO model uses Excel 5.0 workbook format with input spreadsheets and output reports. Help notes provide the user with the option of entering either detailed component-level cost data or total subsystem-level cost data. The only prerequisite to using the UPW COO model is the ability to manipulate computer spreadsheets in Excel. A user's guide with detailed explanations will be included with the model upon distribution by SEMATECH.

4.2 Assumptions

Although, the UPW COO model includes the UPW supply and distribution systems, it does not consider UPW system interactions to process tools, UPW purity level, or system capacity factors. The model requires the user to input data for capital costs, operating costs, average flowrate, and system maintenance and availability. The subsystems, the components, and their attributes were developed by the Water Conservation and Facility Fluids PTAB. The UPW system is composed of a maximum of ten subsystems.

- Pretreatment
- Make up
- Polish
- Regeneration
- Hot UPW
- Point-of-use
- Recycle
- Reclaim
- Distrubtion

4.3 Model Format

Microsoft Excel version 5.0 is required to use the UPW COO model. The model file, “upw.xls,” consists of five worksheets. A brief description of each worksheet follows.

4.3.1 Component Selection Worksheet

This is a detailed input sheet on which the user inputs the capital costs of components within a subsystem. This sheet provides a detailed list of components for which capital costs may be entered for any of the ten subsystems. The user may bypass the detailed component analysis and enter overall subsystem costs in the “Subsystems Inputs” sheet.

4.3.2 Selection Summary Worksheet

This sheet summarizes the costs of the components that the user entered in the “Component Selection” sheet. Specific subsystem capital or consumable part costs not included in the worksheet list are entered in “Other Equipment Cost” and “Other Consumable Part Cost.”

4.3.3 System Inputs Worksheet

This sheet allows the input of system-level information such as utility rates, labor rates, financial rates (interest, depreciation), system life in years, and system prove-in costs. The system maintenance, reliability, and scheduled production hours are input here to calculate the system availability to produce UPW. The average consumption versus maximum capacity of the system is included to comprehend system utilization and to calculate UPW cost per gallon.

4.3.4 Subsystem Inputs Worksheet

This sheet allows the input of subsystem capital, consumable, and operating costs. Capital and consumable costs are entered directly into the subsystem sheet or automatically updated from the "Selection Summary" sheet. Labor and utilities consumption per subsystem are required inputs. This sheet includes a "Water Flow Balance Matrix" to characterize the volume of water in and out of each subsystem. The water flow balance data and the subsytem cost data are used to estimate the cost of the water produced and consumed in each subsystem, allowing the user to compare the cost of various recycle and reclaim design options.

4.3.5 Reports Worksheet

Based on the maintenance/reliability data and scheduled production, this sheet calculates system availability and maximum flow output per year from the UPW system. Other calculations include total equipment costs, production costs, support services costs, leased equipment costs, training and prove-in costs. A 5-year cost summary using a straight line depreciation method and user input inflation rate is also provided. The final output is expressed in terms of cost per gallon based on required flowrate and cost per gallon based on maximum system flowrate.

4.4 Summary

The model format as described above has been reviewed and approved by the Water Conservation and the Facilities Fluids PTAB. The algorithms used to calculate outputs in the model are being validated by SEMATECH's UPW department. The model has also been distributed to the PTAB members for beta testing. Modifications to the existing model will be made based on the beta test response. The final model and user's guide will be available July 1995.

5 CONCLUSIONS AND RECOMMENDATIONS

With the current processing and environmental trends, water conservation will clearly remain a desirable if not critical industry objective for the foreseeable future. No single approach to water conservation will be applicable for all semiconductor manufacturing facilities. Each individual site must develop its own water conservation strategy based on its particular attributes and requirements. However, opportunity exists for industry cooperation in facility assessment, sensors, recycle design, and process optimization.

The survey indicated a high level of activity in the planning and assessment phase of water conservation. The planning of corporate and industry strategy and goals has been difficult because of the lack of standard terminology and metrics. The increase in communication at the site, company, and industry level have provided the impetus to establish standard terminology and metrics. A set of working terms for discussion of water conservation topics has been developed by the water conservation PTAB and is provided in Appendix B. A standard metric, incorporating the appropriate site factors, has not been developed and is urgently needed to measure the success of future water conservation strategy implementation. In addition, assessment of water consumption at the fab and facility level has been limited to the documentation of consumption and disposal flows in static matrixes. The industry currently lacks a tool to simplify the assessment and optimization of water consumption facility wide. The utilization of a user-defined tool of this type is expected to be high because each facility has different regional factors and processing requirements. A tool with predictive and simulation capabilities is critical to comprehend site-specific requirements in the evaluation of benefits of water conservation strategies. An assessment tool would also facilitate the integration into a more global resource model allowing the user to incorporate the impact on electrical and chemical resources as well as wafer fabrication requirements into the evaluation of water conservation strategies.

The impact of reclamation on total water consumption is limited by site location and source water quality. The majority of the facilities with reclamation systems achieve only modest reduction in total water consumption of 5–10%. On average, 70% of the total site water consumption is attributed to the production and consumption of UPW. Therefore, only 30% of the total water consumed can be replaced by reclaimed water. The majority of the opportunity for reducing water consumption is in source reduction and recycling systems. Only 40% of the sites surveyed are currently recycling process wastewater to the UPW system for reuse in wafer processing. The primary reason for the low implementation rate is the risk to process. Immediate research and development is needed in the area of real-time sensor technology to provide recycle system quality control and reduce the risk to the production facility. Those facilities currently recycling indicate improved metrology is a top priority. Consequently, they have placed an emphasis on organic compounds that have been implicated in past recycle system failures. In addition, improved recycle system design and components are key to achieve maximum recovery and cost benefits of process water recycling and minimal risk to quality. Efforts to reduce the source consumption have primarily targeted the optimization of utility processes and modification of the rinse processing tool. Less than 30% have changed the rinse process to reduce water consumption. The maintenance of water quality within the tool and rinse efficiency are key issues to be addressed if the industry is to realize the major benefits of source reduction at the wafer processing tool.

The 1994 National Technology Roadmap for Semiconductors proposes an industry goal of 50% reduction in water consumption over 1989 usage levels. To support this goal, SEMATECH has extended the 1994 project and revised its role as coordinator of the technology focus. Working with both member companies and key academic and industry contributors, SEMATECH will ensure that key success factors are achieved in an integrated fashion. The focus of the SEMATECH project will be to integrate existing research programs and to form a technology base for the advancement of water conservation. SEMATECH proposes to team with active university, laboratory, and industrial programs to develop a comprehensive water conservation program that addresses industry needs. The SEMATECH Water Conservation project will examine water usage throughout the semiconductor manufacturing facility to include water used in the support utilities (e.g., cooling towers, scrubbers) as well as the wafer manufacturing rinse process in the development of a comprehensive water conservation strategy.

APPENDIX A

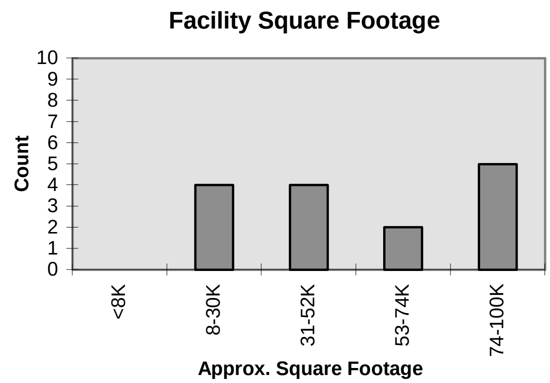
The following frequency graphs are the product of an interpretive evaluation of survey data representing 18 domestic member company facilities. The evaluations are limited to the survey population and cannot be considered predictive of the industry as a whole. The survey question is provided with an accompanying table and graph for demonstration. Sixty-two of the 100 questions are presented. The average response rate for the question set of 100 questions was 70%. Question specific response rates are noted on the top line of each table.

Introductory Questions

#3) What is the approximate area of wafer manufacturing facility in terms of total square footage?

#3) Manufacture Facility Size (rr83%)

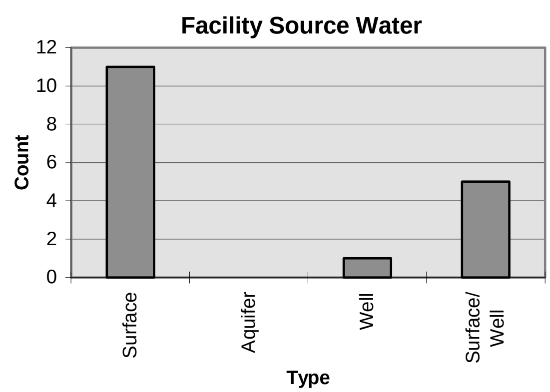
Category	Count	Pct.
<8K	0	0
8-30K	4	27
31-52K	4	27
53-74K	2	13
74-100K	5	33
Total	15	100



#4) What is the source of water for the facility?

4) Source Water (rr94%)

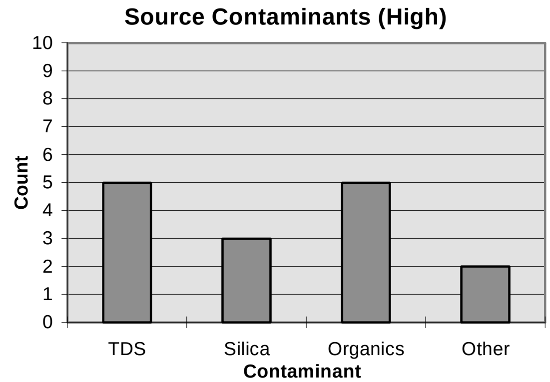
Category	Count	Pct.
Surface	11	65
Aquifer	0	0
Well	1	6
Surface/Well	5	29
Total	17	100



#6) Is the feed source considered high in any of the following contaminants?

#6) Source Quality (rr:72%)

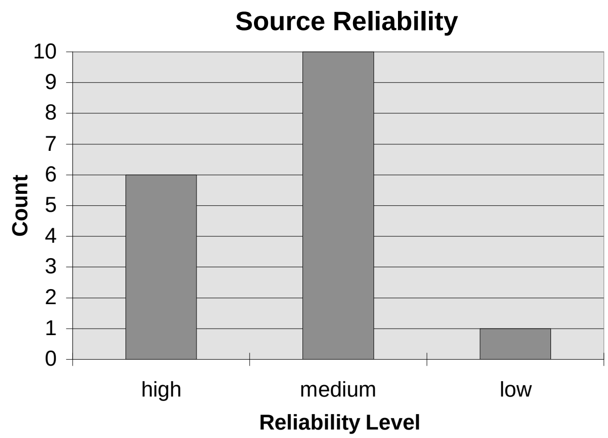
Category	Count	Pct.
TDS	5	33
Silica	3	20
Organics	5	33
Other	2	13
Total	15	87



#7) How would you characterize the (quality) reliability of the DI water source?

#7) Source Reliability -Quality(rr94%)

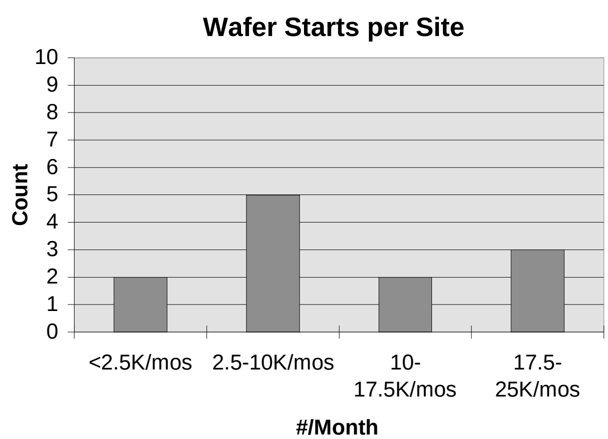
Category	Count	Pct.
high	6	35
medium	10	59
low	1	6
Total	17	100



#8) What is the approximate number of wafer starts at your facility in an average month?

#8) Wafer Starts (rr67%)

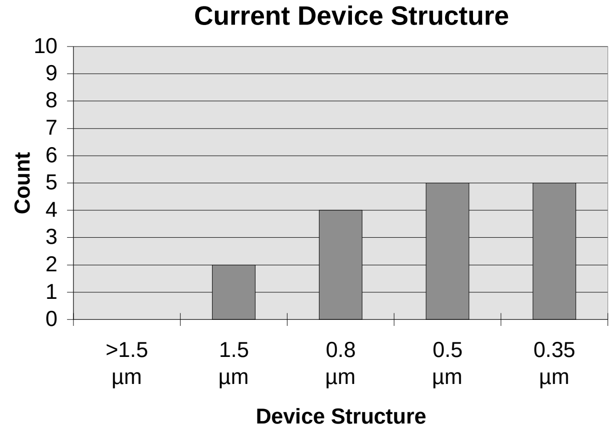
Category	Count	Pct.
<2.5K/mos	2	17
2.5-10K/mos	5	42
10-17.5K/mos	2	17
17.5-25K/mos	3	25
Total	12	100



#9) What is the device structure of the product?

#9) Device Technology (rr83%)

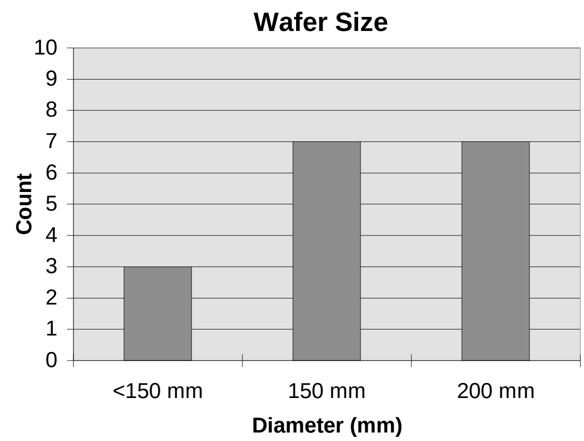
Category	Count	Pct.
>1.5 µm	0	0
1.5 µm	2	12.5
0.8 µm	4	25
0.5 µm	5	31.25
0.35 µm	5	31.25
Total	16	100



10) Which wafer size is this facility currenty using in the manufacturing process?

#10) Wafer size (rr94%)

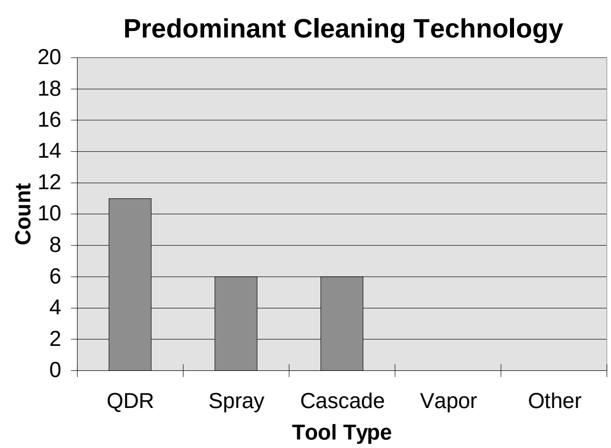
Category	Count	Pct.
<150 mm	3	18
150 mm	7	41
200 mm	7	41
Total	17	100



#11) What is the predominant cleaning technology(s) used at your facility?

#11) Primary Cleaning Technology (rr94%)

Category	Count	Pct.
QDR	11	48
Spray	6	26
Cascade	6	26
Vapor	0	0
Other	0	0
Total	23	100



#14) Do you anticipate trends at your company to include a significant increase in non-liquid (vapor phase, cryogenic) cleaning technologies?

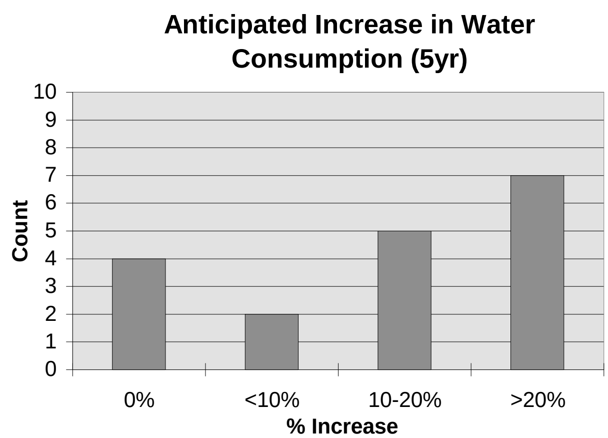
#14) Dry Clean Implement-5yr (rr83%)

Category	Count	Pct.
yes	3	20
no	12	80
Total	15	100

#15a) What percent increase in DI water consumption do you anticipate in wafer processing within the next five years?

#15a) Water Consumption-5yr (rr100%)

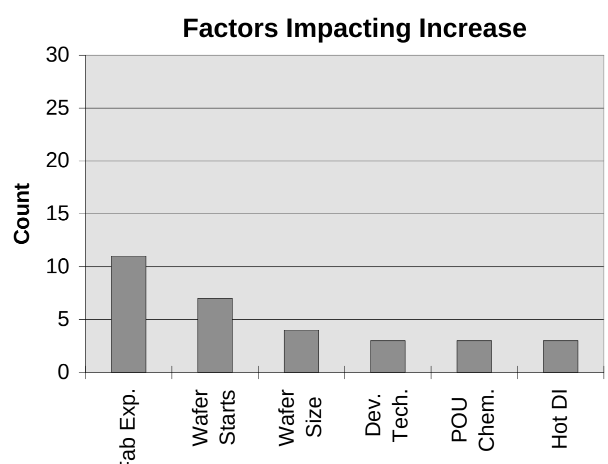
Category	Count	Pct.
0%	4	22
<10%	2	11
10-20%	5	28
>20%	7	39
Total	18	100



#15b) Which of the following factors will prompt the anticipated increase?

#15b) Increase Factors (rr83%)

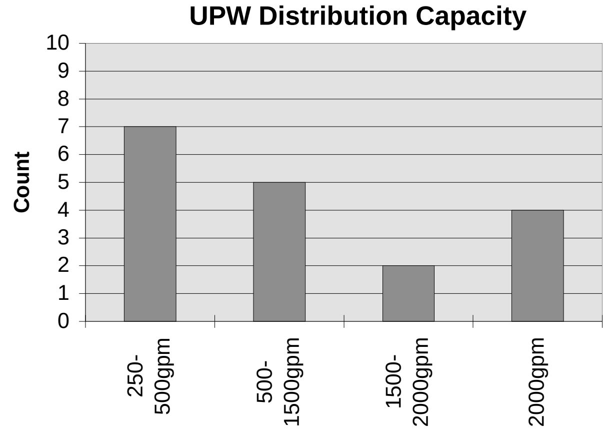
Category	Count	Pct.
Fab Exp.	11	35
Wafer Starts	7	23
Wafer Size	4	13
Dev. Tech.	3	10
POU Chem.	3	10
Hot DI	3	10
Other	0	0
Total	31	100



#17) What is the distribution capacity of the current DI system?

#17) UPW Distribution Capacity(rr100%)

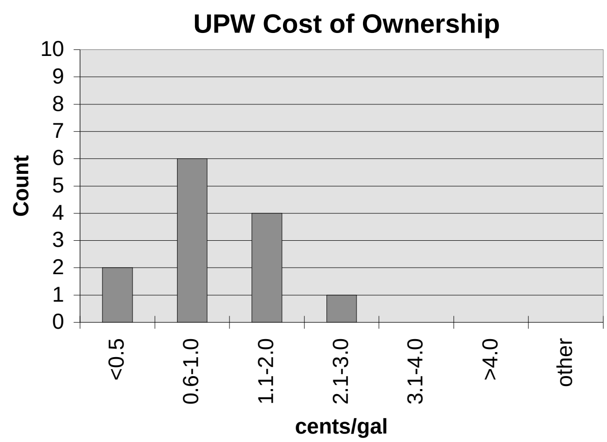
Category	Count	Pct.
250-500gpm	7	39
500-1500gpm	5	28
1500-2000gpm	2	11
2000gpm	4	22
Total	18	100



#18b) What is the average cost to produce a gallon of DI water at this facility?

#18b) Avg. Cost UPW (rr72%)

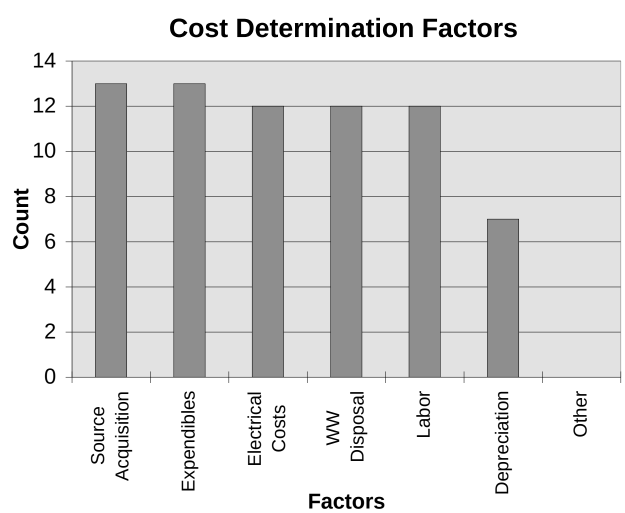
Category	Freq.	Pct.
<0.5	2	15
0.6-1.0	6	46
1.1-2.0	4	31
2.1-3.0	1	8
3.1-4.0	0	0
>4.0	0	0
other	0	0
Total	13	100



#18c) What factors are included in the cost determination?

18C) Cost Determination Factors (rr72%)

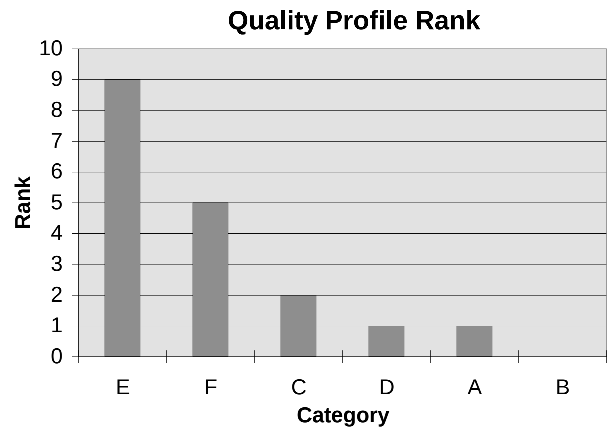
Facility	Count	Percent
Source Acquisition	13	100%
Expendibles	13	100%
Electrical Costs	12	92%
WW Disposal	12	92%
Labor	12	92%
Depreciation	7	54%
Other	0	0%



#19) Which of the following DI water quality profiles best describes the DI water quality at your facility?

#19) UPW Quality Profile (rr100%)

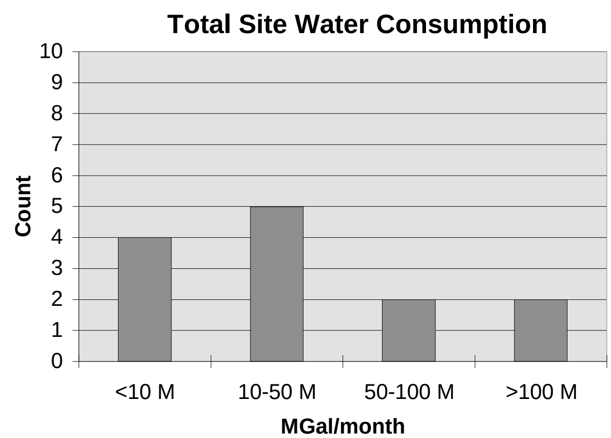
Category	Count	Pct.
E	9	50
F	5	28
C	2	11
D	1	6
A	1	6
B	0	0
Total	18	100



#20) What is the average **total** water consumption at your facility per month?

#20) Total Facility Water Consumption (rr7

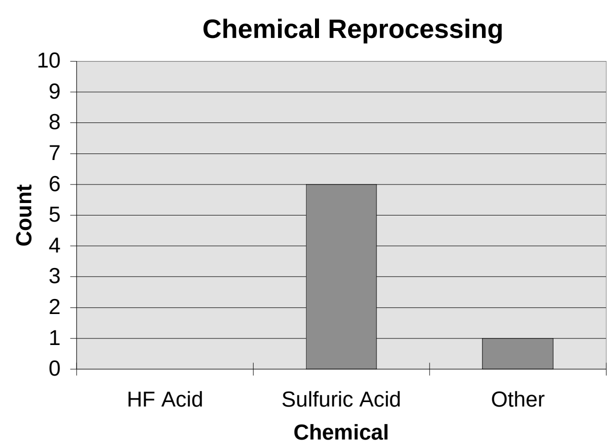
Category	Count	Pct.
<10M	4	31
10-50M	5	38
50-100M	2	15
>100M	2	15
Total	13	100



#24) Does the facility currently reprocess any of the following process chemicals?

#24) Chemical Reprocessing (rr39%)

Category	Count	Pct.
HF Acid	0	0
Sulfuric Acid	6	86
Other	1	14
Total	7	100

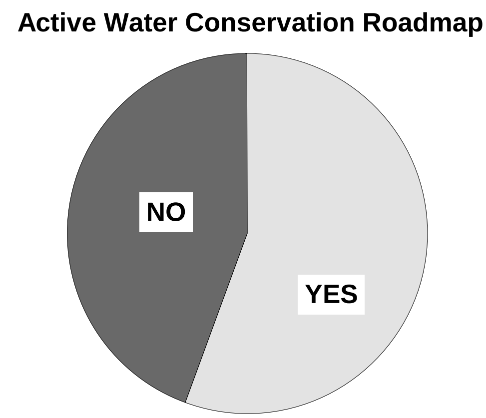


Water Conservation Section

#28) Is water conservation included in a strategic plan or roadmap?

#28) Strategic Plan (rr100%)

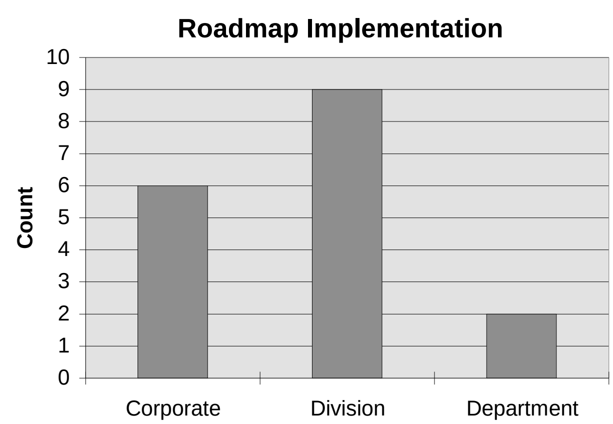
Category	Count	Pct.
yes	10	56
no	8	44
Total	18	100



#29) If yes at what level?

#29) Roadmap Level (rr56%)

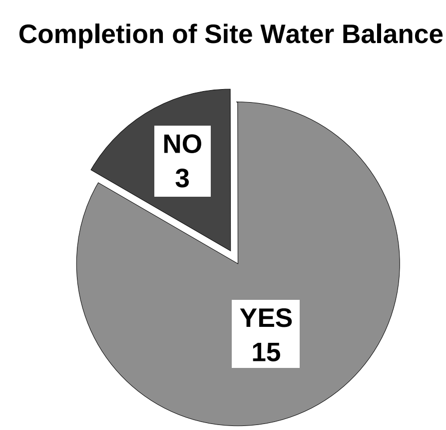
Category	Freq.	Pct.
Corporate	6	35
Division	9	53
Department	2	12
Total	17	100



#31) Has your company/site conducted a site water balance survey?

#31)Conduct Site Water Balance (94%)rr

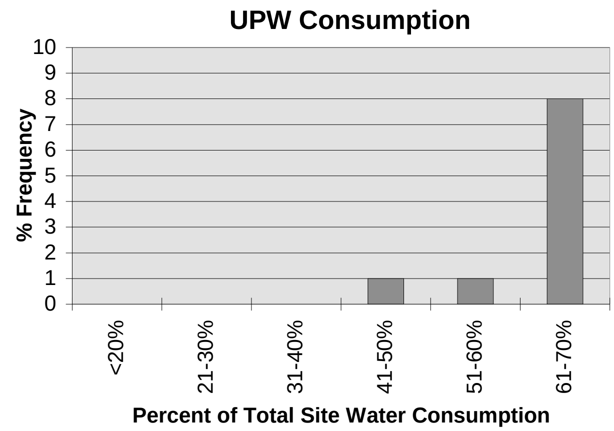
Category	Freq.	Pct.
yes	15	83
no	3	17
Total	18	100



#33) What percentage of the total water consumed by the site is used in the DI processing and wafer manufacturing areas?

#33) UPW Consumption (rr66%)

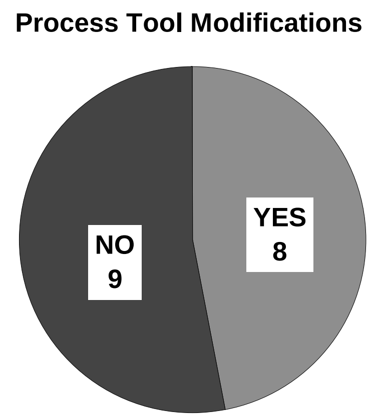
Category	Count	Pct.
<20%	0	0
21-30%	0	0
31-40%	0	0
41-50%	1	10
51-60%	1	10
61-70%	8	80
Total	10	100



#37) Has your company/site implemented tool modifications to reduce DI water consumption?

#37) Tool Modifications (rr100%)

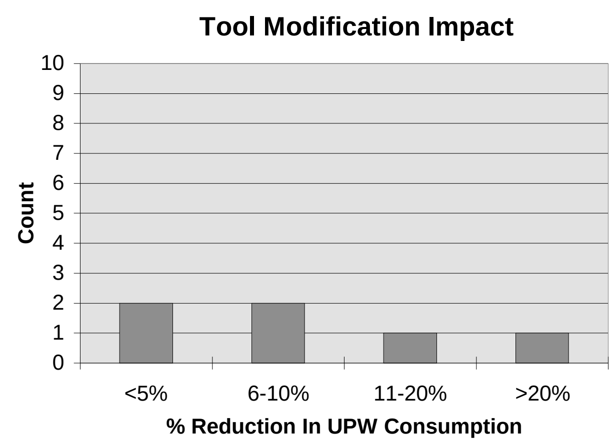
Category	Freq.	Pct.
yes	8	83
no	9	17
Total	18	100



#38) If yes to #37, what percent reduction in DI water consumption was achieved?

#38) Tool Modification Impact (rr39%)

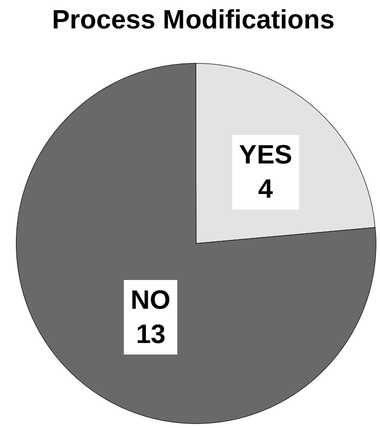
Category	Count	Pct.
<5%	2	33
6-10%	2	33
11-20%	1	17
>20%	1	17
Total	6	100



#39) Has your company/site implemented process modifications to reduce DI water consumption?

#39) Process Modifications (rr94%)

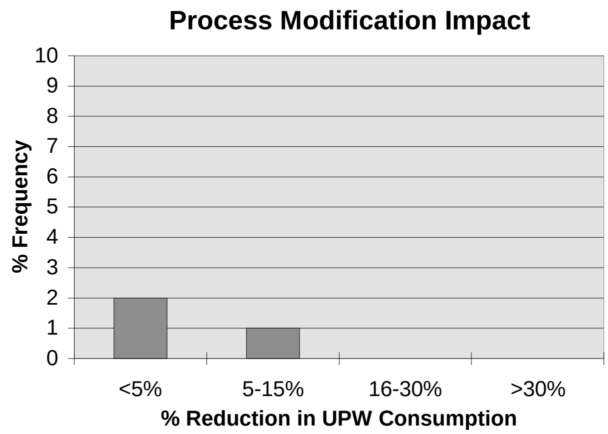
Category	Freq.	Pct.
yes	4	24
no	13	76
Total	17	100



#41) If yes to #39, what percent reduction in DI water consumption was achieved?

#41) Process Modification Impact (rr17%)

Category	Count	Pct.
<5%	2	67
5-15%	1	33
16-30%	0	0
>30%	0	0
Total	3	100

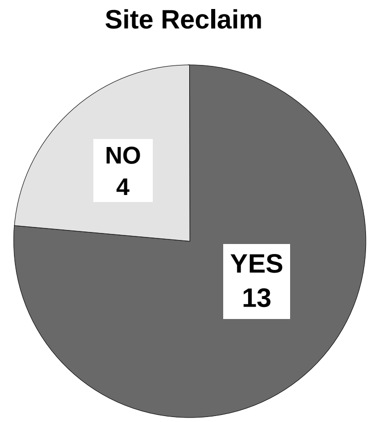


Reclaim Section

#42) Does your company/site currently employ any form of water reclaim?

#42) Site Reclaim (rr100%)

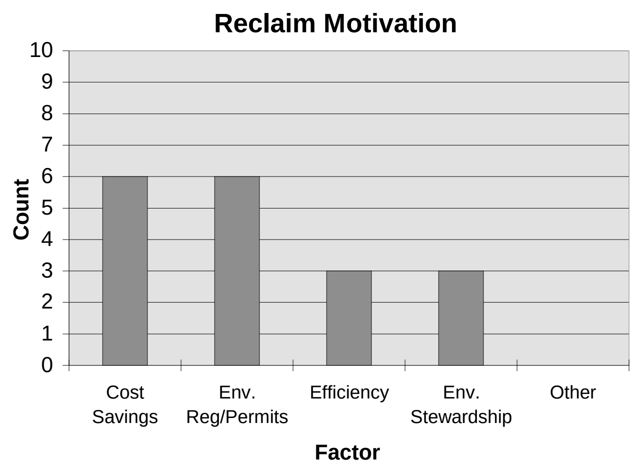
Reclaim	Freq.	Pct.
YES	13	76
NO	4	24
TOTAL	17	100



#43) What was the primary motivation for implementing reclaim measures?

#43) Reclaim Motivation (78%)

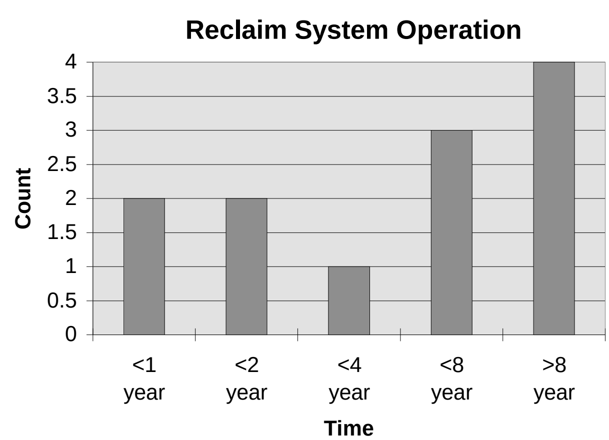
Reclaim	Freq.	Pct.
Cost Savings	6	33
Env. Reg/Permits	6	33
Efficiency	3	17
Env. Stewardship	3	17
Other	0	0
Total	18	100



#45) For what period of time have the reclaim measures been in operation?

#45) Reclaim System Operation (72%)

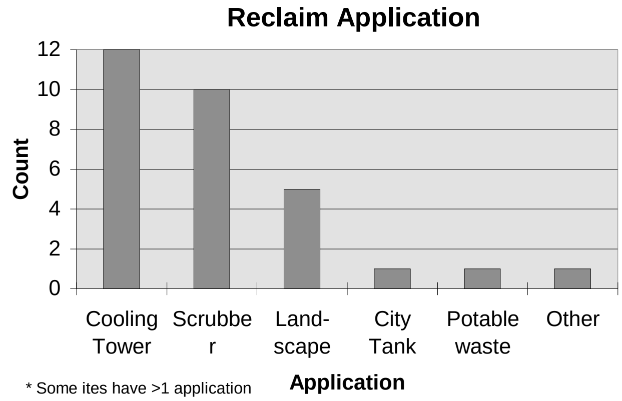
Reclaim	Freq.	Pct.
<1 year	2	17
<2 year	2	17
<4 year	1	8
<8 year	3	25
>8 year	4	33.33333
Total	12	100



#49) In what applications does your site utilize reclaim water as a feed source?

#49) Reclaim Application (rr78%)

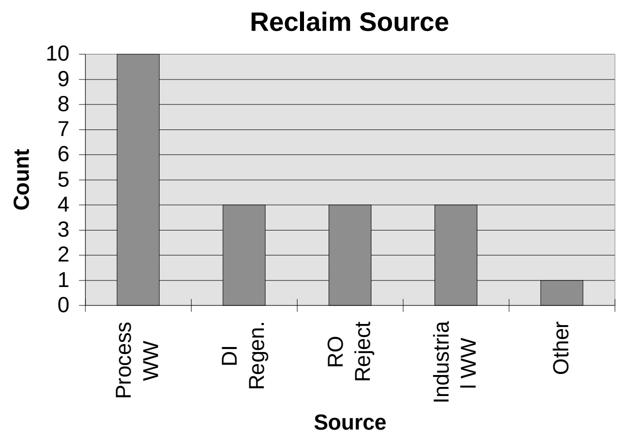
Application	Freq.	Pct.
Cooling Tower	12	40
Scrubber	10	33
Landscape	5	17
City Tank	1	3
Potable waste	1	3
Other	1	3
Total	30	100



#50) What is the source of the reclaim water?

#50) Reclaim Source (rr66%)

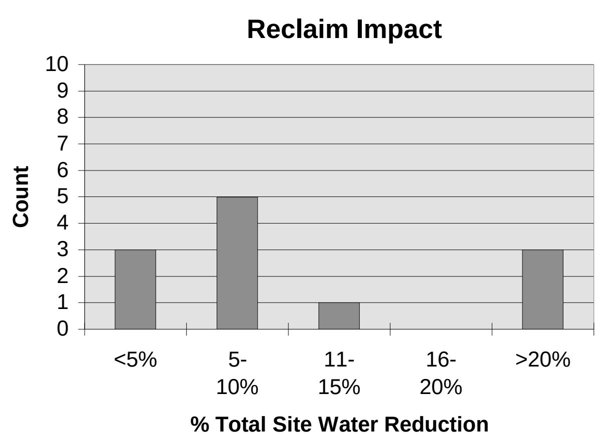
Application	Freq.	Pct.
Process WW	10	43
DI Regen.	4	17
RO Reject	4	17
Industrial WW	4	17
Other	1	4
Total	23	100



#54) What percent reduction of the sites **total** water consumption is realized with the operation of the reclaim process(es)?

#54) Reclaim impact on Total Water Consumption (rr72%)

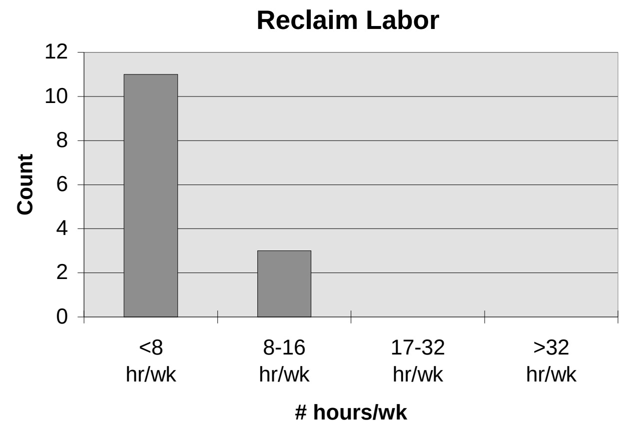
Application	Freq.	Pct.
<5%	3	25
5-10%	5	42
11-15%	1	8
16-20%	0	0
>20%	3	25
Total	12	100



#55) What is the average number of man-hours required to operate and maintain the reclaim system(s)?

#55) Reclaim System Labor (rr78%)

Application	Freq.	Pct.
<8hr/wk	11	79
8-16hr/wk	3	21
17-32hr/wk	0	0
>32hr/wk	0	0
Total	14	100

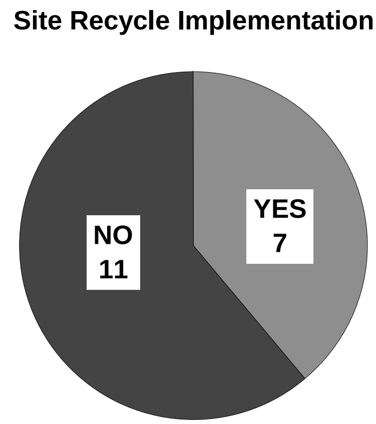


Recycle Section

#59) Is your company/site currently recycling?

#59) SITE RECYCLE

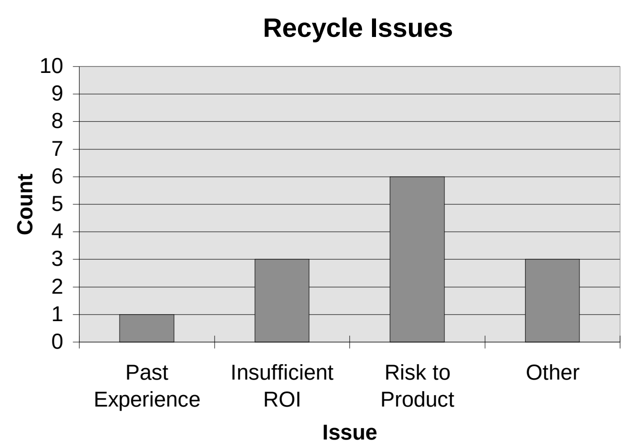
Recycle	Freq.	Pct.
YES	7	39
NO	11	61
TOTAL	18	100



#60) What is the primary reason this site is not currently recycling?

#60) Reason against Recycle (rr56%)

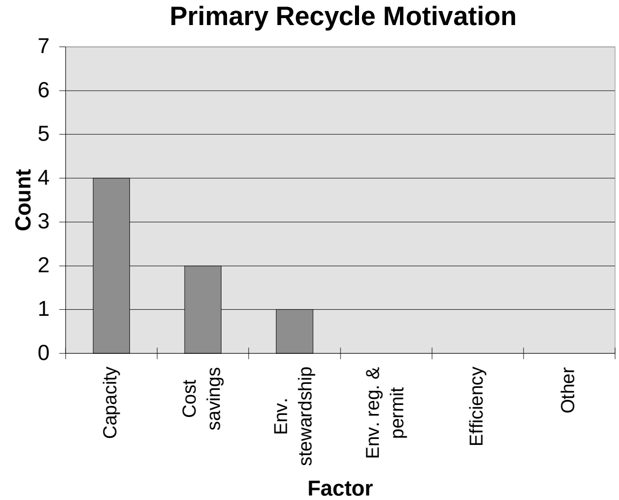
Recycle	Freq.	Pct.
Past Experience	1	8
Insufficient ROI	3	23
Risk to Product	6	46
Other	3	23
	0	
Total	13	100



#63) What was the primary motivation for implementing the recycle system?

#63) Primary motivation for Recycle (rr39%)

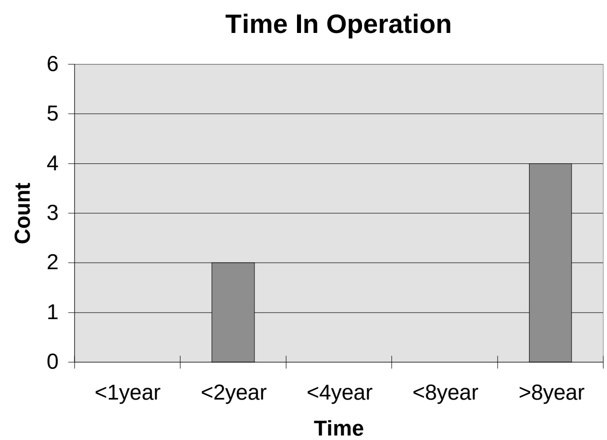
Recycle	Freq.	Pct.
capacity	4	57
cost savings	2	29
env. stewardship	1	14
env. reg. & permit	0	0
efficiency	0	0
other	0	0
Total	7	100



#64) For what period of time has the recycle system been in operation?

#64) Period of Operation (rr33%)

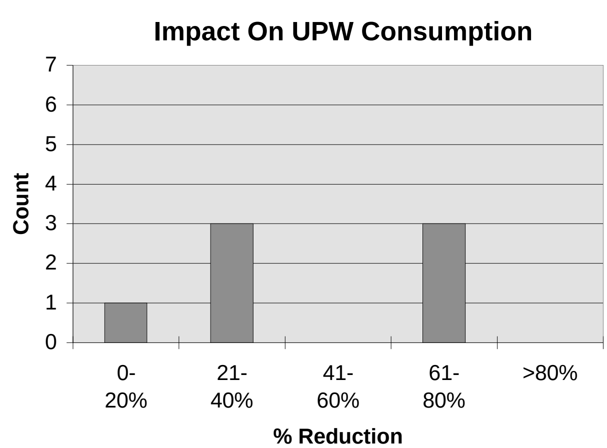
Recycle	Freq.	Pct.
<1year	0	0
<2year	2	33
<4year	0	0
<8year	0	0
>8year	4	67
Total	6	100



#69) What percent recovery of the total DI consumed by the wafer fabrication area is achieved with the current recycle system?

#69) Impact on UPW consumption (rr39%)

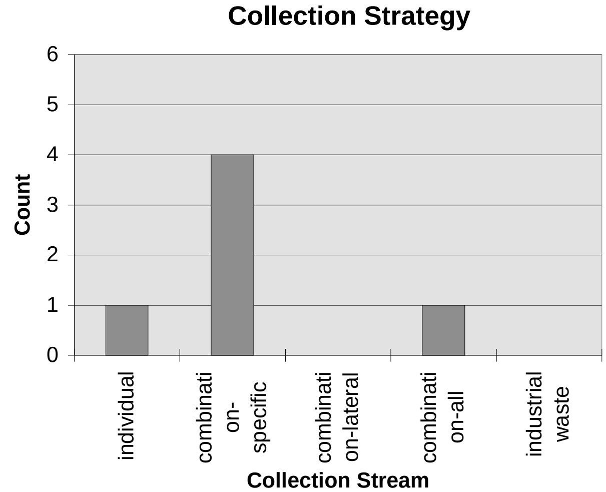
Recycle	Freq.	Pct.
0-20%	1	14
21-40%	3	43
41-60%	0	0
61-80%	3	43
>80%	0	0
Total	7	100



#70) How is the process wastewater collected?

#70) Recycle collection (rr33%)

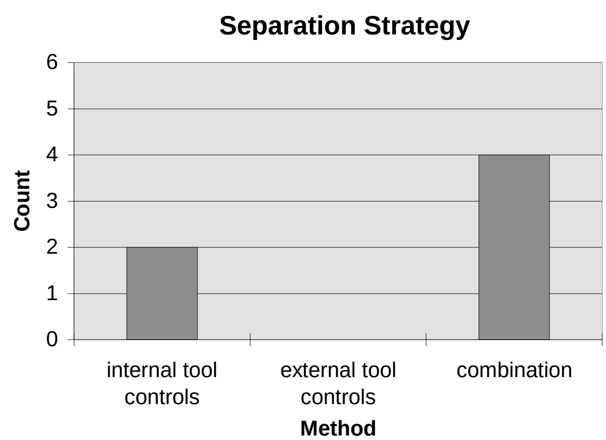
Recycle	Freq.	Pct.
individual	1	17
combination-specific	4	67
combination-lateral	0	0
combination-all	1	17
industrial waste	0	0
Total	6	100



#71) What method is used to separate process wastewater from individual (chemical) waste?

#71) Recycle separation (rr33%)

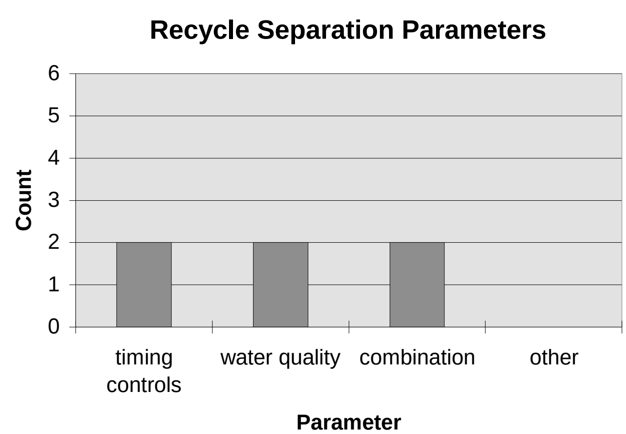
Recycle	Freq.	Pct.
internal tool controls	2	33
external tool controls	0	0
combination	4	67
Total	6	100



#72) What parameters are used to separate process wastewater from industrial (chemical) waste?

#73) Recycle separation parameters(rr33%)

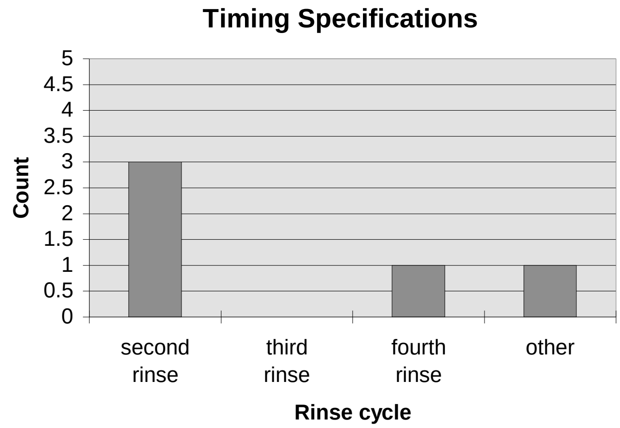
Recycle	Freq.	Pct.
timing controls	2	33
water quality	2	33
combination	2	33
other	0	0
Total	6	100



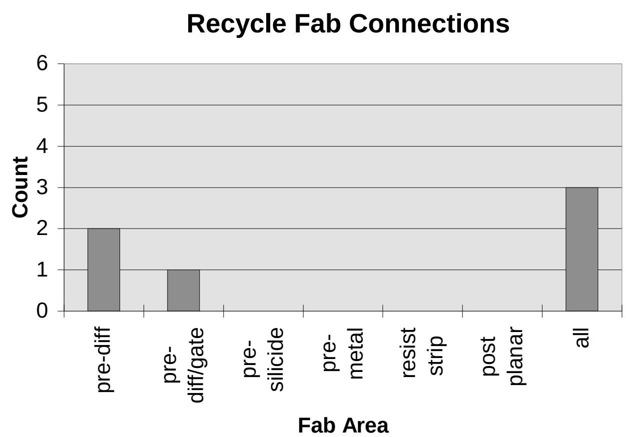
#73) If using timing controls, what portion of the process rinse cycle is diverted to the recycle system?

#73) Recycle timing control specifications(rr28%)

Recycle	Freq.	Pct.
second rinse	3	60
third rinse	0	0
fourth rinse	1	20
other	1	20
Total	5	100



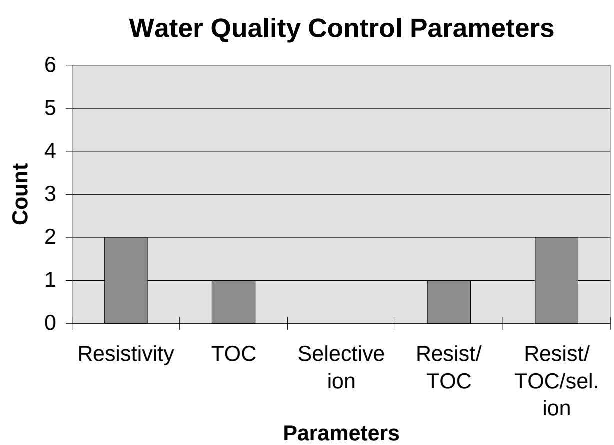
#74) Which wafer fab areas are connected to the collection system?



#74) Fabrication Connection(rr38%)

Recycle	Freq.	Pct.
pre-diff	2	33
pre-diff/gate	1	17
pre-silicide	0	0
pre-metal	0	0
resist strip	0	0
post planar	0	0
all	3	50
Total	6	50

#75) If using water quality controls, what parameters are used to measure rinse wastewater quality?



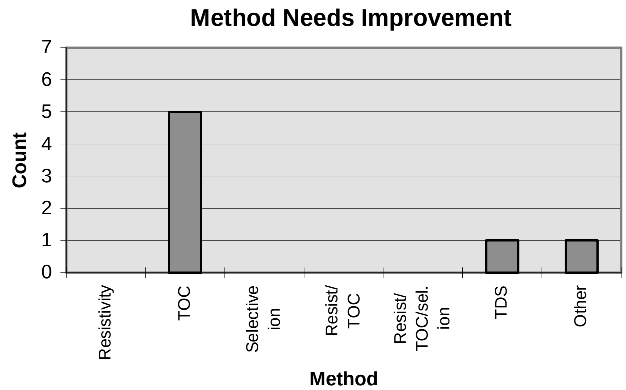
#75) Water quality parameters(rr33%)

Recycle	Freq.	Pct.
resistivity	2	33
TOC	1	17
selective ion	0	0
resist/TOC	1	17
resist/TOC/sel. ion	2	33
pH		
other		
Total	6	100

#78) Are the existing methods/instrumentation adequate for use in recycle systems?

#78) Method inadequate (rr38%)

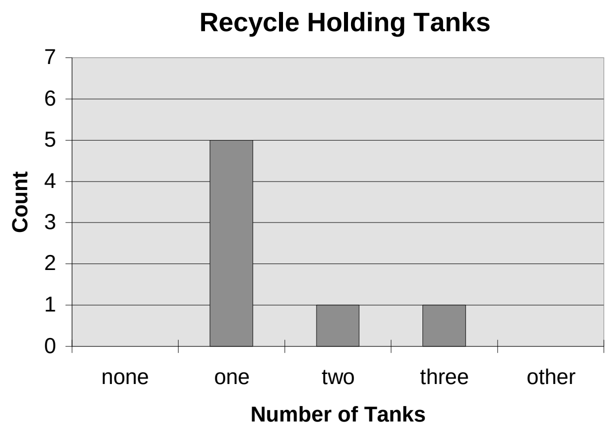
Recycle	Freq.	Pct.
resistivity	0	0
TOC	5	71
selective ion	0	0
resist/TOC	0	0
resist/TOC/sel. ion	0	0
TDS	1	14
other	1	14
Total	7	100



#81) How many holding tanks are utilized in the recycle system?

#81) Number of Holding tanks (rr38%)

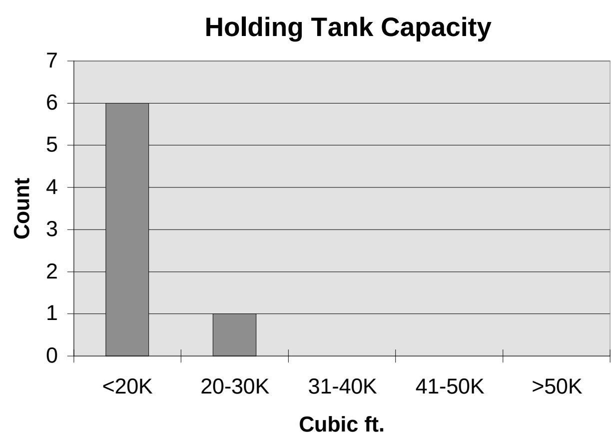
Recycle	Freq.	Pct.
none	0	0
one	5	71
two	1	14
three	1	14
other	0	0
Total	7	100



#82) What is the capacity of the holding tank(s)?

#82) Tank Capacity (rr38%)

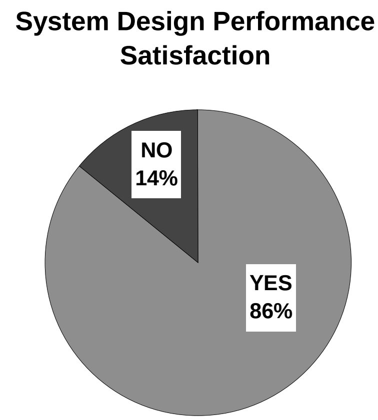
Recycle	Freq.	Pct.
<20K	6	86
20-30K	1	14
31-40K	0	0
41-50K	0	0
>50K	0	0
Total	7	100



#83) Are the existing design/control methods adequate in detecting and diverting unacceptable process water?

#83) Existing design adequate (rr38%)

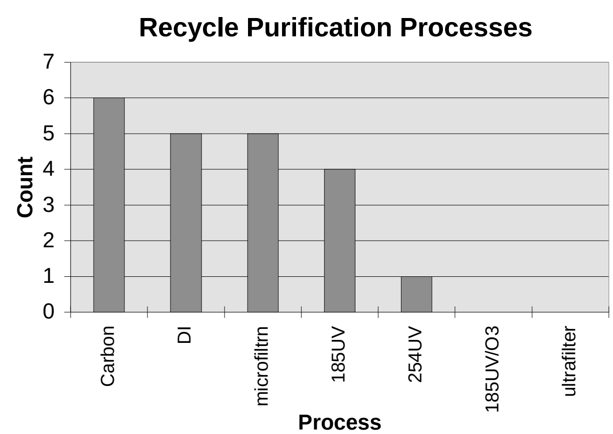
Recycle	Freq.	Pct.
yes	6	86
no	1	14
Total	7	100



#84) What purification processes are employed prior to returning to the DI system?

#84) Recycle purification processes (rr38%)

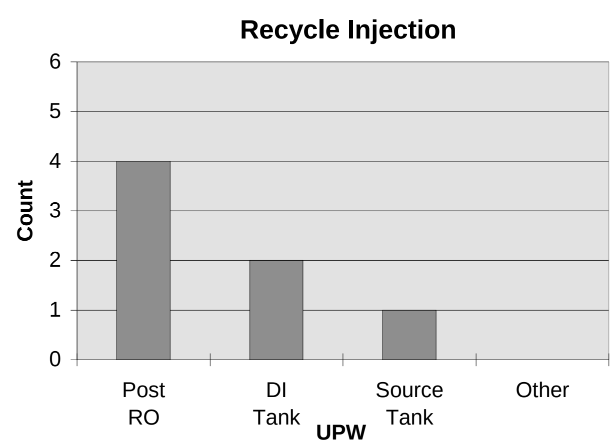
Process	Freq	percent
Carbon	6	27
DI	5	23
microfiltrn	5	24
185UV	4	18
254UV	1	5
185UV/O3	0	0
ultrafilter	0	0
Degas	1	5
Total	22	101



#85) At what point in the DI system is the recycled process water introduced?

#85) Recycle Injection (rr38%)

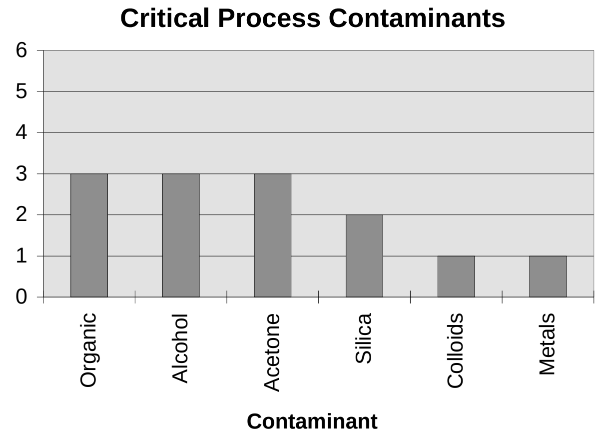
Recycle	Freq.	Pct.
Post RO	4	0
DI Tank	2	71
Source Tank	1	14
Other	0	14
Total	7	100



#87) Which process wastewater contaminants pose the greatest risk to the recycle system/wafer fab?

#87) Critical Process Contaminants (rr38%)

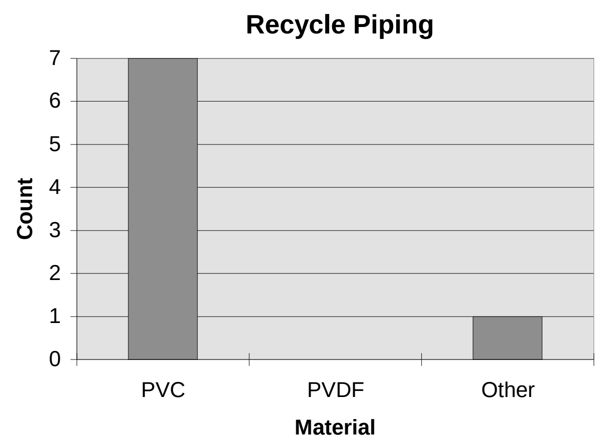
Recycle	Freq.	Pct.
Organic	3	23
Alcohol	3	23
Acetone	3	23
Silica	2	15
Colloids	1	8
Metals	1	8
total	13	100



#88) What is the material of construction of the recycle system?

#88) Recycle system piping (rr38%)

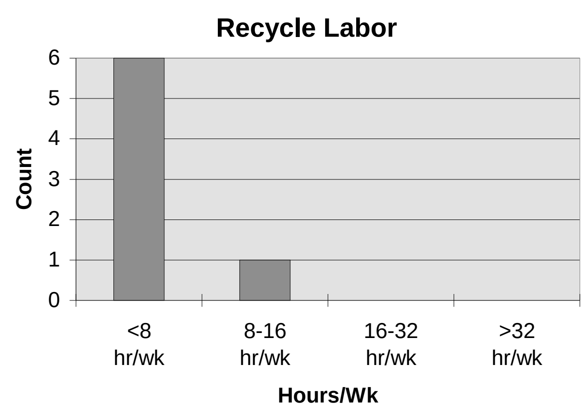
Recycle	Freq.	Pct.
PVC	7	88
PVDF	0	0
Other	1	13
Total	8	100



#89) What is the average labor required to operate and maintain the recycle system?

#89) RECYCLE LABOR (rr38%)

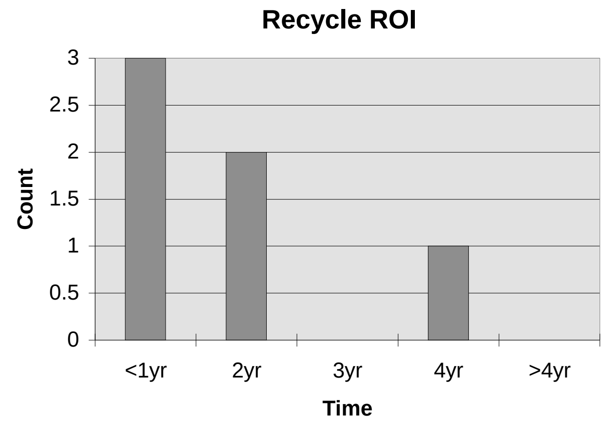
Recycle	Freq.	Pct.
<8 hr/wk	6	86
8-16 hr/wk	1	14
16-32 hr/wk	0	0
>32 hr/wk	0	0
Total	7	100



#90) What is the estimated ROI on the recycle system?

#90) RECYCLE ROI (rr33%)

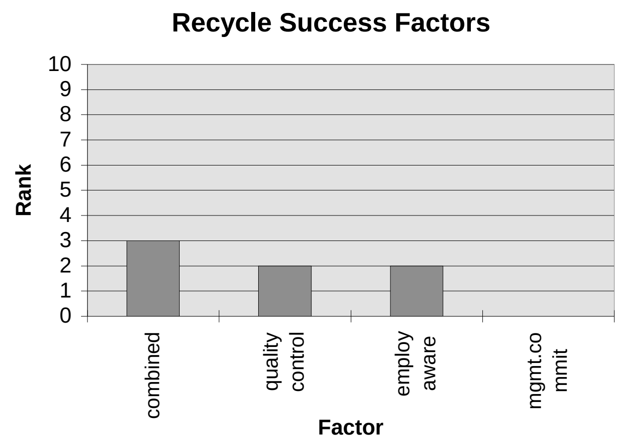
Recycle	Freq.	Pct.
<1yr	3	50
2yr	2	33
3yr	0	0
4yr	1	17
>4yr	0	0
Total	6	100



#91) Which of the following has had the greatest impact on the success of recycling at this site?

#91) Recycle Success Factors (rr39%)

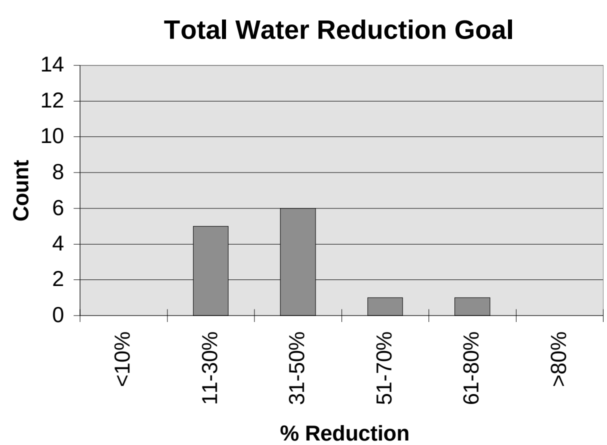
Category	Count	Pct.
combined	3	43
quality control	2	29
employ aware	2	29
mgmt.commit	0	0
Total	7	100



#92) What percent reduction in total water consumption represents a realistic goal for the year 1998 for the semiconductor industry?

#92) Total Water Reduction Goal -1988 (rr83%)

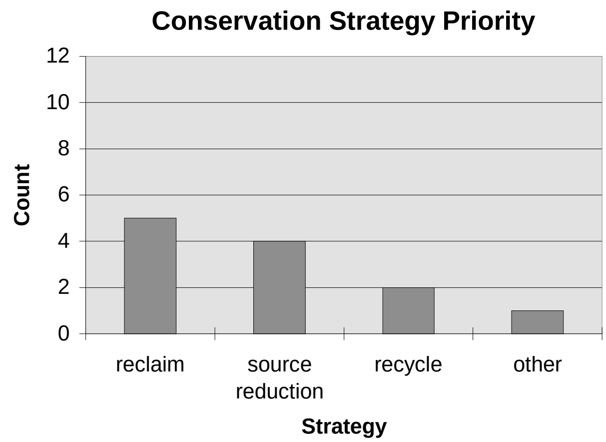
Future	Freq.	Pct.
<10%	0	0
11-30%	5	38
31-50%	6	46
51-70%	1	8
61-80%	1	8
>80%	0	0
Total	13	100



#93) Please prioritize the following areas in significance in achieving the above goal?

#93) Priority strategies

Future	Freq.	Pct.
reclaim	5	42
source reduction	4	33
recycle	2	17
other	1	8
TOTAL	12	100



#98) Is your facility currently examining recycle options?

#99) Is your facility currently examining reclaim strategies?

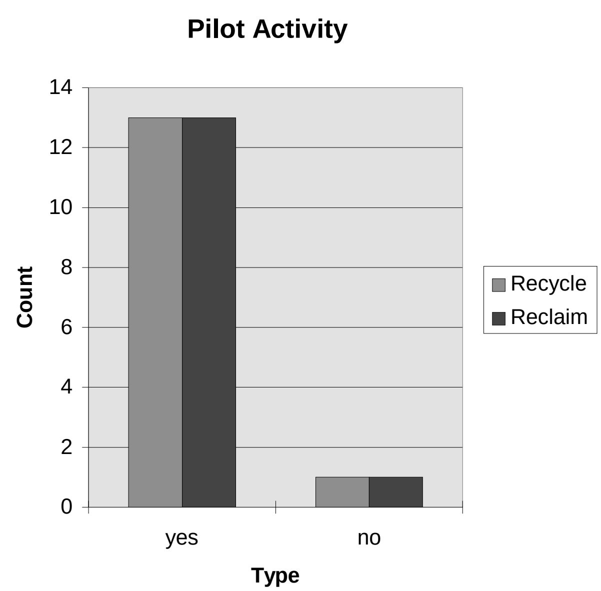
#98) Pilot Recycle (rr78%)

Recycle	Freq.	Pct.
yes	13	93
no	1	7
Total	0	100

Process	yes	no
Recycle	13	1
Reclaim	13	1
Total	26	102

#99) Pilot Reclaim (rr78%)

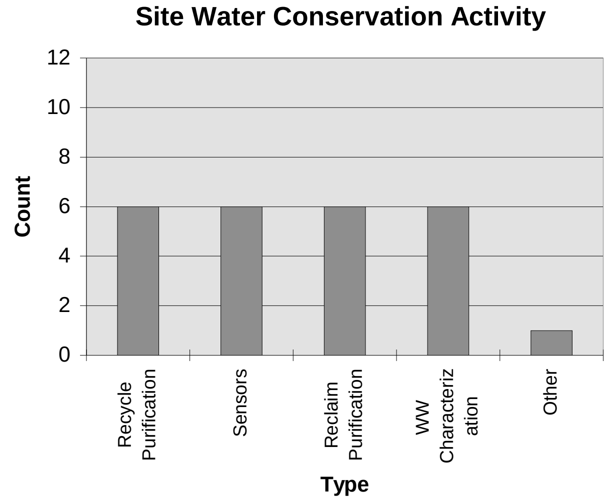
Reclaim	Freq.	Pct.
yes	13	93
no	1	7
Total	0	100



#100) Is your company/site currently evaluating any of the following?

#100) SITE EVALUATION (rr67%)

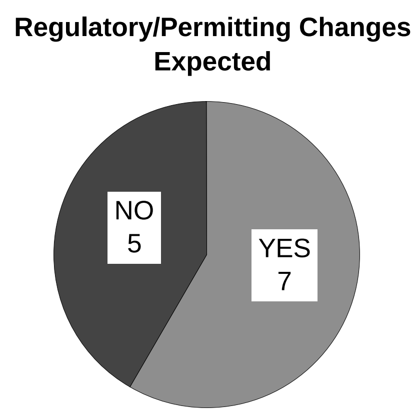
Future	Freq.	Pct.
Recycle Purification	6	24
Sensors	6	24
Reclaim Purification	6	24
WW Characterization	6	24
Other	1	4
Total	0	100



#101) Do you anticipate changes in regulation and permitting during the next five years to significantly impact water consumption or wastwater disposal at your site?

#101) Regulatory & Permitting Changes

Future	Freq.	Pct.
YES	7	58
NO	5	42
TOTAL	12	100



APPENDIX B
Water Conservation Standard Terminology

1. Water conservation— Reduced consumption of water by reclaim, recycle or reduced usage
2. Recovery— Water available for reutilization
3. Recycle— Reutilization to original use
4. Reclaim— Reutilization to alternate use
5. Greywater— Nonpotable water
6. Potable water— Water meeting the quality criteria for human consumption
7. Process water— Water directly contacting the wafer surface
8. Wafer process effluent— Effluent from wafer rinsing process
9. Wasterwater— Waste effluent from manufacturing facility
10. Deionized return— Distribution UPW returned to the UPW system having no contact with the process tool.

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