PROJECT XL FINAL PROJECT AGREEMENT

MANAGEMENT OF SEMICONDUCTOR RINSEWATERS FROM A COPPER PLATING PROCESS

submitted by the

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I. PROJECT SUMMARY

This Project XL application seeks a site specific process exemption from the F006 listing for the copper plating process rinsewater. IBM Burlington has introduced a copper plating process to create electrical interconnections between device levels for new semiconductor technologies. This plating process will replace the aluminum Chemical Vapor Deposition process which is in use today for previous generation semiconductor device technologies. Addition of the 400 gallons per day of copper plating rinsewater (present generation rate, rising to approximately 4000 gallons per day in the year 2001) to the other process wastewaters generated at the Burlington Semiconductor Manufacturing facility (which are not regulated under RCRA) has required the site to classify the sludge generated by the wastewater treatment process as an F006 hazardous waste under the mixture rule.

Management of rinsewaters in a segregated treatment system to prevent mixing of the plating rinsewaters with the general treatment system influent will require an initial capital investment of $200-350 K and annual operating costs of 25-50 K/yr while minimally increasing the copper discharge to the receiving water. Given that IBM is not presently incurring any additional costs due to the classification of the wastewater treatment sludge as an F006 hazardous waste, there is no economic driver to install a segregated treatment system. The reclassification has, however, increased IBM's reported hazardous waste production by 167 % per year, from 2.25 M pounds to 5.99 M pounds (1997 actuals), and waste management costs by approximately $3.5 K/yr.

IBM believes that there is no environmental benefit or justification for classifying the sludge as an F006 waste because of the introduction of the copper plating rinsewaters and that a site specific process exemption should be considered. In order to achieve a significant environmental benefit on this project, IBM is asking that its voluntary effort to reduce global warming gas emissions through the introduction of an alternate process chemistry in the silicon dioxide chamber clean process be recognized as a significant environmental benefit. IBM is investing $2.0 M at its Burlington semiconductor manufacturing facility for the installation of process piping and gas cabinets to convert the chamber cleaning process from C2F6 to Nitrogen Trifluoride, resulting in a 40-60% reduction in global warming gas emissions, adjusted for production changes, against a 1995 baseline measurement. IBM is voluntarily taking this action well ahead of any regulatory requirements, the requirements of the Memorandum of Understanding negotiated between USEPA and the Semiconductor Industry Association, and actions taken by other semiconductor manufacturing companies.

II. FACILITY AND PROCESS DESCRIPTION

A. FACILITY DESCRIPTION

IBM Essex Junction, Vermont is a semiconductor facility located near Burlington, Vermont. The facility encompasses 1.81 million square feet of which 627 thousand square feet are dedicated to semiconductor manufacturing operations. There are approximately 7500 IBM employees and 1500 contractor employees working at the site. The facility manufactures and tests semiconductor memory and logic devices through a complex, multi-step manufacturing process.

B. MANUFACTURING DESCRIPTION

1. Overall Process Description

The manufacturing process utilizes chemicals to convert a silicon wafer into a multi-layer semiconductor device. Figure 1, found in Attachment C, schematically depicts the basic process flow and chemical usage of the semiconductor manufacturing process. The general process, which repeats itself five to fifteen times depending on the complexity of the semiconductor device, is as follows.

The surface of a silicon wafer is cleaned and passivated with the production of a very thin silicon oxide layer. An organic photoresist is applied to the wafer and a circuit pattern is exposed onto the resist by shining light onto the wafer through a mask. The exposed photoresist is washed away, while the remainder is hardened to protect the insulating layer. After this is completed, the wafer is treated with inorganic liquids and gases to create the doped circuits which provide the semiconductor function. The hardened resist is then ashed or removed with organic solvents. At certain points in the process, metallization techniques are used to electronically connect the stacked layers of the semiconductor device. Wafer cleaning and rinsing steps, using mixtures of inorganic acids, oxidizers, and deionized water, occur after many of the process steps. This process cycle is repeated until a fully functional memory or logic device has been produced. After the circuits are built on the wafer, minute amounts of metal are deposited onto the wafer to produce the connections which will marry the semiconductor to a module or circuit board for use in a computer. Finally, the wafer is sliced into individual chips for test and placement onto substrates or modules for use in computer systems.

2. Detailed Unit Process Descriptions

a. New Copper Metallization Step

IBM recently introduced a new, innovate copper metallization step into the manufacturing process to provide interconnection of the device circuits. It is anticipated that as the next generation of semiconductor technology is introduced into the Burlington manufacturing facility over the next three years, that usage of the copper metallization step will expand by a factor of ten to twenty times the present production rates. The manufacturing process involves the use of a copper plating process to deposit a layer of metal on the wafer. The plating process uses a specialized tool which brings only one side of the wafer into contact with a copper plating solution and applies an electrical current to plate copper onto the wafer surface. The wafer is then rinsed. The wafer is exposed to less than a gallon of plating solution, which is recirculated within the tool from a 40 gallon reservoir, during the plating step. Approximately 0.070 grams of plating solution, containing 0.001 milligram of copper is carried over to the rinse step and approximately one gallon of rinsewater is used per wafer. Present projections for the wafer throughput of this process show that the mass of copper and the volume of rinsewater will likely increase from 0.7 grams per day and 675 gallons per day in the fourth quarter of 1998 to 5.7 grams per day and 5500 gallons per day when the process is fully deployed in the year 2001 (Table 1, page 16) .

b. Chamber Cleaning Process for Removal of Silicon Dioxide Deposits

Silicon oxide layers are used in the semiconductor manufacturing process to insulate between operating levels or layers and to serve as the base material for the construction of the circuits on the semiconductor chip. These layers are deposited by oxidizing silicon containing materials onto the surface of the wafer. During each step, this oxide layer is deposited on the tooling surfaces, as well as the wafers, requiring that the chamber be cleaned periodically. These chamber cleans are achieved by converting hexafluoroethane (C2F6) to gaseous hydrofluoric acid to remove the silicon oxide on the tool hardware. The tools inject the C2F6 gas into a plasma stream which dissociates the gas into gaseous hydrofluoric acid. Conversion rates of the C2F6 to gaseous HF range from twenty to thirty percent depending on the tool and process type. The unreacted gas, and the reaction byproducts such as CF4, are vented to the atmosphere after treatment in a water scrubber. The perfluorinated compounds, C2F6 and CF4, are global warming gases. IBM Burlington has developed an innovative process, using nitrogen trifluoride (NF3) to remove the oxide layer and reduce the process emissions of the global warming gas by over 90%. These modifications will be discussed in Section IV.

c. Wastewater Treatment System

The IBM Burlington facility has an on-site wastewater treatment system which discharges to the Winooski River. The discharge is regulated by a National Pollution Discharge Elimination System (NPDES) permit issued by the state of Vermont which regulates the daily mass and concentration discharge levels of the metals and other materials used in the semiconductor manufacturing process. Of specific interest to this application, the plant has a mass based monthly average discharge limit on copper, based on water quality criteria for the receiving water, of 6.86 pounds per day. Rinsewaters from the various processes are collected in the drain system for Dilute Industrial Rinsewaters and Inorganic Wastewater for treatment through a lime precipitation process. The process removes metals, phosphorous, fluorides and solids from the wastewater stream. Present flow through this wastewater treatment system is 4.1 Million Gallons per Day (MGD). Production increases and the installation of additional tooling at the facility are projected to increase the flow to 5 MGD by the year 2000.

d. Sludge Disposal

Treatment of this wastestream results in the production of approximately 5.6 tons of wastewater treatment sludge per day. The sludge is classified as an F006 hazardous waste as a result of the addition of the copper plating rinsewaters to the wastewater system in April of 1998. The dried sludge (40-60% solids) is shipped to the Stablex facility in Canada, where it is stabilized in a concrete matrix and disposed of in a secure landfill. IBM presently ships approximately 2000 tons of sludge per year.

IBM periodically analyzes the wastewater sludge to provide data demonstrating that the sludge is non-hazardous per the RCRA requirements. Attachment B provides the TCLP data for metal and organics that has been collected since 1990. The data demonstrates that the sludge is not hazardous for characteristics.

III. REGULATORY FLEXIBILITY

A. INTRODUCTION

IBM is seeking a site specific process exemption under 40CFR260.22 which would exempt the rinsewaters generated from the copper plating processes used within the wafer manufacturing lines from regulation under RCRA. Under the existing Resource Conservation and Recovery Act (RCRA) regulations, sludges or solids created from the treatment of wastewaters which include rinsewaters generated from an electroplating process carry the F006 listing (40CFR261.31). Mixing of the copper plating rinsewater with the other wastewaters generated at the site (which were not previously regulated under RCRA) has resulted in the wastewater treatment sludge being classified as a F006 hazardous waste under the mixture rule.

B. BACKGROUND

IBM Burlington has implemented the copper plating process at its facility. Prior to May of 1998, the copper plating rinsewaters were collected and drummed for off-site disposal. Beginning in May, the volume of rinsewater generated from the process (approximately 250 gallons per day) became sufficient to make it an operational necessity to mix the copper plating process rinsewaters with the general wastestream and classify the wastewater treatment sludge as a F006 hazardous waste. Classification of the sludge as a RCRA hazardous waste requires IBM to prepare and track US hazardous waste manifests for all sludge shipments and secure permission from the USEPA and the Canadian and Quebec Environmental Ministries for international shipment of the hazardous sludge for disposal in Canada. It increases the annual quantity of hazardous waste generated by the IBM Burlington facility from 2.25 M pounds per year to 5.99 M pounds per year (1997 actuals).

C. PROPOSED REGULATORY FLEXIBILITY

In this application, IBM will present data to demonstrate that the F006 listing of the sludge does not provide any additional environmental protection while adding paperwork and reporting requirements and significantly increasing the quantity of hazardous waste generated at the Burlington facility. IBM proposes that the EPA exempt the copper plating process from the F006 definition through a site specific process by rulemaking in accordance with the requirements of 40CFR260.22.

1. Reassessment of the F006 Listing

IBM is seeking a site specific reassessment of the application of the F006 RCRA listing, as defined in 40CFR261.31, to the rinsewaters generated by the semiconductor wafer copper plating process. The F006 RCRA listing states, "Wastewater treatment sludges from electroplating operations except from the following processes: (1) sulfuric acid anodizing of aluminum; (2) tin plating on carbon steel; (3) zinc plating (segregated basis) on carbon steel; (4) aluminum or zinc-aluminum plating on carbon steel; (5) cleaning/stripping associated with tin, zinc, and aluminum plating on carbon steel; and (6) chemical etching and milling of aluminum." are F006 wastes. The

documented hotline and compendium rulings. The F006 listing, as promulgated, was primarily focused on large scale plating operations used to plate large metal parts for the finished goods industry. These operations utilized plating and rinse baths consisting of hundreds or thousands of gallons of plating and rinsing solutions which typically processed large parts with extensive geometries. As parts moved from the plating bath to the rinse bath, they carried over significant quantities of plating solution into the rinsewaters, resulting in significant levels of metals in the wastewater treatment sludges.

The copper plating process discussed in this application is very different than the electroplating that was performed twenty years ago. Perhaps most importantly, the chemicals used in IBM's process do not contain the heavy metals, listed in Appendix VII to Part 261 (Basis for Listing Hazardous Waste) which were the focus of the original F006 definition. The plating process and equipment have also been engineered with negligible environmental impact in mind. The process has been designed to minimize the use of the chemical in the plating process and the quantity of chemical dragged out from the plating process to the rinse step. The quantity of copper released through the discharge of the rinsewaters (which is further discussed in this application) is negligible. The process has been developed to maximize the efficient use of the copper metal and minimize the release of the materials into the wastewater system.

2. Impacts of the Rinsewaters on Wastewater Concentrations and Sludge Concentrations

a. Sludge Impacts

IBM has based its request for a site specific process exemption from the F006 regulations on the evaluation of the impact of the copper plating rinsewaters on the IBM wastewater treatment plant influent and sludge. It is IBM's belief that the F006 listing as originally promulgated was not intended to capture the operations performed at the IBM Burlington facility and should not be applicable to the proposed copper plating semiconductor manufacturing process for the following reasons:

♉
the guidance documentation dated August 1979. Appendix VII of Part 261 does not identify copper as a reason for the F006 listing. Copper metal is also not regulated under the Land Disposal Restriction (LDR) standards for wastewaters or non-wastewaters. The LDRs do not set standards for copper, as the metal does not represent a significant environmental threat when materials are land disposed. The TCLP results, provided in Appendix A, demonstrate that the sludge is not hazardous for characteristics.

As described above, the total mass of copper projected to be introduced into the plating rinsewaters for the copper metallization process at full production is 5.7 grams per day and the total volume of rinsewater generated from the process is projected to be 5500 gallons per day. The impact of this wastestream on the composition of the wastewater treatment sludges is inconsequential.

♉ After the copper metallization step, the wafer is subjected to mechanical polishing. This operation results in the generation of 99.4% of the copper mass (2004 grams in the year 2001) generated from the introduction of the copper plating process. Under the F006 definition, this process wastestream does not result in the generation of a regulated hazardous treatment sludge as the polishing process is not in-line or directly associated with the copper plating process.

The impacts of the copper plating and mechanical polishing processes on the wastewater treatment sludge are minimal. At full deployment of the two, distinct processes, the mass of copper transferred to the sludge will increase from approximately 170 grams per day (baseline) to 1102 grams per day, resulting in an increase in the sludge concentration from 34 mg/kg to 180 mg/kg. Again, 99.4% of the increase results from the unregulated mechanical polishing process. The sludge would also not come under regulation under the RCRA Toxic Characteristic test, as copper is not a regulated material.

b. Wastewater Discharge Impacts

In IBM Burlington, the environmental impacts of the wastewater discharge are significantly below the water quality standards for the receiving water and the discharge requirements of the site NPDES Permit. IBM has completed jar testing of the removal of copper in the wastewater treatment system. Baseline copper loadings (YE97) to the wastewater treatment system averaged 309 grams per day and the mass of copper in the wastewater effluent was 147 grams per day. Full deployment of the copper plating and mechanical polishing process will raise the influent copper loadings to 2004 grams per day and effluent copper loadings to 902 grams per day. A discharge of 902 grams per day to the Winooski River represents approximately 28% of the allowable discharge limit of copper set for the facility based on the water quality requirements for the river. The introduction of this process wastestream to the industrial waste treatment system has been reviewed with the Vermont Department of Environmental Conservation and a discharge permit modification processed to incorporate the copper plating and mechanical polishing processes into the permit. Specifics regarding the wastewater discharge will be discussed in the Section on Environmental Results.

3. Alternative Regulatory Authority

Under this Project XL application, IBM is proposing that EPA grant a site specific process exemption from the F006 regulation for the semiconductor wafer copper plating process under the authority granted by 40CFR 260.22. While this authority is provided for in the RCRA regulations, it has been infrequently if ever exercised by the Agency. The June 12, 1998 Federal Register Notice "Solicitation of Additional Pilot Projects Under Project XL to "Reinvent" Environmental Regulations and Policies" (pp.34161-34170) states on page 34164, "In summary, XL is about testing new approaches which: ....-- Test a different way of doing something even if EPA already has the authority to do so under the current system, but is not doing it." Several other XL projects have utilized a site specific rulemaking, published in the Federal Register, to promulgate specific regulatory changes to allow the implementation of Final Project Agreements under Project XL.

IV. ENVIRONMENTAL BENEFITS

Two benefits result directly from the site specific process delisting for the copper plating rinsewater: a reduction in the quantity of hazardous waste generated by the IBM Burlington facility and a decrease in the IBM, State of Vermont, and EPA administrative requirements due to the elimination of the need to receive export permission and process United States hazardous waste manifests for the shipment of sludge to the Stablex facility in Quebec, Canada.

IBM is also proposing that its efforts to reduce emissions of global warming gases from the chamber cleaning process for removal of silicon dioxide deposits be recognized as an environmental benefit associated with this project. IBM has independently developed an alternative process, using dilute Nitrogen Trifluoride, to clean silicon dioxide coated tooling chambers which will reduce the overall global warming gas emissions at the Burlington manufacturing facility by 40-60% in the year 2000 when measured against the 1995 base year emissions despite significant increases in manufacturing output from 1995 to 2000. Conversion of process equipment to the dilute NF3 process, however, will require a capital investment of $2.0 M at the Burlington facility for the installation of gas cabinets and distribution piping. The conversion work is slated to be done in 1998 and 1999 at Burlington and through the year 2001 at other IBM semiconductor manufacturing sites. IBM is voluntarily taking action to reduce these emissions well ahead of any regulatory requirements, the requirements of the Memorandum of Understanding negotiated between USEPA and the Semiconductor Industry Association, and actions taken by other semiconductor manufacturing companies.

A. RATIONALIZATION

Changes in the level of regulation of these rinsewaters and their attendant sludges have a minimal environmental impact. A site specific process exemption for the copper plating rinsewaters is environmentally neutral: the impact on the environment, while minimal, from the addition of the copper in the wastestream is the same whether or not the regulatory relief is granted. In the project and process description above, the focus has been on demonstrating that regulation of the copper containing rinsewaters as F006 is not logical given the lack of environmental hazards associated with the process. The direct benefits of the regulatory change are reduced paperwork and regulation resulting in some small economic benefits.

Development of a workable process exemption would provide a significant benefit to industry and EPA. As companies have focused on designing processes to minimize environmental emissions, some process related hazardous waste definitions have become less applicable with time. Processes such as the IBM copper plating process were not the focus of the original F006 listing. The capability to exempt these types of processes from a process based listing would eliminate unnecessary regulatory burdens and oversight for both industry and the EPA.

Given the minor nature of the economic benefits and the lack of any significant environmental benefit from the regulatory relief, IBM proposes to demonstrate an environmental benefit on this project by receiving recognition for its voluntary implementation of a process change for the silicon dioxide chamber cleans which will reduce the global warming gas emissions by 40-60% from the Burlington semiconductor manufacturing facility. In its proposal for "Regulatory Reinvention (XL) Pilot Projects" in the May 23, 1995 Federal Register (pp.27282-27291) the EPA proposed that ""Cleaner Results" can be achieved directly through the environmental performance of the project or through the reinvestment of the cost savings from the project in activities that produce greater environmental results." While the cost savings from the site specific process exemption are minimal, IBM is requesting that its voluntary investment of $2.0 M to implement the alternate cleaning chemistry on the silicon dioxide chamber cleans at Burlington be recognized as a suitable environmental performance improvement to justify the implementation of the site specific exemption for the copper plating process. IBM is presently in the process of implementing the alternate chemistry at its Burlington manufacturing facility and has developed a plan to implement the process across the IBM Corporation over the next three to four years.

B. TIER 1 AND TIER 2 ENVIRONMENTAL ASSESSMENTS

In the April 23, 1997 Federal Register notice, "Regulatory Reinvention (XL) Pilot Projects" (pp.19871-19882), USEPA expanded on the requirements for demonstrating "superior environmental performance relative to what would have been achieved through compliance with otherwise applicable requirements." (p.19874) A two tiered assessment system was established. Tier 1 sets the baseline which establishes the level of environmental performance which would have occurred absent the program. Tier 2 provides the qualitative and quantitative factors which clearly demonstrate the merits and improvement in environmental performance achieved through the project. The Federal Register Notice also requests information on pollution prevention efforts undertaken on the processes or activities involved in the XL project.

1. TIER 1: Baseline data for the Copper Plating and Mechanical Polishing Process

The baseline effluent loading used in this document is an average calculated from 1996 copper concentration data using the analytical detection limit of .02 mg/l for those analyses where copper was reported as non-detectable. Influent loading was determined by the same technique using data from 1994-1996. Using the influent and effluent loadings, an average removal efficiency in the treatment system for copper of 55% was determined. This value is conservative, as copper concentrations in the influent and the effluent are often at or near the analytical detection limit. The expected baseline copper loadings to the wastewater treatment system were calculated by multiplying these average values times the expected flow through the wastewater treatment plant over the years 1997-2001.

Measurement and calculation work was performed to determine the mass of copper carried into the rinsewater and removed by the mechanical polishing process. To determine dragout, the process engineers weighed a wafer prior to its introduction to the process and then weighed it again prior to introducing it to the rinsing step. Several measurements were taken to verify that the value measured was reproducible. The quantity of copper removed by the mechanical polishing step was calculated by taking the average thickness of the layer of copper applied to the wafer, the thickness of the final copper depositions after polishing and the wafer surface area to calculate the quantity of copper removed. These per wafer values were then multiplied times the wafer processing plan to calculate the additional mass of copper introduced into the wastewater treatment system. Combining these values with the baseline generated the information provided in Tables 1 and 2 (pp. 16,17).

The baseline copper loadings were then combined with the calculated electroplating rinsewater and mechanical polishing loadings to determine the impact of the copper processes on the IWTP sludge and wastewater effluent stream. Projected sludge generation was calculated from projected discharge flows and historical data on sludge production per volume of wastewater treated (Table 2, p.17).

The IWTP discharge is regulated under the Clean Water Act, NPDES permit number 3-1295. The permitted discharge limit for copper was set by the State of Vermont Water Quality Division based on in-stream water quality standards for the receiving water. The monthly average copper discharge limit is 6.86 pounds per day and the daily maximum limit is 9.75 pounds per day. Table 1 (p.16) shows the baseline loading of YE 1997 then the progressive increases in copper loadings in the wastewater influent and effluent as the number of wafers passing through the copper plating process is increased. The baseline loadings per unit of wastewater flow are then multiplied by the projected effluent flows to approximate the baseline data and the projected copper loadings to the wastewater treatment plant through the year 2001.

2. TIER 1: Baseline data for Global Warming Gas Emissions From the Silicon Dioxide Chamber Clean Process

Comparison of global warming gas emission data is made using 1995 as the baseline year and making adjustments for variations in production volumes. Table 3 (page 20) provides this comparative data. Use of 1995 as the baseline year is in accordance with the conditions of the MOU. Emissions were slightly higher in 1996, when compared to 1995, while production volume was relatively constant. The decrease in emissions in 1997 is due to reductions in the volume of C2F6 used in the cleaning of the deposition chambers based on the results of the process optimization work discussed below. Without the introduction of the optimized cleaning process, 1997 emissions would have increased over 1996. While the introduction of the improved process reduced emissions, the volume reductions would not be sufficient to prevent future year to year emissions increases.

3. Tier 1: Pollution Prevention Efforts Undertaken Over the Past Three Years

IBM has been a leader in the semiconductor industry in optimizing the performance of processes which use global warming gases for in-situ cleaning of process equipment. IBM engineers responsible for the chamber cleaning process developed the experimental protocol and process concepts to test alternate cleaning approaches. Utilizing a Radio Frequency Metrology System, IBM engineers measured the process endpoints of various clean steps. Analysis of this data indicated that reductions could be made in the cleaning cycle time and the quantity of gas used without compromising the effectiveness of the clean step. Implementation of the findings from the study resulted in the following benefits:

1. A 50% reduction in C2F6 gas usage was achieved in this process step. This translates into 1.2M liters (185 cylinders) of gas and a cost savings of $265K at projected 1995 production levels. This yearly savings rate will have increased as production increases have occurred at the facility since the implementation of this modified process.

2. The cleaning cycle time in the tool was reduced by 25%. This reduced the energy usage of the cleaning process step by 25% and increased the time that the equipment is available to process wafers.

Global warming gases are presently used in metal etching processes as well as for chamber cleaning. As the metal etch process requirements are more precise, development of a replacement chemistry is not as simple for the etch processes as for the chamber clean processes. Work is underway to find alternatives or treatment/recycle options, but this work is in its preliminary stages.

4. Tier 2: Environmental Benefits, Copper Plating Process

a. Copper Additions to the Wastewater Influent, Effluent and Treatment Sludge

As discussed in the Project Summary, regulation of the copper plating rinsewaters and the resulting treatment residuals is an environmentally neutral activity. Revising the regulatory regime does not change the environmental impact of the implementation of the copper plating and mechanical polishing process at IBM Burlington.

Table 1 (p.16) details the impacts of the copper plating and mechanical polishing process on the influent to the wastewater treatment plant and the discharge effluent. The baseline loading increases with time, because production increases on the baseline process increase wastewater flows and the mass of copper discharged from the base process. Increases in copper loading are relatively moderate through 1998, with numbers increasing more dramatically from 1998 to 2001 as the copper plating process is fully deployed into the facility product line. Even with the additional process loadings, the copper discharge levels will only be 28% of the water quality limits for the Winooski River. The additional loadings do not represent a significant environmental impact to the receiving stream.

The table below summarizes the increased copper loading data.

Table 1

PROJECTED COPPER LOADINGS: BASELINE & WITH NEW COPPER PLATING AND MECHANICAL POLISHING PROCESSES

All Values in grams per day

	YE 1995	YE 1997	YE 1998	YE 1999	YE 2000	YE 2001
Baseline Influent Cu	235	309	329	378	378	378
Cu Plating Influent Cu	0	0.06	0.7	2.0	5.4	5.7
Cu Mechanical Polishing Influent Cu	0	18	208	558	1536	1620
Total Cu Influent	235	327	538	938	1919	2004
Total Cu Effluent	139	147	242	422	863	902

Table 2 details the impact of the increased copper loading on the wastewater treatment plan sludge. Table 2 details daily mass loadings of copper to the sludge (in grams per day) and the final sludge copper concentration (in milligrams per kilogram). As was discussed earlier, copper is not regulated as a specified material in the F006 listing or in the TC test. In fact, if IBM was to attempt to delist the sludge, the concentration of copper in the sludge matrix would not even be part of the evaluation and decision process.

The copper is bound up in the sludge matrix and processing of the sludge at the Stablex facility results in further stablization of the sludge in a concrete matrix for ultimate disposal in a clay lined landfill cell. This increase in copper concentration does not measurably increase the environmental impact of the sludge.

Table 2

PROJECTED COPPER MASS IN THE SLUDGE: BASELINE & WITH NEW COPPER PLATING AND MECHANICAL POLISHING PROCESSES

All values Grams per Day Unless Otherwise Indicated

	YE 1995	YE 1997	YE 1998	YE 1999	YE 2000	YE 2001
Sludge Mass (kg/day)	3,800	5,100	5,400	6,200	6,200	6,200
Baseline Sludge Copper Mass	170	170	181	208	208	208
Copper Plating Addition	0	.03	0.4	1.1	3	3.1
Mechanical Polishing Addition	0	10	114	307	844	891
Total Sludge Copper Mass	170	180	296	516	1055	1102
Total Copper Sludge Conc. (mg/kg)	34	36	56	84	173	180

The data in Tables 1 and 2 show that over 99.4% of the increase in the mass of copper in the facility wastestreams and the sludge results from the unregulated mechanical polishing process. The plating process rinsewaters which results in the F006 code in the sludge are projected to contribute only 3.1 grams per day of copper to the wastestream in the year 2001. The combination of the plating and polishing processes result in a projected total increase of only 894 grams in the sludge, 732 grams in the wastewater effluent and 1626 grams in the wastewater influent.

b. Energy Usage Reduction

The deployment of the copper plating process to replace the aluminum chemical vapor deposition process results in a net reduction in energy usage in the manufacturing process. The chemical deposition process requires the vaporization of the aluminum metal source to deposit the aluminum on the wafer. This requires much more power than is required to run the electrode and pumping equipment required to electroplate the copper onto the wafer. The copper plating process is projected to use 30 to 40% less energy than the aluminum vapor deposition process that it is replacing.

c. Pollution Prevention Efforts in the Copper Plating Process

The bulk of the copper in the plating process resides in the 40 gallon reservoir of copper plating solution. IBM engineers have worked with the plating solution manufacturer and the plating tool manufacturer to develop an in-situ filtering and regeneration process for the plating bath. Preliminary work on the process indicates that the plating bath will need to be replaced infrequently, if at all. The objective of the process engineers is to achieve an infinite bath life for the plating bath. If replacement is required, the plating bath will be drummed for off-site metals recovery or treatment. Spent plating bath solution will not be processed through the IBM wastewater treatment plant.

The tool uses an innovative design to minimize the quantity of plating solution required to plate copper onto the wafer. The plating solution is sprayed onto one side of the wafer in a very thin liquid layer and the copper is electroplated onto the wafer. The wafer is then maneuvered to return the majority of the plating solution to the reservoir before being sent through a cleaning and rinsing process. As a result, each wafer only carries out .0012 grams of copper. The manufacturing process has been designed to optimize the utilization of the plating solution and minimize the dragout to the rinsing system.

The copper plating process also uses less electricity than the previous process of record, aluminum chemical vapor deposition (Al CVD). The specifics of this energy use reduction are discussed as an environmental benefit in the previous section "The Copper Plating Process".

5. Tier 2: Environmental Benefits, Global Warming Gas Emissions Reductions

In order to achieve significant environmental benefit under this Project XL, IBM Burlington is submitting its global warming gas reduction project for consideration as a significant environmental benefit for this Project XL. IBM Burlington is presently executing a project which goes beyond the requirements of current regulations to begin reducing the emissions of global warming gases from its operations.

Presently, there are no emissions limits on global warming gases such as C2F6, which are used for cleaning reaction chambers on the silicon oxide deposition tools and for performing metal etch steps in the semiconductor manufacturing process. IBM has developed an alternate chemistry utilizing nitrogen trifluoride (NF3) to perform the chamber cleaning. NF3 has a much lower global warming potential and it more fully dissociates (80-90% of the gas is converted to Fluoride ions) in the reactor chamber as compared to the use of C2F6 for the silicon dioxide chamber cleans. The site is presently converting the Novellus tools to this process and plans are being made to convert the Applied Materials tools in 1999. These two tool groups do the bulk of the silicon dioxide deposition work at the Burlington facility. This effort goes beyond the requirements of the present regulations, accelerates the activity timetable agreed to under the MOU (explained below), and puts IBM in a clear leadership position on this issue within the semiconductor industry.

IBM proposes to achieve significant environmental benefit through the implementation of the NF3 chamber clean process. In its proposal for "Regulatory Reinvention (XL) Pilot Projects" in the May 23, 1995 Federal Register (pp.27282-27291) the EPA proposed that ""Cleaner Results" can be achieved directly through the environmental performance of the project or through the reinvestment of the cost savings from the project in activities that produce greater environmental results." In this case, IBM will reinvest the savings achieved through reduced paperwork management ($3.5 K). These savings are only a small fraction of the $2 M planned to perform the equipment conversions to support this new process and IBM has committed capital for conversions in 1998 and has planned capital for the remaining conversions at the Burlington site in 1999. IBM is committed to implementing the alternate chemistry regardless of the outcome of the Project XL process, but is seeking to gain recognition for its efforts in this area through consideration of the regulatory relief for the copper plating process.

a. Memorandum of Understanding

In June of 1996, IBM and nine other semiconductor manufacturing companies entered into a Memorandum of Understanding with the USEPA under which the semiconductor manufacturers agreed to study pollution prevention and recycling methodologies over a two year period and propose the most efficient and cost effective manner by which to reduce the mass emissions of global warming gases generated from the semiconductor manufacturing process. IBM has worked closely with the other semiconductor manufacturing companies in performing this evaluation.

b. Alternate Chemistry for Silicon Dioxide Chamber Clean Process

The IBM manufacturing process engineering staff has been independently evaluating alternative process configurations to achieve the reduction of global warming gas emissions through chemical substitution for the C2F6 gas. IBM has placed a continuous focus on achieving emissions reductions through improved utilization of materials within the manufacturing process or through the substitutions of materials with less environmental impact or improved utilization in the manufacturing process. The data in Attachment A details the results of IBM Burlington's effort to reduce chemical usage and emissions and optimize its use and reduce the toxicity of the chemicals required to manufacture semiconductor modules. As discussed in Tier 1, IBM implemented process optimization work in 1996 which resulted in the 50% reduction in C2F6 usage and global warming gas emissions from these cleaning processes on specific sets of tools. Development and implementation of the substitute cleaning process was the next logical step in IBM's effort to reduce global warming gas emissions from these cleaning processes. IBM has completed qualification of its alternate cleaning process and has begun implementing the process across its manufacturing operations, with the first installation conversions being done at the Burlington manufacturing facility. Implementation of the process across IBM is expected to take 2 to 4 years. IBM is working with the equipment manufacturers to make this process chemistry available for general use in the semiconductor industry to fulfill the requirements of the MOU.

Table 3 shows the historical emission levels of global warming gases and the expected potential reduction in emissions levels that are projected as the new cleaning process is implemented at IBM Burlington over the next 18 months. Reductions of global warming gas emissions of greater than 98% percent can potentially be achieved in the chamber clean processes. This translates into a potential overall forty to sixty percent reduction in the total emissions of global warming gases from the Burlington Manufacturing facility once the process change has been fully implemented. This reduction is being achieved without the need to install any end-of-stack treatment or recycle systems.

Table 3

GLOBAL WARMING GAS EMISSIONS

1995 Baseline Comparison

All Values are Normalized for Production Index

	YE95	YE96	YE97	YE98	YE99	YE00
Baseline: No Chamber Clean Red.	1	1.6	1.8	1.9	2.1	2.2
Est. Chamber Clean Emissions	1	1.1	0.95	0.35	0.35	0.4

Total Est. Site Emissions with Reductions	1	1.1	1.1	0.7	0.5	0.5

VI. STAKEHOLDER PARTICIPATION

IBM has been working to develop a Stakeholder's group to develop an FPA for the project to develop a site specific process exemption for the copper plating rinsewaters and evaluate IBM Burlington's plan and progress in implementing the process changes to achieve the reduction of the global warming gas emissions. IBM has contacted four individuals to participate as direct participants. Each has indicated an interest in participating in the project, but no specific commitments have been made at this time:

Patrick Parenteau: Member of the Vermont Law School Staff and former Deputy Administrator of the USEPA.

Elizabeth Courtney: Executive Director of the Vermont Natural Resources Council and former Chair of the Vermont Environmental Board.

Jim Jutras: Chief Operator of the Essex Junction Wastewater Treatment Plant

Gary Gulka: Director of the Technical Assistance Division of the Vermont Department of Environmental Conservation.

Al McIntosh, a professor of Natural Resources at UVM, has tentatively agreed to participate as a commentor.

All of these people were contacted twelve to eighteen months ago. Their interest will be reaffirmed once the Project XL is accepted.

Efforts will also be taken to add additional members, either as direct participants or as Commentors. IBM is planning to contact additional potentially interested parties to complete the Stakeholders group. In addition, IBM will make public notice of the Project XL and Stakeholder's Group in the local newspaper once the project is accepted by the USEPA for development of a Final Project Agreement (FPA).

IBM envisions holding a minimum of three meetings with the Stakeholders. The first meeting will be an orientation session at which IBM will explain the various aspects of the project: an introduction to the Project XL process, an explanation of the semiconductor manufacturing process, the specific processes of interest to this XL project, and the regulatory issues that the project application is addressing. IBM also plans to have a draft FPA prepared to provide to the Stakeholder's group to review for the next meeting. The second meeting would cover any orientation issues not addressed in the first meeting and begin a discussion of the FPA. It is expected that two to three meetings will be required to review and reach agreement on the FPA, though the dynamics of the stakeholders group may require more meetings. IBM will also work individually with the Stakeholders as appropriate to address and resolve specific issues for presentation to the general group. It would be expected that the FPA could be fully developed within three to six months of initiation of the process.

VII. COST SAVINGS AND PAPERWORK REDUCTION

Granting of a process exemption for the copper plating rinsewaters and the resulting declassification of the wastewater treatment sludges results in several benefits to IBM, USEPA, and the State of Vermont.

1. Classification of the sludges as non-hazardous will remove the sludge from the annual RCRA report. Despite a minimal change in sludge composition with the addition of the copper plating process, IBM will increase its reportable hazardous waste production by approximately 167 %, from 2.25 M pounds per year to 5.99 M pounds per year based on 1997 actuals. While a minimal paperwork burden, reclassification of the sludge does have a significant potential for causing negative publicity for the IBM Burlington facility despite the fact that the environmental impact of the sludge and the operations has not appreciably changed.

2. IBM will not have to file an annual "Request for Export of Hazardous Waste" to Canada. Preparation of the application requires 2 hours of engineering time and then 2 to 3 hours of phone calls and follow-up to assure that the application is being processed expeditiously. The USEPA will not have to process and track the Request for Export resulting in some manpower savings to the Agency.

3. IBM will not have to prepare manifests for each shipment of sludge. IBM is presently making 2 sludge shipments per week to a Canadian disposal facility. Preparation, tracking and close-out of a RCRA hazardous waste shipment manifest is estimated to take 1.5 hours per shipment. This represents 150 hours per year of additional effort at a cost of $3.5 K/yr. Similar savings will be accrued by the state of Vermont and the Canadian Waste Disposal facility.

VII. PROJECT GOALS AND SUCCESS

A. PROJECT DURATION AND PERFORMANCE COMMITMENTS

IBM is requesting that the project time period will be 5 years from the effective date of the FPA for the Project XL. Specific conditions of continuation will be proposed in the FPA negotiated after acceptance of the IBM project as a Project XL. At this time, IBM envisions the following enforceable or voluntary conditions will be met to ensure continuation of the project:

1. The Burlington manufacturing facility operates under an NPDES permit which regulates the daily mass and concentration discharge levels for the metals used in semiconductor manufacturing processes. IBM would continue to abide by the conditions of the NPDES permit and any subsequent amendments for the life of this project. Under the Project XL Notice published in the April 23, 1997 Federal Register, pages 19872-19882, this would be an enforceable commitment.

2. The rinsewaters generated from semiconductor plating processes will discharge metals concentrations below the levels established in the process exemption. As part of the FPA work, IBM will negotiate the appropriate exemption levels. Compliance with the exemption levels will be an enforceable commitment under the FPA.

3. Under the FPA, IBM will present its schedule to complete conversion of the chamber cleaning process from the present hexafluorinated ethane (C2F6) based process to the dilute NF3 process at the IBM Burlington manufacturing facility. The conversion commitment will require the capability to be adjusted based on production schedules and tool availability for conversion. IBM proposes to negotiate the status of this commitment as enforceable or voluntary as part of the FPA development process.

4. Given the complete conversion of the chamber cleaning processes to the dilute NF3 process, IBM Burlington will enter into a voluntary commitment for a reduction in its PFC global warming gas emissions and provide a methodology by which the extent of the reduction will be demonstrated and documented.

Any other appropriate commitments developed through the Stakeholder Group Meetings and Review of this project will be incorporated into the proposed FPA.

As discussed above, IBM proposes that this project be initiated through a documented, site specific process exemption to the F006 requirements.

B. PROJECT MEASUREMENT AND REPORTING

For the copper plating process, IBM Burlington proposes to implement a mechanism to track the concentration and quantity of copper discharged in the plating rinsewaters. The specifics of this monitoring activity would be negotiated as part of the FPA. The requirements for ongoing monitoring contained in Section 261.36 a-d of the proposed Hazardous Waste Identification Rule (HWIR) regulations (Federal Register, December 21, 1995 pp.663443-66469), applied specifically to copper, can serve as a logical starting point for these discussions. Use of this protocol for the purposes of this Project XL does not in any way suggest that the HWIR regulations should be used in any other way in this Project XL. As part of the FPA, IBM will negotiate the specific methodology for determining and verifying that the concentration of copper, or any other metal constituent, does not exceed the exemption limit. The HWIR offers three options by which to demonstrate attainment of the exemption levels. The FPA will also propose the frequency of resampling and review necessary to maintain the exemption. The measured copper concentrations would be reported as part of the quarterly reports proposed below for monitoring of the conversion to the NF3 alternate process chemistry. IBM will work with the Stakeholders to determine a reporting frequency for the copper data based on the frequency of the sampling for the period of the FPA after the NF3 conversion work is completed.

For the global warming gas reductions, IBM proposes to track C2F6 usage and estimate the reduction in emissions rates based on the reduction in chemical usage. Work sponsored by Sematech has characterized the conversion rates of C2F6 in the clean steps, providing a means to reliably estimate emissions from gas usage. Use of the conversion factors will provide an estimate within plus or minus ten percent of the actual performance.

Similar conversion data is available for dilute nitrogen trifluoride, the replacement gas for C2F6. NF3 is a moderate global warming gas, but has a significantly lower global warming potential than C2F6 and a significantly higher conversion rate in the process. As Table 3 illustrates, the use of the dilute NF3 process results in a significant reduction in global warming gas emissions from the chamber clean process. IBM is proposing that the measured conversion rate of NF3 in the cleaning process, the quantity of NF3 used in the cleaning process and the known carbon equivalent potential of the NF3 be used to calculate the global warming impact of the revised process.

As part of the FPA negotiation, IBM will propose a means by which to measure tool conversions. From a preliminary assessment, IBM would recommend providing a quarterly report of the number of tools converted and remaining to be converted along with an update of the calculated global warming gas emissions for the facility, both in terms of total mass emitted and in terms of mass emitted per some specified production index. This report would continue until the conversion effort is completed.

VIII. ADDITIONAL CONSIDERATIONS

A. INNOVATION/MULTI-MEDIA POLLUTION PREVENTION

The information on Innovations in the Semiconductor Processes and efforts to achieve pollution prevention are addressed in the Section on Tier 1 and Tier 2 Environmental Results.

B. TRANSFERABILITY

The project as defined is transferable to other semiconductor manufacturers.

The copper plating process being implemented at IBM is similar to the process that will be used by other semiconductor manufacturers. In addition, The Novellus Corporation has announced that it will sell wafer manufacturing tooling which utilizes the IBM copper plating technology to the general semiconductor industry. The level of copper present in the process wastewater discharge and any resulting wastewater treatment sludges will be similar. An F006 process exemption provided under 40CFR261.22 will allow for more realistic regulation of plating processes incorporated into the semiconductor manufacturing operations.

The basic chemistry involved in the modified cleaning process that has been developed by IBM has been presented as a conference paper at the Semicon West Semi Conference. The Novellus Corporation has certified the NF3 cleaning process as a standard process for its tooling. IBM is presently working with Applied Materials to achieve certification and acceptance of the NF3 clean as a standard AME process. Acceptance of the process by the tool manufacturers will facilitate the distribution of this process technology to other semiconductor manufacturers.

C. PROJECT FEASIBILITY

As discussed above, all aspects of this project have been demonstrated to be feasible.

D. SHIFTING OF RISK BURDEN

The project does not result in the transfer of risk. The implementation of the modified cleaning process results in reduced environmental risk through the reduction of the emissions of global warming gases from the semiconductor manufacturing process. Any risks associated with the treatment of the copper plating rinsewaters are the same regardless of whether the process is or is not regulated under the RCRA F006 provisions, though the risks associated with the process, the treatment of the rinsewaters and the management of the sludge are believed to be minimal.

IX. CONCLUSION

IBM appreciates the opportunity to propose an alternative approach to managing copper plating rinsewaters at its Burlington semiconductor manufacturing facility. The work that manufacturers have done to embrace pollution prevention concepts, improve their process efficiencies, and reduce the emissions of the raw materials that are used in their manufacturing processes has, to some extent, rendered the F006 process listing obsolete. Evaluating an alternative regulatory approach to the F006 listing offers the EPA an opportunity to improve the efficiency of its regulations and regulate those wastestreams and processes truly requiring regulation. After successful demonstration of this approach on a single process at a single facility, IBM is willing to work with the EPA staff to broaden the discussion to encompass the many processes which make up the semiconductor manufacturing process.

ATTACHMENT A

POLLUTION PREVENTION PROJECTS AT IBM BURLINGTON 1994-1997

	METHYLENE CHLORIDE	DIBASIC ESTER
‘88	LARGE CHLORINE GAS CYLINDERS	LIQUID SODIUM HYPOCHLORITE
‘88-’92	CFCs	WATER,IPA,HCFCs,XYLENE,ACID
‘89-’94	CELLOSOLVE RESISTS	NON-CELLOSOLVE RESISTS
‘93	PERCHLOROETHYLENE	XYLENE
‘93	ETHYLENE DIAMINE/PYROCATECHO	GALLIC AND ABSORBIC ACIDS

	L	

SPECIFIC PROCESS/TOOL REDESIGN EFFORTS

A. Replacement of the STI Tools in the Manufacturing Process: Burlington process engineers worked with a STI, a wafer cleaning tool manufacturer to improve the wafer clean process and reduce the use of IPA, NMP, and NBA by the tool's processes. STI was offering a 50 wafer per batch tool which used double the chemical throughput of the 25 wafer batch tools. Through the initiative of the Burlington tooling and process engineers, the tool wafer basket and onboard filter recycle system were modified to double the wafer batch from 25 to 50 wafers while maintaining the chemical flow rates used on the 25 wafer batches. These modifications reduced chemical usage in the process by greater than 85 percent. The doubled wafer batch size also has reduced power consumption, clean room floor space, and other facilities costs associated with these solvent processes resulting in an additional savings of $420 K/yr, for a total yearly savings for the modified tool of $920 K/yr**.**

B. Redesign of the LAM Research Corporation (LRC) 9608 TCP system for metal etch processes: The metal etch process utilizes a chlorine based chemistry to define the aluminum and titanium interconnect wiring within the semiconductor device. IBM worked with the tool vendor to modify the tool mainframe and process to achieve the following innovations:

1. Eliminate the use of tetrafluoromethane (CF4), chloroform (CHCl3) and trifluoromethane (CHF3) from the metal etch process and reduce the use of Boron Trichloride (BCl3) and Chlorine (Cl2) . Table 3 summarizes the success of this work.

TABLE 3: SUMMARY OF RESULTS OF THE LRC 9608 TCP SYSTEM REDESIGN

CHEMICAL	PERCENT USE REDUCTION FROM PREVIOUS PROCESS	ANNUAL USAGE REDUCTION (pounds)	ANNUAL COST REDUCTION (dollars)
CHLORINE	2.1	30	1,060
BORON TRICHLORIDE	32.6	1,200	132,000
TETRAFLUORO - METHANE	100	930	15,000
CHLOROFORM	100	750	8,000

TRIFLUORO - METHANE	100	80	1,000

2. The number of cylinder changes for Boron Trichloride is reduced by 32 per year and 3 per year for chlorine. The other cylinder changes have been eliminated. Because of the connection work, cylinder changes offer one of the most likely points in the gas handling and use process for a release to occur. Reducing the number of cylinder changes reduces the potential for a release.

3. The use of greenhouses gases, CF4 and CHF3, are eliminated. This eliminates the emissions of greenhouse gases from this process. IBM is committed, under a Memorandum of Understanding (MOU) with the USEPA, to attempt to reduce its emissions of greenhouse gases from the semiconductor manufacturing process. Elimination through process modifications such as these are an efficient means to reduce emissions.

4. The productivity of this manufacturing process is increased considerably, improving process yields by 5 to 10 percent over the previous process.

C. Use of Ozonation to Replace Nitric Acid in the Sulfuric/Nitric Clean Process: IBM engineers have worked with a wet bench tool supplier and a manufacturer of ozonators to develop a tool which uses ozone to act as the oxidizer in the sulfuric/nitric clean process. IBM engineers designed the ozone diffuser, the critical component in the process redesign, and coordinated the interaction of the wet bench and ozone generator manufacturer to develop an integrated system. The process is presently partially implemented in manufacturing and will be fully implemented upon purchase of two additional tools over the next two years. The following benefits were derived from this work.

1. The process, when fully implemented, will eliminate the use of 3000 liters per year of Nitric Acid from the process at a savings of $5400/year.

2. The bath life is extended from 1 day to 7 days, which will save 24000 liters of sulfuric acid a year at a savings of $21300 per year when the process is fully implemented. Preliminary analysis indicates that the bath life can be further extended to 30 to 60 days resulting in additional reductions of 5400 to 6000 liters per year in the use of sulfuric acid.

3. The process has applicability to the sulfuric peroxide process, which is a significantly larger chemical user. A plan is in place to test ozonation as a replacement for peroxide in several processes over the latter half of 1996.

These three process and tool redesign projects represent a significant improvement in the efficiency of chemical usage. By reducing chemical use, reductions are also achieved in chemical emissions, potential worker exposures, and process costs for the processes.

PROCESS MODIFICATIONS AND ADJUSTMENTS

Over the past two years, the fabricator areas have continued their strong focus on chemical use reduction as a means to reduce fabrication costs and potential environmental, health, and safety impacts of the process. Reductions in chemical usage reduce the quantity of chemicals which are exhausted, the potential personnel exposure during chemical system change activities, and the quantity of organic or inorganic chemicals sent to drain systems for treatment or disposal. Significant chemical use reductions have been achieved in and shared between the CMOS IV and CMOS V manufacturing lines, while other projects have reduced chemical usage in the packaging lines or the mask house area..

A. Reduction in Xylene and IPA Usage on the Module Clean Tool: Perchloroethylene was replaced with a xylene/IPA process in 1993. Through process optimization work performed over the past two years, the bath life of the xylene/IPA bath has been extended from 50 to 80 cycles, reuse of the IPA in the spray wash step was extended to 4 cycles, and software modifications improved process control and reduced chemical usage. The net yearly reduction in xylene usage was 37500 pounds and IPA usage was 76000 pounds.

B. Reduction of Greenhouse Gas Usage in the TEOS CVD Clean Process: The tool and process engineers on the TEOS CVD Clean Process used endpoint metrology to define the clean process endpoint for different mixtures of cleaning gases. Through this work, the cleaning cycle time was reduced 25%, usage of hexafluoroethane (C2F6) was reduced by 33%, and nitrogen trifluoride (NF3) usage was eliminated. The work performed at IBM Burlington was presented to a SEMATECH conference and recognized as an innovative means to reduce the use of greenhouses gases in these processes. The following benefits were realized from this work.

1. C2F6 gas usage was reduced by 1.2 million liters per year at a cost savings of $265 K.

2. NF3 usage of 39000 liters per year was eliminated at a cost savings of $41 K.

3. Better process control reduced the damage to the tool internals, reducing the cost of consumable parts by 50%. Overall per wafer cost for this process step was reduced from $7.65 to $2.87.

4. This process analysis work had applicability to several other chamber clean steps, providing significant cost savings in those processes as well.

5. Overall emissions of greenhouse gases were reduced for this process, as 70 to 80 percent of the chemical used is exhausted to the atmosphere.

C. Resist Shot Size Reduction: Work has been performed in the manufacturing areas to further reduce the resist shot sizes applied to the wafer. In the 1994 , work had been done which reduced the average resist shot size by 40%. Further work has been completed in 1996 which has reduced resist usage in the manufacturing processes. The savings are quantified in Table 4.

TABLE 4: RESIST USAGE REDUCTIONS

RESIST	SHOT SIZE REDUCTION	YEARLY VOLUME REDUCTIONS	YEARLY COST SAVINGS
TMR 3250	4.5 milliliters	3480 liters	584 K
JSR	1.7 milliliters	2400 liters	366 K

Additional work is underway to capture an additional $1350 K per year of savings through the utilization of the TMR 3250 and JSR resists in other processes.

D. Elimination of the Reduced Piranha Step on the FSI Wafer Clean Process: Process analysis work was completed to eliminate the piranha step from the wafer clean process. Elimination of this step has resulted in reductions in 4200 liters per year of sulfuric/peroxide usage at a cost savings of $62.4 K/yr.

E. Introduction of Dilute Chemistries in the Wafer Clean Process: An IBM project, involving personnel from facilities at Burlington, Yorktown and Essonnes, identified a series of process steps in which the desired process results could be achieved in comparable cycle times using diluted chemical mixtures. In the Huang A mixture chemical concentrations were reduced from 8:1:1 (water:peroxide:ammonium hydroxide) to 40:2:1. In addition, it was determined that the chemical bath life could be doubled. Introduction of these modified chemistries into the CMOS V process lines generated the benefits listed in Table 4. Similar savings were achieved in the CMOS IV process line.

TABLE 5: CMOS V CHEM REDUCTIONS USING DILUTE CHEMISTRIES

CHEMICAL	VOLUME REDUCTION	COST SAVINGS ($)
Peroxide	54300 liters	11,000
Ammonium Hydroxide	38974 liters	37,000
Hydrochloric Acid	39000 liters	136,860

F. Conversion of Hot Process Pre-Cleans from FSI Tools to ARCPS/Steags Tools: B970 has converted the hot process pre-clean step from a spray FSI tool to a wet bench tool. This conversion has significantly decreased chemical usage by achieving better utilization of the chemical in the tool bath. Savings are detailed in Table 6.

TABLE 6: HOT PROCESS PRE-CLEAN CHEMICAL REDUCTIONS

CHEMICAL	YEARLY USE REDUCTION (liters)	YEARLY COST SAVINGS ($)
Sulfuric Acid	21,900	18,200
Peroxide	21,500	67,400
20:1 DHF	39,100	30,900
Ammonium Hydroxide	9,500	17,000
Hydrochloric Acid	9,500	12,000

G. Arsine Waste Reduction Through Process Modifications: Burlington is utilizing Safe Delivery System Arsine in place of solid arsenic sources. The SDS system adsorbs the arsine on a zeolite matrix. The gas is slowly released to the process when the cylinder is exposed to pressures equal to or less than atmospheric pressure. These systems reduce the potential for significant releases of arsine gas during processing or cylinder changes and reduces the quantity of wastes generated from the cleaning of parts and solid arsenic sources.

H. Recovery and Usage Reduction of Fomblin Oils Used in Precision Vacuum Pumps: Burlington has increased its focus on reclaiming Fomblin oils from vacuum pumps. Because of the high cost of Fomblin oils, manufacturing has placed an increasing emphasis on reclaiming filters and spent oils. This effort has resulted in the recycle and reuse of approximately 500 gallons in 1994 and 600 gallons in 1995, significant improvements over previous years. In addition, the site is transitioning to dry pumps where appropriate, which eliminates the use of Fomblin oils in the process. As a result, overall use of the oils has been reduced.

I. Megasonics Huang A Dilution: The Huang A chemistry for the Megasonics Huang A in a wet bench had concentrations reduced from 5:1:1 (water:NH4OH:H2O2) to 40:1:2. Table 7 shows the chemical savings.

TABLE 7: MEGASONICS HUANG A DILUTION CHEMICAL SAVINGS

CHEMICAL	YEARLY USE REDUCTION (liters)	YEARLY COST SAVINGS ($)
Peroxide	20,000	62,800
Ammonium Hydroxide	23,400	41,800

J. M2 Memory N-Methyl Pyrollidone (NMP) Clean Step Removal: The NMP clean step was replaced with an ultrasonic/DI cleaning step. This eliminated 2800 l/yr of NMP usage at an annual cost savings of $5.8 K.

K. Optimization of the Peroxide/Ozone Groundwater (GW) Treatment System: Studies performed by Dartmouth University students and supported by the IBM GW engineering staff have resulted in the further optimization of the ozone/peroxide treatment system. This has resulted in a reduction of 25 to 50 percent in the peroxide required for the treatment process.

ATTACHMENT B

SLUDGE DATA: 1990-1998

ATTACHMENT C

FIGURE