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A CASE STUDY OF POLLUTION PREVENTION IN PRINTED CIRCUIT MANUFACTURING

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ABSTRACT

During the past two decades, industry in the United States has been driven to comply with an increasing amount of environmental legislation. The main thrust of the regulations has been to control the end result of the manufacturing process by creating and enforcing environmental discharge limits. However, these "command and control" techniques have not slowed the rate of toxic waste generation, and the volume of hazardous waste produced each year has continued to increase. In an effort to stem the increase in waste production, regulatory agencies have been promoting pollution prevention. This article explores the implementation of these concepts at a printed circuit manufacturing facility in support of the company's total quality management philosophy.

INTRODUCTION

Waste management and hazardous waste management in particular are not new to America or mankind. From the earliest times, waste disposal problems have required attention at locations of production activity and communal living. These problems, which have been created by the beneficial production of goods and services, may manifest themselves after years or even centuries of dormancy and may detrimentally affect the health and safety of people exposed.

In the past two decades, industry in the United States has been inundated with environmental legislation and regulatory advice on how to manage the discharge of industrial wastes. The main thrust of the regulations has been to control the end result of the manufacturing process by creating and enforcing environmental discharge limits. However, the use of these techniques of "command and control"

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has not slowed toxic waste generation. The volume of hazardous waste produced each year has continued to increase. It is estimated by the U.S. Environmental Protection Agency (USEPA) that at the close of World War II the United States generated about one billion pounds of hazardous waste per year. By 1987, the amount of waste generated had reached twenty two billion pounds per year [1, p. 1].

When actual data was collected in 1987 in the first Toxic Release Inventory (TRI), the actual amount of waste generated was almost three times the Environmental Protection Agency's pollution estimate for 1987. The regulatory agencies, the public, and industry were stunned. Public attention was heightened and terms such as *Ozone, Acid Rain, Greenhouse Effect, Pollution Prevention*, and *Waste Minimization* increasingly were brought to the forefront of public awareness [2, p. 71]. In an era of cheap natural resources, inexpensive disposal options, and little environmental interest from the community, industry had little incentive to change its historical practice of end-of-pipe waste management. Faced with the reality of an environmentally aware public, both government and industry have realized that a major change in attitude is essential.

As a highly industrialized and technology-driven society we have striven to create technologically efficacious and fair solutions to the waste disposal problem. In the United States, the first step has been to enact and carry out an increasingly far-reaching set of environmental regulations. While this has in many cases improved the environment, many observers think that further developmental gains can only be realized by prevention, not by outright regulation of generated wastes. In recognition of this change, the United States Congress passed the most significant piece of pollution prevention legislation to date, the Pollution Prevention Act of 1990, which declares it to be the

> . . . national policy of the United States that pollution should be prevented or reduced at the source whenever feasible; pollution that cannot be prevented should be recycled at the source whenever feasible; pollution that cannot be prevented should be recycled in an environmentally safe manner, whenever feasible; pollution that cannot be prevented or recycled should be treated in an environmentally safe manner whenever feasible; and disposal or other release into the environment should be employed only as a last resort and should be conducted in an environmentally safe manner [3, p. 773].

POLLUTION PREVENTION—BENEFITS AND IMPEDIMENTS

The goal of an effective waste management program is to use the most efficient affordable means to dispose of waste and to comply with waste disposal regulations. "Pollution Prevention has been referred to as business planning with environmental benefits" [4, p. 5]. Good planning can result in an efficiently operated business, leading in turn to profits and economic growth. benefits from a well managed and operated Pollution Prevention program, it is thought, can significantly benefit the financial aspects of a manufacturing process. For example:

- A reduction in waste disposal cost may occur because less waste is produced, so less waste must be managed.
- As less waste is produced the need to meet regulatory requirements is reduced.
- The Superfund Amendments and Reauthorization Act (SARA) of 1986 makes the generator of hazardous waste materials responsible for the environmentally safe management of those waste materials from the time generation to the time of ultimate destruction (cradle to grave). A reduction in the amount of waste generated and disposed significantly reduces the risk of being cited in a Superfund action.
- An increase in the efficiency of an operation through pollution prevention beneficially impacts the quantity of raw materials required in the manufacturing process and increases profitability.
- Produce less waste and decreasing employee exposure to toxic materials has a favorable impact on employee health. The decrease in exposure levels and exposure times reduces the risk of long term employee medical costs and potential litigation, and helps to comply with increasingly complex and costly regulations.
- A reduction in either the quantity or toxicity of a waste stream can result in reduced permitting requirements.
- By implementing a Pollution Prevention Program, companies can assure the public that they are alert to community environmental concerns.

However, impediments to institutionalizing a Pollution Prevention Program can be significant:

- Due to the regulator's past emphasis on end-of-pipe waste control, regulatory agencies have been slow to adopt the pollution prevention philosophy. Further complicating the adoption of this philosophy is the conflicting, complex regulatory requirements of existing statutes. This complexity creates problems in understanding and implementing changes, and may cause industry to be reluctant to share successes and failures with other industries and the regulatory agencies, due to fear of infringing upon an unknown or poorly understood statute, and being cited. It may be necessary to acquire costly new permits, modify existing permits or apply for expensive and time consuming approvals from governmental agencies before project implementation begins.
- A lack of funds can frustrate the implementation of a pollution prevention opportunity. this can take the form of insufficient capital for purchasing

equipment and services, or lack of money to procure technical assistance during the planning and implementation phase.

- Technical problems associated with not understanding the manufacturing process or a lack of understanding of a pollution preventative alternative can be detrimental to achieving success. Manufacturing conditions such as lack of space, incompatible adjacent processes, and safety considerations also contribute to failure.
- Management may not support pollution prevention measures because of internal politics, fear of failure, lack of company commitment, and reluctance to admit that the current process is not optimal. Concerns over production quality and client attitudes can effect management commitment [5, pp. 4-5].

PRODUCT DEVELOPMENT

Consultants, environmental and safety personnel, and facilities engineers have long been familiar with the traditional forms of environmental compliance. In order to advance pollution prevention projects the United States Environmental Protection Agency (USEPA) has issued a proposed format for projects. This format identifies a sequence of steps that can be implemented in many kinds of manufacturing operations:

- The planning and organization stage obtains management commitment to the pollution prevention effort, sets overall program goals, and organizes personnel to be involved in the program task force. Data assessment, collection, and evaluation, including site inspections, allow candidate targets and strategies to be compared. At this stage all ideas must be brought forth for inspection. The criteria that will be used to assess the success of the project will be identified.
- The feasibility phase assesses options from a technical and economic viewpoint. Literature reviews and pilot plant testing allow the ranking of the most technologically feasible options and the elimination of others. Economic evaluation tools can then help distinguish between the remaining pollution prevention options. On the basis of the full technical and economic evaluation, each option is evaluated according to the criteria set earlier.
- The implementation phase initiates the pollution prevention project. The performance of the project is monitored and evaluated to assess compliance with project goals.

This effort clearly entails continuous support and continuous improvement: Once the highest priority waste streams have been identified and assessed—both tasks can be difficult—and process modifications have been implemented, the assessment process can address other waste streams. The ultimate goal of the pollution prevention program is to reduce pollution to the lowest feasible level.

CASE STUDY—PRINTED CIRCUIT MANUFACTURER

We discuss the pollution prevention program of a major producer of electronic test systems and backplane connection systems (for the electronics and the telecommunications industries) in the northeastern United States, with supporting manufacturing facilities throughout the continental United States. Since its inception, the company has striven to ensure that it remains in environmental compliance, and to adopt pollution prevention and waste reduction programs wherever feasible. Toxic chemical usage and waste reduction is the principal index of both divisional and corporate environmental performance.

The internal pollution prevention strategy, which seeks to promote waste reduction and resource conservation, is a voluntary effort championed by the senior operations management team and the environmental management team. The program seeks to go beyond the limits of environmental compliance by aggressively raising the environmental consciousness of employees generally, strongly promoting pollution prevention strategies, and making key employees aware of pollution prevention opportunities.

Since 1989 the company managed its business through the use of "total quality management" (TQM). This refers to a system of techniques for structured problem solving that has been adopted widely in recent years. In order to apply the TQM approach to the environmental aspects of the business, data was collected in 1991 to ascertain whether or not there was an opportunity for reducing waste. This data showed that the primary producer of hazardous waste materials was the company's printed circuit facility (Figure 1), which generated of 471,780

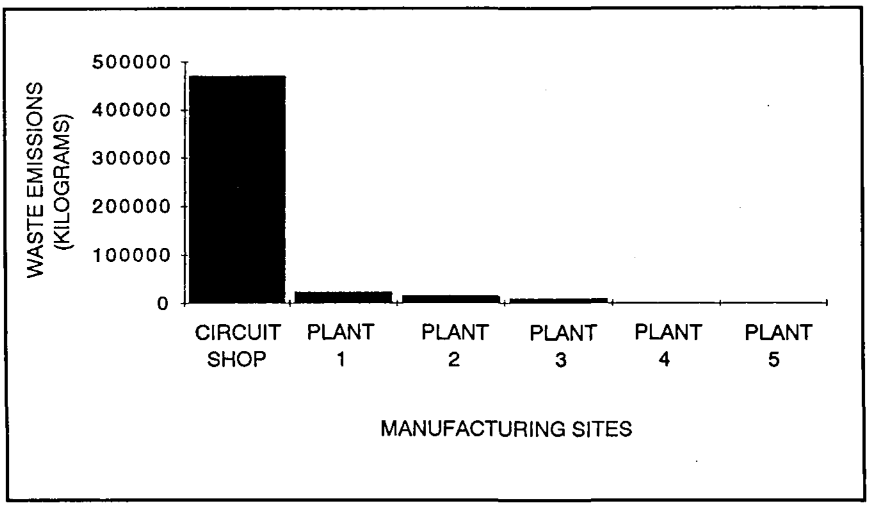

Figure 1. Waste emissions from manufacturing sites.

kilograms of waste materials (not including general trash) or 90.1 percent of all manufacturing wastes. This revelation, coupled with a strong desire to decrease its environmental "exposure" and to reduce costs, led senior management to implement a pollution prevention project at that facility.

The printed wiring board, or printed circuit board, was developed in England in 1944 in order to produce miniaturized proximity for fuses for anti-aircraft artillery shells. Since that time it has virtually replaced hand wiring as the means of connecting electronic circuitry in military and commercial applications. The company's manufacturing operation can be divided into five relatively distinct production areas. These areas include Design, Innerlayer Processes, Mechanical Processes, Plating, and Final Assembly. Sequential processing of the raw material stock through each of these areas produce the finished printed circuit board.

In order to proceed with the collection of facility data in what was perceived to be a complex and interrelated manufacturing process, it was decided to follow the EPA's pollution prevention steps summarized above.

Planning and Organization

The ongoing TQM effort had led the company to examine all aspects of the business with particular emphasis on reducing operating waste, as noted. Further data was assembled by a task force drawn from the company's environmental health and safety, manufacturing and process engineering, quality support, purchasing, and facilities/maintenance branches. The team reviewed technical options, initiated any necessary capital appropriations requests, negotiated purchase prices with potential equipment vendors, managed equipment installation, and provided startup and early operational assistance.

Assessment Phase

Waste material balances were compiled on the basis of hazardous waste manifests, internal material transfer documentation, and site inspections. Water flow measurements were charted using either on-site rotameters or timed-flow measurements. Copper metal in the rinse effluent (the primary parameter used to measure environmental compliance) was analyzed using USEPA-approved procedures.

Waste data was compiled for each process stream (Figure 2). The leading waste producer was the innerlayer etch process, which produced 247,625 kilograms of 65 percent of the waste produced each year. Further ranking of the processes within the innerlayer area showed that the etch operation generated 231,463 kilograms of spent etchant waste, 92 percent of the total waste from the area (Figure 3).

An inspection of the innerlayer process area determined that a large portion of the waste generation was due to antiquated equipment that used poor process control techniques, environmentally unfriendly chemicals, poor process area

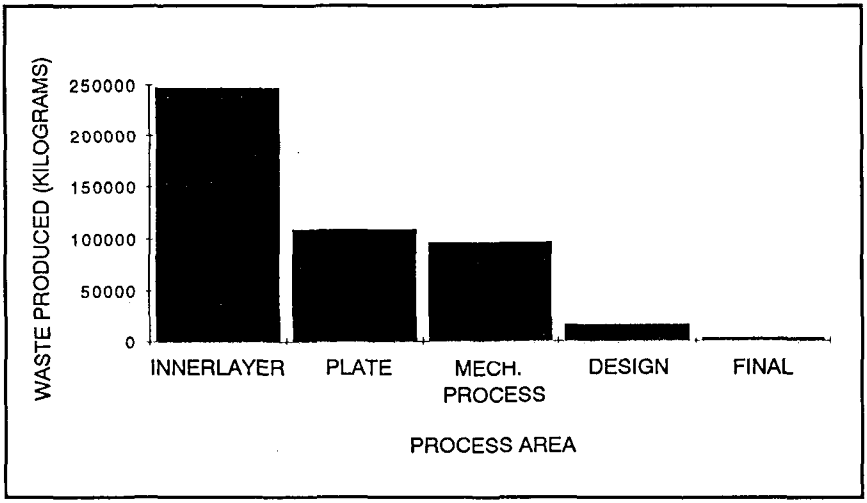

Figure 2. Waste produced in the printed circuit facility.

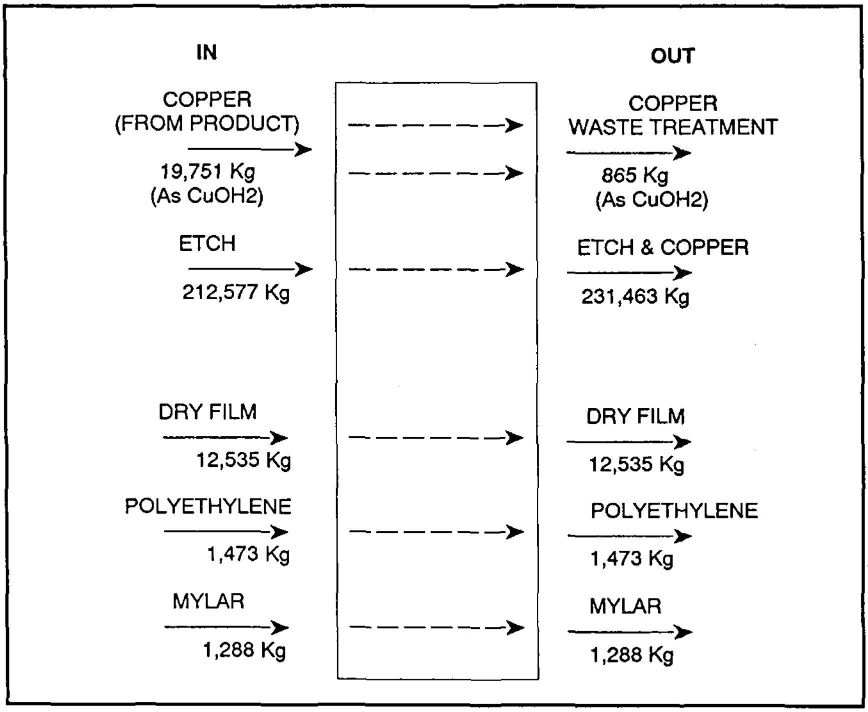

Figure 3. Waste material balance—innerlayer area.

layout and space utilization, and manual handling of materials. Modern process automation and quality control systems were not employed. The pollution prevention team decided that the innerlayer processing area, particularly on the etching process, was the prime candidate for process improvement.

Feasibility Analysis Phase

One of the major process steps in the printed circuit manufacturing facility is the subtractive etching of the copper material from the raw circuit board. The printed circuit industry uses great quantities of etching chemicals to dissolve areas from the raw board to produce circuit traces. The copper-etched area may represent as much as 70 to 80 percent of the total surface area of the final board.

A number of etchant chemicals such as peroxide sulfuric, ferric chloride, cupric chloride and ammoniated alkaline etchant were reviewed against the pollution prevention and production requirements. An initial investigation showed that ferric chloride and peroxide sulfuric etchants produced poor product quality. This led to their being eliminated from further consideration and testing.

Further investigation of the remaining cupric chloride and alkaline ammoniated etchants compared expected production quality, the ability of the dry film photoresist to resist the etchant during processing, the means by which spent etchant materials were to be disposed, and the impact to the waste treatment process. Traditionally the company had used proprietary alkaline ammoniated etchants to etch the copper material from the raw substrate.

Based upon a detailed site inspection, it was determined that the current innerlayer process was characterized by antiquated processing equipment, frequent handling steps, product requirements that stretch process capabilities, poor batch process control, tools with inadequate tolerance capability, additional and varied processing for differing product types, and small operating time windows.

The purchase, installation, and operation of new equipment, incorporating advanced computer process control and automated systems, was seen as a competitive advantage. The proposed quality control improvements yielded a net operating savings $600,000 (U.S. Dollars).

In order to create a circuit pattern on the circuit board it is important to mask areas of the raw material that will not be etched. In order to insure that the proposed process would not attack the dry film mask (used during further processing) a test was devised to compare the current ammoniacal etching capabilities with the characteristics of the proposed cupric chloride process. The results of the tests indicated that the cupric chloride etchant was considerably superior to the current ammoniacal etchant with respect to dry film survivability.

Ammoniacal etchant is a proprietary chemical provided by a small number of specialty chemical suppliers. As a marketing tool these companies agree to dispose the spent hazardous waste etchant in return for future sales. Cupric chloride (the proposed etching chemical) is a commodity chemical, and has not fixed disposal location or company. It used to be the common industry practice to ship used cupric etchant off-site for disposal. However, what with more stringent environmental laws and regulations and the increased liability during transport and disposal, many generators have seen disposal options eliminated. In order to ascertain the viability of off-site disposal for cupric chloride etchants, members of the environmental staff performed site audits of two major disposal facilities in the eastern United States. Based upon the results of these audits which showed unacceptable levels of risk, the company deemed both sites unacceptable and it was decided that the off-site disposal option should not be pursued.

An emerging means of waste etchant management is electrolytic recovery and regeneration. In this process, etchant high in copper content is pumped from the etching equipment through a heat exchanger and into the anolyte loop of a regeneration cell. When the etchant passes through the anolyte loop it is oxidized by electrolytic oxidation and the etchant is regenerated. The free copper ions pass through the cationic membrane and into the catholyte loop. In the catholyte loop the fluid passes through a heat exchanger and into an area that is contacted with a cathode. At this cathode high purity copper is plated and periodically removed (Figure 4).

Major advantages of the electrolyte regeneration system are the virtual elimination of hazardous waste, the manufacture of saleable copper metal, and increased process control capability due to incremental copper removal. Based upon the advantages gained in manufacturability, and in the ability to reduce the amount of

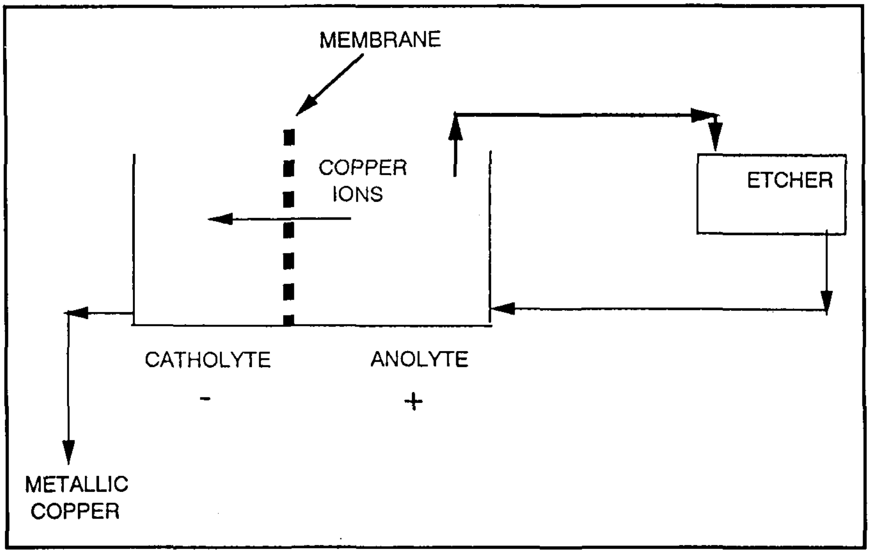

Figure 4. Cupric chloride regeneration system.

generated hazardous waste by the introduction and operation of the electrolytic regeneration system, cupric chloride was determined to be the etchant with the least environmental impact.

In order to fully evaluate a pollution prevention option it is necessary to evaluate the plan's economics. Based upon the proposed innerlayer process with the cupric chloride etchant, the pollution prevention team designed a process which entailed significant changes in the company's current innerlayer process. Operational savings included $600,000 from quality improvements and $1.1 million from expected chemical and waste treatment savings and from labor savings to be realized upon full process automation. At an expected capital cost $2.2 million dollars, the return on investment was estimated to be more than 75 percent per year.

Project Implementation Phase

After the pollution prevention option had been technically and economically analyzed it was approved by the senior management team. At the end of the startup period when the process had reached steady state, (arbitrarily chosen as three months) the pollution prevention team was charged with evaluating the actual performance of the process. The team's measurements showed that 231,463 kilograms of spent etchant waste were directly eliminated, and that there was an additional reduction of 865 kilograms of copper per year from the effluent discharge due to tighter process controls. An additional 14,896 kilograms per year of high purity copper material was available to be sold as raw material. This represented a waste reduction in the innerlayer of 94 percent and a plant-wide reduction of 49 percent.

After evaluating the operation of the new innerlayer process for three months, the team found that the actual process savings based upon quality improvements associated with the operation of modern equipment, material savings from using environmentally-friendlier, cheaper process chemicals, and labor savings from increased automation was $1.3 million. The return on investment of 61 percent.

The consensus of both the pollution prevention team and senior management was that as the process matured, further savings would accrue and the return on investment would approach the originally projected level.

CONCLUSION

Pollution prevention has evolved into a major strategy of environmental protection. The Pollution Prevention Act of 1990, as noted, states that pollutants should be released to the environment only as a last resort. The very great potential for avoiding wastes and pollution implicit in this and related mandates is only now becoming clear. The "total systems" redesign at the printed circuit board plant, which produced striking reductions in wastes and in waste disposal costs, is a case in point.

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