New Jersey Department
of Environmental Protection

Design of Programs To Encourage Hazardous Waste Reduction: An Incentives Analysis

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THE DESIGN OF DEMONSTRATION OR EXPERIMENTAL PROGRAMS TO ENCOURAGE WASTE REDUCTION: AN INCENTIVES ANALYSIS

FINAL REPORT

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I. <u>INTRODUCTION</u>

A. Objectives

This project was undertaken to develop a methodology for designing multi-media initiatives which induce industry to reduce significantly the hazardous waste it generates. By investigating current industry practices, including economic performance, regulatory constraints, and attitudes, and the available and emerging waste reduction technologies, we considered options for reducing the generation of pollution. This project contains a mix of strategies (Task 5) for DEP's consideration to serve as the basis of an experimental program to encourage waste reduction in the electroplating industry and the degreasing process.

In order to develop a broad methodology for understanding the resistance to waste reduction technologies, an industry and an industrial process were chosen for analysis. These choices were then approved by the OSR of the New Jersey Department of Environmental Protection. The fundamental structural difference between an industry segment and an industrial process is the widespread application (in many different industries) of the latter. This difference might give rise to somewhat different barriers to the future adoption of waste reduction technologies. Somewhat different incentives to promote waste reduction are, therefore, suggested for each of these cases.

B. Scope and Limitations of the Study

The ultimate purpose of this study is methodological. We sought to design a set of strategies that can be used in an experimental effort by NJDEP. This experimental program will focus on a small number of electroplaters and of firms using degreasing to encourage changes in technology to reduce the generation of hazardous waste.

This study necessarily focused on average or typical firms. The strategies developed in this effort may not be applicable to all firms or even to the vast majority of firms. The success of the strategies used has to be assessed <u>after</u> the initiation of the experimental program by monitoring the results.

While we have attempted to be comprehensive in our <u>approach</u>, a detailed data collection or interviewing effort was beyond the scope of this project. We balanced the need to be accurate in our understanding of the factors necessary for strategic design with artful and creative thinking for the design itself. It will be easy to identify the limitations of the study. Hopefully, the benefits will also be appreciated.

The scope of the project was to develop a methodology for evaluating strategies that promote the application of waste reduction technologies in industry. One relevant element of such a project is the economic evaluation of available waste reduction technologies. The economics of waste reduction can be presented and analyzed in various levels of detail. The level of detail required depends on the specific purpose of such an analysis. A detailed, case-specific economic analysis, for example, is important for explicitly presenting the benefits and costs of waste reduction technologies. Such an analysis can thus be used as a means of convincing a specific company manager of the advantages of waste reduction practices.

Very detailed economical evaluations can only be attained through plant case studies, however, which require investigating a firm's production process from start to finish, including mass balances. Case studies are very specific and thorough, requiring access to proprietary information. Because of the myriad of variables associated with a specific firm's operations, such as local utility costs, sources of water, type of electroplating process, type of product, etc., specific details are extremely beneficial to a particular firm but have limited value for policy makers faced with the "whole picture" of the industry. Only by conducting a significant number of such case studies is it possible to gain sufficient statistical confidence to infer a general tendency of the economic benefits of waste reduction. This was beyond the intended scope of our project.

More general, mostly non-monetary figures, however, can be found through literature studies, contacts with suppliers, and environmental agency staff, as was done during the project. With a general understanding of the economic realities of the industry combined with a thorough understanding of the waste reduction technologies themselves, including their general economic and environmental benefits and costs, conclusions about the waste reduction technologies can be drawn and assessed. These conclusions are sufficient for the development of strategies to encourage the implementation of waste reduction technologies by industry.

C. Organization of the Report

This Report is organized as follows. Section II examines the general barrier structure of industries, including technological, economic, and attitudinal barriers. Sections III and IV present the electroplating industry and the degreasing process, respectively. Both sections include (A) a summary of the factors which resulted in the selection of electroplating and degreasing as targets of the project;

(B) an examination of existing and emerging waste reduction[1] technologies and important cost factors; and (C) the specific benefits, costs, and barriers associated with each selected waste reduction technology. Section V presents an experimental program for encouraging technologically-based waste reduction in both the electroplating industry and the degreasing process.

[1] For the purpose of this study, "waste reduction" includes source reduction, recycling which is part of the production process, and good operating practice. It excludes waste treatment, incineration, and other end-of-pipe technologies.

II. BARRIERS TO IMPLEMENTATION OF WASTE REDUCTION TECHNOLOGIES: GENERAL DISCUSSION

Most individuals and firms support the concept of protecting the environment. Why then haven't greater strides been achieved since the environmental movement of the 1970's? It certainly can't just be economic considerations because there are many profitable waste reduction technologies currently available (with relatively short payback periods that greatly reduce the production of pollution and actually lead to a greater firm profit). The resistance must then be attitudinal as well as economic. In fact, the attitudes of managers and their technical familiarity with waste reduction opportunities can be as significant as the bottom-line economics.

The word "change" evokes different reactions in people; some believe change is for the better, whereas others prefer the status quo. For an industrial firm change is often undesirable, even if the change can improve profits. Thus, in order to understand the firm's resistance to the implementation of waste reduction technologies, an examination of the way firms (managers and employees) think and react to change is necessary.

METHODOLOGY

To obtain an overview of the range of possible arguments brought forward by companies opposed to implementing waste reduction technologies, several sources of information[1] were utilized (see Appendix II-1 for the sources of information for electroplating and Appendix II-2 for degreasing). First we investigated the available literature, which contains sporadic information about barriers. Discussions with staff of several state waste reduction programs as well as non-regulatory agencies helped us to gain information about the variety of arguments presented by industry. Furthermore, talking to vendors and industry representatives, as well as to consultants, during the January, 1988 AESF/EPA "Conference on Pollution Control in the Metal Finishing Industry" in Florida, provided insightful information about relevant barriers for investing in waste reduction technology. We believe that from these sources of information, we identified the broad range of barriers, particularly since we confirmed our conclusions by comparing the barriers mentioned in the responses to questionnaires,

[1] The same methodology was used to determine the barriers as for gathering technological information. (Refer to Appendix II-1 for further details.) However, the literature, especially the scientific journals, did not prove to be very helpful in revealing the barriers to technological implementation. Personal conversations with state-agency staff, as well as with vendors and platers, at the 9th AESF/EPA Conference turned out to be more informative.

sent to a number of large companies from various industrial segments, by the Center of Environmental Management at Tufts. The individual answers to the questions were published at the "Woods Hole Conferences" over a period of three years. Several questions and answers were pertinent to our research interest and could thus be used to complete the survey of barriers. (For results of the analysis of the "Woods Hole Conference" see Appendix II - 3.)

DESCRIPTION OF BARRIERS

In trying to categorize the different barriers, we developed the graphical survey presented in Appendix II - 4.

The following description explains in more detail the observed barriers as they are perceived by members of the electroplating industry as well as by staff and federal agencies that are involved in promoting waste reduction.

In comparing the barriers identified as pertaining to the electroplating industy and degreasing process to the barriers indicated in the "Woods Hole Conferences," it is clear that many barriers are valid for the electroplating industry and degreasing process as well as for other industrial segments.

(1) technological

- availability of technology for specific applications
- performance capability of technology under certain economic requirements and process design standards
- lack of (some) alternative substances to substitute for the hazardous components
- higher degree of sophistication with operation of some waste reduction technologies
- skepticism in performance of certain technologies and therefore a reluctance to invest
- centralized recovery facilities are not available in the area
- floor-space and headroom restrictions
- process inflexibilities

(2) financial

- research and development costs of technology
- costs related to risk of process changes in regard to consumer acceptance and product quality
- non-comprehensive cost evaluations and cost-benefit analysis as well as cost calculation method
- lack of understanding and difficulty in predicting future liability costs (e.g. of waste disposal)

- short-term profitability calculations resulting in low tolerance for longer pay-back periods of equipment investment
- alleged drawback in competitiveness as other companies are not investing into waste reduction technologies
- lack of capital investment flexibility due to low profit margin
- economies of scale prevent smaller companies from investing in waste reduction options (e.g. in-plant recovery technologies)
- investment in process modification can be inefficient for old companies
- financially (and even technically) tied up due to recent investment into wastewater treatment plant
- actual cost of current technologies masked in operating costs

(3) <u>labor force related</u>

- lack of person(s) in charge of management, control and implementation of waste reduction technology
- reluctance to employ trained engineers for the alleged time-consuming design of waste reduction technologies
- inabiltity to manage an additional program within the company, therefore reluctance to deal with a waste reduction program
- more management requirements with implementation of waste reduction technologies

(4) <u>regulatory</u>

- disincentives to invest in reuse and recovery technologies due to RCRA permit application requirements for recycling facilities which go along with compliance requirements, application costs, etc. (work-intensive)
- depreciation tax laws
- RCRA waivers only for hazardous waste treatment technology or process
- uncertainty about future environmental regulation
- regulatory focus on compliance by use of conventional end-of-pipe treatment technology (may result in investment in those treatment technologies rather than waste reduction technologies)
- being in compliance with discharge standards and by thus having "EPA off your back" provides no incentive to invest in waste reduction

(5) <u>consumer related</u>

- tight product specifications (e.g. military purposes)
- risk of customer loss if output properties change slightly or if product cannot be delivered for a certain period

(6) <u>supplier related</u>

- lack of supplier support in terms of product advertising, good maintenance service, expertise of process adjustments, etc.

(7) <u>managerial</u>

- lack of top management commitment
- lack of engineering cooperation to break hierarchical separation of areas of responsibility (e.g., production engineers do not cooperate with environmental engineers in charge of the treatment and disposal of hazardous substances)
- reluctance on principle to bring about change in the company ("Uncle John did it this way, therefore we are doing it the same way !")
- lack of education, training and motivation of employees (e.g. "good housekeeping" methods or O & M of recovery technologies)
- lack of expertise of supervisors
- public relations image might be harmed since it is alleged that recycling does not necessarily have a good reputation in society in general

Most of the barriers mentioned above can be disaggregated to a more detailed level. One could ask, for example, why there is a lack of top management commitment. This might be caused by various factors:

(a) lack of information from the financial department of the company to top management concerning the profitability of waste reduction technologies in general
(b) lack of confidence in performance of new technologies
(c) lack of managerial capacity and capital to deal with the transition costs of reorganizing the production process, educational programs, consumer demands, or discharge waivers
(d) lack of awareness of long-term benefits of waste reduction approach resulting in waste reduction being a low-priority issue.

In conducting this more detailed analysis of relevant barriers, one notices that some of the same arguments are presented by various actors in the firm's decisionmaking process. The arguments will differ among various companies in the same industrial segment or application depending on their specific process situation. In analyzing waste reduction methods and technologies, we feel the need for categorizing the available options into (1) good operating practice, (2) substitution, (3) complete process changes, and (4) reuse and recovery technologies. The reason for this categorization lies in the nature of the different levels of waste reduction options ranging from more "radical" process changes to additional installation of recovery equipment. We suspect that the above barriers are similar within the elements of each waste reduction category but differ among the four categories.

Appendix II-1 : **Sources of Information for Electroplating**

(1) relevant industry-specific journals published in the U.S.:

* Plating and Surface Finishing
  published by the American Electroplaters and Surface Finishers Society, Inc., Orlando, FL
* Metal Finishing
  Hackensack, NJ
* Products Finishing
  Cincinnati, OH

(2) Conference Proceedings:

* AESF/EPA Conferences on Pollution Control in the Metal Finishing Industry
  - January 1988 conference was attended
  - conference proceedings of the previous years were read in relevant areas
* SUR/FIN International Technical Conference
  - environmental sessions of the conference proceedings from recent years were investigated
* Massachusetts Hazardous Waste Source Reduction Conference
  - the 4th conference in October 1987 was attended
  - conference proceedings from the previous three conferences were investigated
* Hazardous Waste Reduction Audit Workshop by NJDEP and EPA, November 1987
  - proceedings investigated
* 8th Symposium on Hazardous and Industrial Solid Waste Testing and Disposal, Clearwater, FL, November 1987
  - proceedings investigated
* Illinois Hazardous Waste Reduction '87, Chicago, IL
  - proceedings investigated

(3) Publications by trade associations:

* for various relevant publications see "Educational and Technical Materials for the Surface Finishing Professional", AESF publications

(4) Literature Research:

After confirming with members of trade associations, we concluded that published information on technological development pertaining to the electroplating industry in the U.S. is highly concentrated in the above mentioned specialized scientific literature. Therefore we decided that a computerized literature research on our own would not be very time-efficient. We concluded that it was faster to read through the issues of the previous eight years of the journals mentioned above. In addition, we included relevant information from the publication index "Metal Abstracts" and referred to two waste reduction bibliographies: (i) Pollution Prevention Bibliography, North Carolina Department of Natural Resources & Community Development, September 1987 and (ii) EPA - Bibliographic Series: Waste Minimization: Hazardous and Non-Hazardous Solid Waste (1980 to Present), EPA/MSD-87-007, September 1987. Furthermore publications from EPA's Office of Research and Development (ORD), especially the Cincinnati Hazardous Waste Engineering Research Laboratory, presented information about important EPA publications. Finally, the annual extensive surveys in Metal Finishing, one of the scientific journals, on technical developments in the years 1986 and 1987, were very helpful in presenting new information as well as verifying the information gathered up to that point.

(5) Contacts with vendors:

Definition:
Vendors are suppliers to the electroplating industry who sell technical equipment as well chemicals necessary for the plating process. In some cases the latter can also be the manufacturers of the chemical(s) (i.e., plating baths).

Technological areas pertaining to waste reduction:
Scientific journals turned out to be very helpful in retrieving the initial addresses and contacts to vendors. Vendors were chosen in the following areas:

- bath substitution (trivalent chromium, cyanide-free bath solutions)
- control equipment
- ultrasonic enhanced plating processes
- recovery technologies (evaporation, reverse osmosis, ion-exchange, electrolytic recovery, electrodialysis)

Selection of vendors:

A screening phase was intended to establish initial contacts to vendors in the particular technology areas of interest already determined by the previous literature work. The first personal contacts with exhibiting companies were established at the fourth Massachusetts Hazardous Waste Source Reduction Conference and later to a larger extent at the AESF/EPA Conference on Pollution Control in the Electroplating Industry. Those contacts were matched with listings from the "Metal Finishing Suppliers' Association" and SUR/FIN Conference exhibit addresses to achieve two goals:

(i) identify a variety of vendors in order to make sure that no important technologies were neglected during the previous literature survey

(ii) receive detailed technical information from the vendors about their products (performance, life-time, recovery-rate, end-product quality, in-fluence, labor and maintenance requirements, etc.)

The latter information in particular is valuable for conducting the environmental and economic analysis of the effects of the application of certain waste reduction technologies.

Due to the time constraints of the project, we contacted only some of the major vendors in each technological area, including bath substitution.

(6) Contacts with states with waste reduction programs:

In a letter to states which have implemented waste reduction programs, the following questions were asked:

(i) outline and current projects of the waste reduction program

(ii) experience with technical assistance for the electroplating industry

(iii) most common waste reduction technologies applied in the electroplating industry

(iv) experience with the electroplating industry's response to more "radical" waste reduction options such as changes in bath composition

(v) experiences with a waste reduction incentives program

Response:

- reports and/or short descriptions of the waste reduction program of the state (helpful to put the following information in context)

- general examples of technological achievements of electroplaters due to the use of the state's technical assistance (helpful to learn what technologies are advised by the states)

- reports on waste reduction technologies and incentive studies
  (helpful for more detailed information)

- references to further contacts
  (helpful for contacting experts on the state agency level for further discussion of the industry response to our questions)

- statements about barriers to electroplaters implementing waste reduction based on the experiences of the technical assistance program
  (helpful to get an idea of the state's perspective and the most frequent barriers they were/are confronted with in respect to electroplaters)

- statements about what has to be done in order to promote the use of waste reduction methods and technologies (helpful to get an idea on what the states feel are reasonable tools to promote waste reduction)

- conference programs
  (helpful for further contacts and as examples of the topics relevant to states in the area of waste reduction)

- technical information given to electroplaters (fact sheets, short reports)
  (helpful for our technology analysis, partly helpful for economic analysis)

(7) <u>Findings at the AESF/EPA conference</u>: A Brief

While talking to the majority of exhibitors on the AESF/EPA conference and attending the presentations of papers that largely referred to waste reduction, we obtained information in the following areas:

- what are the waste reduction technologies currently available and emerging

- what are the difficulties and limitations of those technologies

- what is the distribution (degree of application) of those technologies among electroplaters

- what are the requirements that those technologies pose for the electroplater who might be interested in applying them

- what are, according to suppliers, consultants, papers presented, and other conference attendees, the barriers to applying waste reduction technologies

- what are the variables that describe the electroplating process

- what difficulties might arise when conducting a general analysis of economic effects of certain technological options considering the enormous variation within the electroplating industry (size of company, type of plating process, type of workpieces plated, site-specific factors, current wastewater treatment technology, current waste reduction technology possibly already in use, drag-out variations, frequency of changes in plating sequence, etc.)

- what role do the landfill-ban provisions of HWSA play in the electroplating industry

- what effect could a national clearinghouse for hazardous waste information have

Appendix II-2 : **Sources of Information for Degreasing**

1. Accomplishments of N.C. Industries: Case Summaries, Pollution Prevention Pays Program, NC Dept. of Natural Resources and Community Development.
2. Alliance, Handbook of Organic Industrial Solvents, 5th Edition.
3. American Society for Testing and Materials, Cold Cleaning with Halogenated Solvents, 1967.
4. Calhoun, Thomas, Ultrasonics. Production Engineering, Oct. 1981, p 59-61.
5. Hazardous Waste Reduction Strategies, Vol II, Nov. 1987, Rhode Island DEM.
6. ICF Consulting Associates, Inc. Guide to Solvent Waste Reduction Alternatives, Final Report, Oct. 10, 1986.
7. ICF Consulting Associates, Inc. Solvent Waste Reduction Alternatives Symposia, Conference Proceedings, Oct. 1986.
8. Pollack, A., and P. Westphal, An Introduction to Metal Degreasing and Cleaning. Robert Draper LTD, 1963.
9. RICOSH, Solvent Substitution: A Resource for Occupational and Environmental Health, 1987.
10. Section 5.0, Waste Minimization Processes and Practices.
11 United States Environmental Protection Agency (USEPA), Center for Environmental Research Information. Solvent Waste Reduction Alternatives Seminar, Speaker Papers.
12. Waste Reduction - The Ongoing Saga June 1986, Woods Hole, Ma., Sponsored by CEM, Tufts University and League of Women Voters of Massachusetts.
13. Toy, Wesley M., Waste Audit Study: Automotive Repairs. Prepared for Alternative Technology Section Toxic Substance Control Division, California DHS, May 1987.
14. Wittcoff, Harold and B.G. Reuben, Industrial Organic Chemicals in Perspective, Part I and II.

Appendix II-3 : **Results of the Woods Hole Conferences**

WASTE REDUCTION CONFERENCES AT WOODS HOLE, MASSACHUSETTS:

The Tufts University Center for Environmental Management and others (League of Women Voters of Massachusetts and the U.S. Environmental Protection Agency) sponsored three annual waste reduction conferences held at Woods Hole, Massachusetts. One important element of the conference was questionaires sent out to major companies in the U.S., documenting their waste reduction accomplishments.

Based on all three volumes of the conferences from 1985 through 1987, the following summary is an excerpt of several questions and answers. These are of interest to the investigation of barriers to the implementation of waste reduction technologies.

The answers to selected questions from volume I, II and III are summarized below [1], [2], [3] :

QUESTIONS :

I. Q. 5 : What do you feel are the major barriers to waste reduction and how can we overcome them?

II. Q. 5. (a): In the future, what new internal capability or new internal arrangements do you feel you need to develop to ensure maximum and effective waste reduction?

II. Q. 5. (b): What were the leading factors causing you to develop programs to increase your waste reduction this past year?

II. Q. 5. (c): Do you need additional incentives to increase your waste reduction program?

III. Q. 1. (c): What were the leading factors that caused you to alter your waste reduction efforts during the coming year?

III. Q. 1. (m): How are you going to maintain or accelerate the momentum and awareness of your waste reduction program in the year ahead?

III. Q. 1. (q): Are there any specific barriers to achieving significant waste reduction levels, that your corporation, particular divisions, or process streams face?

-

NOTE that all companies asked have varying definitions of waste reduction. This is reflected in their answers to the above questions.

NOTE that this summary tries to leave out those answers of companies which are similar to answers mentioned previously by other companies.

A N S W E R S :

VOLUME I :

I. Q. 5. : Barriers

Allied Corporation, Chemical Sector, Morristown, N.J. :

* cost to develop technology (major barrier)
  (helpful to encourage R&D at universities and others, nationwide.)
* economical justification to invest capital for installation of treatment facilities
  (in favor of centralized treatment plants)
* regulatory barriers deriving from RCRA regulations:
  RCRA requires permit application for companies reclaiming waste (register as a waste treater or storer).
  Generators who engage in on-site volume/toxicity reduction efforts face the disincentives of permit application costs, agency compliance requirements, together with exposure to public hearings,
  PR linked to recycling business which has negative connotation.

Chevron Chemical Corp., San Francisco, CA

* external barrier:
  - changing definition of hazardous waste by EPA and states
  - proposed rules to regulate burning of hazardous waste as fuel = disincentive to "make use of these wastes"
* internal barriers:
  - process changes can rarely be justified on waste reduction alone
  - time consuming design of process-changes until implementation

Chrysler Corp., Detroit, Michigan

* technological innovations have not kept pace with need to remove hazardous waste from process. (e.g., water-based technology)
  There has not been the priority to develop the needed technologies
* pattern of estimating costs in a company has been considering only "front-door" costs without regard to "back-door" costs. This is changing but still takes time. This factor has caused the delayed introduction of new technologies.

Eastman Chemical division, Eastman Kodak Co., Kingsport, Tennessee

* state and federal hazardous waste regulations, limiting the reuse and recycyling options.
  Regulations, especially on recycling, might force companies to abandon the best management method due to the costs of complying with the new regulations.
  (Issue: Should hazardous waste which will be recycled still be declared hazardous waste? Compliance with hazardous waste requirements can thus prevent recycling.)

E.I. DuPont de Nemours & Co., Inc, , Wilmington, DE

* high costs of process changes/transition
* "overregulation" :
  - incoming product is charged an incoming freight rate of $X, leaving process for reclamation, the freight rate is $2X, due to waste label
  - recycling obstacles, costly applications, is a hassle and too complicated. Firm can make catalyst without a permit, but to recycle the "spent" catalyst, costs mount.

Exxon Chemical Americas, Houston, Texas

* replacement of old technology in old production facilities is often very costly, time consuming, difficult
* waste reduction programs within a company are just one of many other programs. There is a saturation point, where no more programs can be managed effectively.

Hewlett Packard, Palo Alto, CA

* limited availability of waste treatment/recycling facilities as alternative to landfilling (convenience in distance; for cost efficiency of small generators)
* disincentive to perform on-site treatment (regulatory, societal)

IBM, White Plains, N.Y.

* internal barriers: - reluctance to change process

ICI Americas Inc, Wilmington, DE

* technology and available capital
* need to remain competitive with producers who do not spend comparable resources for waste reduction

3M, St.Paul, MN

* lack of understanding of future costs and liabilities associated with waste disposal
* risk of product and process changes regarding product quality and customer acceptance
* non-flexible technology-based regulations instead of flexible performance-based regulations

Monsanto Company, St.Louis, Missouri

* limited technical resources
* economic constraints of the chemical industry (exports, competition, dwindling capital, etc.)
* understanding and awareness among the plant employees

Occidental Chemical Corp., Niagara Falls, N.Y.

* capital and R&D needs
* difficulty in performing waste reduction in existing facilities rather than in new ones
* regulations function sometimes as disincentives
* uncertainties in regulatory requirements
* since most process changes are confidential, companies are constrained in their ability to share information on waste reduction options

Olin Corp., Stamford, CT

* delisting process too time-consuming and burdensome. This limits resources which could otherwise be directed towards recycling.

PPG Industries, Inc., Pittsburgh, PA

* lack of alternative raw material substitutes for hazardous components

Rohm & Haas, Philadelphia, PA

* unnecessary tight product specifications
* "overregulation" --> recycling of waste (see above)
* artificially low raw material prices (foreign dumping, federal controls on oil and natural gas prices)
* certain tax laws encouraging disposal (not specified)

Shell Oil Company, Houston, TX

* international competition / balance of trade, lack of equivalent regulatory requirements, result in higher priced domestic products
* new standards of technology and liability will first focus on waste treatment before focusing on waste reduction

Union Carbide Corp., Danbury, Connecticut

* environmental laws: dictate schedules that agencies are not able to comply with => delayed deadlines
  fail to provide priorities
  no coordinated overall environmental impact-based approach
* environmental rules :
  - overly complicated
  - inflexibility
  - divert resources that could be devoted to waste reduction
* industrial emphasis on present costs and short-term saving

VOLUME II :

Dow Chemical, Midland, MI

5(a): New internal capabilities and arrangements to ensure effective waste reduction:
- * Waste Minimization Issue Management Team composed of all major areas within company
- * establishing a program including various segments of DOW in the waste minimization program, including consumer demands
- * employ full time issue manager for waste minimization, to insure that goals of Team are met

5(b): * economic and social aspects were the leading factors to increase waste reduction

5(c): * no additional incentives needed

Eastman Chemicals Division, Eastman Kodak Co., Kingsport, TN

5(a): * no new internal capability or arrangements to ensure effective waste reduction

5(b): * desire to optimize use of available capacity of waste management units to reduce compliance costs formed the major factor to increase waste reduction

5(c): * modifications of state and federal regulations to encourage recovery and reuse operations by exempting these activities from compliance with costly hazardous waste regulations was viewed as a needed additional incentive

E.I.DuPont de Nemours, Wilmington, DE

5(a): * no new internal capability or arrangement to ensure effective waste reduction

5(b): leading factors to increase waste reduction:
- * market competition increased pressure for lowering product costs
- * corporate waste reduction policy
- * minimization of liability for treatment and disposal
- * RCRA waste minimization plans

5(c):
- * no additional incentives needed
- * best incentive are economic factors
- * avoid more regulations
- * existing legal requirements provide waste reduction incentives

Exxon Chemicals Americas, Houston, TX

5(a): * greatest need for flexibility in waste regulations related to reclamation without burdensome regulatory process to ensure effective waste reduction

5(b): leading factors to increase waste reduction

- * increased waste disposal costs
- * threat of future liability
- * sometimes costs of product saved

5(c): * no additional incentives needed

Hewlett Packard, Palo Alto, CA

5(a): new internal capabilities or arrangements to ensure effective waste reduction:

- * maximize information exchange between firm divisions regarding waste reduction options
- * determine relevant waste streams that need to be addressed within firm
- * offer incentives to equipment vendors to do R&D for waste reduction technologies

5(b): * increased awareness about potential environmental and liability risk associated with waste generation

- * increased waste disposal costs were the leading factors to increase waste reduction

5(c): * no additional incentives needed

IBM, White Plains, N.Y.

5(a): * improved communication and awareness of need to use less-hazardous materials and develop new product presented the new arrangement to ensure effective waste reduction

5(b): * limited hazardous waste disposal options and the negative business effects that would result therefrom were the leading factors to increase waste reduction

5(c): * no additional incentives needed

Rohm & Haas, Philadelphia, PA

5(a): new internal capability or arrangement to ensure effective waste reduction :
- continue strong tracking program (computerized, in-plant, survey all waste recovered, burned, shipped off-site, waste classes, all hazardous waste; also used to prepare Quarterly Hazardous Waste Report)
- report results forwarded to upper management
- educate employees on environmental issues

5(b): * reduced landfilling was major leading factor to increase waste reduction

5(c): * no additional incentives needed
Forces of regulations and increased costs appear to have had the effect of waste reduction. Let's wait and see for a while.

VOLUME III :

Allied Signal Inc., Morristown, N.J.

1(c): leading factors to alter waste reduction efforts:
- costs and increasing difficulties in disposing waste
- anticipation of expansion in regulatory requirements
- reduction of future corporate liability costs

1(m): how to maintain momentum and awareness of waste reduction program
- video tapes and written material to upper management
- centralized accumulation of data and development of performance statistics
- communication of waste reduction technologies
- inclusion of waste reduction program into environmental assurance review process
- potential use of waste audits

1(q): barriers :
- regulations discouraging recycling
- contracts & specifications which limit the use of reclaimed material
- small waste streams which are difficult to justify spending money on

American Cyanamid Company, Wayne, N.J.

1(c): leading factors to alter waste reduction efforts:
- reduce waste disposal costs
- reduce additional regulatory requirements of organization

1(m): * new computerized tracking system is introduced to maintain momentum and awareness of waste reduction program

1(q): barriers :
- (repeated in arguments already mentioned above)

Chevron Corp., San Francisco, CA

1(c): * long-term liability costs become obvious therefore are a leading factor to alter waste reduction efforts (other arguments presented which are already mentioned by firms above)

1(m): how to maintain momentum and awareness of waste reduction program:
- articles published in company magazine
- Videos
- recognition of employees

1(q): * permitting of facilities linked to corrective action presented as one of the major barriers in addition to those already mentioned above

Digital Equipment, Maynard, MA

1(c): * leading factors to alter waste reduction efforts were already mentioned by firms above

1(m): how to maintain the momentum and awareness of waste reduction program:
- more training and education
- more management awareness
- more emphasis on process engineering decisions

1(q): * people who generate the waste are not responsible for it; (try to overcome with education and accounting changes) - this is seem as an important barrier to achieve significant waste reduction levels

E.I.DuPont de Nemours, Wilmington, DE

1(c): * leading factors to alter waste reduction efforts were already mentioned by firms above

1(m): how to maintain the momentum and awareness of waste reduction program:
- * Wasteline Newsletter
- * Waste Reduction Symposium for DuPont employees
- * cash awards to employees

1(q): barriers:
- * limited resources to implement programs
- * not all programs are cost effective

General Electric, Fairfield, CT

1(c): * leading factors to alter waste reduction efforts were already mentioned by firms above

1(m): * activities on how to maintain the momentum and awareness of the waste reduction program were already mentioned by firms above

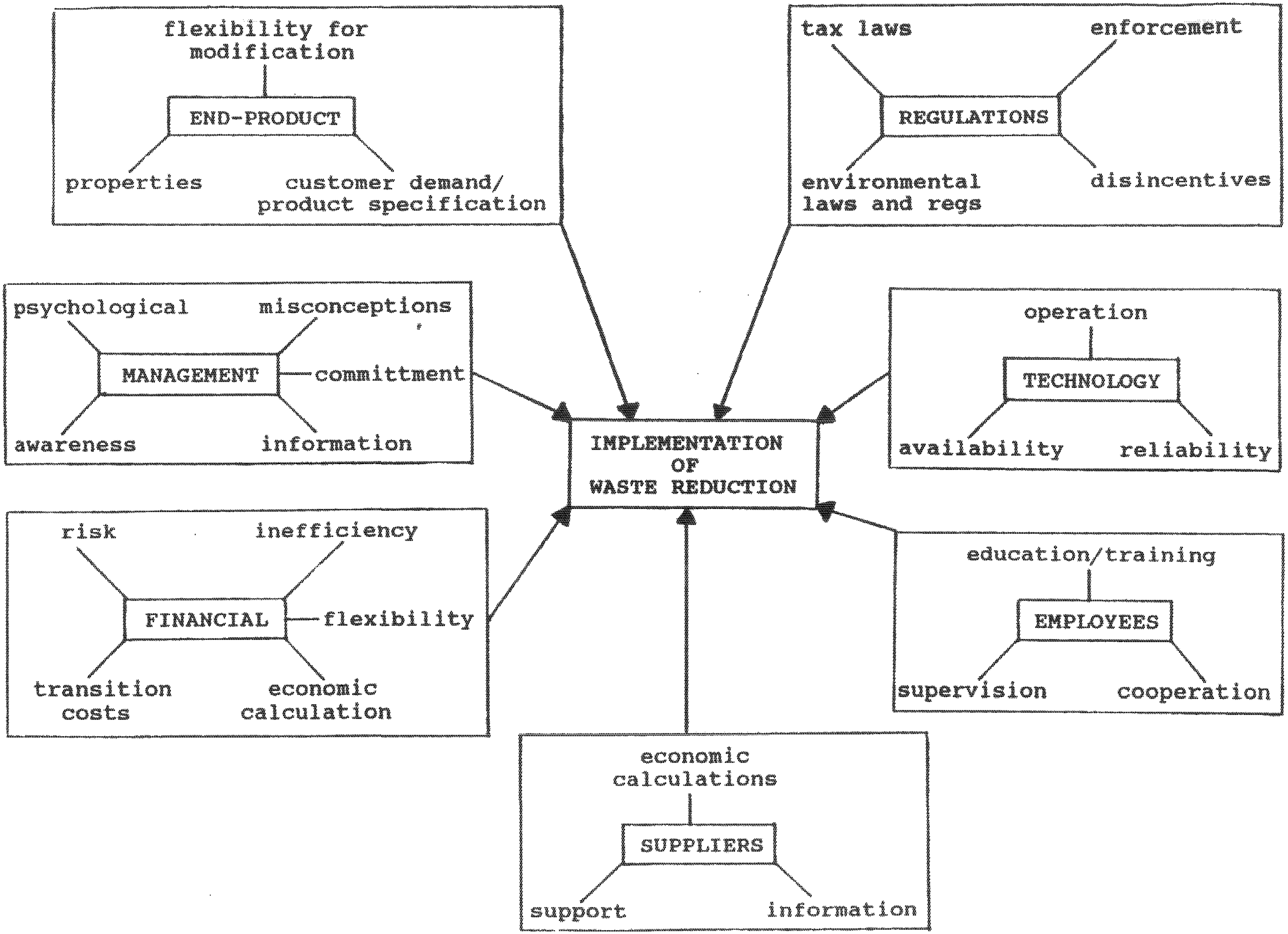
1(q): barriers:
- * manpower resources, competing with other projects, just because waste reduction saves money, it will not be implemented until it is of greater benefit than other competing project (shift to factoring in long-term liability costs)
- * government specifications, especially military
- * uniqueness of some processes restrict the variety of chemicals that can be used, as well as hardware, R&D is necessary in those cases

References:

[1] Waste Reduction - The Untold Story, June 19-21, 1985, League of Women Voters of Massachusetts, Environmental Management Center at Tufts University, U.S. EPA, Woods Hole, 1985.

[2] Waste Reduction - The Ongoing Saga, June 4-6, 1986, Center for Environmental Management at Tufts University, League of Women Voters of Massachusetts, U.S.EPA, Woods Hole, 1986.

[3] Waste Reduction - The Hurdles Ahead, June 3-5, 1987, Center for Environmental Management at Tufts University, League of Women Voters of Massachusetts, U.S. EPA, Woods Hole, 1987.



Appendix II-4: Barriers to the Application of Waste Reduction Technologies and Measures

III. ELECTROPLATING: TECHNICAL DISCUSSION

A. Identification of Relevant Industrial Processes [Task 1]

ELECTROPLATING

(1) Introduction

Electroplating is considered to be a metal finishing process that can basically be described as a surface coating procedure. By means of an electric current between two electrodes, a protective metal surface is plated onto the workpiece from a plating solution. In many cases several layers of metal are deposited on top of each other in order to satisfy certain product specifications.

The electroplating process is used by specific electroplating shops (job shops) as well as by manufacturing companies (captive shops). If a firm electroplates products manufactured by another firm, that firm is considered an electroplater and falls under the electroplating SIC code. If, however, a firm both manufactures a product and then electroplates that product, the firm is considered a metal finisher and falls under the specific SIC code for the product. For example, a car manufacturer will produce the metal parts for the car, clean the parts (typically using the degreasing process), and then electroplate the parts before they are installed in the final product. Such a manufacturer would fall under the SIC code for automobile production, not electroplaters. For additional information refer to Appendix III-1.

(2) Relevance to New Jersey

Metal-containing sludges contribute significantly to the manifested hazardous waste in New Jersey. Of the total of 277 electroplating facilities in New Jersey, only 34 are required to manifest their hazardous substances (mainly metal-containing sludges) [2].[1] Note that the number of facilities only refers to those companies under the electroplating SIC code (SIC 3471), the so-called "job shops." They do not include all those firms, the captive shops, where the firm itself is registered under another major SIC code but does operate an electroplating process

[1] A recent ERM study (Environmental Resources Management) [2] has developed estimates which suggest that the rest of the 243 electroplaters in New Jersey could be small quantity generators of hazardous waste (firms that generate between 100 and 1,000 kilograms of hazardous waste per month) according to Susan Boyle of the Hazardous Waste Facilities Siting Commission (in a telephone conversation on May 26, 1988). The Commission is currently investigating the amount of hazardous waste generated by small quantity generators in New Jersey.

and thus might have to manifest the electoplating waste (depending on size). A focus on the hazardous waste problem alone, however, does not sufficiently describe the environmental problems posed by the electroplating industry. Large amounts of metal-containing wastewater are discharged either directly or indirectly into the surface water [3].[2] Although approximately 90% of the electroplaters are in compliance with the current wastewater discharge requirements,[3] one should be aware that metals are not biologically degradable substances and therefore accumulate in the environment over time. In fact, in numerous situations the agricultural use of sludges has been prohibited due to high concentrations of heavy metals.

(3) <u>Analysis of RCRA Manifest Data for New Jersey</u> [1],[5]

Based on hazardous waste manifest data for the years 1985, 1986, and 1987 for the New Jersey generators, an analysis of only the waste described by RCRA waste codes F006, F007, F008, and F009, which all pertain to electroplating operations, yields several important facts (see Appendix III-6 for the basic data). The F006-F009 wastes are distributed over a wide range of SIC codes from SIC 2511 to SIC 8111. A total of 78 different SIC codes can be found in this range. Looking at only two-digit SIC codes, a total of 26 different SIC groups can be found. Most of the SIC codes are mentioned under SIC 33, SIC 34, SIC 35, and SIC 36. Most of the hazardous waste manifested as F006-F009 waste was reported by SIC groups 32, 33, 34, 35, 36, 37, 38, and 39, with SIC 3429 being particularly dominant in the years 1985 and 1986. SIC group 34 is a major contributor to the specific wastes followed by SIC group 35 and 36. A total of 1,195,108.73 tons of F006-F009 waste was generated over the years 1985-1987 by the whole industry. A significant decrease in manifested waste from 827,872.43 tons in 1985 to 13,550.73 tons in 1987 can be noted among the whole industry. However, this reduction should be viewed with caution, since it could be the result of plant shutdowns or other changes which do not necessarily reflect the implementation of waste reduction practices.

[2] In [3], an analysis of the metal finishing universe contains a survey of the distribution of direct and indirect dischargers on the national level among job shops, the printed circuit board industry, and the captive sector. The majority of companies are indirect dischargers. Even when assuming thet all are in compliance with the federal end POTW standards, the continuous emission of metals such as cadmium, chromium, nickel, copper, etc., contributes to the distribution of those metals in the environment (i.e. sludges of POTWs and sediments). Another study has shown that the majority of metals and cyanide discharged by industry into waterways comes from metal finishing facilities, primarily from electroplating processes [4].

[3] Conversation with Mary Jo Aiello, DEP, Sept. 9, 1988.

Under SIC 3471, describing electroplating, a total of 2,685.18 tons have been manifested over the period of 1985-87. This equals 0.22% of the total of F006-F009 hazardous waste generated over the same period. Looking at 1987 data alone, under only SIC 3471, a total of 738.43 tons of the specific waste are manifested. This is equivalent to 5.4% of the total F006-F009 hazardous waste manifested by the whole industry in this year. Although three years are not sufficient to allow tendencies to be determined, it is obvious that SIC 3471 only constitutes a small portion of the total amount of F006-F009 hazardous wastes that are manifested by the whole industry. The small percentage contributed by SIC 3471 and the fact that the electroplating process is found in many different industries has to be taken into account for the development of any progam that is geared towards encouraging the use of waste reduction practices among electroplaters.

(4) <u>EPA landban on metal-containing wastes</u>

On August 8, 1988, EPA is required under the land disposal restriction provisions of RCRA Subtitle C to promulgate final rules concerning the "Best Demonstrated Available Technology" (BDAT) for the "first third" of the hazardous wastes (see list in FR 261). Congress has established three categories of hazardous waste with separate deadlines for the implementation of the land disposal restriction for each:

(i) solvents and dioxins
(ii) the 'California List' wastes
(iii) the 'scheduled' wastes

The first one-third of the chosen hazardous wastes have a deadline for land restriction by August 8, 1988. The last two-thirds are scheduled for restictions by June 8, 1989. An important distinction is the fact that even small quantity generators as well as the large quantity generators are affected by the landban provisions [6]. Among the "first third" are the F006, F007, F008, and F009 wastes, which are all specifically generated by electroplaters. EPA has recently proposed BADT's for a subgroup of the "first third" wastes, which does not include the F-group wastes.

The uncertainty concerning the upcoming regulations has already induced extensive discussion among the electroplaters about stabilization processes[4] as well as

[4] A process is called <u>stabilization</u> or chemical fixation when metal-containing sludges are mixed with so-called stabilization materials (i.e. mixtures of fly ash and lime), in order to improve the leachability properties of the sludge to be disposed of in a landfill. No later than August 8, 1988, EPA will propose performance-besed leachability standards for sludge constituents. If a sludge after stabilization meets EPA standards it is allowed to be landfilled and does not fall under the landfill ban [6].

increased use of waste reduction technologies. The analysis of possible incentives to promote the application of these technologies is very timely and will be helpful in assisting the New Jersey electroplaters to cope with future expected EPA landban rules.

(5) Data accessibility

The purpose of this project is to develop a methodology for conducting an incentives analysis aimed at the promotion of waste reduction technologies rather than merely developing a data base of waste reduction technologies. Consequently, one criterion for selecting an industrial segment was the availability of sufficient data that could reduce the time needed to become acquainted with the relevant technologies. For example, we could refer to experts in various state agencies who are familiar with state technical assistance programs for waste reduction and who can assess industry's receptiveness to the implementation of waste reduction technologies.

(6) Structural criteria

In order to conduct an incentives analysis with general applicability, it is important to take into account differences in:

(a) the degree of homogeneity of the industry under examination, and

(b) the type of desirable technological response that best addresses the problem at hand (i.e., technological diffusion or technological innovation[5]).

As an example, the electroplating industry is a relatively heterogeneous industry [7] where primarily "technology diffusion" would promote waste reduction. (As elaborated in more detail in section III.B., we have concluded that the waste reduction technologies for the electroplating industry are largely available on the market with few technologies still in their emerging state. Therefore, with respect to the electroplating industry, "technology diffusion" will be the primary focus.)

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[5] Innovation is defined as the first successful use of a new technology or new application. Diffusion is the subsequent spreading of use of technology in other firms.

B. Identification of Waste Reduction Technologies for the Electroplating Industry
[Task 2]

METHODOLOGY

For the first phase of the project, the available and emerging waste reduction technologies were surveyed through the general technical literature on waste reduction. The second phase was oriented towards more specific searches of technologies. Relevant industry-specific journals, conference proceedings, publications of the trade associations, and the academic literature, as well as EPA research papers and Development Documents, were investigated. Selected vendors from each of the technology areas of interest were then contacted for verification. We also contacted states[6] which have implemented a waste reduction program and are currently offering technical assistance to industry. Finally we attended the AESF/EPA[7] Conference on Pollution Control in the Electroplating Industry in January 1988, including an EPA Technology Transfer Seminar on Solvent Waste Reduction Alternatives.

ELECTROPLATING

(1) Baseline technology

Based on publications by EPA[8] as well as general technical literature, the following processes constitute the conventional wastewater treatment technology used in the electroplating industry to comply with federal and state effluent standards:[9]

* cyanide oxidation
* chromium reduction
* neutralization/precipitation
* clarification
* sludge dewatering

6 These states include California, Connecticut, Illinois, Indiana, Michigan, Minnesota, New York, North Carolina, Pennsylvania, and Wisconsin.

7 The American Electroplaters and Surface Finishers Society (AESF).

8 For example, see "Development Documents for Proposed Effluent Limitations Guidelines New Sources Performance Standards for the Metal Finishing Point Source Category". [8]

9 For a general description of the electroplating process, see Appendix III-1.

The application of these end-of-pipe technologies constitute the standard equipment of the electroplating industry.[10] An analysis of possible optimization steps in this area to ensure more cost-efficient compliance was not included in our study, since the intended focus is on front-end options involving process changes.

(2) Waste reduction methods and technologies

Numerous means that generally fall under the category of good operating practice can be introduced without noticeable capital expenditure or process changes [10], [11].[11]

Examples :
* prevent spills
* increase drainage time of plated product
* improve the cleaning process
* conduct proper rack and tank design
* use purer anodes
* clean tank properly before bath change

The second waste reduction category which requires slightly higher investment is control equipment used for analyzing plating bath and rinsewater tanks on a frequent or continuous basis. Improved control over bath and rinsewater conditions ensures a more efficient process performance (e.g., increased bath life, fewer rejects, and reduced water use). For instance, conductivity and pH tests inform the plater of undesirable changes in the plating bath composition, which would result in reduced product quality or even increased rejects. Flow regulators on rinse tanks can significantly reduce water consumption [12].

Examples :
* flow meters
* temperature measurements
* solution conductivity devices
* pH control

Finally the third category of waste reduction options refers exclusively to the application of technology and process changes. The following list subdivides the various options:

(a) **Input requirements**

* improve cleanliness of incoming workpiece
* use distilled process water

[10] The treatment of metal finishing wastes by neutralization followed by gravity settling and/or precipitation and sludge dewatering as well as, in certain necessary cases, cyanide oxidation and chromium reduction has become so widely used by electroplaters (in order to comply with effluent standards) that this is usually referred to as "conventional" wastewater treatment technology. Due to its widespread application, we refer to this as the baseline technology [9].

[11] For a description of benefits of waste reduction technology see Appendix III-2.

(b) **Plating bath**

--> substitution of metal
* substitute cyanide-free zinc for cadmium
* substitute trivalent chromium for chromic acid

--> substitution of composition
* neutral chlorine bath for zinc cyanide
* acid zinc baths for zinc cyanide
* electroless nickel plating for Watts nickel
* alkali zinc baths for zinc cyanide

--> reduction of composite concentration
* use low cyanide bath

--> minimize drag-out[12]
* use effective wetting agents
* recover drag-out from rinse-tanks (combine with evaporation and counter-current rinse tanks)

--> increasing bath life
* use purification technologies : filtration, activated carbon adsorption, physical/chemical treatment, electrolytic treatment
* prevent drag-in (e.g. by good rinsing)

--> recovery
* recycle metals of spent baths by downgrading them using electrolytic recovery technologies (in-plant or off-plant)

(c) **Rinse water**

--> drag-out reduction
* increase bath temperature
* reduce plating bath concentration
* install drainboard and drip-tank

--> minimize water use
* install counter-current rinse tanks
* install fog-nozzles and spray-rinses
* install still-rinsing tanks
* use agitation by air-knives

[12] After having immersed the workpiece into the plating bath, it gets removed from the bath and is drained for a while above the bath. Due to the viscosity of the plating solution, some droplets always adhere to the workpiece and are carried over (=dragged out) into the rinsing system. The solution which is removed from the plating bath in this way is called drag-out.

(d) **<u>Reuse and recovery technologies</u>**
- --> evaporation (atmospheric and vaccum evaporation)
- --> ion-exchange
- --> reverse osmosis
- --> electrolytic recovery
- --> electrodialysis
- --> ultrafiltration

The above survey presents a list of essentially all major changes which are possible (i.e. which can be diffused) within the electroplating industry to reduce the amount of hazardous wastes generated starting at the front-end of the process. It is important to note that details within each of the waste reduction technologies and measures do not receive further attention in this listing. To study the options and their impact on industry performance (economic as well as product oriented), we would have to scrutinize the differences in the characteristics of the technology (e.g., various sizes and types of ion-exchange units or the economic efficacy of centralized recovery plants compared to in-plant recovery equipment).

In addition, the <u>level</u> of recovery comes into play. Is the spent metal recovered in a way that enables the reuse of the product or will it be downgraded and sold as scrap-metal on the secondary material market? These types of questions are very case specific, precluding further study.

Furthermore, there are many <u>combinations of waste reduction technologies</u> possible, and sometimes required, to achieve the desired process effectiveness. Examples include combining reverse osmosis with evaporators in order to provide the proper concentration of the recovered rinsewater for return into bath (or evaporate plating bath to be able to add the recovered metal solution); adding ultrafiltration before reverse osmosis to filter out certain impurities; combining counter-current rinse system with evaporators to be able to recover dragout metals from the first rinse tank in addition to reducing the amount of rinse water used; combining ion-exchange with electrolytic recovery to recover scrap metal sheets; and adding an evaporator in front of ion-exchange to concentrate metals in rinse water.

Having investigated the available technologies that are applicable within the electroplating industry, we conclude that the <u>primary issue in promoting waste reduction in this industrial segment is the diffusion of available technology rather than innovation in emerging technologies</u>. All listed technologies are used by electroplaters to a varying extent, although they are not standard equipment. The mentioned technologies have to be installed with caution. Since they generally require more sophisticated operation and maintenance as well as more process understanding than conventional technologies, they demand prudent engineering process design and in many cases trial periods. Recovery technologies like reverse osmosis or ion-exchange can be applied to electroplating processes but still need further R&D to extend their applicability to a larger range of bath variations or to optimize their individual performance. This indicates that the electroplating industry needs incremental innovation of these existing technologies beyond their present level of application.

In summary, important waste reduction technologies are already available for the electroplating industry. Thus, from a technological point of view, proven waste reduction equipment exists for electroplaters to invest in.

As mentioned before, various combinations of the above cited waste reduction options are possible. In order to conduct an incentives analysis, we restrict further study to a selected group of <u>technological</u> options. Table III-1 represents a matrix of selected waste reduction technologies (WRT) for four key metal plating baths. The subset of possible waste reduction candidates for the construction of an incentives analysis is indicated by "***".

<u>Criteria for selecting waste reduction options for further study:</u>

(1) available case studies or vendor's record of sales
(2) proven applicability under (1)
(3) waste reduction technology is represented in at least one place in the matrix
(4) combination of waste reduction technologies reading in a column is applicable
(5) selection of plating baths mostly used
(6) transferability of analysis of options to other company sizes within the electroplating industry

Table III-1 : Waste Reduction Technology Options for the Electroplating Industry

	Chromium		Nickel		Zinc		Cadmium
WRT\EPP	hard	decorat.	EN	Watts	CN	Cl	CN
substn.		***					***
haz.subst. reduction					***		
bath life increase				***			
minimize dragout	***					***	
minimize wateruse	*** CCR	*** CL	*** FR/CE		*** OL	*** SR/AA	
RO				***			
Evap.	***						
IX		***					
ED							***
ELR					***		

<u>abbreviations</u> :

*** : waste reduction options for consideration
CCR : counter-current rinse
Cl : chloride based bath
CL : closed loop
CN : cyanide based bath
decorat. : decorative chromium plating
ED : electrodialysis
ELR : electrolytic recovery
EN : electroless nickel
EPP : electroplating process
Evap. : evaporator

Table III-1 (Continued)

FR/CE : flow regulators and control equipment
hard : refers to hard chromium plating as opposed to decorative chromium plating. Hard chromium plating results in thicker chromium deposits
haz.subst.: hazardous substance
IX : ion-exchange
OL : open loop
RO : reverse osmosis
SR/AA : spray rinse and air agitation
substn. : substitution
Watts : Watts nickel bath, most commonly used nickel plating bath
WRT : waste reduction technology

(3) Cost Considerations

To get a general idea of the cost distribution within an electroplating company, we can refer to the available literature. Figure III-1 describes the relative importance of several plant operating costs over a period of years (January 1983 - June 1986). Figure III-2 depicts the cost breakdown of average total annual wastewater treatment costs of 14 electroplating firms assuming that conventional wastewater treatment technology is used (e.g., cyanide oxidation, chromium reduction, metal hydroxide precipitation, and sludge dewatering).

Fig. III-1 : Plant Operational Costs of One Plant over the Period January 1983 - June 1986 [13]

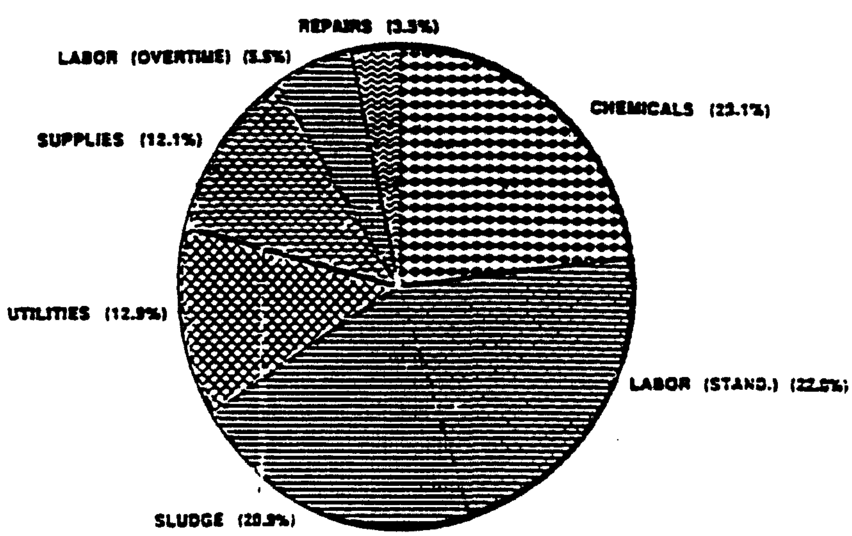
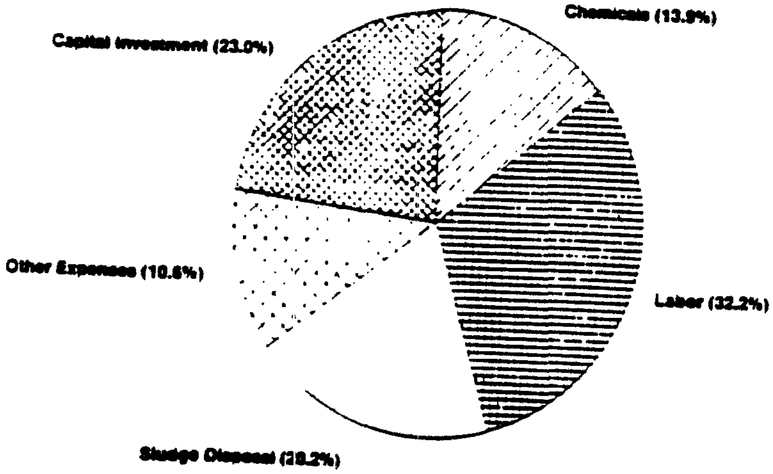


Fig. III-2 : Cost Breakdown of Average Total Annual Wastewater Treatment Costs [14]



These charts can serve as the basis for calculating the relative effects of certain technology changes. We can, therefore, categorize the relevant information for the <u>cost</u> elements of the economic analysis in the following way:

- raw materials/chemical use/supplies
- labor (O&M, utilities, supervision, analysis)
- sludge disposal (including transportation)
- other assumed costs (total installed costs, insurance and taxes, permit costs, record keeping, reporting)

Note that the costs for wastewater treatment are also ordered according to the above pattern; therefore they do not appear as a separate cost item. O & M costs include utility costs and repair costs.

Although this cost breakdown is helpful for further economic analysis, it has its limitations. Generally there are large variations of costs among companies, up to an order of magnitude (normalized by flow) [15]. Average labor burden varies significantly, as well as disposal costs, so that wastewater treatment costs per unit volume show remarkable differences. As a result, the cost structure of the baseline case can only indicate an <u>average</u> cost relationship.

Cost savings are generally a function of the following variables :

- reduced raw material costs
- value of recovered material
- reuse potential of water
- reduction of wastewater treatment costs
- reduction of sewer fees
- reduction of disposal costs
- reduction of liability-related costs

These cost saving factors are examined for each waste reduction option in section III C. For a general discussion of economic parameters and sources of economic information, see Appendix 1.

C. Benefits of and Barriers to the Implementation of Waste Reduction Technologies for Electroplating [Tasks 3 & 4]

INTRODUCTION

From the options of waste reduction technologies presented in Table III-1, a smaller set was chosen as the basis for further study. The first survey conducted relied mainly on technical data gathered from the literature and manuals from suppliers. It does not present a detailed cost and benefit analysis indicating the economic and environmental changes corresponding to the application of a certain waste reduction technology (see Appendix III-7). After this initial screening phase, a more detailed study was conducted, focusing on selected waste reduction technologies. We utilized a questionnaire (see Appendix III-3) directed to suppliers of waste reduction technologies for the electroplating industry for verification. The following four options were chosen in order to guarantee a broad spectrum of the various levels of waste reduction technologies, from the most radical option (substitution) to the ones on the lowest level of waste reduction (i.e., recovery at the end of a production process):

(1)	Substitution	:	Trivalent chromium bath (Tri)
(2)	Minimize Water Use	:	spray rinse possibly in combination with evaporators
(3)	Recovery Technology	:	Reverse Osmosis (RO) Electrodialysis (ED)
(4)	Good Operating Practice (GOP)	:	increase drainage time by using drip bars to hold parts over tank use also air knives

Remarks

(1) We did not enquire into combinations of technologies that would include all possible waste reduction technologies. We, therefore, did not determine the maximum efficiency of a process in terms of waste reduction that could theoretically be achieved.

(2) We needed to determine the specific application of the recovery technologies. Reverse osmosis (RO) can be used to achieve several goals: (i) to concentrate the wastewater stream and thereby make the wastewater treatment more efficient, (ii) reuse the wastewater in the process or discharge without further treatment, (iii) return the concentrate to the plating bath, (iv) use the concentrate for metal recovery on-site (i.e., electrolytically) and sell the scrap metal, (v) hand the concentrate over to a recovery facility off-site either for further recovery of scrap metal or for reuse of metals to be returned into the plating bath. Whichever option was chosen by a particular company determined the financial benefits as well as the payback period of the waste reduction technology.

For the interviews we assumed the most favorable use of the recovery technologies. This would imply the return of the recovered concentrate into the plating bath for both recovery options and thus the implementation of a closed loop system.

(3) All benefits and costs related to the selected waste reduction technologies are primarily valid for the specific waste stream for which they were implemented. Cost statements or reduction of environmental pollution cannot be given for the overall plant since other practices might interfere with the cost and benefit balance. For instance, the implementation of spray rinses at a point of the production process would result in a reduction in water usage costs. The overall process, however, could encounter increased water usage costs as production was expanded or additional equipment was purchased which resulted in additional water usage.

METHODOLOGY FOR THE SURVEY OF SELECTED SUPPLIERS

We conducted the interviews by selecting representative suppliers of the chosen subset of waste reduction options. We chose to address questions to selected suppliers rather than individual electroplaters because (a) suppliers have experience with a broad range of electroplating companies and (b) time constraints did not allow interviews with an extensive number of electroplating firms, which would have permitted more extensive examination of the variety of applications of specific waste reduction technologies and the range of electroplater behavior. We were well aware of the fact that the information from the suppliers was likely to be biased, with technical difficulties or restrictions omitted. To compensate for this limitation, we referred to the technical literature read previously, which revealed performance problems observed with the specific waste reduction technology. We are convinced that this combination of interviews and technical literature provided us with the necessary information to assess the barriers to waste reduction.

Our main interest in talking to the suppliers was to understand the barriers to an increased application of the waste reduction technologies they offer. We wanted to hear their opinions about why electroplaters are reluctant to invest in their products. We also asked suppliers about the incentives which they view as beneficial and effective for encouraging electroplaters to invest in waste reduction technology. Furthermore, we tried to understand what were, according to their perceptions, the motivations of the electroplaters to invest.

In some cases, we had to include questions about the specific technology. Where possible, we tried to obtain information concerning the economics of the application of their product at specific electroplating facilities. Some suppliers could refer us to published case studies which then were used as an example for economic costs and benefits. Those suppliers who had not published economic information on their products were asked for approximate cost figures for investment, installation, operation, and maintenance costs of their equipment as well as perceived payback periods.

Appendix III-3 lists very detailed questions[13] to discuss with either suppliers, electroplaters and/or consultants in order to conduct a comprehensive in-depth barrier analysis. However, due to the large variations among electroplaters in size, product line, wastewater treatment technology, or waste reduction options applicable, most of the questions can only be answered on an individual, case-specific basis requiring a large amount of specific process data. This kind of in-depth analysis was not feasible to perform during the research project. Furthermore, we suggest that a more detailed analysis was not needed for the final incentive analysis. Since an industry-wide incentives program would not be able to respond in such a finely-tuned way so as to take into account the specifications of a single electroplating plant, case specific data were not needed.

[13] The questionnaire does not include specific technical questions since a sound understanding of the waste reduction technologies was a prerequisite for respondents.

ASSESSMENT OF SURVEY RESULTS OF BENEFITS OF AND BARRIERS TO THE CHOSEN SUBSET OF WASTE REDUCTION OPTIONS

(1) Substitution : Trivalent Chromium Bath

(a) **Introduction**

In chromium plating one has to differentiate between hard chromium plating and decorative chromium plating. Hard chromium plating and decorative chromium plating have approximately equal shares of the total chromium plating field [18]. The difference between the two lies mainly in product requirements, with hard chromium plated metals achieving high resistance to heat, corrosion, and wear. Thus in the case of hard chromium plating, the deposits on the workpiece are usually thicker.

Decorative chromium plating is commonly used in the automobile and small appliance industries to add luster to the final finish (and also to increase the durability) of metal parts. [19]

Taking decorative and hard chromium together, there are more chromium electroplating lines in the United States than any other metal [20].

Hard chromium plating and decorative chromium plating generally use different bath compositions. A concentrated bath is usually required for decorative chromium plating whereas hard chromium plating needs a more dilute bath. However, using the same chromic acid concentrations for both types of deposits may give excellent results if performance is not dependent on best coverage and best plating speed [21]. The dilute baths work at slightly higher current efficiency, have lower conductivity, and thus require a higher voltage for a given current density. Because dilute baths are also more sensitive to changes in catalytic acid concentration (sulfuric acid) and impurities, they require a higher degree of maintenance and control [22]. The more concentrated baths used for decorative chromium plating have a higher current efficiency, a higher tolerance for impurities, and require lower voltage for the deposition process [23].

Depending on the metal properties of the workpiece and the product requirements, the final chromium layer is preceded by nickel or copper-nickel layer(s). The basic electroplating principle is the same for both the hard and decorative process, but the hard plating achieves a thicker chromium layer.

(b) **Technology**

The trivalent chromium bath can be used only for substituting the hexavalent chromium in decorative plating. Necessary end product properties of hard chromium plated workpieces, particularly resistance and hardness, cannot be achieved with the trivalent bath.

The development of the trivalent plating bath has gone through several important development stages. Improvements of the plating performance could be achieved in the areas of color of deposits, covering power, build-up of hexavalent chromium, and current densities. Two different technologies can be applied with trivalent chromium plating:

(a) one bath with the trivalent chromium solution, the so called single-cell process

(b) an anode box system which segregates the plating solution surrounding the cathode from the anode using ion selective membranes, the so called double-cell process

Technology (b) is a more recent development which has overcome many of the problems associated with trivalent chromium plating. One major problem for instance is the migration of the trivalent chromium to the anode where it is then oxidized to hexavalent chromium. Because of the selective membrane used in the anode box system, oxidation reactions at the anode are virtually eliminated. Therefore no additives are needed in the plating bath to prevent this oxidation. The result is easier maintenance of the solution due to its simpler composition [24]. A disadvantage of the anode box system might be found in the vulnerability of the anode box to damage by workpieces while leaving the tank. Severe damage would result from the mixing of the plating solution around the cathode and the solution in the anode box [25].

A general problem with the trivalent chromium bath is its sensitivity to impurities, mostly in the form of heavy-metals [26]. Increased application of trivalent chromium, however, seems to indicate that, in certain cases, the impact of impurities is lower than originally anticipated [18]. Still, in this respect, the trivalent chromium bath requires better maintenance than the hexavalent process. First, anode boxes need to be cleaned approximately monthly because of the formation of sludge due to the material's passing the semi-permeable membrane. The boxes are then emptied, a new anode solution is filled, and the old solution is treated in the wastewater system. Next, the trivalent solution requires continuous filtering to prevent the accumulation of organic contaminants. [27] The drag-in of impurities can, however, be reduced significantly by improving the rinse stage of previous plating steps. Also, low current electrolytic recovery can be applied for the removal of impurities in the trivalent plating tank. Impurities, which can be introduced by parts dropped in the plating tank, by the workpiece itself, or by salts dragged in through the tap water, slowly dissolve. Contamination of metals still adhering to liners from the previous hexavalent process can be avoided by exchanging the tank liner for a new one [26]. Other options for acommodating the higher sensitivity to impurities is the use of deionized water for the plating bath and even for part rinsing in case the drag-out is planned to be returned to the bath.

The developments of the second generation of the single cell process as well of the anode box system represent advanced technologies that have increased the applicability of alternative plating options in the decorative chromium plating field [28].

(c) <u>Environmental Benefits</u>

(i) No use of hexavalent chromium

Unless trivalent chromium migrates to the anode and therefore oxidizes to the hexavalent form (which can be prevented to a large extent by either using anti-oxidizing agents in the bath or applying the anode box system), the alternative plating bath does not contain hexavalent chromium. This provides benefits on several levels :

==> no exposure of workers to hexavalent chromium. Occupational exposure[14] to chromic acid has been shown to cause ulceration of the skin, ulceration and perforation of the nasal septum, and inflamed or bleeding nasal mucosa. Contribution to liver damage was reported but seems to need additional proof. There is not yet sufficient evidence that chromic acid contributes to an increase in cancer.[15] [29]

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[14]The exposure usually happens as hydrogen bubbles build up at the cathode which then carry parts of the plating bath into the air space above the plating tank and result in a chromic acid spray. The spraying itself is not deleted at the cathode with the use of trivalent chromium, but clearly it is no longer in the form of chromic acid.

[15]Although hexavalent chromium is certainly much more hazardous to human health than the trivalent chromium form, sufficient research has not yet been conducted to determine whether and possibly to what extent, trivalent chromium poses a potential health hazard.

==> trivalent baths have a higher pH (approximately 2.3 - 4.0). The hexavalent baths have a lower pH due to the presence of chromic acid. A higher pH poses less risk to workers in addition to the risk reduction of avoiding the use of hexavalent chromium. Risk reduction also takes place while handling the plating bath.

(ii) No treatment for hexavalent chromium reduction

Since the process does not use hexavalent chromium, the chromium treatment step usually required with chromium plating is no longer needed. This saves fixed capital costs, labor costs, and other operational costs. The process only requires the chromium hydroxide precipitation step.

(iii) Reduced chromium concentration

The trivalent chromium bath has a very low concentration of chromium, usually 5 -10 g/l with the double-cell system (the anode-box system) [24]. The single cell process has a chromium concentration of 20-23 g/l [30]. In comparison, the concentrated bath, used for decorative chromium plating contains 400 g CrO_3/l (chromic acid) which equals about 200 g Cr/l[16]. (Note however, that suppliers compare the trivalent chromium with the dilute chromium bath at concentrations of 250 g CrO_3/l.) Thus the trivalent bath is more appropriate from an environmental perspective.

(iv) Reduced sludge production

According to the suppliers, trivalent chromium plating produces only one seventh of the sludge produced with hexavalent chromium [30]. Other sources compared both baths and came up with a 3.6-fold reduction in sludge while using the trivalent chromium [26].

(v) Less drag-out

Another advantage of the low chromium concentration is the reduced viscosity of the bath. Reduced fluid viscosity reduces the surface tension of droplets with the result that they do not adhere to a surface as strongly. Thus, workpieces can be drained more easily, even without using additional wetting agents. The result is that less bath liquid is dragged out, which increases the bath life as well as decreases the concentration of chromium which needs to be treated at the end or returned to the bath. Finally, less rinse water is needed to rinse off the remaining droplets.

[16] For comparison, the dilute bath used for hard chromium plating has an average concentretion of 250 g CrO_3/l which equals about 120-140 g Cr/l [5].

(v) Good Product Quality

The trivalent bath is capable of producing light color deposits, very close to those produced by hexavalent chromium deposits [28].

Lower metal concentrations and moderate current densities result in a significant reduction of burning occurrences (resulting in blackening of deposits) [30].

In many cases, wear resistance of the trivalent deposits is the same as typically obtained with the hexavalent decorative deposits [30].

In most cases, trivalent chromium processes show an improved throwing power. This indicates that the degree of uniformity with which the metal is plated on an irregularly shaped workpiece (cathode) is higher using the trivalent bath [31]. Thus workpieces of complicated shapes can be better plated with trivalent chromium. Furthermore, more workpieces can be placed per rack and more racks per workbar. This results in productivity improvements [31].

An additional advantage affecting product quality is that current interruption is not detrimental [19]. Since only half as much current is required to plate out the trivalent chromium as the hexavalent chromium and since the trivalent bath operates at a much higher cathode efficiency, the power consumption of the trivalent bath should be less than 25% of that used for a hexavalent bath [18].

(d) **Economic Benefits**

Generally speaking, the economic benefits of substituting the trivalent for the hexavalent bath, in the area of decorative chromium plating, would result in savings in the following areas:

(i) Reduced disposal costs

The lower concentration of chromium in the plating tank combined with the reduced drag-out results in a significant reduction in sludge generation. Thus, the company facilitating the substitution would save disposal fees, which are likely to increase drastically in the future.

(ii) Reduced treatment costs

Due to the fact that there is basically no hexavalent chromium in the plating bath, the chromium reduction step in the wastewater treatment is no longer necessary. This contributes to the overall savings.

(iii) Savings in raw material

The chromium concentration in the trivalent chromium bath is lower than with the decorative bath; thus raw material costs, measured by the chromium concentration, can be saved. However, the replenishment solutions for the bath, as well as the bath itself, are more expensive than the hexavalent chromium bath for decorative plating [30]. Savings in raw materials also appear in the form of reduced usage of rinse water due to the lower viscosity of the plating bath.

(iv) Reduced air pollution

During the plating with chromium, hydrogen bubbles are formed at the cathode, which result in chromium misting. The chromic acid in the mist is regarded as an occupational health hazard. The use of trivalent chromium plating uses no hexavalent chromium, thus the misting does not contain chromic acid and would probably be less hazardous.

(v) Reduced workers' health compensation costs

As a result of (iv) a company is likely to reduce its future liability costs as well as workers' compensation payments.

The level of the benefit in each of the categories depends on the process arrangement. Although the use of trivalent chromium baths will, by itself result in less sludge production, the additional installation of drag-out minimization and recovery equipment could contribute to savings in addition to those described for the implementation of trivalent chromium baths. In this sense, the recovery of trivalent chromium is best achieved by also installing an evaporative recovery unit at the plating bath. The solution from the first rinse tank can then be returned to the plating tank provided that deionized water is used [19], [26].

The most significant savings would probably occur in the categories of disposal costs and treatment costs.

(e) **Economic Costs**

Substituting the trivalent chromium bath for the hexavalent chromium bath in an existing process line or deciding initially to purchase the trivalent chromium bath instead of investing in the hexavalent process needs to be differentiated on the basis of investment and transition costs.[17] In both cases, the investment costs are higher than for the installation of a hexavalent bath, the costs level depending on the whether the single cell or the double cell process is used. Companies which decide to change to trivalent chromium plating will need to pay for the disposal of the hexavalent chromium baths used previously. Maintenance costs do not seem to be different from the ones required by hexavalent chromium plating [24], [25], [30].

(f) **Barriers**[18]

(i) Skepticism Related to Performance

Building on the seemingly deeply-rooted belief that the trivalent chromium baths are not a close substitute for the hexavalent chromium plating, many of the electroplaters are skeptical about the performance of the trivalent chromium bath.

(ii) Perception of History

Many electroplaters perceive that the performance of the trivalent chromium bath will not correspond with their end-product requirements. This perception stems from the performance of the first generation of the trivalent baths, where the workpieces obtained a darker color and the plating process was not as reliable and more sensitive to impurities than the new bath generation currently marketed. Although most of the technical performance problems have been remedied, the perception of the performance of the old bath types is still connected with the trivalent chromium baths of today.

(iii) High Initial Investment (make-up) Costs

The trivalent chromium bath has much higher initial investment costs. The higher capital requirements might not be achievable for some electroplaters.

(iv) Diposal Cost of Hexavalent Chromium Bath

The installation of a trivalent chromium bath leaves the electroplater with the old hexavalent bath to be disposed of. This seems to be an organizational as well as an financial problem, since we are dealing here with solution volumes up to 2,000 gallons or even higher and

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[17] Transition costs are defined as those costs which the company has to pay indirectly while designing and discussing a new installation of equipment; the cost for changes in production and/or pilot stage experiments required for the final operation are also included.

[18] The following barriers were mentioned during the interviews with the two main suppliers of the trivalent chromium bath: Harshaw/Filtrol on June 21, 1988 (Mr. D.K. Dickie), and Frederick Gumm on June 17, 1988 (Mr. Bill Sizelove).

concentrations up to 32 oz/gal (250 mg/l) of chromic acid. If the plater does not have a wastewater treatment system or a sufficient capacity for the wastewater treatment system, there will be a disposal problem. Some suppliers, however, offer to take the old bath to recover the chromium.

(v) Lack of Future Need for Application

Particularly in the automotive industry (bumper plating), it is unclear how the future demand for chromium plated products will develop. Facing the possibility that other materials will be used for the same purposes, the investment in trivalent chromium baths may not yield sufficient payback; thus platers in these areas are reluctant to invest.

(vi) "Inertia"

Platers who have been using the hexavalent process for decorative plating for several decades have become very familar with the operation so that they do not see any necessity for change. Therefore, the hexavalent process, although requiring more extensive wastewater treatment, is still prevalent.

(vii) Specifications

The automotive industry has developed specifications for end-products requirements. These specifications create some impediments to the application of the trivalent process. Without the "blessing" of the automotive industry, accepting the trivalent process as a viable alternative, it does not seem possible to reach the large group of platers that plate parts for this customer.

(g) **Case Example**

A New Jersey company, Pioneer Metal Finishing, has been successfully applying trivalent chromium for eight years. Besides less hazardous waste generation and reduced treatment costs, the company can now meet discharge limitations without any difficulties. Pioneer Metal Finishing has been using the single cell plating bath (Harshaw/Filtrol). They are experimenting with another trivalent bath with even lower concentration (Envirochrome), which is the double-cell process [32].

(2) Minimize Water Use : Spray Rinses

(a) **Introduction**

In the electroplating process, the rinsing step is estimated to consume about 90 percent of the water used in the plant operation [33]. At least one and normally a set of rinse tanks is lined up behind each plating or cleaning tank.

A number of options are available to reduce the amount of process water needed. One major option is the reduction of water usage by rinsing with a low-volume spray and/or agitation.

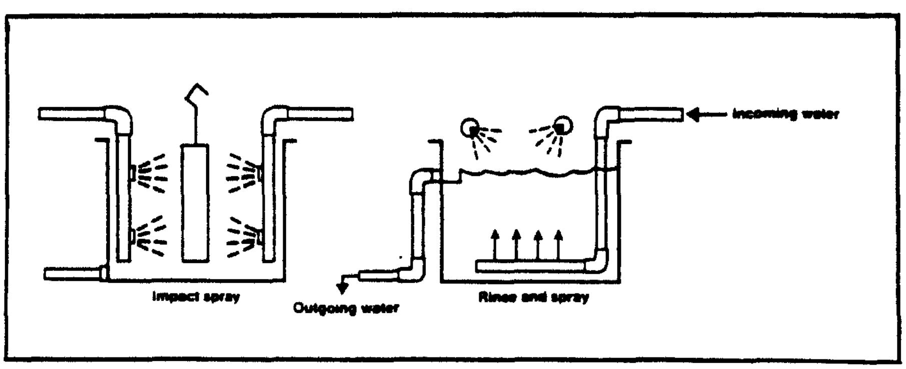
The following analysis of the benefits of waste reduction will focus on reducing the usage of water through the application of spray rinse techniques.

(b) **Technology**

In general, two different types of equipment need to be distinguished. There are spray nozzles which spray water droplets directly on the workpiece and fog nozzles which use water and air pressure to produce a fine mist. Fog nozzles consume even less water than spray nozzles.

Spray rinses can either be installed as a separate spray or in combination with the immersion of the workpiece (see Figure III-3).

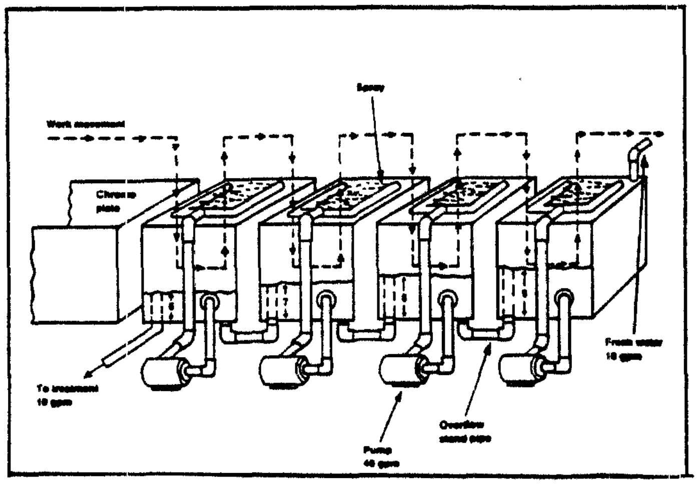
Figure III-3: Spray Rinses



Source: [20]

To install a rinse water recovery system at the same time, spray rinses could, for example, be used over still-rinse while the metal-containing rinse solution is returned to the bath. Furthermore, the still rinse could be followed by countercurrent rinse tanks. In some cases, additional recovery technologies would have to be installed to maximize the reuse potential for the drag-out. Spray rinses could also be used as counterflow rinse systems as depicted in Figure III-4.

Figure III-4: Countercurrent Spray Rinses



Source [20]

With this setup, the workpiece is moved through the spray rinse but is not immersed into the rinse water. For each tank, the rinse water is reused for the spray rinse step. Counterflow spray rinses have been used successfully in the electroplating industry due to their high efficiency [20]. Spray nozzles over rinse tanks have been commercially proven to reduce the amount of wastewater generated by as much as 50% [34].

Spray rinses could also be positioned directly over the plating bath. A prerequisite for this would be that the bath has a relatively high temperature with a high surface evaporation to prevent overflow. In general, the corrosive atmosphere above the plating tank might prevent the use of spray rinse equipment at this process step.

Installing spray rinses requires only inexpensive equipment and simple process modifications relative to other waste reduction technologies. There are, however, restrictions concerning the applicability of spray rinsing. The technique works best on flat sheets and does not perform efficiently with distinctly shaped forms of workpieces like holes [35].

The use of spray rinses requires good monitoring to verify the effectiveness of the rinsing. If the rinsing step is not properly conducted, higher metal concentrations in additional tanks might result, as well as inadequate rinsing, which could have negative effects on subsequent baths.

(c) **Environmental Benefits**

(i) Reduced usage of rinse water

In spray rinses less rinse water is used. In one spray rinse application in the rinse system, over 5000 gallons of rinse water could be saved, which was equal to a 93% reduction of the total amount of water used [36]. In addition to the installation of the spray rinse system, reclamation of rinse water took place. Thirty-nine percent (178/460 gallons per day (gpd)) of the water entering the rinse system was recycled and reused for bath make-up water. Forty-eight percent of the water entering the rinse system was sent to the wastewater treatment system. The remainder was calculated to have evaporated (based on materials balance calculations) [36].

(ii) Reduced usage of wastewater treatment chemicals

Due to the reduced volume of wastewater, fewer chemicals are used because they can be applied more efficiently in higher concentrated solutions (not so much above the stochiometric equilibrium concentration). Moreover, less use of tap water results in less calcium and magnesium, which precipitates with the heavy metals and increases the sludge volume.

(iii) Reduced sludge production

Due to reduced wastewater, sludge volume will be reduced for the same reasons mentioned under (ii).

(iv) Less drag-out

In cases where the spray nozzles are installed above the plating bath, a significant reduction of drag-out is achieved, which can be measured in the removal efficiency of the metal. Less drag-out results in less wastewater treatment and less sludge. Note, however, that this is not the case with the application of spray rinses over rinse tanks. Here additional recovery equipment needs to be installed, which could either be in the form of simple pipe systems pumping the metal-concentrate back into the plating tank or collecting tanks, from which part of the solution is pumped back into the plating tank. Up to 94% of the metal entering the rinse system was reported to be returned to the bath [36]. In the latter cases, only deionized water should be used for rinsing in order to prevent the buildup of impurities.

(d) **Economic Benefits**

Based on the environmental benefits and the technological principle of the spray rinses, one can assess the economic benefits. The major benefit will be found in the saving of process water as well as plating metals, and probably to a lesser extent in the saving of treatment chemicals. In some cases the amount of wastewater can be reduced by 50% (rack-plating) while the spray rinse was used over the rinse tanks [34]. In another case [34], the installation of a spray rinsing system (based on the savings of water costs alone) was not economically justifiable because it would have had a payback period of 8.3 years. This payback was determined to be too long. The spray rinse was planned to be installed by converting four and in another case nine existing continuous rinse tanks [34]. Another application of the spray rinse, however, resulted in a payback period of 2.2 years, which was perceived as an acceptable time.

A factor which affects the economics of the installation is whether the racks are sprayed manually or whether they are applied on continuous tanks, with the latter preferable.

(e) **Economic Costs**

Spray rinses are a low-cost method to achieve reduction in water usage. Cost increases, however, can be expected when additional equipment needs to be purchased to optimize the application of the spray rinses, aiming at closed-loop systems.

(f) **Barriers**[19]

(i) Limitations of Product Applications

Spray rinses can only be applied with certain shapes of workpieces, mainly flat parts and parts with irregular shapes which do not have large hollow areas. The other limitations observed are more economic in nature. Some metals in the plating bath are too inexpensive to be economically recovered and costs of raw materials like process water are too inexpensive to develop a motivation for the investment in water- and raw material-saving technologies. (Note that this argument applies especially to the more expensive recovery technologies mentioned in this report.)

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[19] The following barriers were mentioned during interviews with several suppliers who sell spray rinse equipment: Haviland Products on June 22, 1988 (Mr. Joal Kusmierz), Baker M.E. Co., June 21, 1988 (Mr. David Crox), Michigan Association of Metal Finishers, June 20, 1988 (Mr. Gary Trahey, electroplater).

(ii) Health Hazard

Applying the spray rinses with the chromium plating process is likely to result in more misting of chromic acid. The spray used to remove the adhering drag-out from the workpiece after the rinsing step will also contain the chromic acid which was just rinsed off. This results in additional air pollution in the plating shop and can be controlled only by using automated hoods above the spray rinses that provide appropriate ventilation.

(g) **Case Example**

In the case of the installation of a spray rinse within the rinse system of a nickel plating line, significant amounts of rinse water were saved. Together with the additional reclamation of rinse water, thirty-nine percent (178/460 gallons per day (gpd)) of the water entering the rinse system was recycled and reused for bath make-up water. Forty-eight percent of the water entering the rinse system was sent to the wastewater treatment system. The remainder was calculated to have evaporated (based on materials balance calculations) [36].

Due to the reclamation step, 94% of the metals entering the rinse system were returned to the plating bath. The annual savings of plating chemicals, as large as $7,890, turned out to be the major saving factor. The second largest factor was the saving in water costs of $1,990 followed by savings in wastewater treatment costs and sludge disposal costs with each about $1,200. An economic analysis estimated a payback period of 1.4 years. Since the installed equipment was a prototype, it is anticipated that the average payback period would be much lower due to reduced investment costs of future installations [36]. (see Table III-2)

Table III-2: Economics of a Spray Rinse System

Installed Cost ($/Yr):	
Equipment (pumps, piping, control box, liner, etc.)	$ 4,800
Installation	3,500
	$ 8,300
Annual Operating Costs ($/Yr):	
Labor Maintenance	$ 500
Materials (filter cartridges, plating chemicals)	653
Utilities (energy, water)	440
Wastewater Treatment	50
Sludge Disposal	90
Plant Overhead	200
	$ 1,933
Annual Fixed Costs ($/Yr):	
Depreciation (10% of investment)	$ 830
Taxes & Insurance (1% of investment)	83
	$ 913
Annual Savings ($/Yr):	
Water	$ 1,990
Wastewater Treatment	1,231
Sludge Disposal	1,231
Plating Chemicals	$ 7,890
	$12,392
Net Savings ($/Yr) = [Annual Savings - (Operating Costs + Fixed Costs)]	$ 9,546
Net Savings After Taxes ($/Yr), 48% Tax Rate	$ 4,964
Cash Flow ($/Yr) = (Net Savings After Taxes + Depreciation)	$ 5,794
Payback Period (yrs) = (Investment/Cash Flow)	1.43

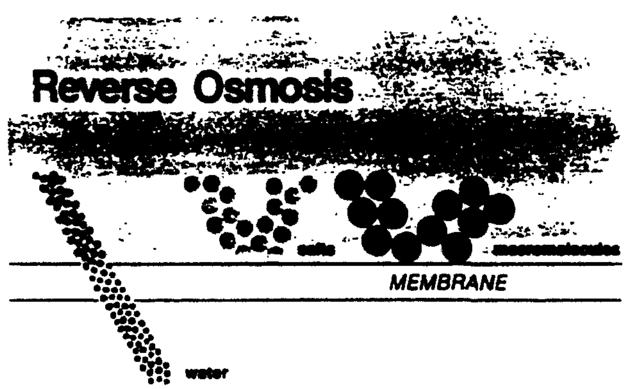
from: Design and Application of a Spray Rinsing System for Recycling of Process Waters, M.L. Apel et al., Ind. Env. Research Lab., Cincinnati, Ohio, Oct. 1984, EPA/600/D-84/246, PB 85-106722 = [18]

(3) Reverse Osmosis

(a) **Introduction**

Reverse Osmosis (RO) is a recovery technology which basically increases the concentration of the metals in the wastewater stream. RO applies the same principle as ultrafiltration (UF). In both cases, the water moves through a semipermeable membrane enhanced by pressure pumps. (see Figure III-5). UF membranes have a larger pore diameter than RO and thus salts and low-molecular organic wastes are not rejected. Due to the pore diameter, UF only needs a low pressure pump and therefore requires less energy. RO membranes are capable of rejecting salts and organics [37]. The largest application of RO to date is in the desalination and purification of water [38].

Figure III-5: Simplified Reverse Osmosis Schematic



Source: [38]

"Osmotic pressure" is a phenomenon which occurs in nature where semipermeable membranes separate fluids. If the salt concentration of a solution (mainly water-based) inside (i.e. a cell) increases, the osmotic pressure also increases in the cell. The "reaction" of the solution in the cell is to take up water in order to dilute itself. In the environment in general, concentration potentials are usually evened out by the movement of the substance of high concentration to a location of reduced concentration. This is called diffusion. In cells, the phenomenon of osmotic pressure results in a different process. Here, water moves to the location of high concentration to dilute the solution.

Reverse Osmosis, as the name suggests, literally turns the osmotic principle upside down. Using high pressure pumps, water is forced out of the "cell" with the result that the concentration of substances inside the cell increases. The "cell"-membrane of the RO equipment is composed of layers of semipermeable membranes through which the feed stream (wastewater) containing salts and organics is pumped. The water then permeates the membranes and forms what is called the permeate while the concentrate is built up between the membrane layers. While the concentration of the solution is increasing, the osmotic pressure of the solution increases as well until a certain point at which very high pressure would be required to pump more water through the membranes. At this point, there is a trade-off between attaining a higher concentrated solution and the utility expense of creating the pressure. Clearly the osmotic pressure creates a limiting factor in the output of the RO system [38].

(b) **Technology**

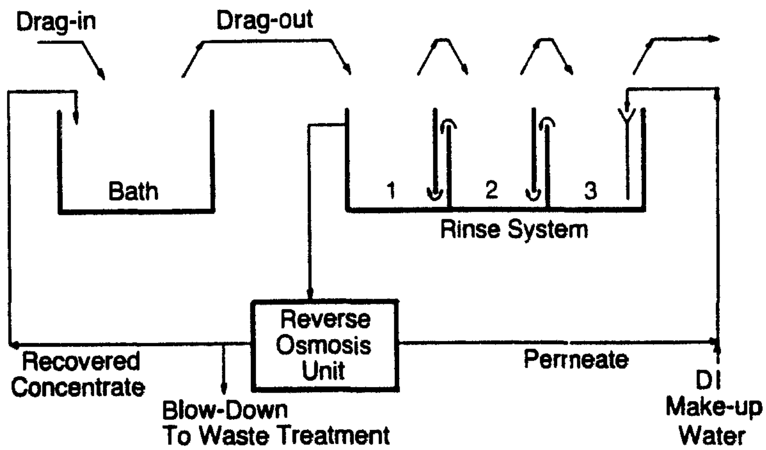
Although the basic principle of reverse osmosis has been understood for years, the technology has only been commercially available since about 1969 [38]. The usage of RO for metal-containing liquid wastewater started later than this. However, after evaporation, RO has the most long-term operating history among recovery technologies in the electroplating industry [39]. RO uses considerably less energy than evaporators for the same flow rate of rinse water [39] and is designed for continuous operation and minimal floor space requirements [40].

The RO system has primarily been used with the nickel bath plating line, predominately Watts nickel. 99.5 percent of RO applications in plating shops are with Watts nickel [41]. RO has also shown potential applications with copper and zinc sulfate as well as brass and copper cyanide [42]. Current research is focusing on the applications of the RO with the more acidic and basic baths [43]. RO can achieve a recovery efficiency in the range of 87% to 97% [42].

(i) Application in the rinse water system

Due to the character of the RO technology, it can first be applied at the rinse water stage of the process, primarily using the first rinse tank, which already has the highest concentration of metals. In some cases, RO can also be installed at some subsequent rinse tanks in order to concentrate the metal solution. To achieve a closed-loop system with ambient temperature baths, the concentrate is concentrated further (i.e., by evaporation if the system temperature is not high enough). (See Figure III-6 for a schematic.)

Figure III-6: Reverse Osmosis Metal Reuse Schematic

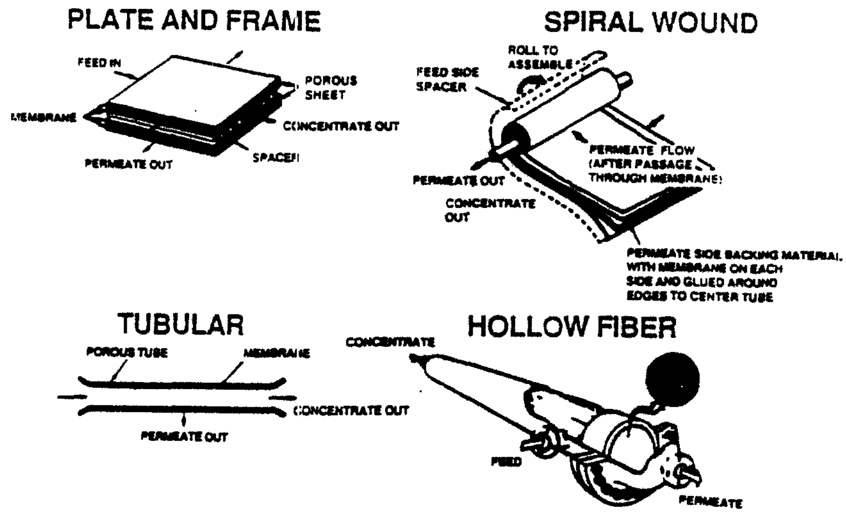


Source: [39]

Given a relatively high bath temperature, additional evaporators are not required for concentrate recovery (i.e., to the plating bath). The permeate flow is typically pure enough to be directed into the last rinse tank [42]. Still, some make-up water needs to be added since there are losses from evaporation in the rinse system. In sum, high temperature baths, such as Watts nickel baths, are ideal for the use of RO to develop a closed loop system. But there are some firms currently marketing a reverse osmosis system that can be applied to the more acidic and basic baths.

The membranes of the RO units come in various configurations. The devices (single elements) are "packaged" either in tubular form, hollow fiber arrangements, spiral wound types, or plate and frame forms made of sheet membranes (see Figure III-7).

Figure III-7: Reverse Osmosis Memebrane Configurations



Source: [38]

The spiral configuration is by far the most common. A second important characteristic is the material of the membrane. Most of the membranes in use are made of cellulose acetate but more recent developments have introduced polyamide membranes and Thin Film Composites (TFC), as well as other new membranes like poly-benzimidazolone or polyethyleneimine, on the market [43].

(ii) Application with the wastewater treatment system

A second application of RO, as yet less frequently used, is in wastewater treatment. After the chemical treatment step, the effluent may still contain metals or other components which would have to be removed. Here RO can be used to clarify the effluent. The feed stream is, as usual, separated into the concentrate, which then can be treated more efficiently, and the permeate, which can be reused at the rinse water stage [38].

(iii) Limitations of RO

Several major limitations restrict the application of RO. First, the osmotic pressure of the concentrate limits the level of concentration that can be achieved. Evaporation is necessary to achieve a higher concentrated recovery solution from the initial rinse water, preventing a dilution of the plating bath [39].

The phenomenon of osmotic pressure also constrains the application of RO with solutions of high metal content to achieve additional concentration of the solution [39].

Another problem with RO is the membrane sensitivity to certain pH and temperatures. Furthermore, current RO membranes are affected by strong oxidizing agents (i.e., chromic acid) of plating solutions as well as solvents causing dissolution of the membranes. The concentration of the bath components by the RO also decreases the pH of the solution and increases other substances like oxidizing agents. This is one reason why the application of RO has until now been limited to the recovery of some plating baths [40], [43].

For some compounds of low molecular weight, RO does a poor job of rejecting organic wastes (i.e., organics of low molecular weight) [43].

Fouling problems of the membranes are another major difficulty which can be partially solved by treating the inflowing wastewater stream before it enters the RO unit, applying filtration. Filtration is essential to ensure optimum bath life. Typically a 5 micron filter is used before the rinse water stream enters the reverse osmosis system [42].

In order to prevent the drag-in of impurities into the plating bath from the recovery process, the solution concentration of the plating bath should be monitored to ensure proper end-product quality. In some cases, it is advisable to install activated carbon adsorption equipment to prevent organic impurities from entering the plating bath [44].

Membrane sensitivity is one important reason why further research is being conducted in this field. The use of RO, although of proven application for particular baths, could proliferate if more durable membranes were found.[43] One new (one year old) company, however, has developed a more sophisticated system which overcomes many of these drawbacks.[45]

(c) **Environmental Benefits**

Given the optimal closed loop application at the rinse system, the major environmental benefits will be found in savings of raw materials.

(i) Reduced usage of rinsewater

Rinsewater is saved because the permeate from the wastewater of the first rinse tank generated by the RO can be returned to the final rinse.

(ii) Reduced usage of plating metals

The concentrate produced by the RO equipment can be returned to the bath. Since the major portion of the drag-out is removed in the first rinse-stage, significant amounts of raw materials for the bath are saved and only limited amounts of bath replenishments have to be purchased.

(iii) Reduced wastewater treatment

As a consequence of (i) and (ii), less wastewater, in terms of volume and concentration, is generated and therefore needs to be treated. Reduced wastewater volume requires a smaller scale of wastewater treatment system. In some cases, the RO equipment is capable of producing a permeate which complies with the effluent standards of the company. This is likely if the inflowing concentration in fairly low, so that the osmotic pressure of the concentrate building up will not be as high.

(iv) Reduced sludge production

As a consequence of (i) and (ii) less sludge is produced since there are fewer metals from the rinsewater system which need to be treated.

(d) **Economic Benefits**

Referring to the application of RO in the electroplating line, the areas of economic benefit will lie mainly in the same areas as the environmental benefits, and are the following:

(i) Reduced disposal costs

Provided that the concentrate from the RO unit is either returned to the bath or, less favorably, treated by electrolytic recovery, the drag-out from the plating bath is recycled. This results in less metal in the wastewater treatment system, which then results in reduced disposal volume.

(ii) Saving in raw materials

The metals that are recovered, as well as the reused rinse water from the permeate, result in a reduction in raw material consumption. This will result in substantial savings. However, some raw materials (i.e., zinc) are currently inexpensive so that material recovery would be not economical.

(iii) Reduced treatment costs

As mentioned under (i), the recovery of plating metals as well as rinse water means treatment costs can be saved.

(iv) Reduced sewer fees

Since many electroplaters are mainly indirect dischargers, a reduction in the amount of metal the company discharges daily might change the discharge category the firm is currently in. The level of savings depends on the value of raw materials, sewer and disposal fees, and the reuse potential of the water.

(e) **Economic Costs**

Unit investment ranges approximately from $25,000 to $100,000 depending on the bath with which the RO unit is to be used [44]. Operating costs like electrical consumption for the high pressure pump, membrane element life, cleaning frequency of the membranes, and filter maintenance are important cost factors (see Table III-3). The most significant cost factors are the electricity consumption associated with the application of the high pressure pump and the membrane life [42]. Still, the energy requirements are lower than for evaporation under comparable conditions [43].

Due to the fact that the membranes are sensitive to various bath parameters, the RO equipment has to be chosen and maintained carefully to guarantee maximum life and performance. The equipment size should be carefully chosen. An oversized unit results in frequent shutdowns, which affect the wear as well as the cost of the equipment. Too small units are not able to treat the feed stream so that parts of the feed stream will leave the RO unit without treatment [46].

Depending on the plating bath, the membrane life varies between one to two years [47], [37]. However, according to interviews with suppliers, the lifetime of the membranes was estimated to be between three and five years [48].

Reliability of the systems depends primarily on the performance of the RO membranes. Life time and fouling behavior are important factors in evaluating the reliability [47].

The payback periods observed varied between six months and two years [41], [37].

Table III-3: Economics of Reverse Osmosis System for Nickel Salt Recovery, Operating 4,000 h/yr.

Item	Amount
Installed cost, 550-ft^2 unit ($):	
Equipment:	
RO system including 25-um filter, pump less 10 membrane units	17,000
Activated carbon filter	2,000
Auxiliaries, piping, and miscellaneous	3,000
Subtotal	22,000
Installation, labor and material	3,000
Total installed cost	25,000
Annual operating cost ($/yr):	
Labor and maintenance at $10/h	1,600
General plant overhead	1,000
Raw materials:	
Module replacement, 2-yr life (10 x $350/module) x 0.5 yr	1,800
Resin for carbon filter	500
Prefilter element (25-um)	700
Electricity costs ($0.45/kWh)	1,100
Total operating cost	6,700
Annual fixed costs ($/yr):	
Depreciation, 10% of investment	2,500
Taxes and insurance, 2% of investment	500
Total fixed costs	3,000
Total cost of operation	9,700
Annual savings ($/yr):	
Plating chemicals:	
4 lb/h nickel-salt at $1/lb	16,000
1.5 oz/h brightener at $0.10/oz	600
Water and sewer charges: saving 270 gal/h at $0.80/1,000 gal	900
Total gross annual savings	17,500
Net savings = annual savings (operating cost + fixed cost) ($/yr)	7,800
Net savings after taxes, 45% tax rate, 7,800 x 0.55 + 2,500[a] ($/yr)	6,800
Average ROI = net savings after taxes/total installed investment x 100 (%)	27
Cash flow from investment = net savings after taxes + depreciation ($/yr)	9,300
Payback period = total installed investment/cash flow (yr)	2.7

[a]10% investment tax credit = $2,500 (or 0.10 x 25,000).

(f) **Barriers**[20]

(1) Skepticism about performance

The barriers to implementation of the reverse osmosis system stem from perceived difficulties with the technology and resistance to change. Although most electroplaters are aware of the existence of the technology, they do not necessarily trust that it will work and they do not understand the technology and fear the complexity.

(2) Perception of History

Further diffusion of the technology is hampered by the history of RO. Initial introduction of RO technology was marked by ineffective, unreliable equipment that has left a negative perception on the electroplaters that must be overcome.

(2) Compliance oriented

The electroplaters tend to focus on compliance with the standards (wastewater treatment) rather than recovery technologies, even though recovery offers a relatively short payback, economic savings, and reduces liability.

(3) Small demand from electroplaters

The reluctance and skepticism of the electroplaters has created a small demand for the equipment which, in turn, has lessened the marketing and the research of the suppliers. The suppliers must utilize an extremely "hard sell" approach even to interest the electroplaters, which has often then resulted in rejection.

(4) More work and "don't fix what ain't broken"

Many electroplaters perceive recovery as simply additional work, creating more risk (of problems with the equipment), worry, and more expense. There exists an attitude that there is no need to complicate the system, spend more money, and add more equipment if the process works fine and the firm is complying with present regulations.

(5) Lack of technical competence to operate RO

Although the suppliers of the RO system install the equipment and train the electroplaters, the principle of the

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[20] The following barriers were mentioned during interviews with several suppliers of reverse osmosis equipment: Water Technologies, Inc., June 22, 1988 (Mr. Ron Rich), Osmonics, Inc., June 21,1988 (Mr. Skip Ellis), C_3 International, June 20, 1988 (Mr. Peter Cartwright).

technology is not well understood. This lack of understanding makes the electroplater insecure, and he then fears his lack of technical competence in operating the system.

(g) **Case Examples**

Two cases have been analysed more closely in North and South Carolina. In the North Carolina plant, nickel salts were recovered from the rinse system with savings of $40,000 a year and a payback period of two years. Over 90% of the savings was due to reductions in the usage of deionized water, of nickel chloride, and of nickel sulfate as well as a reduction of waste treatment sludge. Approximately an 80% reduction was achieved through the reduction of boric acid, another plating bath ingredient. The total costs of the installation was $62,000 (in 1980 dollars), which includes $39,000 for the RO unit [50].

The South Carolina electroplating company also recovered nickel salts with the help of a RO unit installed at the still rinse tank, returning the nickel salts to the plating bath. The purchased unit was a used one which cost $24,000. The company anticipated a 1.3 year payback period. No further information was provided about the savings derived from specific cost factors [50].

(4) Electrodialysis

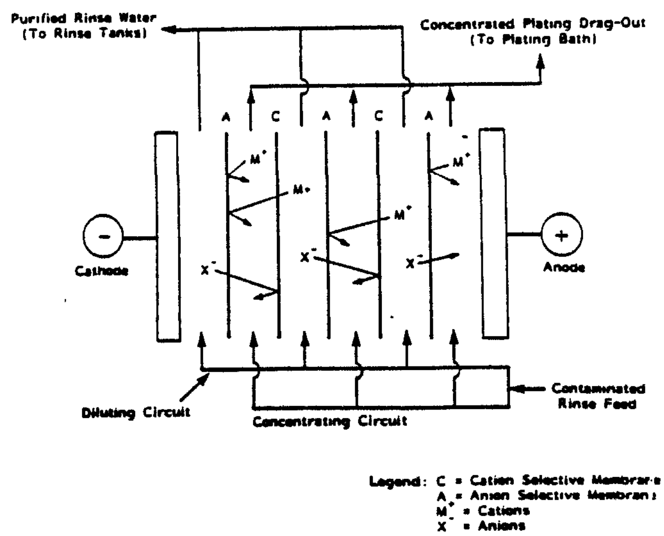
(a) **Introduction**

Like reverse osmosis, electrodialysis is a recovery technology which produces solutions of higher concentration from the feed stream. In this respect, electrodialysis competes with reverse osmosis and, in some cases, ultrafiltration for market share.

The technique did not achieve any commercial application until durable ion-selective membranes were developed in the 1950's [40]. Electrodialysis was originally developed for application in the desalination of brakish water. Only since 1975 has it been used in the electroplating industry to treat metal-containing wastewaters [40].

Electrodialysis utilizes membrane technology combined with an electric current as the driving force for the ions in solution. A number of ion exchange membranes are arranged in "stacks" next to each other, closely spaced, alternating cation-selective membranes and anion-selective membranes (see Figure III-8). A feed stream of metal-containing wastewater runs through every other chamber. Through each of the membranes, ionic substances are selectively transported by the voltage provided by two electrodes at the ends of the unit. The feed stream, which needs to be initially quite concentrated, is separated into a concentrate carrying the ions and a highly dilute stream containing mainly non-ionic substances.

Figure III-8: Simplified Electrodialysis Schematic



Source: [40]

The advantages of electrodialysis are its low energy consumption compared to evaporators and its ability to produce a highly concentrated solution up to bath strength which is approximately an order of magnitude higher than the performance of RO [37]. One supplier, for instance, promises recovery capacity up to 82 g/l and requires a feed stream of 0.2 oz/gal (1.5 g/l) or more which is significantly below the one in the first rinse tank [46]. Therefore, electrodialysis can often be used without additional equipment (i.e., evaporators) to achieve a closed-loop system.

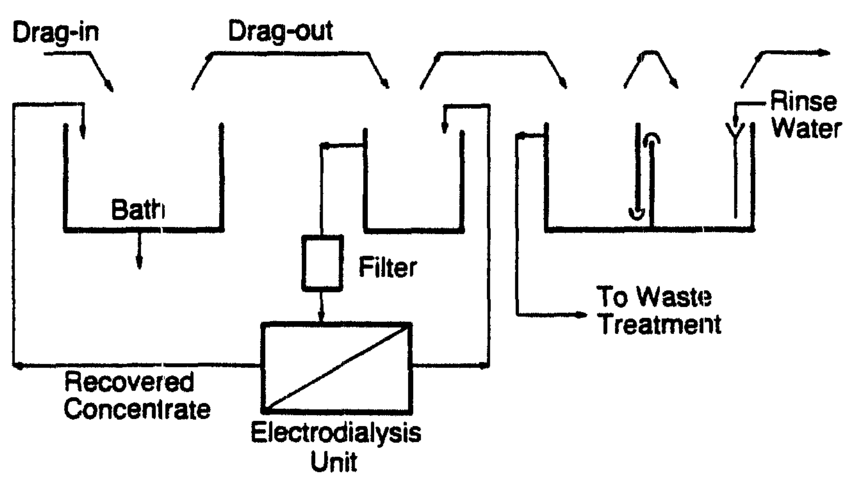
One disadvantage of electrodialysis is the fact that it is a membrane process which requires proper operation and careful maintenance [39]. To some extent the typical membrane fouling problem can be addressed in a better way than with reverse osmosis. With advanced electrodialysis units, the so called electrodialysis-reversal plants, the electrical field can be frequently reversed (polarity reversal), providing a simultaneous interchange of dilute and concentrate streams. This reduces fouling while sacrificing capacity and efficiency due to the lag time necessary for readjustment of the voltage after reversal [51]. Due to this mechanism, descaling and complexing agents do not need to be continuously added. The electrodialysis reversal unit, developed in the early 1970's, shows a basic improvement in what is called scale control, advancing the classical electrodialysis units which could transfer ions in one direction only [51]. Both units, whether the classical or the advanced, require pre-filtering of the feed stream [39].

Another disadvantage is that electrodialysis does not remove non-ionic substances such as organics and can therefore produce a less pure permeate than that of the RO system. However, this disadvantage, in respect to the rinse water recovery, is positive for the concentrate returned to the plating bath because non-ionic impurities are rejected [41].

(b) <u>Technology</u>

Like RO, electrodialysis can be used with the rinse system (e.g., the stagnant rinse) to concentrate the wastewater. The unit can be installed for closed loop operation of the rinse system with the metal ion-containing concentrate returned to the bath (see Figure III-9). Close monitoring, however, is required to ensure a continuous bath quality and identify the build-up of impurities. The treated wastewater from the electrodialysis unit can be used for make-up water in the rinse process although there seem to be limitations concerning the content of non-ionic substances [41]. The application of electrodialysis for use after the regular chemical wastewater treatment is not suggested because the metal-ion concentration would be below the minimim concentration for the proper operation of the unit (lack of conductivity).

Figure III-9: Electrodialysis for Metal Recovery Schematic



Source: [39]

Electrodialysis is being used successfully on rinse systems from precious metal plating baths like gold, platinum, silver or palladium, as well as others like nickel, copper, cadmium, tin, tin-lead, and zinc baths, but this practice is rare due to the preponderance of other equipment for these metals [37], [41], [40]. To this point, the use of electrodialysis in the electroplating industry is not widespread [51], [52].

(c) **Environmental Benefit**

(i) Reduced usage of bath raw material

In cases where the electrodialysis unit is installed in a closed loop system, the metal-ion containing concentrate is returned to the plating bath and substantial amounts of plating metals can be saved.

(ii) Reduced usage of treatment raw material

The reduction in metal consumption directly results in a reduction in required wastewater treatment capacity so that less precipitation chemicals are needed.

(iii) Reduced sludge production

A result of (i) and (ii) is the reduced sludge generation at the facility. Looking at indirect effects, this results as well in reduced hauling of sludges to the respective landfills, which means less use of gasoline and reduced air pollution.

(iv) Reduced usage of rinse water

Given the closed loop application, wastewater treated by the electrodialysis unit can be returned to the rinse system so that less water is required in the system.

One should again keep in mind that even the use of concentration and recovery technologies like electrodialysis does not render methods for drag-out reduction obsolete. In any case, it is more cost-effective first to minimize the drag-out of the plating bath and then use concentration technologies for the drag-out which cannot be prevented.

(d) **Economic Benefits**

The major areas of savings again correlate with the environmental benefits and are manifested in the following areas:

(i) Savings in raw materials

Similar to the RO process, raw materials could be saved by applying electrodialysis with the rinse water system. The consumptions of plating bath ions, mainly plating metals, could be reduced while at the same time make-up water for the rinse water system is generated that could be returned to rinse tanks.

(ii) Reduced disposal costs

The reduction in metal consumption directly results in a reduction of metals entering the wastewater treatment system. Therefore, less metal needs to be treated and the volume of hazardous waste to be disposed of is reduced, which decreases disposal costs.

(iii) Reduced wastewater treatment costs

Similar to (ii), the reduced volume of wastewater requires a smaller wastewater treatment system, which is less expensive.

(iv) Reduced sewer fees

Increased metal reuse improves compliance with discharge standards. In some cases, a company might even transfer into another discharge group, which will reduce its sewer fees.

(e) **Economic Costs**

Unit investment costs for electrodialysis vary between $15,000 and $100,000, depending on the size, and averaging around $30,000 [53]. The costs of operation are primarily determined by membrane replacement costs as well as maintenance and labor costs [53]. Investment costs are mainly a function of the number of cell pairs in the electrodialysis stack [40]. Average membrane lifetime ranges between 1.5 and three years [54]. Estimated payback periods were on the order of from nine to 15 months ([54], [53]), and in some cases even up to 2.6 years [51].

(f) **Barriers**[21]

Similar to RO, electrodialysis has attitudinal as well as economic and feasibility barriers.

(i) The profit margin of other technologies

Although electrodialysis is effective and creates a more concentrated outlet, other technologies, such as ion-exchange, are considerably less expensive. Because it takes two to three years for electrodialysis to overcome the

[21] The following barriers were mentioned during interviews with several suppliers of electrodialysis equipment: Ionics Inc., June 20, 1988 (Mr. Tam van Tran), Baker Brothers/System, June 22, 1988 (Mr. Tim Howard).

initial price differential, electroplaters obtain a greater profit margin with the other technologies.

(ii) Capital cost intensive

The initial investment in equipment is quite large, ranging from $15,000 to over $100,000 but averaging around $30,000.

(iii) Fear of the complexity

Similar to RO, electroplaters do not understand the technology and do not trust its effectiveness.

(iv) Low demand for the product

The reluctance of the electroplaters to purchase the electrodialysis equipment has created a lack of marketing by the suppliers of the equipment. Electrodialysis equipment is manufacturing by only a few companies and represents a small share of those companies' production line, thus creating little incentive for aggressive marketing.

(v) Influence of chemical suppliers

Because the implementation of any recovery technologies would reduce the quantity of chemicals purchased from the chemical manufactures, suppliers of these technologies have suggested that the chemical manufactures have "bad mouthed" the recovery technologies.

(g) **Case Example**

A economic analysis conducted after the installation of an electrodialysis unit for a nickel bath showed that the return of nickel salts was the most important savings factor, resulting in more than 50% of the total annual savings ($40,100). Second ranking was the savings due to reduced water usage ($12,000) and finally an annual savings of $6,000 for sludge disposal costs. The total installed cost of the electrodialysis equipment was $51,500. The payback period turned out to be 2.6 years assuming a membrane life of two years [51]. Membrane replacement consists of almost 50% ($3,000) of the total annual operating costs ($ 6,750). Membrane replacement, labor, and maintenance are the most important operation cost factors, with depreciation being the largest item ($5,150) [51]. (See Table III-4 and Table III-5)

Table III-4: Economics of Electrodialysis Reversal Process for Nickel Salt Recovery from Plating Rinse water

Economics of Electrodialysis Reversal Process for Nickel Salt Recovery from Plating Rinse Water

Items	*North Central Plant*	*Eastern Seaboard Plant*
1. Installed Cost		
• Equipment	$ 50,000	$ 100,000
• Installation, labor and materials	1,500	1,500
• Total	51,500	101,500
2. Annual Operating Cost (Estimated)		
• Labor, 100 hours/year @ $10/hour	1,000	1,000
• Maintenance @ 2½% of investment	1,250	2,500
• Raw Materials		
Filter Cartridges	750	1,000
Membrane Replacement[1]	3,000	6,000
• Electricity ($0.05/KWH)	750	1,500
• Total	6,750	12,000
3. Annual Fixed Cost		
• Depreciation, 10% of investment	5,150	10,150
• Tax and Insurance, 1% of investment	515	1,015
• Total Fixed Cost	5,665	11,165
4. Total Cost of Operation	$ 12,415	$ 23,165
5. Annual Savings		
• Plating Chemicals	$ 21,000	$ 110,000
• Sludge Disposal Cost[2]	6,000	6,600
• Water Treatment Chemicals	1,100	2,200
• Water Usage	12,000	–
• Total	$ 40,100	$ 118,800
6. Net Savings (annual savings – (operating + fixed cost))	$ 27,685	$ 95,635
7. Net Savings After Tax 48% Tax Bracket	$ 14,397	$ 49,730
8. Average ROI (%) (net savings after tax/total investment)	27.9	49.0
9. Cash Flow from Investment (net savings after tax + depreciation)	$ 19,547	$ 59,880
10. Payback Period = Total Investment/Cash Flow	2.6	1.7

[1]Assuming 2 year membrane life

[2]@ 35% solids for North Central plant and @ 95% solids for Eastern Seaboard plant

Table III-5: Evaluation of Electrodialysis Recovery for Cadmium Cyanide Plating

TABLE 4 : EVALUATION OF ELECTRODIALYSIS RECOVERY FOR CADMIUM CYANIDE PLATING[a]

Item	Amount
Performance factors:	
Rinse tanks needed	2 (1 dead, 1 running)
Dead tank cadmium concentration (mg/l)	480
% recovery:	
Cadmium	96
Cyanide	96
Rinse rate (l/min):	
Dead tank	NA
Running	10
Running rinse cadmium concentration (mg/l)	15.
Cost factors:	
Unit cost ($)	38,000
Installation cost ($)	3,000
Operating cost ($/yr)[b]	1,400
Cost savings ($/yr):	
Cadmium	9,200
Cyanide	6,100
Treatment and solid waste savings	28,600
Annual operating saving ($/yr)[c]	42,500
Return on investment (%)[b]	103
General:	
Return of impurities	Yes
Effluent cadmium in mixed wastewater at 100 l/min (mg/l)	1.5

[a]Drag-out is 20 l/hour at 12,000 mg Cd/l, 48,000 mg CN/l; 4,000 hour/yr.

[b]Does not include maintenance, labor, or membrane module replacement.

[c]Does not include costs for depreciation, labor, etc.

NOTE: NA = not applicable.

(5) Good Operating Practice

(a) **Introduction**

Good Operating Practice (GOP) is a primary waste reduction activity whose applicability should always be scrutinized by the company. Many options are possible, as indicated in Appendix III-5. GOP methods are characterized by low cost, but high cost-effectiveness and simple technology.

From a methodological point of view, it is sometimes difficult to make a distinction between simple GOP and methods which require more technological understanding, addition of chemical substances, or might also result in effects on product quality. The use of wetting agents, for example, results in drag-out reduction, as does the increase in drainage time. Wetting agents, however, comprise an additional expense and chemical additive which might result in problems in other sequences of the process. Therefore wetting agents would not be categorized as GOP.

(b) **Technology**

The increase of drain time results in a reduction of drag-out. The number of droplets which adhere to the surface of the workpiece is, to a certain extent, a function of the drain time. However, a longer drain time has to be weighed against plating speed required for process efficiency. With longer drain time the drag-out of the plating bath solution can be reduced by as much as 50%. [41]

Parts which are manually immersed in the plating bath can be put on drip bars during the drain period. This allows as well for shaking of the workpiece to enhance drain efficiency. In barrel plating, the barrel should be rotated for a while above the plating tank to reduce drag-out [41]. The alternative to the increase in drainage time would be the installation of air knives. This allows for an increase in the removal of adhering plating bath droplets without necessarily expanding the residence time of the workpiece above the plating tank.

Air knives are basically an air corridor above the plating tank which provides an air stream strong enough to "tear" adhering droplets from the workpiece into the plating bath. It is important to use clean air to make sure that no impurities are carried into the bath via the air knives.

(c) **Environmental Benefits**

(i) Reduced usage of plating metals

Drag-out reduction results in a decrease of metal consumption due to improvements in process efficiency. Particularly if this method is used at an very early stage of the product line, a maximum level of return is achieved without any additional process requirements (like the installation of evaporators to increase the recovery potential of certain waste reduction technologies). The environmental benefit of this particular GOP can be followed up through the plating line: reduced drag-out results in less wastewater treatment and produces less sludge.

(d) **Economic Benefits**

Along with the improvement in engineering efficiency, the following areas of savings are relevant:

(a) Savings in raw materials
(b) Reduced wastewater treatment
(c) Reduced disposal costs
(d) Reduced sewer fees

(e) **Barriers**

Specific barriers to the implementation of good operating practices are difficult to present since each electroplating shop has a large number of different options. From talking to inspectors and environmental agency staff, it seems that many electroplaters don't think about the simple changes that could significantly reduce their production of pollution.

(f) **Case Example**

Case examples are difficult to find since such case-specific alterations are typically not documented and suppliers are certainly not aware of such changes. Many of the changes are so simple and yet can have significant effects in the production of pollution.

SUMMARY

In trying to analyze the benefits and barriers associated with electroplating waste reduction options, a subset of technologies was selected. As mentioned as one of the limitations in the beginning of the report, it is difficult to derive detailed data about environmental or economic costs and benefits for a specific technology. Variations in production processes do not permit generalizations about those costs and benefits. While investment costs can be given in some cases for defined equipment sizes, operation and maintenance costs again cannot be derived without giving very specific process details. The information given in the analysis is therefore of a qualitative nature; reflects aggregate information from various sources like suppliers, literature, and conference reports; and is primarily valuable for the specific waste stream in which the waste reduction technology was implemented. Discussions about overall plant benefits depend on the relevance of the waste stream in the production costs and simultaneous process changes that provide benefits. This kind of information about the benefits as well as the barriers is believed to be sufficient for the development of an experimental program encouraging the implementation of waste reduction practices within an industry. However, more intensified research efforts should be directed towards obtaining detailed case-specific information which, in turn, should be used to present the problems and benefits related to certain waste reduction technologies in a way that is helpful for industry.

Barriers, on the other hand, are somewhat easier to analyze, although the crucial limiting factor is the potential bias when asking someone for their perception of the barriers. This report tries to take into account the views from the various participants. While focusing on the suppliers' perspective, their biases are balanced by referring to literature and conversations with environmental agency staff, as well as with some electroplaters.

All the waste reduction technologies selected showed significant economic benefits and all had relatively short payback periods, from less than one year to about two years. The selected waste reduction technologies also showed a significant potential for environmental benefits. The application options differ from simple waste reduction practices, such as better housekeeping methods or the installation of spray rinses, to more sophisticated technologies like reverse osmosis or electrodialysis, with the latter not being very wide-spread among electroplaters. In particular, with those latter technologies, it is likely that small to medium-sized platers will be reluctant to install them since those technologies might be regarded as being too difficult and costly to maintain and operate. Additional studies should be conducted that analyze the potential for smaller electroplating operations to use these metal and water recovery technologies, given that the technology is suitable for the variations in plating processes.

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[50] Kohl, Jerome, et al.: Reducing Hazardous Waste Generation with Examples from the Electroplating Industry, Industrial Extension Service, School of Engineering, North Carolina State University, Raleigh, North Carolina, pp. 26-27.
[51] Tam V. Tran, Recovery of Nickel Salts by Electrodialysis Reversal Process, in: 73rd Annual Technical Conference and Exhibit on Surface Finishing, Philadelphia, June 1986.
[52] Development Document for Proposed Effluent Limitations Guidelines New Source Performance Standards for the Metal Finishing Point Source Category, Richard J.Kinch, EPA -440/1-82/091-B.
[53] Phone conversation with Tam van Tran, Ionics Inc., June 20, 1988.
[54] Phone conversation with Tim Howard, Baker Brothers/Systems, June 22, 1988.

Appendix III-1 : **The Electroplating Process - A Brief Survey of the Principle**

(1) General Process Description
(2) Hazardous Waste Generated by the Electroplating Industry
(3) Distribution of Electroplaters in New Jersey

(1) General Process Description

Electroplating, listed under the SIC 3471, is one subcategory of what is generally called the metal finishing industry. Other operations like electroless plating, anodizing, etching, or conversion coating form further subcategories.

Note that the SIC 3471 includes electroplating, anodizing, polishing and coloring.

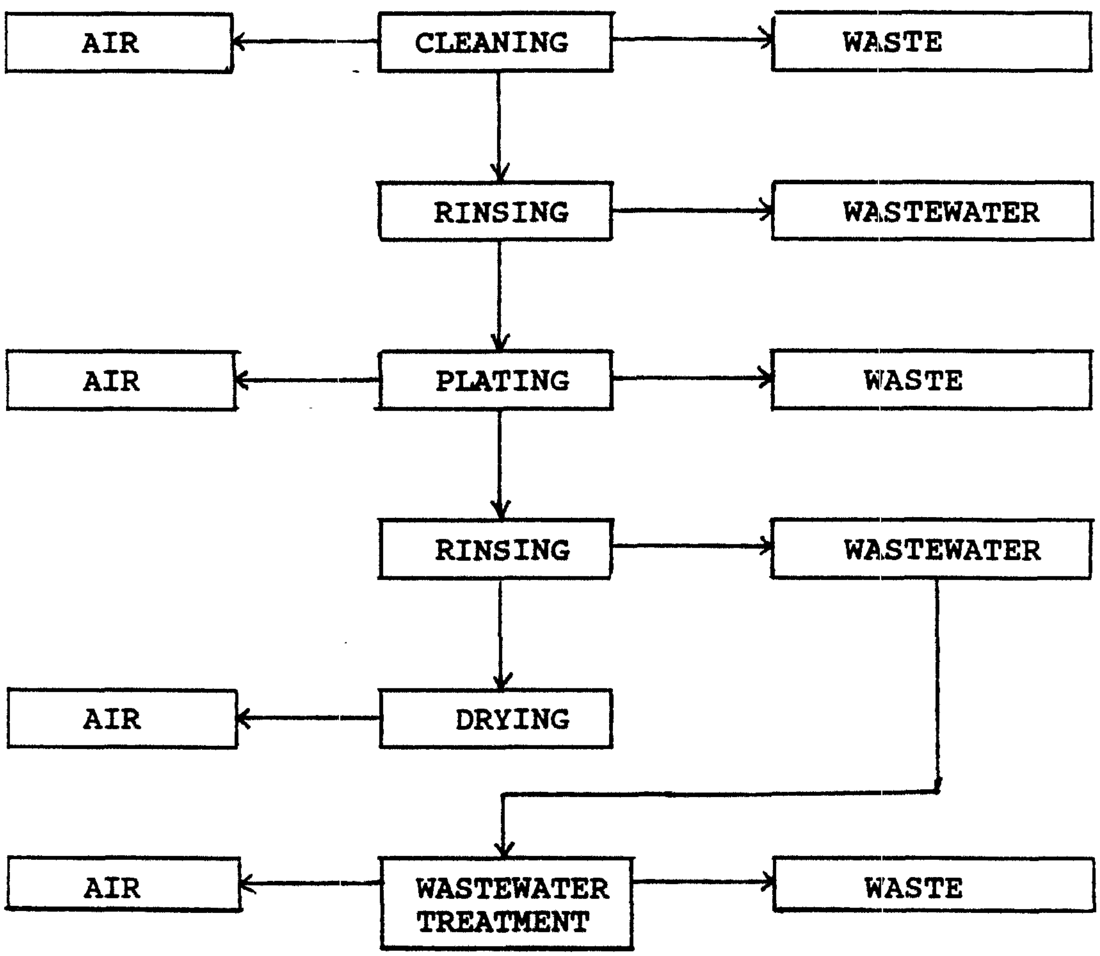
Principle

Electroplating can generally be defined as the electrodeposition of a metal in solution (the plating bath) onto an electrode (the workpiece). Using an electric current with characteristic density, frequency, and efficiency, the metal-ions in the solution are deposited onto the surface, forming the desired surface coating.

In order to achieve the desired surface coating, various process steps are necessary. In many cases several coatings of various metals are plated onto the workpiece (see, i.e., Figure III-8, depicting the general sequences of a plating line). In Figure III-8, the final chromium layer is preceded by a copper and a nickel coating. What kind of coatings of what materials depends on the required properties of the end-product (i.e., corrosion resistance, visual properties, life-time). Hence it is obvious that a multitude of process-specific variables influence the plating process.

In principle, the plating process can be reduced to the following five steps :

Environmental Impact	Plating-Line	Environmental Impact



The first step of each plating process is the cleaning of the incoming workpiece to prevent contamination of the actual plating bath. After rinsing off the cleaning solution, the workpiece is then immersed into the plating bath for a certain time. Followed by a short drainage period, usually of a few seconds, to reduce the adhering droplets from the plating solution, the workpiece is rinsed in various steps. A drying step is sometimes added after the last rinse tank. Finally the produced wastewater needs to be treated.

Each of the depicted steps above is composed of several substeps that are important to guarantee the required performance. The cleaning step can contain acid and alkaline tanks with additional mechanical equipment such as the use of brushes or ultrasonic cleaning machinery. Between each tank, a series of rinsing tanks is usually located, assuring minimum drag-out from one cleaning or plating tank into the other. Drag-out components from one tank are impurities for the following tank, resulting in decreased performance, and therefore need to be removed from the workpiece before entering the next tank. It is not feasible to remove the adhering components completely from the workpiece during drainage. Therefore, several rinse-tanks are necessary to remove all droplets of the drag-out from the workpiece.

The conventional wastewater treatment technologies consist of neutralization, cyanide oxidation (in case cyanide is present), chromium reduction, clarification, and various precipitation technologies (see Figure III-10).

(2) <u>Hazardous Waste Generated by the Electroplating Industry</u>

Table 4 includes the wastes generated by the electroplating and metal finishing industry together with the deadlines according to the land disposal restriction program. They include the wastes from cleaning operations (acid and alkaline cleaning solutions as well as chlorinated hydrocarbons) and from the plating process itself (cyanide- and metal-containing wastewater and sludges and spent plating baths). In cases where air ventilation scrubbers are installed, waste originates also from this part of the process [6].

In addition, leaks can occur in the plating shop, which contribute to pollution.

The largest source of hazardous waste stems from contaminated rinse water. According to a study performed in Cleveland, the average rate of rinse water discharge was 18,500 gallons/day for the shops in Cleaveland. The average spent process solution that was disposed of daily averaged 60 gallons/day [16]. EPA found that of the 34 industries covered by the EPA's toxic wastewater regulations, metal finishers contribute 57% of metals released to sewers [17].

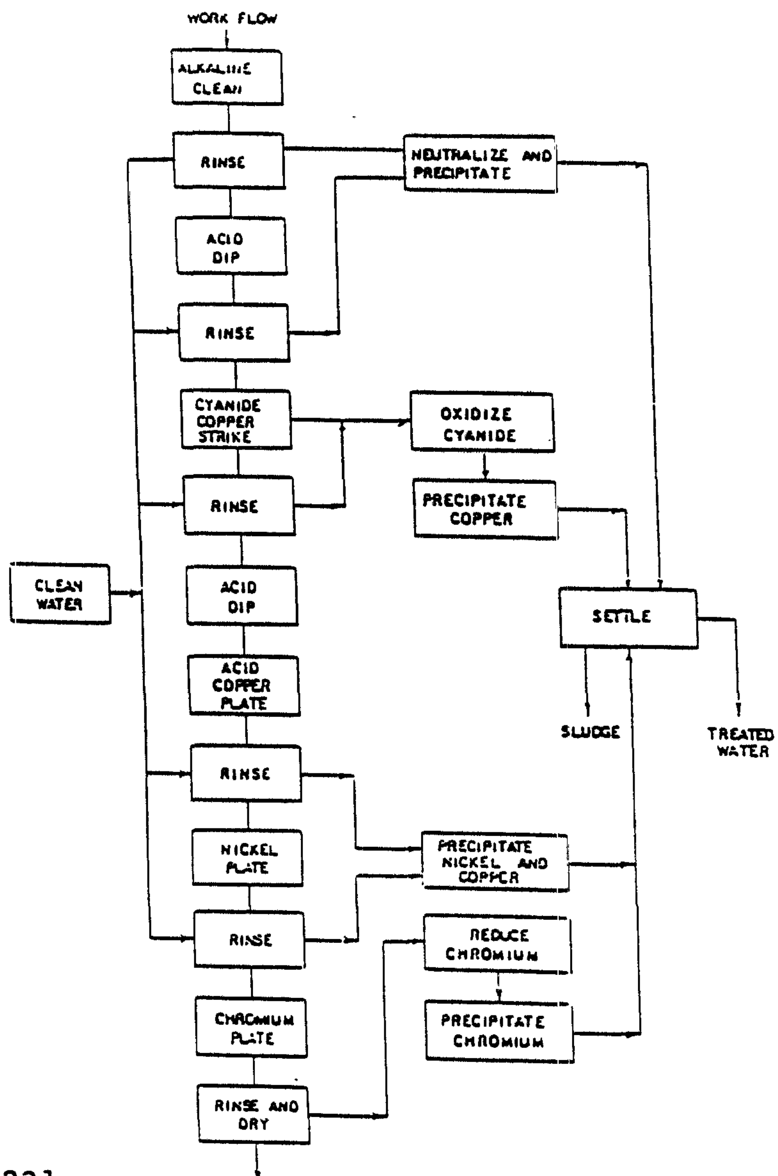
According to the RCRA Manifest Data Base of the Hazardous Facilities Siting Commission [1], the hazardous waste generated in 1986 by electroplating operations in New Jersey was mainly composed of:

15,430	tons	wastewater sludges (F006)
4,063	tons	plating solutions of electroplating operations (F007)
373	tons	strip solutions (F009)
285	tons	plating sludges (F008)

(3) <u>Distribution of Electroplaters in New Jersey</u>

A total of 277 firms were identified in New Jersey to which the SIC 3471 is assigned [2]. The geographical distribution is given in Figure III-11 on the basis of data presented in [2]. Among those 277 firms only 34 manifest their hazardous waste. The quantity of hazardous waste which they generated is listed in Table III-6 together with the information about company size distribution according to [2].

Fig. III-10: Typical Diagram of an Electroplating Line



Source: [23]

Figure III-11: GeographicalDistribution of the Electroplating/Metal Finishing Industry in New Jersey

County	SIC 3471
Atlantic City	1
Bergen	38
Burlington	9
Camden	23
Cumberland	5
Essex	80
Gloucester	11
Hudson	15
Hunterdon	1
Mercer	10
Middlesex	11
Monmouth	7
Morris	6
Ocean	4
Passaic	25
Salem	0
Somerset	3
Sussex	1
Union	24
Warren	4
Total	278

SIC 3471 - Electroplating, Plating, Polishing

* As identified during the Hazardous Waste Source Reduction Study

Table III-6: Waste Generated by the Electroplating and Metal Finishing Industries

Industrial Firm No.	Applicable SIC Codes[1]	Approximate No. of Employees	Quantity In Tons Of Manifested Wastes[2] (1981-1985)		Quantity of Manifested Wastes (Tons) 1983	1984	1985
D-1	3471	>1	929		131	257	298
D-2	3471, 3369	100	63		34	0	0
D-3	3471, 3961	100	22		1	0	14
D-4	3471	20	3		2	1	0
D-5	3471, 3354, 3441	250	27		12	0	15
D-6	3471	20	22		12	9	1
D-7	3471	40	17		1	0	0
D-8	3471	20	2		0	0	2
D-9	3471, 3479	>100	263		63	61	53
D-10	3471, 3479	10	4		0	5	0
D-11	3471	>1	1		0	0	1
D-12	3471	10	2		0	0	0
D-13	3471	5	2		0	0	2
D-14	3471	15	9		3	5	0
D-15	3471	21	0		0	0	0
D-16	3471	25	154		21	40	94
D-17	3471	>1	13		0	0	13
D-18	3471	>20	1382		332	220	201
D-19	3471	10	1185		138	360	490
D-20	3471	20	9		0	5	4
D-21	3471	>1	7		0	2	2
D-22	3471	10	4		0	1	3
D-23	3471	>20	2		0	0	2
D-24	3471, 3479	76	140		35	21	26
D-25	3471, 3079	90	0		0	8	0
D-26	3471, 3444, 3599	100	29		0	0	29
D-27	3471	10	1		1	0	1
D-28	3471	>1	1		0	1	0
D-29	3471, 3479	10	39		12	7	7
D-30	3471	2	3		0	0	2
D-31	3471	>20	9		1	4	3
D-32	3471	>20	2		0	2	0
D-33	3471	>1	1		0	0	1
D-34	3471, 3479	45	106		37	20	11
				Total	816	1,029	1,283

[1] SIC
3079 - Misc. Plastics Products
3354 - Aluminium Extruded Products
3369 - Misc. Nonferrous Foundries
3441 - Fabricated Structural Metal
3444 - Sheet Metal Work
3471 - Electroplating, Plating, Polishing
3479 - Misc. Coating, Engraving
3599 - Misc. Non-electrical Machinery
3961 - Costume Jewelry and Novelties

[3] Based on data edited by NJ Manifest System. All quantities are then converted to tons.

[2] Based on converting raw manifest data in different units to tons.

Source: [5]

Appendix III-2 : **Benefits of Waste Reduction Technology (WRT)**

ELECTROPLATING

WRT\BENEFIT	Air Pollution	Waste Volume	Reduction Toxicity	Occupational Hazards	Raw Material
GOOD HOUSE-KEEPING:					
prevent spills	X			X	X
increase drainage time		X			X
improve cleaning		X			X
proper racks and tanks		X			X
purer anodes		X			X
tank cleaning		X			X
CONTROL EQUIPMENT		X		X	X
distilled process water		X			X
cyanide-free zinc bath	no cyanide		X	no cyanide	
trivalent chromium bath	no Cr 6+	less sludge	no Cr 6+	no Cr6+	less chromium
electroless nickel		X	X	X	X
low cyanide bath	X		X	X	X
use wetting agents		X			X
drag-out recovery		X			X

Benefits of Waste Reduction Technology -Continued-

WRT\BENEFIT	Air Pollution	Waste Volume	Reduction Toxicity	Occupational Hazards	Raw Material
bath filtration		X			X
increase bath temperature		X			X
reduce bath concentration		X	X	X	X
install drainboard		X			X
countercurrent rinse tanks		X			X
fognozzles		X			X
spray-rinse		X			X
still-rinse		X			X
air-agitation		X			X
RECOVERY TECHNOLOGIES		X			X

Appendix III-3: **Summarized Questionnaire from the Interviews of Suppliers for the Electroplating Industry**

(1) Technical

=> To which plating baths is the specific waste reduction technology applicable?
=> Bath concentrations?
=> Temperature range of bath?
=> Bath size?
=> In case of bath substitution, what are the metal concentrations and maintenance requirements?
=> Present rinse water system?
=> In case of a recovery technology: is the unit installed so that the recovered solution is returned to the plating bath (return method) or in a way that the metal-containing solution is recovered off-site or treated in the wastewater treatment system (non-return method)?
=> Is the non-return or the return method used more frequently?
=> Specific system features of the recovery system?
=> In case membranes are used for the recovery technology, which type of membrane is used?
=> What is the sensitivity of the membranes?
=> What is the lifetime of the membranes?
=> What are the pretreatment requirements before the wastewater stream enters the recovery unit?
=> What materials have to be removed from the wastewater stream?
=> What is the minimum concentration of salts and ions in the wastewater stream?
=> Recovery efficiency of the unit? (Maximum concentration in the outlet stream)
=> In case membranes are used, what is their performance in terms of fouling?

Market

=> Total number of companies who are using waste reduction technology in the United States (approx.)?
=> What is the market share of the company asked?
=> How long has the company been marketing the waste reduction technology?
=> What are the characteristics of the electroplating firms who use this waste reduction technology?
=> Does the technology require additional skills of staff?
=> What are the barriers to further market expansion?
=> What in general should be done to increase the implementation of the specific waste reduction technology?
=> What role should the agency play in promoting the use of the specific waste reduction technology?

=> What important elements of technical assistance would foster the use of the specific waste reduction technology?
=> What are the areas of the specific waste reduction technology which require further research?
=> What are the costs of investment and of installation?
=> Operation costs?
=> Maintenance and repair costs?
=> Utility costs?
=> What was the total annual savings observed in cases where the specific waste reduction technology was implemented?
=> Which were the area of savings (raw materials, disposal costs, wastewater treatment costs)?
=> What was the payback period observed?
=> Would the supplier interviewed be willing to meet with the agency, electroplaters, and other suppliers to discuss better ways to develop the technical assistance program?

Appendix III-4: **List of Possible Relevant Economic and Technical Information**

I. INVESTMENT, OPERATING COSTS, AND SAVINGS RELATED TO THE IMPLEMENTATION OF WRT

In order to be able to determine the applicability of waste reduction technologies, the following information related to the economics and the technical reliability ideally should be available.

(1) Total installed costs
- equipment costs ($/unit equipment)
- installation costs ($/unit equipment)

(2) Total annual operating costs
- labor (h/yr)
- maintanance and repair ($/yr or % of investment)
- general plant overhead
- raw materials (excluding repairs and equipment exchange, this is listed under maintenance)
- utilities (electricity, steam, cooling water)

(3) Total annual fixed costs
- depreciation (% of investment)
- taxes and insurance

(4) Total annual costs of operation = (2) + (3)

(5) Total annual savings
- raw materials due to recovery
- water treatment chemicals
- water treatment O & M
- sludge disposal
- water use

(6) payback period
[= total investment/cash flow (yr)]
want discounted present value

II. ADDITIONAL QUESTIONS:

(7) required downtime while installing equipment
(8) required pilot stage to adjust waste reduction technology to process to obtain maximum efficiency
How much fine-tuning is needed before technology is appropriate for application?
(9) downtime during operation of equipment
(10) effect on product quality (effect on sales)
(11) reliability of waste reduction technology
How proven (experienced) is the technology?
(12) possibility for electroplater to end up in a lower waste category and becoming a small quantity generator

(13) additional input of raw materials to accomplish operation of waste reduction technology

(14) number of customers who are already using the waste reduction technology from the specific supplier

(15) bath life and frequency of bath replenishment

(16) characteristics of the customers (size, type of electroplating process, current use of technology, etc.)

(17) Does technology require skills (and staff) not likely to be in firm currently?

(18) To what extent must current production be modified (judgmental)?

(19) Synergistic benefits by combining technologies

(20) How would you describe the applicability of the respective waste reduction technology for small companies (even small quantity generators) in terms of affordability and payback? Which electroplaters are candidate customers?

(21) What is your estimate of the market potential of the respective waste reduction technology?

(22) Do you envision higher demand due to the pending landban provisions?

(23) For how many years has your company been selling the equipment?

(24) Has there been a significant increase in sales over the last years in your company due to an increase in demand by electroplaters?

(25) What do you think are necessary areas of further research with your technology ?

Appendix III-5: **List of Good Operating Practices for the Electroplating Industry**

Good operating practices are defined as being procedural or institutional policies which result in a reduction of waste (see EPA, Waste Minimization - Issues and Options, Volume II, Part B)

(1) Waste stream segregation
[No mixing of plating baths, rinse water tanks connected to different plating lines, cleaning solutions, wastewater streams of different concentrations]

(2) Personnel practices
- Management initiatives
  [Encouraging waste reduction suggestions and practices among employees]
- Employee training

(3) Procedural measures
- Documentation of inflow and outflow of materials, emissions and wastes (material tracking, inventory)
- Proper material handling and storage

(4) Loss prevention practices
- Spill prevention measures
- Good operation of process control equipment,
- Emergency warning and preparedness systems
- Preventive maintenance
- Good process operation

Appendix III-6: New Jersey Hazardous Waste Manifest Data 1985-1987 (by RCRA Code F006, F007, F008, and F009, by year, and by sum of all years)

Company #	SIC Code	Year 1985	Year 1986	Year 1987	Sum of years
1	2511	0.00	0.00	0.46	0.46
2	2800	4.79	0.00	0.00	4.79
3	2641	0.00	26.32	0.00	26.32
4	2819	18.76	130.36	248.31	397.43
5	2841	0.00	0.00	0.69	0.69
6	2842	0.00	62.84	0.00	62.84
7	2869	0.00	0.00	5.21	5.21
8	2892	77.77	4.48	0.00	82.25
9	2899	0.00	1.75	11.01	12.76
10	3079	0.00	0.00	0.46	0.46
	Subtotal	101.32	225.75	266.14	593.21
11	3231	11.05	0.00	0.00	
12	3297	9.31	9.24	8.42	
13	3317	0.00	0.00	12.00	
14	3339	0.00	0.00	1.80	
15	3341	0.00	0.98	20.25	
16	3369	0.00	0.00	18.00	
17	3398	0.00	1.25	0.00	
18	3399	0.00	0.00	1.61	
19	3421	4.13	8.17	0.69	
20	3429	817,379.44	274,634.80	118.33	1,092,133
21	3448	562.54	754.13	1,215.45	2,532.12
22	3452	304.32	981.92	360.05	1,646.29
23	3469	18.79	113.23	84.65	
24	3471	1,080.49	864.27	738.42	2,683.18
25	3479	3.10	29.24	7.13	
26	3494	43.37	0.00	20.85	
27	3496	667.66	818.43	821.72	
28	3497	3,829.96	26,902.58	5,759.51	36,492.05
29	3499	0.00	0.69	44.51	
30	3531	3.02	0.00	0.60	
31	3555	0.00	39.02	0.00	
32	3566	7.81	0.46	0.00	
33	3596	0.00	2.29	0.00	
34	3572	14.18	17.51	10.42	
35	3573	365.83	366.09	163.15	895.07
36	3581	1.80	9.60	12.16	
37	3585	29.24	25.92	25.23	
38	3599	13.09	3.00	1.78	
39	3613	947.00	20.58	128.00	1,095.58
40	3631	0.95	0.00	0.00	
41	3643	0.00	0.00	9.08	
42	3646	0.00	2.06	15.30	
43	3652	80.47	925.50	386.00	1,391.97
44	3661	334.75	0.00	0.00	
45	3662	84.36	306.20	174.94	
46	3674	33.05	32.36	43.70	
47	3675	0.00	0.80	0.00	
48	3676	0.00	0.00	0.05	
49	3677	0.00	0.00	0.21	
50	3679	350.91	3,847.67	1,799.42	5,998.00
51	3694	0.00	41,403.60	50.20	41,453.80
52	3711	273.78	184.26	0.00	
53	3724	2.98	4.92	5.85	
54	3761	29.21	79.66	51.24	
55	3825	0.00	0.38	0.00	
56	3842	0.15	0.00	0.00	
57	3911	1.90	6.98	0.00	
58	3961	0.00	11.05	0.00	
59	3963	7.80	15.00	9.00	
	Subtotal	628,496.21	352,429.84	12,869.72	1,191,816.77
60	4212	0.00	39.34	1.38	
61	4214	0.00	0.00	10.15	
62	4582	276.39	270.15	183.10	
63	4811	491.23	397.61	503.03	
64	4899	0.00	0.00	2.60	
65	4950	0.42	0.00	0.00	
66	4953	27.30	27.15	14.30	
67	5023	0.00	0.00	0.46	
68	5082	9.68	9.72	0.00	
69	5122	0.00	0.27	0.00	
70	5161	0.00	0.00	12.62	
71	5511	0.00	0.00	0.02	
72	6142	0.00	18.00	109.84	
73	6143	176.90	134.78	84.24	
74	6513	0.00	19.87	0.00	
75	7216	0.00	0.00	0.27	
76	7391	276.68	91.33	171.38	
77	7699	2.50	0.24	0.00	
78	8111	13.60	30.68	91.68	
	Subtotal	1,274.96	1,939.14	1,184.87	3,408.91
	TOTAL	627,872.43	353,685.73	13,559.73	1,195,108.89
	all values in	tons	tons	tons	tons

Appendix III-7: Economic Elements: General Description

Economic Elements of Waste Reduction Technologies for Electroplating and Degreasing
[Task 3]

The economic analysis of alternative waste reduction technologies requires calculation of all economic effects associated with the application of each technological option. From the point of view of the firm, only private effects, those internalized by the firm, are pertinent. For the purposes of this study, we make the simplifying assumption that firms are profit-maximizers. Therefore, they will introduce waste-reduction technologies which, they expect, will most increase their profits.

The following equation summarizes the economic relationships:

$$(1) \qquad P_j = \sum_{i=1}^{n} \frac{(R_{ij} - C_{ij})}{(1 + r)^i}$$

where P_j is the firm's profit associated with the j^{th} technological option (for the baseline case, j = 0); R_{ij} and C_{ij} are the firm's total revenues and costs, respectively, associated with the j^{th} technological option in period i; and r is the private discount rate. Note that although waste reduction technologies are normally evaluated in terms of their effects on costs, they are also capable of affecting firm sales, either positively or negatively, by changing attributes of the firm's products. Note also that both capital investments and periodic expenses are captured in Equation (1) because the timing of the expenditures are weighted by the firm's discount rate.

In theory, firms will adopt the technology (or mix of technologies) which offers the highest expected profit, so long as at least one P_j is larger than P_0. Since we are concerned only with relative profits, particularly with reference to the baseline case, we need only examine <u>changes</u> in costs and revenues associated with waste reduction options.

From the policymaker's perspective, all effects, both private and social, are important, and the firm's economic performance is represented by:

$$(2) \qquad P_j^* = \sum_{i=1}^{n} \frac{(R_{ij}^* - C_{ij}^*)}{(1 + r^*)^i}$$

where P_j* is the firm's social return (associated with the j^{th} technological option); R_{ij}* and C_{ij}* are total (social and private) benefits and costs, respectively; and r* is the appropriate social discount rate.[22]

In this formulation, the environmental harm associated with the firm's current production technology is reflected in C_{i0}*. In principle, we would like to be able to monetize the environmental damage caused by the firm's hazardous waste, but in practice, for this project, the "costs" may have to be represented in units of volume and toxicity rather than dollars.[23] Note, however, that some of the environmental effects of the hazardous wastes are borne by the firm (as part of C_{ij}) in the form of disposal costs, regulatory compliance expenses, liability insurance premiums, and legal liability costs.

The policymaker's objective is to motivate firms to adopt the technology for which P_j* is largest. Generally speaking, the primary method of imparting incentives to encourage waste reduction will be to eliminate (or to diminish) the gap between the social and private effects of hazardous waste generation (that is, between P_j* and P_j) or to demonstrate to industry that $P_j > P_0$ for some j.

DATA COLLECTION METHODOLOGY

The level of detail of available information concerning the economics of waste reduction options is (1) significantly lower than for technological information, (2) needs many different sources of information, and (3) is subject to large variations in different plant situations and process applications.

Facing these impediments during the information gathering process, we required a strategy which would permit us to draw reasonable conclusions with a tolerable degree of uncertainty. Subsequently we had to qualitatively estimate the impact of the implicit uncertainties on the results of the incentives analysis.

The relevant economic variables during the incentives analysis are described in Equations (1) and (2) above, all

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22 The social discount rate reflects the rate of time preference and the opportunity costs and riskiness of investment from a social (rather than private) perspective.

23 The reason is that the expected level of human exposure to toxic wastes, the resulting health effects, and the monetary value imputed to these health consequences are currently uncertain and/or controversial.

of which are a function of the specific waste reduction options chosen.

As a first step, we developed a baseline case, referring to the economic situation of an electroplating company. Because the economic variables can differ drastically between different companies, we were more interested in describing the relative relationship among general cost factors as well as between costs and other economic factors. Furthermore, the baseline case referred to an average firm or to typical firms.

Having developed the baseline situation by referring to the specific technical literature available, we turned to the second step, which focused on information verification and more detailed data collection of environmental and economic benefits.

The scope of this project, however, was not to provide a comprehensive survey of the economic variations among electroplaters (or different degreasing applications). Furthermore, we were not be able to examine an extensive number of representative companies to provide a statistically-significant estimate of the economic effect of waste reduction alternatives.

Theoretically, there are several actors who have economic information of interest at their disposal. These include:

(1) Companies

Although companies represent the source of information with first hand knowledge combined with the experience of implementing certain technologies, we can assume that firms, in general, are reluctant to release information concerning the economics of their production process. Trade secret issues, the risk of data "misuse," as well as a general hesitation to publish detailed costs, suggests that we could not expect much support from this important group.

(2) Manufacturers and vendors of plating baths and plating line equipment

Oriented towards increased sales of their products, whether plating baths, control equipment or recovery technologies, this group derives some benefit from sharing its information and expertise. Based on various contacts with equipment vendors, we observed a positive attitude to share more detailed information, especially on cost items. However, we had to filter their information, taking into account the purpose of their business and their biases. Manufacturers and vendors also functioned as "clearinghouses" of information. Through their own experiences, they were able to refer to many specific examples of the implementation of waste reduction technologies. Thus we could achieve a broader coverage of the range of technology applications and barriers.

(3) <u>Consultants</u>

Another valuable source of information is consultants. They have at their disposal the expertise from having worked with/for numerous companies in the field; they may even have designed waste reduction equipment. Similar to vendors, they can provide a good survey of the economic effects from the application of waste reduction technologies.

(4) <u>Agency/permit writers/POTWs</u>

In many cases, agencies, especially the non-regulatory divisions or branches, have some insight into the decisionmaking processes of selected companies. This might be traceable to research efforts particularly focusing on waste reduction issues. Writers of discharge permits or operators of POTWs can additionally provide some insight into the financial reaction of certain companies when confronted with equipment change and investment decisions.

In summary, the latter three groups were predominantly relied upon in order to gain a better understanding of the economic impacts of an investment in waste reduction technologies for Sections III.C and IV.C.

IV. DEGREASING: TECHNICAL DISCUSSION

A. Identification of Relevant Industrial Processes [Task 1]

DEGREASING PROCESS

(1) Introduction

The cleaning of a workpiece or of process equipment is an integral element of many industrial process lines. In fact, improper cleaning can damage the end product or even stop the production line. Cleaning consists of the removal of soils, oils, wax, grease, and any other contaminant from the surface of metals. Degreasing, a subset of cleaning, focuses on the removal of oil and grease adsorbed[1] to the surface of the metal. Specific applications of the degreasing process include parts cleaning, equipment cleaning, and surface coating. Depending on the degree and complexity of the contamination, metal cleaning can be as simple as one step or as complicated as many different treatment steps. For example, in the electronics industry, the manufacturing of circuit boards involves the cleaning and etching of sections and layers of the board selectively, requiring many individual steps. [1]

The specific technique used to remove the contaminant depends on the following:

(i) the type of contaminant - deposits on metals range from aliphatic acids (grease) to metal particulates.
(ii) the type of metal - depending on the base metal, the choice of cleaning process must effectively remove the contaminant without damaging or weakening the base metal.
(iii) the degree of cleanliness required - measured by a test, such as the waterbreak test, the degree of cleanliness can range from removing large particulates to removing molecular level contaminants from a surface.
(iv) the final use of the product - since cleaning is only one step in a production line, the choice of technique depends on what happens to the product next, ranging from electroplating to painting.

[1] Adsorption is a purely physical bond, such as van der Waals forces or gravitational forces, which can be broken without damaging the surface of the metal.

(2) Solvents

The removal of surface contaminants from metal is accomplished by breaking the physical bonds between the metal and the contaminant. A solvent, a substance usually liquid, capable of dissolving or dispersing one or more substances, is used to break this bond. The choice of solvent depends on the dissolution and solubility of the contaminant in the solvent. The cleaning of metals uses a wide variety of solvents, such as aromatic hydrocarbons, oxygenated solvents, aliphatic hydrocarbons, alcohols, and chlorinated hydrocarbons. The degreasing process predominately uses the chlorinated hydrocarbons, but the other solvents, such as mineral spirits or kerosene, can also be used as part of the cleaning line. The choice of a specific solvent depends on the following:

* evaporation rate
* vapor density
* solvent condensate volume
* boiling point
* stability
* toxicity
* flammability
* solvency

The most commonly used solvents consist of the following: (See Table IV-1 for the physical properties of the solvents)

* Trichloroethylene
* Perchloroethylene
* 1,1,1 Trichloroethane
* Fluorotrichloromethane
* Methylene chloride

Table IV-1: Physical Properties of Degreasing Solvents

	Methylene Chloride	*1,1,1-Trichloroethane*	*Trichloroethylene*	*Perchloroethylene*
Chemical structure	CH_2Cl_2	CH_3CCl_3	$CHClCCl_2$	CCl_2CCl_2
Molecular weight	84.94	133.42	131.40	165.85
Boiling point °F (°C)	104° (39.8°)	165° (74.1°)	189° (86.9°)	250° (121°)
Specific gravity 25°C/25°C	1.316	1.322	1.456	1.613
lbs/gal at 25°C	10.98	10.92	12.11	13.47
Water content, max PPM	100	100	63	75
Color, Pt-Co., max	15	10	10	15
Non-volatile residue, Max PPM	10	10	10	25
Acid acceptance (As NaOH) Min. %W	0.23	0.20	0.17	0.10
Free halogens PPM	None	None	None	None
Acidity (as HCl) max PPM	10	10	None	None
Flammability limits LFL	14.8% (25°C)	7.5% (25°C)	8.0% (25°C)	None
UFL	25% (50°C)	15.0% (25°C)	10.5% (25°C)	
Vapor density	2.93	4.55	4.54	5.83
OSHA standards	500	350	100	100
Odor threshold, PPM	100-300	75-100	75-100	20-50

Source: [2]

The above solvents will also have inhibitors added to them. Depending on the solvent, it is typical to add an acid neutralizer (usually butylene oxide), anti-oxidant, ultra violet light inhibitor, and stabilizers to prevent reaction with the metals. [3]

Prior to 1970, trichloroethylene was the dominant vapor degreasing solvent. Because of its toxicity, trichloroethylene now shares this position with 1,1,1 - trichloroethane. Perchlororethylene is the third most popular vapor degreasing solvent followed by methylene chloride and fluorocarbon 113. [1] Table IV-2 presents the effectiveness of the commonly used solvents.

Table IV-2: Effectiveness of Degreasing Solvents

Parameter	Trichloroethylene	Trichloroethane	Perchloroethylene	Trichlorotrifluoroethane Fluorocarbon 113	Methylene Chloride
Flash point	None	None	None	None	None
Toxicity—TLV*	50 ppm	350 ppm	50 ppm	1000 ppm	100 ppm
Solvency	Strong	Moderate	Moderate	Mild	Strong
Photochemical reactivity	Yes	No	No	No	No
Vapor Density (Air = 1.0)	4.5	4.6	5.7	6.5	2.9
Volume of condensate (gals)	1.00	0.86	1.57	0.54	0.19
Stabilization	Yes	Yes	Yes	No	Yes
Boiling point	189 F	165 F	250 F	118 F	104 F
Molecular weight	131	133	166	187	85

*American Conference of Governmental Industrial Hygienists (1981)

Source: [1]

Each solvent has advantages for special applications. Trichloroethylene is the solvent of choice for removing semicured varnish or paint films, heavy resins and buffing compounds. Perchloroethylene, because of its high boiling point, is excellent for removing high melt waxes and for cleaning light-gauge metal parts. It is also preferred for cleaning wet parts since it is more stable with respect to hydrolysis[2]. For cleaning printed circuit boards, electronic components, and electrical motors, 1,1,1-trichloroethane and blends of 1,1,1-trichloroethane are well suited. Chloroflurocarbons are used extensively for defluxing circuit boards because they are less aggressive. These freons are also preferred for degreasing plastics and delicate metal parts that chlorinated solvents would damage. Because of its low boiling point, methylene chloride works very well for temperature-sensitive parts and where aggressive solvency is needed. Economic considerations show that solvent consumption and energy requirements are lowest

[2] Hydrolysis is a reaction between the solvent and water, producing hydrochloric acid.

for 1,1,1-trichloroethane. This solvent also has a higher acceptable OSHA vapor exposure limit and is exempt from air pollution regulations in most states. [2]

(3) Industry Characteristics

The choice of a degreasing process, such as cold cleaning, vapor degreasing, or alkaline cleaning, similarly offers many options and considerations. The choice of technology depends on the following:

(i) a specific company's size and economic flexibility - the size of a user can range from the local car mechanic to an automobile manufacturer.
(ii) application of the degreasing process - the degreasing process is typically utilized to clean parts or to clean process equipment and thus is either a continuous process or sporadically used.
(iii) consistency of type of work - some firms (captive shops) have consistent product lines and thus can afford to invest extensively in one technology, but others (job shops) degrease many different types of workpieces with many different contaminants and need a more flexible degreasing process.

Firms engaged in degreasing range from small automobile garages that clean grease off engine parts to large airplane manufacturers who require highly corrosion-resistant parts to electronic component manufacturers to batch process chemical manufacturers. The following is a list of the most common industries (or users) that generate solvent wastes associated with the degreasing process: [4]

High volume users

* Solvent Reclamation Facilities
* Coatings Manufacturing
* Industrial Organic Chemicals Manufacturing
* Inks Manufacturing
* Semiconductors Manufacturing
* Electronic Components Manufacturing
* Motor Vehicles Manufacturing
* Aircraft Manufacturing
* National Security (Department of Defense)
* Dry Cleaning
* Automobile Service
* Metal Furniture Manufacturing
* Electroplaters

Small Quantity Users

* Printing and Publishing
* Fabricated Metal Products
* Machinery, except electrical

Characterizing the size and financial resources of a firm that generates degreasing wastes can be very difficult. A small automobile garage that employees only 3 people, for example, can generate as much waste as a firm that employees 1,000 people but only has a small degreasing unit.

(4) Wastes Associated with the Degreasing Process

(i) Environmental Pollution Generated

According to EPA Regulations on National Emission Standards for Hazardous Air Pollutants (Part 61), the following chemicals, for which a Federal Register notice has been published, are being considered for regulation because of their serious health effects, including cancer, from ambient air exposure to the substance:

Chemical Abstract #		
56-23-5	* Carbon Tetrachloride	50 FR 32621; Aug. 31, 1985
75-69-4	* Chlorofluorocarbon-113	50 FR 24313; June 10, 1985
75-09-2	* Methylene Chloride	50 FR 42037; Oct. 17, 1985
	* Perchloroethylene	50 FR 52880; Dec. 26, 1985
75-69-4	* Trichloroethylene	50 FR 52422; Dec. 23, 1985

As of July 1988, trichloroethylene has been designated as a possible human carcinagen, downgraded from a classification as a probable human carcinagen. A final decision has not yet been reached on the other solvents.

Trichloroethylene and perchloroethylene are considered photochemically reactive and thus contribute to ozone in the troposphere. Because chlorofluorocarbons do not have any hydrogen (that would react with hydroxides in the lower atmosphere), they reach the upper atmosphere where they decompose due to the ultraviolet light. With a half-life of 86 years, they then give off chlorine that reacts with the ozone, causing serious depletion of the ozone layer. [5]

The above chemicals and 1,1,1-Trichlororethane are also designated as Toxic Pollutants under Section 307 (a)(1) of the Clean Water Act (Table IV-3 gives concentrations of the above chemicals allowed in water after treatment). All the above chemicals are listed in section 101(14) of CERCLA and all are subject to manifest under RCRA. Furthermore, when these substances are used in the degreasing process, they become spent solvents[3]. When these spent solvents are recycled they generate still bottoms, which are designated as hazardous waste and thus are regulated under RCRA.

Table IV-3: Allowable Water Concentrations of Degreasing Solvents

	Wastewater Containing spent solvents (ppm)	All other spent solvent (ppm)	TTB*
Carbon Tetrachloride	0.05	0.96	B
Chlorofluorocarbon - 113	0.05	0.96	B
Methylene Chloride	0.20	0.96	B
Perchloroethylene	0.079	0.05	B
Trichloroethylene	0.062	0.091	B&AC
1,1,1-Trichloroethane	1.05	0.41	SS

* TTB: Treatment Technology Basis
B : Biological Treatment
AC : Activated Carbon Treatment
SS : Steam Stripping

Source: USEPA, Office of Solid Waste. Land Disposal Restrictions Summary, Vol. 1, "Solvents and Dioxins" May 1987

(ii) Relevance to New Jersey

According to hazardous waste manifest data, solvent-containing wastes associated with degreasing operations make up approximately 14,400 tons/year [6], [7], which is 2.5% of the total manifested waste (total of 560,000 tons) in New Jersey. Since not all of the solvent-containing wastes must be manifested (small quantity generators, those who produce more than 100 but less than 1000 kg/month, do not have to manifest their wastes), this figure is only a rough indication of the amount of solvent-containing wastes in New Jersey. Furthermore, the occupational hazards associated with the volatile organic vapors and the federal concern for spent solvents increases the relevency of the problem.

[3] A spent solvent is one that has been contaminated by other substances.

(iii) <u>EPA landban of solvent-containing wastes</u>

EPA estimates that approximately 1,200 million gallons of waste solvents are currently being land disposed of each year. (Table IV-4 illustrates the volume of waste solvent land disposed). [8] The RCRA amendments of 1984 provides steps for a gradual reduction of the amount of hazardous waste being disposed of in landfills until 1990. The goal is to prohibit hazardous wastes from being land-disposed unless "it has been demonstrated to the Administrator, to a reasonable degree of certainty, that there will be no migration of hazardous constituents from the disposal unit or injection zone for as long as the wastes remain hazardous" [RCRA sections 3004, (d)(1)]. On November 8, 1986, EPA promulgated a final rule [51 FR 40572] establishing the regulatory framework for implementing the land disposal restrictions for spent solvent wastes, F001-F005. For the wastes exempted from the November 8, 1986 rule, which includes the small quantity generators, the land disposal ban will become effective November 8, 1988. Between Jan. 1986 and Nov. 1988, RCRA prohibits the land disposal of untreated solvents that contain more than 1% or 10,000 ppm by weight of solvent. Following Nov. 8, 1988, RCRA bans land disposal altogether until the waste meets the treatment standards. EPA's treatment standards require either steam stripping, biological treatment, activated carbon treatment, or incineration with designated quantities of solvent in the final treated waste (see Table IV-3).

Table IV-4: Volume of Waste Solent Land-Disposed

Waste Disposition	Volume	% of Total
Landfill	32.1	2.7
Land Treatment	0.001	<1
Waste Pile	0.743	<1
Treatment only in surface impoundments	389.0	32
Storage only in surface impoundments	318.0	27
Disposal in surface impoundments	8.79	<1
Treatment and storage in surface impoundments	452.0	38

units: million gallons per year

Source: [9]

In view of the land disposal restrictions of solvent-containing wastes, it is important to focus on the increased application of waste reduction technologies related to the use of solvents.

(iv) Incineration

Another means of disposing of spent solvents and/or still bottoms is incineration. Since 1981, there has been a large increase in the number of commercial reclaimers incinerating their wastes. In fact, the percentage of waste fuel blended has increased from 18% to over 90% over the past seven years. [30]

Halogenated compounds have a low heating value and thus must be blended with other wastes or with auxiliary fuel until the chlorine content is reduced to approximately 30% (with a blended heating value of 5,0000 BTU/lb). Natural gas is added to increase the H:Cl ratio such that the mixture has a value of 8,000 BTU/lb. During the incineration process, a mixture of solvent and natural gas is burned such that it emits usable heat. The air effluent is then scrubbed with water to remove any hazardous metals or substances. The scrubber liquid is currently not classified as a hazardous waste. (If it were, the cost of incineration would become prohibitive since the system requires a great deal of water.)

For the halogenated solvents, there is an EPA established limit (air and water quality standard) to the amount of chloride that can be present during the incineration process, further necessitating fuel blending. Cement kilns are most commonly used for the incineration of the halogenated compounds.

Incineration has been one of the most expensive ways of disposing of spent solvents. With the land-disposal restrictions, however, the cost of incineration will soon be comparable to the required treatment before land-disposal. For bulk chlorinated solvents with 3% chlorine content, it costs $2.52 per 100 lbs of solvent. It costs an additional $.50 per 100 lbs for each additional percentage of chlorine in the batch.

(v) <u>Amount of chlorinated solvents currently used</u>

As estimated in 1981 by the EPA, atmospheric emissions from metal cleaning operations amount to 84% of virgin solvents used and approximately the same for the electronics industry. The dry cleaning industry typically emits 88% of its virgin solvents.[5] Table IV-5 provides a survey of the use of chlorinated solvents in the United States in 1984.

Table IV-5: Use of Chlorinated Solvents in the U.S.

	Cold Cleaning	Vapor Degreasing	Electronics
TCE	18	62	
PERC	16	38	
TCA	143	79	21
METH CL	12	6	21
CFC-113	16	5	34

units: metric tons per year

Source: [5]

Table IV-6 provides an additional illustration of the consumption of chlorinated solvents by end use as estimated in 1985 and projected through 1989.

Table IV-6: Consumption of Chlorinated Solvents (by End Use, Millions of Pounds Per Year)

Solvent	Year	Metal Cleaning	Dry Clean., Textile	Chem. Intermed.	Misc.	Total
TCE[a]	'71	440	n/a	n/a	32	472
	'80	185	n/a	5	24	214
	'84	175	n/a	5	25	205
	'89	160	n/a	5	25	190
PERC[a]	'71	110	360	70	84	724
(SRI data)	'80	185	380	110	81	721
	'84	130	300	155	30	615
	'89	125	280	205	35	643
PERC[b]	'76	101	460	95	48/24*	728
(RAND data)	'79	119	473	101	97	790
	'82	81	348	130	44/18	621
	'86	64	337	178	29/26	634
1,1,1-	'71	250	n/a	110	45	305
	'80	440	n/a	20	171	631
	'84	415	n/a	35	181	631
	'89	445	n/a	40	205	690

Sources: a: Hughes et al., SRI International C2 Chlorinated Solvents, 1985
b: Wolf, RAND, Hazardous Waste Management by Small Quantity Gererators--Chlorinated Solvents in the Dry Cleaning Industry (hereinafter "Dry Cleaning", 1987, their adjusments of The Chemical Marketing Report 3/14/83

* Split totals refer to a differentiation of "export " totals from "other" in the RAND data. In each case, the second number excludes reported exports.

(vi) VOC Problem

The very same properties that make organic solvents useful leads to difficulties in both the environment and the workplace. The high volatility and chemical properties of organic solvents result in migration, persistence in the environment, and toxicity[4]. In fact, it is the chemical stability of some organic solvents that enables them to maintain their toxicity and persist in the environment. Many of the non-chlorinated solvents can also dissolve and transport other hazardous materials in a disposal site. [4]

Occupationally, many organic solvents, especially chlorinated solvents, cause respiratory irritation, dermatitis, central nervous system depression, and cancer [10], [11]. Many of the solvents used for degreasing are also precursors to ozone, which currently has an ambient air standard promulgated under the Clean Air Act. Additionally, when contaminants enter the solvent baths, especially water, hydrochloric acid develops. The production of this strong acid can be extremely dangerous to workers and can also result in severe damage to the product.

(5) Current Regulations in New Jersey

Through the New Jersey State Air Laws, specifically the New Jersey Volatile Substances Rules, the state specifies equipment required on degreasing units to minimize the release of volatile organic substances (VOS). See Appendix IV-1 for a list of the equipment-intensive regulations currently imposed on degreasers.

B. Identification of Waste Reduction Technologies for the Degreasing Applications
[Task 2]

METHODOLOGY

For the first phase of study of the emerging and available waste reduction technologies, the technical literature was reviewed. Having become acquainted with the industry, relevant industry-specific journals, conference proceedings, publications of trade associations, EPA research documents, and company brochures were examined. Selected vendors of each of the waste reduction technologies were contacted for verification of the information.

[4] The persistence and migration pertain only to the non-chlorinated solvents used in conjunction with the chlorinated solvents in the cleaning line.

DEGREASING

(1) Baseline Technologies

Metal cleaning is a generic category for many different types of cleaning. Degreasing is one type of cleaning, focusing on the removal of oils, grease, and waxes.
The widely differing application of metal cleaning, for both degreasing and other cleaning purposes, leads to a few "commonly" used processes with many distinct nuances. The commonly used techniques consist of the following:

i. Vapor Degreasing
   * simple vapor degreasing
   * vapor-spray-vapor degreasing
   * immersion-vapor degreasing

ii. Cold Cleaning
   * spray cleaning
   * immersion cleaning
   * diphase cleaning

iii. Alkaline Cleaning

iv. Acid Cleaning

v. Mechanical Cleaning
   * hand cleaning
   * barrel cleaning
   * abrasive blasting
   * flame cleaning

vi. Emulsion Cleaning

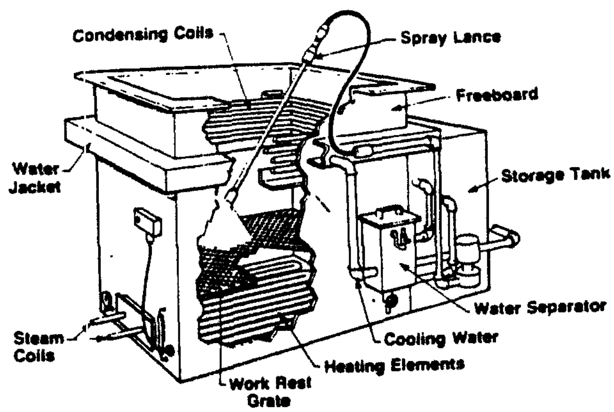
vii. Ultrasonics

Of the above list, the two most common techniques used for degreasing purposes are vapor degreasing and cold cleaning.

VAPOR DEGREASING

The vapor degreasing process consists of immersing a cold metal part in a vapor zone between the boiling solvent and cooling coils (Figure IV-1). Since the solvent vapors are three times (or more) heavier than air, they displace the air and create a pure solvent vapor zone. As the nonflammable solvent condenses on the part, it carries off the deposits and returns to the solvent bath. When the part reaches the temperature of the solvent vapors, it is withdrawn from the vapor zone, drying instantly as it is removed. Because the soils removed have a higher boiling point, the vapor zone remains pure solvent. The continuous heating of the solvent, however, places more severe demands on the solvent than for the cold cleaning process. [1]

Figure IV-1: Vapor Degreaser with Spray Attachment

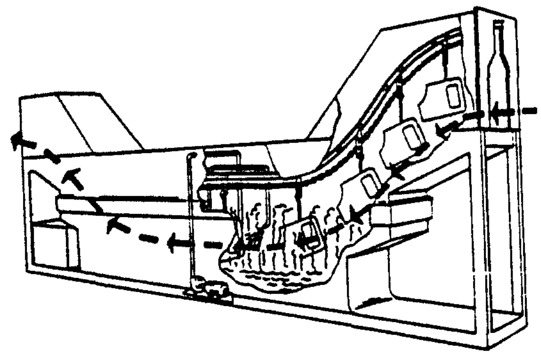


Source: [2]

Industries that conduct large amounts of cleaning typically use vapor degreasing. [4] All of the vapor degreaser designs provide for an inventory of solvent, a heating system to boil the solvent (typically steam, but also electrical resistance heaters, gas combustion tubes and hot water) and a condenser system to prevent loss of solvent vapors and to control the upper level of the vapor zone within the equipment (typically cooling water is used). [1] In 1979, there were approximately 47,000 vapor degreasing units, with 89% being open-top and 11% being conveyor. [12] Open-top units are commonly employed in the electroplating and electronics industries, where easily handled parts are cleaned. Open-top units vary in size from benchtop models with 2 ft^2 of open top area to tanks over 100 ft long, with most ranging between 4 and 8 ft long and 2 and 4 ft wide. The open top degreasers are much lower in cost, permit great flexibility in cleaning different workloads, occupy little floor space and are adaptable to both maintenance and production cleaning.[1] Conveyorized (or fully automated) units are more common in the aerospace and large appliance product coating industries. Of the conveyor units, the monorail conveyor degreaser (Figure IV-2) is the most common.

Because of the need for non-flammable, high vapor density solvents, the vapor degreasing process is more standardized than cold cleaning, relying extensively on halogenated solvents. [4]

Figure IV-2: Monorail Conveyor Degreaser

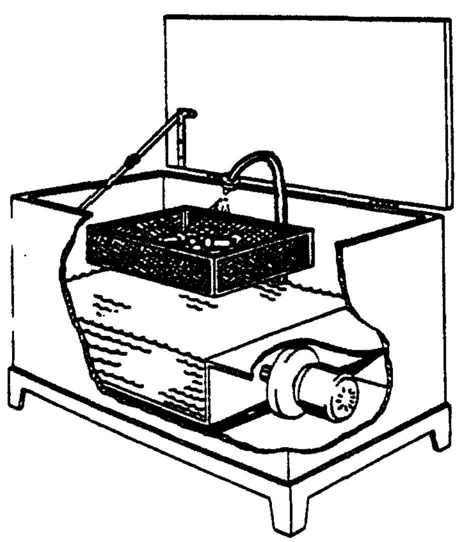


Source: [1]

COLD CLEANING

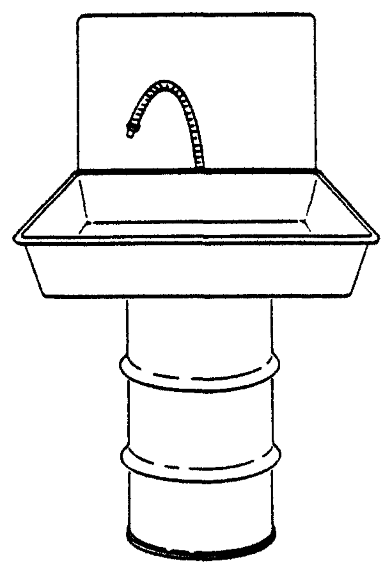
The cold cleaning process typically consists of inserting a part in a container of solvent, allowing it to soak, and then removing the part and allowing the excess solvent to evaporate (or return to the container). (Figure IV-3 and Figure IV-4)

Figure IV-3: Cold Cleaner



Source: [1]

Figure IV-4: Cold Cleaner



Source: [1]

There are approximately 1,000,000 cold cleaning units operating in the United States, with 50% of them used in auto repair shops. [12] Cold cleaning is used seventy percent of the time for maintenance operations. Soak tanks generally hold thirty or more gallons of solvent and have 4 ft^2 of open area. The types of tanks used vary greatly from a desktop unit used for small parts to large tanks used to clean large airplane parts. For cold cleaning, solvent selection is usually based on past experience, and therefore, it is not uncommon to find many different solvents being employed in similar cold cleaning operations throughout industry and even within a firm. [4], [13] For cold cleaning, there are more of the non-chlorinated solvents used, such as mineral spirits or kerosene, than the chlorinated. Nevertheless, there are a significant number of cold degreasers using the chlorinated solvents.

Diphase cold cleaning consists of placing a water layer, usually containing surfactants, on top of a chlorinated solvent. Because water and the solvent are essentially insoluble and the solvent is more dense, the water floats on the solvent. The advantage of this system is that a part can be cleaned with both solvent and water in one process step. Equally important is the fact that the water layer significantly reduces the evaporation rate of the solvent. A disadvantage, however, is that this process leaves the part wet. [1]

Ultrasonics, the use of sound waves to create agitation, can be used in conjunction with both vapor degreasing and cold cleaning to increase the level of cleanliness. The sound waves create cavitation, the rapid formation and violent collapse of minute bubbles in a cleaning liquid, enabling a greater degree of cleaning, especially with workpieces that have many crevices. The agitation does, however, put a greater strain on the cleaning fluid and the tanks used for the process, necessitating the use of special metals for the tank. Ultrasonics is also frequently used with alkaline cleaners to provide the necessary cleaning action to make it comparable to solvent cleaning.

For both vapor and cold degreasing, the composition of the solvent bath, including the amount of stabilizers present, must be continually monitored to avoid the build-up of acid in the system (often additional stabilizers must be added to eliminate any acid formation). If the bath becomes exceedingly acidic, it typically becomes unusable and must be disposed of, an expensive proposition. In fact, an acidic bath will not only destroy the part being cleaned, it will usually damage the metal of the degreasing unit. It is also very difficult to recover acidic solvent because the acid will attack the metals of the recovery unit.

(2) Current Industry Practices

Every industry that utilizes the degreasing process has its own standard operating practices and procedures for dealing with generated wastes. There are, however, some common trends. The larger generators of solvent wastes tend to have recycling units. The still bottoms they generate are placed in drums, usually 55 gallon drums, and picked-up and transported to either a commercial recycler (for further recovery), an incinerator for fuel blending, or an EPA approved landfill. The smaller, large quantity generators (LQG) either recycle on-site or use a commercial recycler.

The smaller generators have a much more difficult time dealing with their wastes. Because they generate only a few drums of waste in a given period of time, it is difficult to find reliable transporters (many transporters no longer haul hazardous wastes because of all the regulations and restrictions) willing to pick-up the small quantities of wastes. The small quantity generator must then store the wastes on-site until enough waste has accumulated to make it economical for both the generator and the transporter. There are, of course, EPA-established regulations concerning how long a waste can remain on-site before the generator is considered a transport, storage, and disposal (TSD) facility. Some of the SQG do indeed recycle, but they then must deal with the even smaller quantity of still bottoms generated (still classified as hazardous waste). Once the wastes are picked-up, they are either recycled, incinerated, or landfilled. [14]

In order to characterize an industry, associations will typically conduct surveys of its members. The National Screw Machine Products Association, for example, sent out surveys to 428 of its job shop members. They received 158 responses, indicating that only 17 of the 158 firms currently recycled solvents (both chlorinated and non-chlorinated). The firms' complaints about the regulations did not center around the regulations themselves, but rather the implementation of those regulations. The major complaints were: [14]

* overlapping jurisdiction
* excessive paperwork
* confusion about the laws
* lack of usable information from the EPA
* fear of going to the EPA for assistance

(3) Waste reduction methods and technologies

(a) **Reformulate Product**

For the degreasing process, changes in the production line or in the actual product may achieve a substantial reduction in the production of wastes. In fact, redesign of the production line could even eliminate the need for degreasing or greatly reduce the quantity of objects needed to be cleaned. For example, if water-soluble cutting fluids are used instead of oil-based fluids for the machining of metals (as a diluent), it is possible to eliminate the degreasing step in the metal finishing industry.

(b) **Good Operating Practices**

An inexpensive yet effective way of reducing the use of solvents is good operating practices. A significant amount of the highly volatile solvents are lost through evaporation, creating fugitive vapors which pose a serious health threat to workers. The use of good housekeeping practices can reduce the rate of evaporation and minimize the threat to workers. The following examples present a selection of relatively simple housekeeping techniques for the cold cleaning and vapor degreasing processes. The sheer number of housekeeping techniques (listed in Appendix IV-2) should suggest the value of such simple but important details.

Examples :
* cover open-top degreasers
* avoid adding water
* avoid compressed air spray
* use floating roofs
* use coarse spray of solvent
* drain parts properly

(c) **Substitution**

The difficulties arising because of the toxicity and persistence of organic solvents suggests that alternative solvents should be investigated. The use of alkaline cleaners is a significant alternative. Water-based solvents consisting of biodegradable, free rinsing, water soluble detergents and surfactants (and specially formulated silicates) can be used to replace the chlorinated solvents in many processes[5].

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[5] For a description of the benefits of waste reduction technology, see Appendix IV-4.

(d) **Recovery**

Recovery technology is well established within the degreasing community.[15]

--> <u>in-house recovery</u>
- distillation recovery equipment
- adsorption process-activated carbon system.
- gravity separation
- batch stills
- solvent extraction
- treatment with additives to restore buffering capacity

--> <u>Out-of-house recycling</u>
- Custom toll recycling
  - spent solvents are kept segregated
- Open market recycling
  - all solvents are joined together and then recycled
- Downgrading
  - use of a contaminated solvent for another purpose within a plant

(e) **Emission Control**

The greatest loss of solvent occurs through evaporation of the solvent. The fugitive vapors[6] pose serious occupational hazards and result in the loss of large quantities of raw material. The following technologies are used to capture the fugitive vapors:

--> <u>Activated Carbon Adsorption</u>

--> <u>Refrigerated Freeboard Chillers</u>

The above set of degreasing process modifications represent the plethora of waste reduction technologies available. <u>The most attractive option, from a source reduction point of view, is either the reformulation of the product or the substitution of the alkaline cleaners for the chlorinated organic solvents</u>. Housekeeping and recycling represent the next best option. Emission control is important from an occupational health standpoint. Although process change is preferred to this end-of-the-pipe technology, it is an alternative.

The least expensive means of reducing the use of solvents is good operating practice, such as keeping a solvent tank

[6] Fugitive vapors are the solvent vapors that escape from a degreasing unit.

covered when not in use. Another range of options, addition of recovery technology or process changes, need a larger financial input as well as more planning time. In some cases (i.e., substitution), the possibility of changes in end-product properties must be evaluated before a change is made. Although both substitution and recycling require large capital expenditures, the savings in raw materials, reduced occupational exposure, disposal costs, and thus liability, offer compensating incentives.

Many of the waste reduction technologies available to degreasers are well established, having been on the market for more than 50 years. The principles of the recovery technologies, including distillation and adsorption, have been widely accepted and used since the beginning of industrialization in all types of industries. The alkaline cleaners, on the other hand, have long been used to remove particulates but only recently have been used to replace solvent degreasers. The alkaline cleaners, therefore, require more investigation and research to develop an appropriate substitute for a particular application.

In order to ascertain the barriers to adoption of the source reduction technologies, specific industrial uses of the degreasing process have been studied in detail, focusing on the economic difficulties as well as the attitudinal resistance to change. By examining the different waste reduction technologies available and their application to the degreasing process, the typical barriers to adoption of such technologies can be discovered. The following matrix illustrates the options available for study:

WRT\DA	Parts cleaning cold	vapor	Process Equipment
Substitution	***	***	***
Housekeeping	***	***	***
Recycle	***	***	***
Product Change	***	***	
Emission Control	***	***	

<u>abbreviations</u>:

*** - waste reduction options for possibilities
DA - degreasing application
WRT - waste reduction technology

(4) Cost Considerations

With the widely varying industries that utilize the degreasing process, it is very difficult to characterize the economic profile of a typical user. The different costs associated with size alone make a generalization impossible. It is possible, however, to highlight and prioritize the important cost factors associated with the degreasing process. The relevant cost elements associated with the degreasing process are the following:

- price of virgin solvent
- disposal
- labor
- utilities
- other assumed costs (initial capital outlay, installation costs, insurance, record-keeping)

These costs vary greatly from firm to firm. The cost is typically dependent upon the size of the operation, the type of solvent used, the area of the country (utility costs), and the availability of safe, reliable transporters and treatment plants.

Cost saving are usually a function of the following variables:

- reduction in virgin solvent demand
- value of recovered solvent
- reduction in spent solvent and/or still bottom volume
- reduction of liability-related costs
- reduction in insurance costs

The above economic factors are discussed more thoroughly for each specific waste reduction technology in section IV.C. For a general discussion of economic parameters and sources of economic information see Appendix III-7.

C. BENEFITS OF AND BARRIERS TO THE IMPLEMENTATION OF WASTE REDUCTION TECHNOLOGIES (WRT) FOR DEGREASING

INTRODUCTION

Current regulations concerning the use of volatile organic compounds, combined with the escalating costs of landfilling and the high cost of incineration, suggest the need for waste reduction technologies. With the premise that the cheapest, most efficient way to deal with waste is not to generate it in the first place, the use of waste reduction technology seems the logical course of action. This section will present the current and emerging waste reduction technologies available to degreasers, the benefits and costs of such technologies, the barriers to implementation of the technologies, the incentives to overcome these barriers, and a case example.

The myriad applications and different users of the degreasing process result in very case-specific difficulties. When promoting waste reduction technologies for such a broad spectrum of users, it is important to remember that not all technologies are universally applicable, even for the same production process. The degreasing process is only one part of a process line, and thus, a company might better reduce its total production of pollution by altering the entire process line or its product rather than by just changing the degreasing process.

METHODOLOGY FOR THE SURVEY OF SELECTED SUPPLIERS

The different waste reduction technologies available to degreasers were found through a literature search and contact with vendors, associations, and consultants. The types of questions asked are contained in Appendix IV-3. The information was substantiated through discussions with many people in the industry and their perception of the effectiveness of the equipment. This information is not intended to be fully encompassing of all possible technologies, but rather serves as a model for identifying barriers to the implementation of a given technology and the incentives needed to overcome such barriers.

ASSESSMENT OF SURVEY RESULTS OF BENEFITS OF AND BARRIERS TO THE CHOSEN SUBSET OF WASTE REDUCTION OPTIONS

(1) Substitution: Water-based Cleaners

(a) **Introduction**

A promising possible technical solution to the control of volatile organic carbons is not to use them. The most promising alternatives to the halogenated solvents are water-based (usually alkaline) cleaners. Alkaline cleaners have been used extensively thoughout the history of metal working to accomplish specific cleaning tasks. It is only recently, however, with the advent of the current regulations that alkaline cleaners have been developed to replace the halogenated solvents. It is thus a "new" product on the market and, as a result, has been subjected to extensive criticism, skepticism, and resistance.

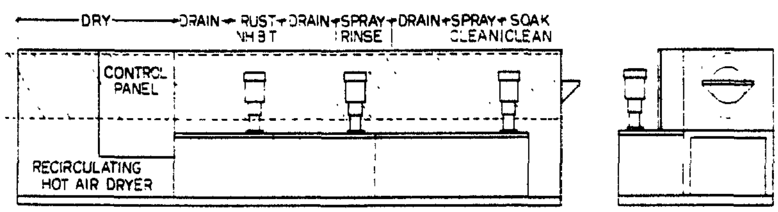
There are many case studies illustrating the applicability and effectiveness of water-based cleaners. [10], [16], [17] Because of the possibility of corrosive action on the base metal and ineffective cleaning action, the proper blend of surfactant, detergents, and water must be achieved. These case-specific problems have added to the resistance to change, but as more water-based cleaners are used for the different types of cleaning situations, there will be a standardization within the community of which type of detergent combination best suits a typical situation (see Figure IV-5 and Figure IV-6 for represenatative water-based degreasing units).

(b) **Technology**

A water-based degreasing unit typically consists of a cleaning bath tank, a rinse tank, and a drying area. [18] Figure IV-5 illustrates the cleaning stations required for detergent cleaning.

Figure IV-5: Water-Based Degreasing Cleaning Stations

A Typical Four-Station Rotary Parts Washer



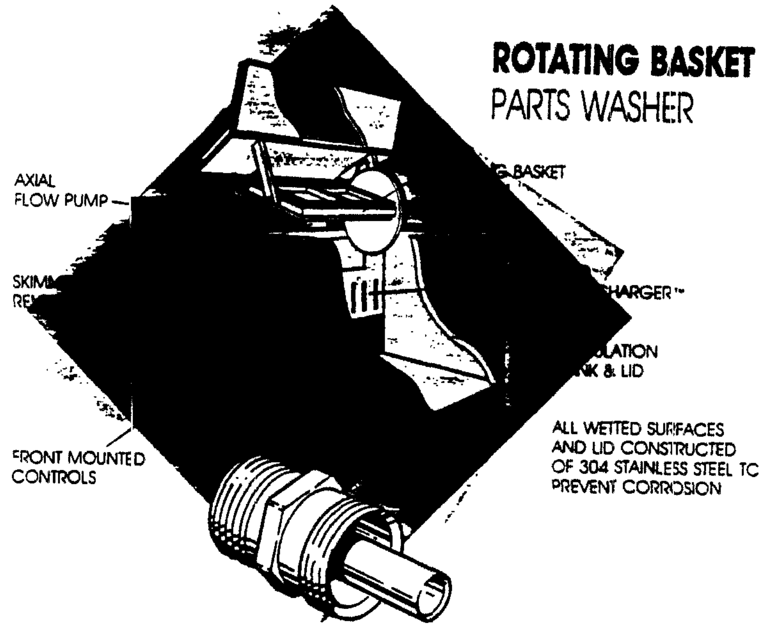
Source: Jensen Fabricating Engineers, Inc.

Many of the difficulties associated with water-based cleaners have recently been overcome. For instance, water-based cleaners tend to need agitation to be effective. Many firms use either ultrasonics, circulating pumps, or propeller-type devices to agitate the water. Once the oil is removed from a part, it floats on the top of the water, resulting in the recontamination of the part as it is removed from the tank. Also, the chemical action of the cleaning fluid has created rapid fluid deterioration as the contaminants are emulsified in the liquid. [19] Many firms use skimmers to remove the oil, while others, such as Bowden Industries, have a fully-enclosed unit that filters the water as it removes the soil and thus reduces the fluid deterioration (see Figure IV-6 for an example of a water-based degreasing unit). Furthermore, a part must often be dried after it has been cleaned, forcing the use of either a dryer or air knives. The detergents can also be corrosive to the tanks, requiring special tank liners.

(i) Applications

Aqueous-based degreasing is not as universally applicable for removing different types of contaminants as the chlorinated solvents. [20] Although aqueous based degreasing can be used in both job shops and captive shops, it is sometimes more practical in a captive shop where all previous metal working is done in-house, providing simple, better control of the contaminants.

Figure IV-6: Water-Based Degreaser



Source: Bowden Industries, Inc.

(ii) Limitations

Comprehensive studies of the type of water based cleaner that will be effective for a particular set of contaminants often must be undertaken, including the chemistry of the process. The combination of surfactants, detergents, and water must be combined precisely to avoid excessive emulsification[7], eliminate saponification[8], provide proper wetting (loosening of the contaminants), and not damage the base metal.

There are currently problems with the use of water based cleaners for the electronics industry. The resins associated with the cleaning of electronics are hard to remove with the current spectrum of water-based detergents. The electronics industry also has very stringent cleanliness requirements, often even resisting using recycled solvents. [21] There

[7] Emulsification is the chemical process by which surfactants penetrate oily soils and break them down into globules sufficiently small to allow dipersion in suspension in the solution. [18]

[8] Saponification is the chemical action by which a fatty acid, a fatty oil, or other reactable soil is converted to a water-soluble compound such as a soap. [18]

is, however, an expanding market for water-based defluxing systems for circuit boards.

(c) **Environmental Benefits**

(i) Elimination of the use of solvents

With the use of water-based cleaners, a degreaser eliminates the need for solvents and thus removes all the liabilities, as well as the environment and occupational hazards, associated with the volatile organic solvents.

(ii) Reduced Air Pollution and Occupational Hazards

With the elimination of the use of chlorinated solvents, the associated air pollution problems will likewise be eliminated. The occupational hazards caused by the fugitive air vapors will also be removed. However, many of the water-based cleaners do have some hazards associated with them, such as dermatitis, that must be investigated and understood.

(d) **Economic Benefits**

(i) Reduction in treatment and disposal costs

The expensive disposal costs associated with the volatile organic solvents, including the escalating costs of land disposal, can be greatly reduced. The contaminants removed from the water (usually with a skimmer) can be either hazardous or non-hazardous. If they are hazardous, they must be dealt with as such. The collected contaminants will typically have a lesser volume with the water-based system than the solvent system (no solvent in the contaminants) though there will be some water and detergent present. In some circumstances (depending on the system and how much the contaminant emulsifies), there will be some costs associated with the treatment of the water waste developed with the alkaline cleaners. The detergents and surfactants tend to be biodegradable, however.

(ii) Reduced workers' compensation costs

Because of the labeling of many of the chlorinated solvents as probable human carcinogens and the central nervous system depression syndrome associated with them, workers' health costs are high and pose potentially serious future liabilities. With the use of less toxic water-based cleaners, workers' compensation costs would decline.

(e) **Economic Costs**

There is usually a large capital outlay required to switch to water-based solvents. The typical costs associated with a water based cleaning system are difficult to characterize because they are so case specific (volume, type of contaminant, type of product line, etc.) Nonetheless, for immersion tanks, costs range from $1,000 for a 10 gallon tank to $40,000 for a 33,000 gallon tank. For conveyor belt systems, costs range from $10,000 to over $500,000. For agitated, rotating basket systems, costs range from $16,000 to $25,000 for the smaller systems.

Since many parts must be dry after cleaning, evaporation units or air dryers are typically required. It costs approximately 10 times as much to evaporate water as it does to evaporate the same amount of solvent. Likewise, compressors for air knives are very costly and are utility-intensive. If the detergent bath (or rinse) is heated, some or all of the water will vaporize when the hot metal part is removed from the bath.

Some water-based systems will emulsify the contaminants, creating a more difficult and expensive filtration and separation problem. For any water wastes that are generated for some water-based systems, treatment might be necessary. Before the used water can be disposed of in the sewer or to a POTW, the metal oxides, oils, grease, and waxes must be removed (to satisfy any state or federal regulations). Again, if evaporation is used, there will be extremely high utility costs.

(f) **Barriers**[9]

(i) History of water-based cleaners

Many of the initial cleaners were ineffective and very corrosive to both the metal workpiece and the equipment. The cleaning solution also deteriorated quickly. These initial difficulties have created skepticism for the new water-based cleaners on the market.

(ii) Skepticism

Since water-based cleaners have only recently been developed to replace the chlorinated solvents, there is a resistance to try a "new" product that has not been widely used on the open market.

(iii) Customer specification

In many job shops, clients specify the type and procedure of cleaning desired, causing problems with substitution.

[9] The following barriers were mentioned in telephone conversations with these vendors: Ed Silva, Jensen Fabricating Eng., July 25, 1988; Donald Bowden and Neal Neuman, Bowden Ind., Inc., June 20, Aug. 2, 1988.

(iv) Capital intensive

Often the high capital costs associated with changing a process seem insurmountable. Many firms "hide" the high costs of their present degreasing system because their accounting system fails to group all the myriad of costs associated with waste generation with the degreaser. Since degreasing is just one step in an industry line, the costs associated with the solvent degreasing system can be grouped in many different accounting categories. Ignoring the cost of disposal, transportation, the liabilities, and the administrative permitting requirements (SARA Title III) associated with chlorinated solvents in an economic comparison can make the water-based system appear unattractive.

(v) Space required for the equipment

Many older shops are constrained by floor space. The water-based cleaning units usually consist of a detergent bath, rinse tanks, and dryers which can require large amounts of floor space.

(g) **Case Example**

EXAMPLE #1 [19]

A firm that wants to remain anonymous attained the following data for savings on operational costs associated with the implementation of a PC-1100 Mulutistage Parts Washing System including wash, rinse, and dry stages from Bowden Ind., Inc. The firm had previously been using a Detrex Vapor Degreaser with a recovery still.

OPERATIONAL DESCRIPTION

The operator uses an overhead crane to place bundles of straight copper or brass tubing (max. 25 ft. length) into the cleaning system tank. The operator monitors the system performance throughout the cleaning cycle.

ANNUAL COSTS:

Vapor Degreasing		Bowden Aqueous Cleaner	
Solvent purchase: Trichlororethylene 12,000 gallons $ 4.00 per gallon	$48,000	Fluid Purchases: BB-100 1320 gallons $6.95 per gallon	$ 9,174
Disposal 24 Barrels (55 gal) $ 50 per barrel	$ 1,200	Disposal	0
Administrative Regulatory Compliance and filings for EPA/OSHA and State/Local Agencies	$ 5,000	Administrative	0
Utilities:		Utilities:	
Heating (190°F)	$ 6,150	Heating (120 °F)	$ 4,200
Cooling (65°F)	$ 3,875	Cooling	$ 0
Manpower/Labor One operator	$20,000	Manpower/Labor One operator	$20,000
TOTAL ANNUAL COST	$84,225	TOTAL ANNUAL COST	$33,374
		ANNUAL SAVINGS:	**$50,851**

Assumptions: Initial cost of equipment and life expectancy of the equipment are comparable for vapor degreasing and aqueous system.

Since the PC-1100 unit costs approximately $35,000, the purchase of the aqueous cleaner to replace the vapor degreasing unit would give a payback period of 8.3 months.

EXAMPLE #2 [10]

Firm: Nulco MFG., Pawtucket, RI
Product: Solid Brass Lamp Pieces
Substitution: Ultrasonic aqueous-based process replaced trichloroethylene.

Nulco now uses a biodegradable aqueous cleaner along with ultrasonic equipment and water rinses for over 90% of the material cleaned. This change was initiated after over 50 workers were hospitalized as a result of exposure to fumes of trichloroethylene. The new cleaner is 5 to 6 times less expensive than trichloroethylene. Other savings include no disposal costs and a major reduction in workplace health and safety insurance. The regulatory benefits include reduced OSHA obligations, elimination of waste requiring manifests for disposal and transport, and reduced air emissions. The water discharge from this system meets pre-treatment standards of the city. The water-based system also has a greater productivity rate, but because it is a relatively new technology, it took approximately a year and a half to debug the system.

The water-based system required the purchase of cleaning tanks, the ultrasonic cleaner, a water deionizer, racks for the parts, and a blow dryer. This system cost approximately $50,000, but the two previously used vapor degreasers were sold. The payback period was less than two years.

(2) Recycling: On-Site and Off-Site

Solvent recycling technologies are very techniques, having been used in many different industries. It was not until the oil embargo of 1974, however, that the recycling industry emerged as a viable independent industry. [22] Today there is a strong market for both in-house and off-site recycling.[15]

Recycling technology has developed in the past twenty years to the point that almost anything can be separated and recovered; there remains only one limiting factor: cost. There are many advantages and disadvantages to both on and off-site recycling. (See below for specifics.) Although there are large capital and operating expenditures associated with on-site recycling, the cost of transportation and the liability associated with using an off-site recycler can be comparable.

ON-SITE RECYCLING

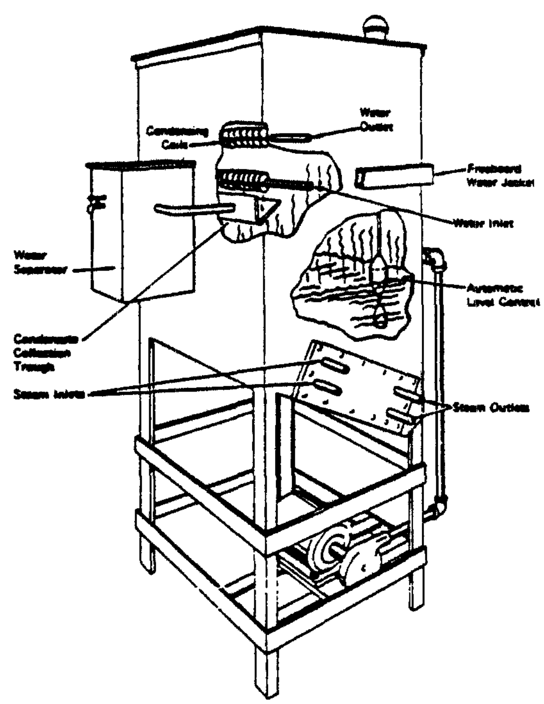
(a) **Introduction**

Distillation is the most commonly used technique for the recovery of concentrated spent solvents. Distillation is an established technology with its industrial use dating back to the beginning of the industrial revolution. In fact, the priciple of distillation is so simplistic that it is commonly used in the household for cooking. According to the EPA, 114.3 million gallons of halogenated solvents were reclaimed onsite in 1981 and 58 million gallons were reclaimed off-site (excluding SQG).[23] Currently, twice as much of the quantity of virgin solvents being purchased is presently being reclaimed, but the potential for recycling is on the order of nine times the quantity of virgin solvent generated. [5]

(b) **Technology**

Distillation relies upon the different volatilities of the solvent and the impurities. When heated, the lower boiling point component (the solvent) will vaporize while the other component remains liquid (and solidifies to some degree). The solvent vapor rises to the top of the column where it is then condensed and recovered. Figure IV-7 illustrates the design of a distillation unit. The costs and size of the equipment needed depend on the relative volatility of the components and the purity desired for the solvent.

Figure IV-7: Distillation Unit

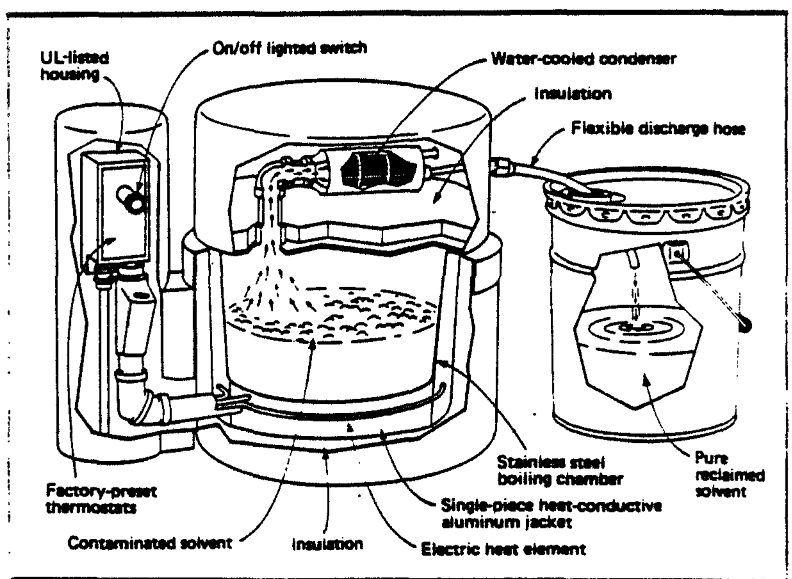


Source: [1]

There are three types of units typically used to distill spent solvents: process stills, batch recovery equipment, and thin-film evaporators. The process stills are used in conjunction with vapor degreasing units. This continuous recovery unit takes solvent from the sump of the vapor degreaser, distills the spent solvent, and returns the regenerated solvent to the vapor degreaser. Process stills tend to give a high recovery yield ranging from 80 to 95%, with a purity of 99+%. Systems are also available under vacuum to reduce the boiling point of the solvent and thus to reduce energy requirements for heating and cooling the solvent. The vacuum units are, however, more expensive, so they are usually used only when recovering high boiling point solvents (320°F to 500°F).

The batch solvent recovery equipment is used for intermittant distillation, usually for a small quantity generator or cold cleaning operations. The system requires the collection and storage of spent solvent to accumulate so as to fill the equipment. Once enough spent solvent has accumulated, it is distilled. The recovered solvent is then stored for reuse. The single stage batch distillation units have a capacity ranging between 3 and 1000 gallon/batch, with most small units varing between 5 and 25 gal/batch. Figure IV-8 shows a representative small distillation unit.

Figure IV-8: Distillation Unit - Small



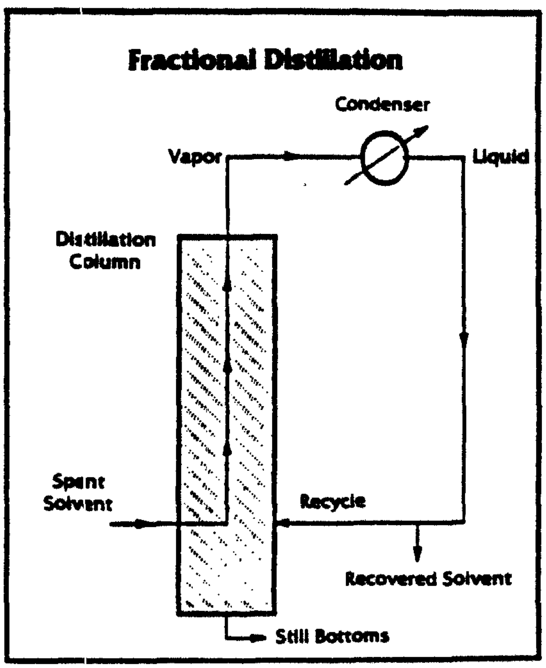
LS-Jr reclaimer processes solvents with boiling points up to 320F at a rate of 3-5 gal in 8 hr; for higher boiling points, a vacuum-equipment option is available

Source: [24]

Thin-film evaporators are used for high-volume, continouous flow solvent recovery. The system consists of an internal heated surface and a rotary blade that spreads the solvent over the heated surface. The solvent is then flash vaporized and either condensed and collected or sent to a fractionating unit for further separation. The thin film evaporator is able to process more viscous solvent mixtures, allowing for greater recovery of spent solvent. Since the system is fed from an external tank and operated continuously, the thin-film evaporator, unlike the stills, offers the advantage of not being limited by the size of the pot. It is also self-cleaning (also reduces fouling) due to the highly turbulent thin-film washing effect caused by the rotors that spread the spent solvent over the heated surface area. Thin-film evaporators are used predominately by commercial recyclers, although some larger generators also use them on-site.

In order to separate solvents of a relatively small volatility or to attain greater purity, a multi-stage distillation unit, commonly called a fractional distillation unit, is required. Such units require either packed beds (porcelin saddles), sieve plates, or trays in order to have maximum contact between the vapor and liquid[10]. This system also utilizes a reflux in which part of the distillate is returned to the column, enabling a better separation (see Figure IV-9 for an illustration of a fractional distillation unit). There are economic trade-offs between size of the unit and quality of the product: the taller the column (more trays), the greater the purity and the larger the capital cost; the larger the diameter, the greater the thoroughput and the larger the operating costs. Such systems are usually custom designed with a capacity ranging from 1 to 1,440 gal/hr.

Figure IV-9: Fractional Distillation Unit



Source: [25]

[10] These internal components of a fractional distillation unit allow for more contact of the vapor and reflux distillate in order to improve equilibration and thus to attain greater purity.

The distillation units create still bottoms which contain the oil, grease, waxes, and soils removed from the cleaned part and 5 to 20% solvent. These remains are classified as hazardous wastes and are thus subject to regulations found in RCRA. The bottom residues are either sent for further recovery or are properly disposed of. If the bottoms contain up to 30% oil, they are generally sent to contract reclaimers; between 30-90% oil, they are fuel blended; 90% and above are disposed via thermal destruction. [26] For some SGQ degreasers, spent solvents are sometimes allowed to evaporate [20].

Secondary recovery units, such as the SRU offered by Progressive Recovery Inc., allow for the additional recovery of solvent from high particulate-laden solvent with solid content of 40 to 90%. These systems are capable of reducing contaminated sludges to 1/2% solvent content. The design (patent pending) uses multi-compartment heating and cooling zones to affect the necessary thermal transfer. [27]

(i) Advantages of on-site over off-site

Although on-site recovery requires a large capital outlay, it does offer some distinct advantages over shipping spent solvent to an off-site recycler. The following is a list of those advantages:

* less waste leaving a firm
* less solvent waste stored on-site
* control of production
* return of a purer product
* higher recovery yield
* reduced liability
* reduced cost of transportation and disposal
* reduced reporting
* possible lower unit cost of reclaimed solvent

If an off-site recycler makes a mistake or uses unlawful practices, the generator remains liable for any damages that occur.

(ii) Limitations

The principal limitations associated with in-house recycling are linked with good operating conditions. If the solvent bath is allowed to go acidic (by contamination such as water), it will not only destroy the degreaser, but it will also destroy the recycling unit. It must therefore either be treated to neutralize it or it must be disposed of. Another difficulty found with recycling has been the shift in solvent use to 1,1,1-Trichloroethane. Because 1,1,1-Trichloroethane is more sensitive to hydrolysis, it can be more costly to recycle, often times requiring a water removal step. Removal of excessive moisture or trace water requires either filtering through an absorbing or adsorbing dessicant (usually anhydrous calcium chloride used for the drying - which causes disposal problems), ion-exchange resin, or molecular sieve bed.

Since most small distillation units are single-stage batch units, separation is limited to separation of the volatiles from the non-volatiles. If there are volatile contaminants, however, they will aggregate in the recovered solvent, resulting in a lack of quality. The recovered solvent must be monitored and sometimes restabilized because some of the stabilizers have distinctly different boiling points and thus will not separate with the solvent. (According to the vendors, most stabilizers used today will distill with the solvent.)

Another possible difficulty with distillation units is the fouling of the internal components or the heat transfer area. Fouling is caused by thermal degradation or polymerization of compounds present in the bottoms. [4] Most distillation units are equipped with scrapper blades[11] to minimize fouling and keep the contaminants in suspension to allow for better heating. Other units utilize liners to prevent fouling and facilitate the easy clean-up of the bottom stills.

(c) **Environmental Benefits**

(i) Reduces storage of hazardous materials on-site

Since on-site recycling facilitates the recovery of spent solvent as it is generated or allows for the accumulation of just enough solvent to distill a batch of solvent, it greatly reduces the amount of wastes stored on site. Since there are economies of scale with off-site recycling (it is just as expensive to transport half a truck as a full one), a generator must often store spent solvent on-site until enough has accumulated to make off-site recycling economical. Storage of wastes presents a potential liability for the generator and is also regulated by the EPA (90 days for a LQG and 180 days for a SQG).

(d) **Economic Benefits**

(i) Saves on Raw Material

The recovery of spent solvents can greatly reduce the quantity of virgin materials required. Since cold cleaning baths lose their effectiveness with 10% contamination and vapor degreasing units with 25-30% contamination, virgin

[11] Scrapper blades remove solidified contaminants from the sides of the distillation units.

material requirements would be extensive if there were no reclamation. Furthermore, the degreasing process does not harm the solvent (unless through bad operating practices or excessive cooking); it merely uses the adsorbing and solubility properties of the solvents.

(ii) Reduces hazardous waste disposal costs

Since recycling reduces the volume of waste from solvent and contaminants to the still bottoms generated through distillation, it greatly reduces the disposal costs. Depending on the abilities of the distillation unit and the degree of contamination of the solvent, disposal costs can be reduced by 80 to 95%.

(iii) Lessens Liability

With the reduction in wastes disposed of (through either incineration or treated and land-disposed), the level of liability decreases significantly.

(iv) Permitting Requirements

If a firm recycles on-site, EPA considers it a part of the process and it thus qualifies as fulfilling the minimization declaration of RCRA. Likewise, there is no federal EPA permit required (Federal Regulation 40, Part 261.6).

(v) Saves on labor costs

For distillation units continously connected to vapor degreasers, the labor costs associated with cleaning the vapor degreasing units can be reduced and a more continuous process can be achieved. Since the solvent is continously cleaned and the contaminants are not allowed to build-up, the vapor degreasing unit requires less frequent cleaning. Periodic cleaning of both the distillation unit and the vapor degreaser will still be required, however.

(e) **Economic Costs**

The economic costs of distillation equipment depends on the amount of spent solvent to be processed, the type of solvent, and the type and quantity of wastes. For a small, 5 gallon distillation unit, the capital cost will be approximately $3,000. The larger distillation unit can cost well over $100,000. The more typical size, 55 gal/shift unit, costs approximately $20,000, while the slightly larger unit, 110 gal/shift, costs $27,000. For a small unit, a vacuum attachment costs between $2,000 and $5,000. Fractionation units are typically custom made, costing $30,000 and up for a small unit. Thin-film evaporator can cost from $18,000 for a thoroughput of 50 lbs/hr to well over $500,000.

Operational costs similarly vary, but generally range between .35 - .50 $/gal, which includes labor, electricity, water, and drum liner. It typically requires 30 minutes to 1 hour of labor time. The usual payback period for a small distillation unit ranges from 6 to 24 months.

For a comparison, to purchase and then landfill tricholorethylene or 1,1,1-trichloroethane costs 6-7 $/gal and 15-16 $/gal for freon. [26] According to a study by Seymour Schwartz, the rate of return for small electronic firms for distillation equipment was 81%. For larger firms, the rate of return was 723.9%. [15] It typically costs 1.00 $/gal to incinerate still bottoms of chlorinated solvents. [28] Solidifying and landfilling still bottoms cost between 75 and 105 $/55 gal drum.

Cost of Virgin Solvents

	$/55 gal drum	in bulk
Freon*	13.00	12.50
1,1,1-Trichloroethane	5.02	3.71
Trichloroethylene	4.90	3.45
Perchloroethylene	4.71	3.10
Methylene Chloride	3.83	2.51

note: 1988 dollars, not delivered
less than 45,000 lbs ordered, must arrange for own transportation
Source: Vulcan Chemicals
* Source: [4]

(f) **Barriers**[12]

(i) Resistance to change

There is a prevailing attitude in industry that "if it ain't broken, don't fix it." Many people in industry feel their current system works well and any change would be disruptive and costly. Many managers and workers also fear that if they suggest a change and it does not work, their jobs will be in jeopardy.

[12] The following barriers were mentioned in telephone conversations with these vendors: Jerry Marchand, Finish Eng., July 25, 1988; Elizabeth Miller, Recyclene Products, Inc., July 25, 1988; Richard Jordan, Baron Blackeslee, July 26, 1988; Luwa Corp., Aug 9, 1988; and Seymour Schwartz.

(ii) Product oriented

Managers are typically product oriented and thus reluctant to justify any economic resources for equipment that does not improve the quality of the product. Since a recycling unit in no way improves the end-product, it is difficult to persuade managers to make the investment unless there is a very short payback period.

(iii) Economics for small quantity generators

Most SQG's will not find onsite recovery feasible; small firms are very sensitive to costs, unwilling to spend even 50 $/month for legal disposal. They also tend to have slim profit margins, making it difficult to finance an initial investment.

(iv) Perception of lack of quality in recycled solvent

Some in the market perceive that recycled solvent is not as good as virgin solvent. Since the degreasing process does not alter the solvent, proper care of both the bath and the recycling unit will result in a recycled product as pure and useful as raw material. Even some possible differences, such as purity, color, or odor, seldom affect performance.

(v) Location of equipment

Because the solvent vapors are considered explosive as they are heated, the placement of the equipment must conform to NFPA regulations and standards. This constraint makes it difficult to find floor space for already existing plants.

(vi) Disposal costs

With the land-ban of solid wastes, it can be less expensive to dispose of the liquid spent solvent wastes than the solid residue still bottoms.

(vii) Lack of knowledge of the law

Some firms, reluctant to be involved in any type of regulation or permitting process, are unaware of the environmental regulations of recycling and its designation as part of the processing line.

(g) **Case Example**

Example #1 [24]

Elizabeth Carbide Die Co. Inc. (McKeesport, PA) was shipping 300 gallons of contaminated 1,1,1-trichloroethane off-site every few months. After processing, the company would buy back about 250 gallons of reclaimed solvent at .80 $/gal and purchase 50 gallons of fresh 1,1,1-trichloroethane at 4.50 $/gal. The company purchased a Model LS-Jr reclaimer from Finish Co. Inc (Erie, PA) that reclaims 3 to 5 gallons of solvent per shift. The cost of reclaiming solvents is said to be between .04 and .10 $/batch. Residue generated from the reclaimer is shipped off-site for disposal at an approved landfill with 1/2 gallon of residue being generated for every 5 gallons of spent solvent. Because of the reclamation, the company also saves on disposal which according to Gene Uziel, Plant Superintendant, can be up to $500 for a 30 gallon drum.

Example #2 [32]

Type of change: Recycling of Methylene Chloride Company: Union Carbide Corporation of Shelby, NC Activity: Union Carbide has a closed-loop system for recycling methylene chloride. The solvent never leaves the wash system, and the only waste which is disposed of is the still bottoms resulting from the recycling process. This system has resulted in a 75% decrease in raw materials purchased. Motivation: Minimize liability under RCRA. Payback Period: six months.

OFF-SITE RECYCLING

(a) **Introduction**

Off-site recycling is used by both small and large quantity generators of spent solvents. It offers convenience in that it enables a firm to avoid the technical, economic, and managerial demands of on-site recovery. It does, however, lessen the control a generator has, potentially increasing the liability. The transportation cost and liability of transferring wastes also pose large costs.

Because of the increases in regulation and liability and the lack of insurance available for commercial recyclers, many of the smaller commercial recyclers are leaving the market. The current number of commercial recyclers is also declining because many of the larger firms are purchasing the smaller firms. In fact, five years ago, there were 150 commercial recyclers, but today there are fewer than 100 (with an additional reduction to below 50 expected by 1992). Since no recycler is currently operating above 60% of its potential capacity, there should be enough firms to handle an increase in the use of off-site recycling. [4]

(b) **Technology**

Like on-site recyclers, off-site recyclers use distillation as the primary means of recovering spent solvents. A commercial recycler will typically have either a fractional distillation column and/or a thin-film evaporator. The fractional unit enables greater purity, whereas the thin-film evaporator allows for large, continuous volume recovery. The thin-film unit can also recover greater amounts of solvent because it is able to process very viscous substances (as long as they are pumpable).

There are two different types of off-site recycling: batch toll processing and open-market recycling. For batch toll processing, a commercial recycler will pick up a firm's spent solvent, transport it to its facilities, distill the solvent isolated from any other firm's waste, and return the waste to the original generator. The commercial recycler generally charges 75 to 90% of the price of virgin solvent for the recovered solvent. Although these savings are not dramatic, when the disposal costs that would have occurred without the recycling step are taken into consideration, the recycling option becomes extremely attractive.

Open-market recycling consists of recycling a firm's spent solvent with many other firm's similar wastes. For such a process, the original generator may or may not purchase the recovered solvent, but rather uses the recycler as a way of disposal. Depending on the price of the virgin solvent and the costs of disposal of the still bottoms, a commercial recycler will either purchase the spent solvents from the generator or charge them for the process. The recycler will then sell the recovered solvent to either the generator or another firm. A generator of spent solvent would not recover its own wastes on-site with the purpose of selling the recovered wastes to another firm (downgrading) because that generator would then qualify as a transport, storage, and disposal (TSD) firm, requiring many different and expensive permits.

There are numerous commercial recyclers on the market today. Some only receive bulk (and large) loads of spent solvent. Others, such as Safety Kleen, Inc., offer service to the smaller (drum) generators. In fact, Safety Kleen leases the process equipment and solvents as one system, picks-up the dirty solvent on a regular basis, distills the spent solvent, and resells the recovered product at a cost of 90% of the virgin solvent price.

(i) Advantages of off-site over on-site

Off-site recycling offers many conveniences to a generator. It does not require an initial capital outlay and does not require operational costs and maintenance. In fact, one of the difficulties associated with on-site recycling is that it is labor intensive. Many of the small distillation units require personnel to fill the top of the distillation unit manually with spent solvent. This not only creates a potential health hazard, but increases the possibility of spilling the wastes. Additionally, it takes 15 to 30 minutes per batch for workers to fill the distillation unit. When the distillation is complete, the generator is still left with a disposal problem. Although the volume is much less, they still must dispose of the still bottoms.

Since most of the solvent vapors are considered explosive, the distillation process presents a potential workers' health liability. Most units sold, however, are explosion proof. Because of the possibility of an explosion, the unit must be placed in a controlled space, creating installation and space problems.

(c) **Environmental Benefits**

(i) Potentially reduces the amount of illegal dumping

For those firms unable or unwilling to spend the capital for on-site recycling, off-site recycling offers a viable alternative.

(ii) Reduces the market for halogenated solvents

The amount of solvent recovered will correspondingly reduce the market for new solvent.

(d) **Economic Benefits**

(i) Reduces disposal fees

With the elimination of landfilling (without treatment) and the limit to the concentration of chlorinated solvents allowed for incineration, recycling is a must. It is less expensive to reduce the volume of waste through recycling first, before incinerating or landfilling the remaining sludge, than it is to just incinerate or landfill.

(ii) Reduces quantity of virgin solvent

If the generator buys back recovered solvent from his process, he will greatly reduce the quantity of virgin solvent needed.

(e) **Economic Costs**

For off-site recycling, the fees depend on the difficulty of separation and the market supply and demand conditions. Toll recyclers typically charge between 75 and 100% of the new solvent cost. Open-market prices can range from free disposal to $50 per 55 gal drum. The price of either method depends upon the following:

* processing cost
* disposal cost of still bottoms
* transportation costs
* degree of contamination
* type of impurities
* quantity of waste (economies of scale)

(f) **Barriers**[13]

(i) Liability of transportation

One of the most dangerous activities known to mankind is driving. Combining that fact with the transportation of hazardous chemicals makes the liability and the insurance for transportation potentially astronomical. There are firms who do transport hazardous waste, but this does not relieve the generator's liability.

(ii) Economies of scale

For small quantity generators, it can be difficult to find a firm willing to accept only a few drums a month or less. For transportation costs, it costs the same to transport half a load as a full one. In fact, the more drums (or bulk amount) shipped, the lower the unit processing price.

[13] The following barriers were mentioned in telephone conversations with the this vendor: Jim Breece, Safety-Kleen Corp., Aug. 9, 1988.

(g) **Case Example** [17]

Company: Hamilton Beach Division - Scovill, Inc.
Location: City of Clinton, North Carolina
Product: Home appliances (SIC 3634)

Description: Scovill reduced the quantity of waste generated and the amount of raw materials it purchases. The quantity of 1,1,1 trichloroethane used for degreasing was reduced by substituting a water soluble synthetic cleaner for the solvent in many of the degreasing operations. For the 1,1,1 trichlororethane that is still used at the plant, the spent solvent is recovered off-site for reuse at the facility. To further reduce operating costs and waste generation, Scovill has instituted an employee-incentive cost saving program. Teams of employees are formed to make recommendations and the team responsible for the greatest annual cost savings receives a bonus check.

Savings: The use of water soluble synthetic cleaner resulted in an annual cost savings of $12,000 in reduced raw material costs. Recycling and reuse of 1,1,1 trichlororethane reduced raw material costs by 34% and provided an annual savings of over $5,000. Additionally, waste disposal costs have been reduced over $3,000 per year.

(3) Emission Control: Activated Carbon Adsorption and Refrigerated Freeboard Chillers

ACTIVATED CARBON ADSORPTION

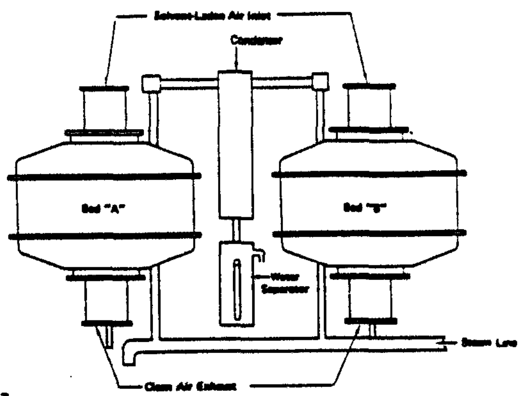
(a) **Introduction**

Carbon adsorption, like distillation, is a very established technology. Its use varies from the recovery of fugitive vapors in the air to the recovery of trace solvents found in water. It is commonly used to concentrate small quantities of solvent from dilute, large volume media.

(b) **Technology**

Carbon adsorption is based on the selective adsorption of solvent to activated carbon. It is used for the removal of solvents from aqueous streams as well as air streams when a very low concentration in the effluent is desired (or required). Activated carbon has a large internal surface area for adsorption, is relatively inexpensive, and has low polarity (which gives it a low selectivity to water vapors) making it extremely applicable to solvent recovery. The ability to regenerate the adsorbed solvent through the use of heat (steam, hot nitrogen, hot air, vacuum) enables the solvent to be recovered and recycled. A state-of-the-art carbon adsorption system has a multi-bed design in which one bed adsorbs solvent from a waste stream while the other bed is being regenerated. Figure IV-10 illustrates an activated carbon adsorption system.

Figure IV-10: Activated Carbon Adsorption System



Source: [1]

Steam regeneration is the most common technique used to regenerate the adsorbed solvents, but this method causes great difficulties with water-susceptible solvents. In fact, it typically requires 7 gallons of steam condensate to recover 1 gallon of solvent. Hot nitrogen can be used with a fluidized bed carbon adsorption system for easy recovery of water soluble solvents. A very established technology in Japan, there are only twelve such systems currently used in the United States. A vacuum system can be used to reduce the temperatures needed to regenerate the solvent. This facilitates less solvent breakdown from heating, but increases the length of the desorption period and slows the heat transfer (currently only used with isobutane). [1], [29]

(i) Applications

Most of the carbon adsorption systems are used for the large degreasing units. In fact, in some states a system, such as carbon adsorption or refrigerated freeboard chillers, is mandated by law for the larger units.

(ii) Limitations

Because of 1,1,1 Trichloroethane's susceptablity to hydrolysis, additional, expensive processing (usually requiring drying or azeotropic distillation and restabilization) is required to regenerate it. With the more frequent shift from trichloroethylene to 1,1,1-trichloroethane, the market for carbon adsorption systems with degreasers has been reduced. Methylene chloride also poses problems because of its 2% water solubility. The water can also cause serious corrosion problems in the degreasing unit (requiring expensive metal coatings to prevent damage). Likewise, the stabilizers are usually stripped from the solvent during the adsorption process. If the solvent is recovered for reuse, it must be restabilized. The stabilizers can themselves be extremely toxic, causing more health risks if they must be stored on-site and added to the bath.

When highly concentrated waste streams are fed through the carbon adsorption system, the carbon quickly becomes exhausted, necessitating either large beds or constant regeneration. The air can also require a filtration system to remove gross impurities.

(c) **Environmental Benefits**

(i) Reduction in Emissions to the ambient air

A carbon adsorption system can capture in excess of 95% of the vapors emitted from a degreasing unit. The effluent released to the atmosphere from the carbon adsorption system can contain as little as 1 to 2 ppm solvent.

(ii) Reduction in air exposure for workers

The carbon adsorption system is designed to capture 95% of the air above the freeboard of a degreasing unit. It is thus capturing the fugitive vapors from the degreasing unit, dramatically reducing worker exposure.

(d) **Economic Benefits**

(i) Saves on raw material

If the solvent recovered from the carbon adsorption system is reused, the amount of virgin solvent needed can be reduced by 40 to 50% (Hoyt Corporation estimates 85 to 90%).

(e) **Economic Costs**

According to the Electroplating Engineering Handbook, carbon adsorption has the highest capital and utility costs and demands more maintenance than any of the other recovery technologies. [1] It is most economical for large degreasing systems operating on a multi-shift basis. According to vendors, expected payback periods range from 1 to 2 years. The system utilizes low pressure steam, water, and electricity. Small units can cost about $15,000, but most practical units cost $100,000.

Based on the throughput of vapors through the carbon adsorption unit, typical capital costs for a conventional steam-regenerated system are $15-20/ft^3 min. For VOC concentrations in the inlet of less than about 300 ppm, a "thin bed" can be used that lowers the capital costs to about 10$/ft^3/min. The cost of VOC recovery increases very rapidly as the VOC mass flow rate decreases to below 100 lb of VOC/hr. [29]

Operating costs typically include steam, electricity, and condenser water. Steam usage is reported to be about 6 lb steam (@15 psig)/lb of VOC. Electricity usage will be about 2.9 to 4.5 kW/1,000 ft^3/min and condenser water is about 12 gal/min 100 lb steam. Carbon replacement typically costs about $7 per lb VOC per hour per year.

(f) **Barriers**[14]

(i) Cost

The capital outlay required for the carbon adsorption system can be prohibitive. The operational costs can also present barriers. In practice, only the larger firms have been able to purchase the unit and even they resist the purchase.

(ii) Product oriented

Firms do not like to spend money on equipment that is not necessary or does not improve the product. There is also resistance from production management concerned about output (i.e., if the equipment has problems or just for initial installation, there will be down time).

REFRIGERATED FREEBOARD CHILLERS

(a) **Introduction**

In some states, including New Jersey, the use of refrigerated freeboard chillers or a similar technology is mandated by law for the larger degreasing units.

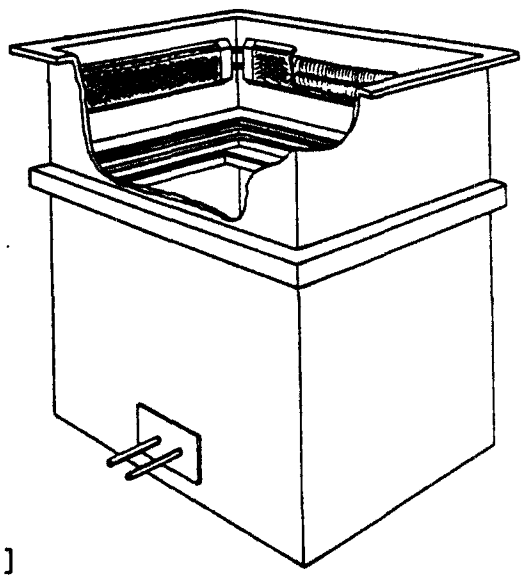
(b) **Technology**

The refrigerated freeboard chiller is an extension of the technology currently used for vapor degreasers. All vapor degreasing units must have cooling coils above the vapor air zone of the vapor degreaser. The refrigerated freeboard chiller consists of similar cooling coils placed above the freeboard. These refrigerated coils are typically kept at a lower temperature, around - 20 ^oF, than the standard water-cooled cooling coils (see figure IV-11 for an illustration of refrigerated freeboard chillers). Their purpose is to

[14] The following barriers were mentioned in telephone conversations with the following vendor: Derek Oakes, Hoyt Corp., July 25, 1988.

create a secondary barrier of chilled air to further prevent the loss of solvent vapors. The chilled, dense air creates a blanket above the vapor zone and also decreases the diffusion rate of the solvent.

Figure IV-11: Refrigerated Freeboard Chiller



Source: [1]

(i) Limitations

Because of the humidity in the air, water will condense on the coils, necessitating a collection trough. Although a separate trough should be used for the refrigerated coils and the cooling coils, many firms will try to save money by using only one. This can result in excessive build-up of water in the bath. If the freeboard chillers are kept below the freezing point of water, frost will accumulate, requiring a periodic defrost cycle.

The use of freeboard chillers requires good operating practices. If the air is allowed to become turbulant, through either a fan, an open door close to the unit, or a window, the degreasing unit will become unstable. Since the solvent is heated from the bottom, the vapors want to rise. The freeboard chillers create cold air that wants to move downward. If this mixture of hot and cold is excessively disturbed, there will a disruption in the bath, resulting in fugitive vapors actually being pushed out of the unit. Also, if baskets are moved quickly in and out of the unit, the vapor zone will again become unstable.

(c) **Environmental Benefits**

(i) Reduction in emissions

Refrigerated freeboard chillers can reduce emissions of fugitive solvent vapors by 40 to 60%.

(d) **Economic Benefits**

(i) Reduction of use of virgin solvent

With a reduction in the loss of fugitive vapors, less virgin solvent will have to be purchased.

(e) **Economic Costs**

Compared to the carbon adsorption system, refrigerated freeboard chillers are relatively inexpensive. In fact, costs can range from $2,000 to $3,000. Operating costs depend on how cold the chillers are kept.

(4) Good Operating Techniques

(a) **Introduction**

Good operating practices are essential in any type of operation. Large amounts of solvent are lost as fugitive vapors because of improper conditions such as fans placed near a vapor degreaser in order to provide workers more comfort (these fans disturb the solvent vapor space, actually drawing the fumes out of the tank). Dramatic reductions in the amount of raw material needed, on the order of 25 to 60%, can be accomplished through simple housekeeping.

(b) **Technology**

Good operating techniques consist of anything from placing covers on open tanks when not in use to reducing the amount of solvent "drag-out"[15]. Similarly, a significant amount of solvent is lost because of the quick lowering of a part in a vapor zone, resulting in a piston effect that pushes the solvent vapor out of the tank. A stop and go technique in which a part is slowly lowered until the vapor zone drops approximately 2 to 4 inches and stopped, allowing the vapor zone to reestablish, and then lowered again can greatly reduce fugitive vapors. [30]

[15] When a part is withdrawn from a tank or vapor zone quickly, it carries solvent, termed "dragout," with it that then evaporates into the air.

Likewise, good bookkeeping and monitoring can make a firm cognizant of the losses and thus motivate the firm to reduce them. Multi-stage countercurrent cleaning can also greatly reduce solvent use. If tanks are used progressively in a row of three such that the first tank is allowed to get relatively dirty and the last tank is fairly fresh and each tank is refurbished from the tank after it, solvent life can increase greatly. Instead of having to replace an entire tank of solvent, only some of the solvent would be replaced and at a much higher level of contamination. Similarly, if a centrifugation unit is used initially to remove the bulk surface contaminants on parts, one could greatly reduces the amount of hazardous waste solvent generated by limiting the amount of contaminants actually entering the degreasing unit. See Appendix IV-2 for a full list of good operating procedures.

(ii) Limitations

There is no limit to good operating procedures. Although those who currently have very bad practices will see the most improvement, every firm will see an improvement in solvent losses from proper technique.

(c) **Environmental Benefits**

(i) Reduction in fugitive vapors

(d) **Economic Benefits**

(i) Save on raw material

(e) **Economic Costs**

The costs of good housekeeping range from nominal to the cost of covers for open tanks. There can be labor costs required to implement good, safe procedures, but in many cases, the workers can become better organized and more efficient. Training and managerial supervision might be necessary, but if the employees become more cognizant of the dangers they are working with, there can be a corresponding decrease in the risk of injury.

(f) **Barriers**

(i) Management

The implementation of good housekeeping techniques requires high level management support to be sucessful. In this case, ignorance is neither an excuse nor a justification for any injury or lack of compliance.

(g) **Case Example** [32]

Company: Westinghouse Electric Corporation, Control Div. of Asheville, NC

Activity: In the past, Westinghouse Electric practiced a two-stage cleaning process to prepare manufactured parts for plating. The first stage consisted of a hot water/caustic wash, and the second stage was vapor degreasing the part with 1,1,1-trichloroethane. After reevaluating the process, the firm realized that the caustic wash alone sufficiently removed grease and dirt from the parts prior to plating. The 1,1,1-trichloroethane step was totally eliminated.

Motivation: Wanted to eliminate the 1,1,1-trichloroethane waste stream.

Sold to Management:
- No investment necessary to change to the caustic wash, since the system was already in place.
- Eliminated 1,1,1-trichloroethane waste stream

Payback Period: immediately

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Appendix IV-1: **Current equipment intensive regulations in New Jersey**

Unheated Open Tank

i. with open area more than 6 ft^2 but less than 25 ft^2, freeboard ratio of 0.5 or greater.
ii. with open area more than 25 ft^2, freeboard ratio of 0.75 or greater.

Heated Open Tank (below boiling point)

i. freeboard ratio of 0.75 or greater or 0.5 and separated from other activities.
ii. is free from the influence of any local exhaust ventilation system unless such ventilation system collects at least 80% by volume of the vapors and reduces content by at least 85%.
iii. is operated with a condenser having heat removal capacity equal to or greater than the heat input.
iv. is equipped with a device which automatically shuts off heat input if temperature above the condenser exceeds limits specified.
v. is equipped with a freeboard chiller or other apparatus approved by the Department as being equally effective.

Unheated and Heated and Vapor Conveyorized System

i. is equipped with a vapor control system which reduces the total emissions of VOS by at least 85% by volume.

Appendix IV-2 : **Good Operating Practice for Degreasing Applications**

COLD CLEANING

1. Use covers.
2. Use a water layer on top of the solvent where acceptable.
3. Control ventilation.
4. Use a coarse spray or solid stream of solvent instead of a fine spray.
5. Use a deep tank with a high freeboard.
6. Use specially designed containers with automatic lids and drains.
7. Drain parts properly to capture as much of the solvent as possible.
8. Don't use compressed air sprays to blow dry parts or to mix cleaning baths.
9. Capture and distill any wastes.
10. Dispose of sludges at the proper time to avoid stressing the solvent.

VAPOR DEGREASING

1. Leave the unit on to maintain the vapor level unless it won't be in use for long periods of time.
2. Don't expose heating coils to vapor.
3. Use the least amount of heat required to keep the solvent at a slow boil and to give adequate vapor production.
4. Regulate the cooling level.
5. Reduce exhaust velocities to provide adequate protection of workers, yet not draw vapors out of the degreaser.
6. Cover open-top degreasers.
7. Extend the freeboard. Units with freeboard heights that are 40% of the width of the degreaser can use up to 40% more solvent than units with ratios of 75-100%.
8. Use cold traps.
9. Avoid adding water, dewater the solvent, and install a separate water trough for refrigerated coils.
10. Ensure parts are up to temperature before removal, move the work slowly, don't overload the degreaser, use properly sized baskets and drain the parts.
11. Avoid using solvent carriers and solvent-absorbent materials.
12. Ensure proper solvent composition.

13. Improve efficiency by installing automatic slide covers, increasing freeboard, installing refrigerated freeboard chillers, using carbon adsorption lip exhaust, attaching air refrigeration on the vent recycle, and installing programmable transporters.
14. Lower the temperature of the heating medium and increase the fluid viscosity.
15. Maintain cooling water quality.
16. Use floating roof tanks or inert gas blanketing.

Since the degreasing process is also used to clean batch reactors and pieces of equipment, judicious decisions about when and how to clean can reduce solvent usage.

CLEANING EQUIPMENT

1. Maximizing dedication of process equipment to a single process function.
2. Proper production scheduling.
3. Avoidance of unnecessary cleaning.
4. Mechanical cleaning and onstream cleaning rather than chemical cleaning.
5. Clean in place system (CIP).

Appendix IV-3 : **Questions asked Vendors, Associations and Consultants**

I. Technology:

(1) Technical: Substitution

=> Equipment size:
=> Is the system used with both vapor and cold degreasing? or some other type of technology?
=> What types of metals can be cleaned by your system?
=> What kind of metals cannot be cleaned?
=> What is the degree of cleanliness that your technology can achieve?

(2) Technical: Recovery Equipment

=> What solvents can be used with your system?
=> What is the maximum concentration possible in the inlet of contaminants?
=> What types of contaminants can have an effect on the efficiency of your unit?
=> Do you sell a vacuum option and how much does it lower a firm's utility requirements?
=> What is the purity of the condensate? percentage (max. conc. achieved in the outlet stream):

(3) Market

=> Total number of companies who are using the technology in the US. (approx.)?
=> market share of the technology?
(How long has your company been marketing the product?)
(market potential)
=> Characteristics of companies which use the technology?
does the use of the technology require additional skill or staff?
size of typical user:
=> what are the barriers to further market extention?
=> what, in general, should/could be done to increase the application of the technology?
=> what role should the agency play in promoting the use of your technology? (permitting, effluent standards, monitoring, enforcement, subsidizing investment (grants, loans), TAP, regulatory and non-regulatory agencies)
=> what are important elements of a TAP that would foster the use of your technology?
=> What areas of your technology require further research?
=> costs of the technology?
investment cost with installation:
operating costs:
maintenance and repair:
utilities:

=> total annual savings in cases where your technology has been implemented?
raw materials:
disposal costs:
wastewater treatment costs:
payback:

=> What were the main costs savings factors users observed?
maintenance:
operation costs:
disposal costs:
wastewater treatment costs:

=> Would you be willing to meet with the agency, others in the industry, and other suppliers to discuss better ways to develop the technical assistance program?

Appendix IV-4 : Benefits of Waste Reduction Technologies

Technique	Reduction in Solvent Loss	Profitability
Tank Covers	25 to 59%	Generally Profitable
Increased freeboard height	25 to 55%	Generally Profitable
Refrigerated Chillers	40 to 60%	Generally Profitable
Distillation Units	80 to 95%	Profitable above 350 gal solvent/year

Source: [31]

WRT\BENEFIT	Air Pollution	Waste Reduction Volume	Waste Reduction Toxicity	Occupational Hazards	Raw Material
Substitution	X	X	X	X	
Recycling	X	X			X
Housekeeping	X	X		X	X
Emission Control	X			X	

V. AN EXPERIMENTAL PROGRAM TO ENCOURAGE THE ADOPTION OF BETTER WASTE REDUCTION TECHNOLOGIES IN THE ELECTROPLATING INDUSTRY AND DEGREASING PROCESS

A. An Experimental Incentives Program for the Electroplating Industry in New Jersey

Introduction

The analysis of the electroplating industry in New Jersey was conducted in order to facilitate the development of an incentives program which promotes the implementation of waste reduction technologies.

The goal of the research is to suggest a demonstration project to achieve the following:

(1) reduction of environmental and health hazards of current industrial practice

(2) reduction of technical risk of implementing waste reduction technologies

(3) fostering of the private sector (suppliers and consultants) to compete in providing waste reduction technologies and managerial expertise and assistance

The suggested incentives aim to provide a comprehensive approach to stimulate investment in waste reduction technologies. The proposed incentive system is composed of the following elements:

(1) technical assistance[1]
(2) economic (financial) incentives
(3) regulatory requirements

Note that these elements may well overlap. For example, technical assistance, even if not subsidized, may provide economic benefits by lowering technical risks (which impose costs on the firm) and by reducing the risk of regulatory non-compliance (e.g., through fail-soft strategies). In addition, not all elements may be required during a specific phase of the incentives program. For example, it appears that some waste reduction technologies inure to the benefit of many (and perhaps all) electroplaters who adopt them. For these firms, economic incentives may not be needed, or may be relegated to a secondary role, at least during the demonstration phase. Finally, as suggested above, different

[1] Another potential element of the incentive system would be R&D assistance, in those cases in which R&D bottlenecks have been identified (and in which the important barrier is not diffusion of existing technology).

incentives may be deployed in different phases of the incentives program.

The set of incentives must have the proper balance of "carrots" and "sticks" to be effective. However, in terms of agency or private resources, there should be minimum concern with traditional measures of "programmatic efficiency" in the short run. The purpose of the demonstration project is to learn which incentives work and which don't, under which circumstances, and for what reasons. Therefore, the success of the demonstration program can be measured primarily by what is learned from it. The construction of a comprehensive, efficient program would be premature at this stage (but would be appropriate following the demonstration project).

A Technical Assistance Program

Because of the existence of waste reduction technologies which are currently profitable in the electroplating industry,[2] we tentatively propose to place the focus of a demonstration project on technical assistance. The structure of the proposed technical assistance program is outlined in the following discussion:

First step :	develop a profile of the electroplating industry in New Jersey in order to assess the need for technical assistance

Answer the following questions:

* What plating baths are electroplaters using? (and what are their other process characteristics?)

* Who are the suppliers to the industry?

* Which consultants do the electroplaters refer to?

* Where do the electroplaters sell their products?

* To what technical information/assistance do the electroplaters have access?

The agency, as part of the profile, should attempt to uncover any related source reduction technology for which R&D is not needed, but for which marketing is needed.

In addition, the agency needs to provide a screening for the safety of new chemicals introduced to promote source

[2] See the Second/Third Quarterly Report for a discussion of the technological and economic basis for identifying appropriate waste reduction opportunities.

reduction. This particular agency function is perpetual (unless subsumed by some other state or federal agency); all other elements of source reduction may ultimately (or currently) be taken care of by the market.

If this profile indicates that technical assistance is needed (and the market is not supplying it), then proceed to the next step. Note that the suppliers and consultants may be either a good or a poor source of information to the firms (e.g., Monsanto and PCB's or end-of-pipeline engineering consultants). Indeed, a major reason for the state to provide technical assistance is that firms are being advised by the "wrong" suppliers and consultants.

Based on the expertise of inspectors from the New Jersey DEP, it appears that the electroplating industry in New Jersey would benefit from technical assistance, particularly concerning non-sophisticated waste reduction practices. Even though 90% of the companies under the electroplating SIC code are currently in compliance with wastewater discharge requirements, waste reduction practices could reduce the costs of wastewater treatment for the industry and result in more efficient production.

<u>Second step</u> : design a workshop on the topic of waste reduction to assist consultants, suppliers, and electroplaters

The workshop should be easy for New Jersey participants to attend (in terms of fees, location, and time). The participants would include electroplaters, consultants, suppliers, and related DEP personnel. A thorough demand analysis should be conducted in advance to make sure that the needs of the audience for particular information are included in the workshop. This could be done in the form of a telephone questionnaire to find out what consultants and electroplaters would like to know in order to be more responsive to the possible implementation of waste reduction technologies. (However, in many cases the respondents themselves may not know the answers or may not believe it to be in their interest to tell you.) Also asking suppliers about the most frequent problems they face with their customers in distributing their products could be helpful in gaining a better understanding of the needs for education and information.

The workshop should address the various waste reduction options available and explain the advantages and consequences of an optimal plant design, taking into account the simultaneous implementation of the appropriate technologies.

It would enhance the effectiveness and popularity of the workshop (in the sense of the workshop being accepted) if it were organized with the regional branch of the American Electroplaters and Surface Finishers Society (AESF) or other relevant professional associations. This would present a good opportunity to cooperate with the respective associations to promote the application of waste reduction technologies.

The workshop should have two functions. On the one hand, it should focus on detailed technological descriptions of emerging but commercially available waste reduction technologies. Here, well-analysed case studies of companies which have already applied specific waste reduction technologies should be presented to the audience. The limitations of the technological options and their variability from firm to firm, as well as the advantages, should be discussed.

The second focus of the workshop should be to provide a detailed economic analysis of the benefits as well as the costs related to the implementation of a specific waste reduction technologies. Discussion of the economic effects should assist electroplaters in conducting a comprehensive economic analysis of their plant (thereby eliminating mistakes caused by limited cost evaluation). The workshop should avoid general statements of the costs and benefits of waste reduction technologies. It should rather provide very specific technological and economic information. Finally, the electroplaters, as well as the consultants, should utilize a multi-media approach in evaluating technological options.

Several booklets need to be developed for the workshop and also for distribution among electroplaters that present detailed technical and economic cost-benefit information for the individual waste reduction technologies.

<u>Third step</u> : conduct individual surveys at selected, manifested electroplating firms

Under the technical assistance program, interested individual firms should apply for a comprehensive environmental and engineering survey. Firms will be selected from among applicants for survey by the agency on the basis of their technical, economic, and managerial characteristics (and history) which suggest that such a survey might lead the firm to adopt source reduction technology. The agency will also attempt to select a variety of firms in terms of size, technology, and other characteristics (since firms are generally more responsive to related success stories). Note that these surveys involve substantially more than a compliance assessment conducted by an environmental engineer. Since the purpose of the survey is to suggest waste reduction options appropriate for the firm that may go beyond regulatory requirements, the skills of a process engineer conversant with the industry or a person experienced in industry processes from a source reduction perspective are a necessity.

It is likely that the survey will be conducted for a firm under some regulatory obligation. The agency can use the survey as a occasion to re-permit the firm. Other candidates for a survey would be those firms which would benefit from the reduction of existing compliance costs or those firms which could reduce their wastes sufficiently to be relieved of permitting requirements.

The agency should help to broker the technical assistance of qualified consultants in the area. One way of accomplishing this, while at the same time stimulating firms to apply for the survey, may be to subsidize the cost of the survey during the demonstration phase (i.e., charging the firm only a nominal fee but paying the consultant his usual, or some reasonable percentage of his usual, rate). Note, however, that qualified consultants may be difficult to locate, so that the agency may have to engage in a consultant screening or training process.[3]

The surveys should be of a multi-media character and should focus on technological as well as economic considerations. Multi-media waste reduction survey manuals developed by EPA should be improved upon (because they are currently geared too much to end of the pipe approaches) and then suggested to the electroplaters for usage.

<u>Fourth step</u> : develop and conduct coordinated air and wastewater permitting procedures in the agency

The three steps discussed above primarily represent what are generally called the "carrots" of a waste reduction program. Providing information alone, however, may not be a sufficient incentive to promote the application of waste reduction technology. In some cases, waste reduction may not be economically justified, from the firm's viewpoint, because of low raw material or disposal costs. In these cases, the agency needs to undertake activities that affect the relative costs confronting the company. One option is

[3]It may be possible to use the New Jersey university system to assist in these activities (e.g., use grants from Rutgers to educate professionals who might later serve as consultants).

restructuring the permitting procedures in the agency for the firms selected to participate in the demonstration program.[4] Specifically pertaining to the nature of the electroplating industry, air and wastewater discharge ought to be coordinated in anticipation that multi-media coordination would eventually be conducted across DEP. This program would prevent the transfer of pollutants among the different environmental media. It would require the cooperation of staff from other media divisions in the agency (i.e., air and water).[5]

An important requirement would be that the agency possess a reasonable level of technological expertise. Of course, the agency might well encourage the support of experts in electroplating to develop sound permits. Here, the resource potential at the New Jersey universities, such as Rutgers University or the New Jersey Institute of Technology, should be used to enhance the cooperation between the agency and academic research sectors.

Renewal of permits may provide an opportunity to promote the implementation of waste reduction technologies in companies which are already operating. Certain technological requirements can be developed that would be mandatory (possibly with the use of waivers where necessary) for further operation. In addition, voluntary re-permitting should be encouraged as another option. This differs from the renewal of permits insofar as companies are encouraged to modify their production process with respect to waste reduction, resulting in less toxic or voluminous, or even different waste streams that would reduce their permitting burden. Onsite inspections by agency staff conducted before each permit renewal provide a good opportunity to communicate to the company about re-permitting options and possible waste reduction practices.

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[4] In developing protocols for evaluating multi-media risks (to be applied to cross-media permitting), the agency may wish to adopt whatever protocols have been developed in the state for Superfund sites. (This is what is being done in Massachusetts.)

[5] However, we do not wish to minimize the serious complications involved in cross-media permitting, particularly because of the constraints imposed by associated federal statutes. For example, since federal law establishes air emission permits for the lifetime of the firm, the state may not be allowed to renew (or withdraw) air permits (except for new firms or by creating explicit state statutory provisions).

<u>Fifth step</u>:	coordinated enforcement of multi-media compliance of companies with both air and water pollution problems

The agency should employ staff (or consultants) who are experts in the electroplating industry to conduct multi-media compliance monitoring (this role could possibly be performed by the "field offices"). This requires the development of new and more comprehensive monitoring methods. The current procedures of having monitoring staff from the various divisions of the agency visit the companies at different times needs to be revised to promote more effective environmental management. Again at this stage of the experimental program, the agency would focus its multi-media compliance effort on the firms selected to participate in the demonstration program.

In the case of enforcement, too, waste reduction assessment surveys and technical assistance should be introduced into the system. Companies should be encouraged to conduct assessment surveys to enable and ease compliance with discharge and emission standards. The agency should provide to electroplaters the names of companies which have already implemented specific waste reduction technologies and are willing to demonstrate their operation to other firms. Visits to these companies would help to convince platers of the benefits of waste reduction and create more opportunities for discussion of the problems encountered while implementing specific technologies. By using operational case examples as an active element of technical assistance, the credibility of waste reduction practices will grow. The agency should not encounter liability problems since it is not recommending specific technologies, but merely referring to examples of the successful adoption of waste reduction practices.

An example of a broader inspection that takes into account other environmental media occurs in the Division of Water Resources of the NJDEP. With each permit-related plant visit, the inspectors fill out an "Industrial Pretreatment Inspection Report," in which information about air emissions, waste generation, toxic organics management, and wastewater discharges are collected. In cases where the inspectors detect non-compliance in the other media, they notify the responsible staff in other DEP divisions. This kind of inspection should be expanded, focusing on waste reduction practices and not exclusively on compliance.

<u>Sixth step</u> : enforcement of compliance of companies with only wastewater permits

Electroplaters in New Jersey (and to a certain extent in the United States) are typically smaller firms that are mostly small quantity generators under RCRA. All electroplaters must have wastewater permits but only approximately 30% have air permits. The wastewater discharge permits are either direct or indirect discharge permits with most of the electroplaters being indirect dischargers. In the latter case, more and more companies are being inspected by the POTW into which they are discharging. Increasing numbers of POTWs are authorized by the state DEP to issue permits to the discharging companies. Modifications of the permitting procedure and the management of coordinated permitting have to take this additional decentralization of authority into account. Not only the state environmental agency but also the local POTWs need to be included in the demonstration project.

The electroplaters that have only wastewater discharge permits should be made aware of the fact that reductions in air emissions would be profitable even if those air emissions are under no permit and if no other regulations exist for them. In addition, improved process operation and implementation of other waste reduction practices are able to decrease wastewater treatment costs and overall production costs. These issues should be brought to the attention of electroplaters via technical assistance. Again inspections of the companies should be viewed as an opportunity to communicate the benefits of waste reduction.

The generation of hazardous waste by electroplaters is not required to be permitted and will be difficult to address on the regulatory level with respect to waste reduction. Nonetheless, options should be considered that could be added to the hazardous waste performance standards that EPA has already issued to some extent and will issue under the landban provisions. According to these standards, companies may dispose of their waste in landfills only if the waste complies with certain performance standards pertaining to the leachability of the wastes. As EPA develops these standards on a federal level, New Jersey could add its own, possibly stricter performance standards.

Following steps four, five, and six, the agency should examine the efficacy of implementing detailed options available in the permitting process as well as the enforcement procedures pertaining to the promotion of waste reduction practices.

Seventh step : develop a partnership between the agency and the regulated firms

As part of technical assistance, a program needs to be developed to establish a partnership between the agency and regulated firms. By creating a relationship with industry that involves the continuous enchange of information, both the agency and industry gain. Firms are able to reduce the costs associated with regulatory uncertainty (at least at the state level) and the agency is able to regulate more effectively.

Eighth step : refinement of the approach

The technical assistance program needs to be reevaluated after a certain period of its application. The evaluation of the technical assistance program should be an on-going process. This will be helpful for understanding the need for program modifications and refinements for broader application.

Ninth step : foster coordinated permitting

To promote coordinated permitting, the state may wish to develop a facility "masterfile" which provides a summary of all environmental activity of that facility (including media permits, fines, etc.) and a reference to the other file materials contained in the agency.

The "Industrial Pretreatment Inspection Reports," which are filled out by the inspectors of the Division of Water Resources from the NJDEP, could be an useful starting point to set up a "master file" for companies. These reports gather information about air emissions, wastewater generation and treatment, waste quantities generated and toxic organics management.

A Postscript on Technical Assistance

Technical assistance specifically for waste reduction practices has not yet created a market for many consultants. One reason is that the financial pressure on the electroplaters has not yet been strong enough to stimulate them to invest in waste reduction technologies. This again is likely to be a consequence of low disposal costs and sewer fees, until recently, and relatively low costs of raw materials. In the case of electroplaters, low enforcement is probably not one of the reasons insofar as this industry group has achieved high compliance rates with respect to wastewater discharge limitations (approximately 90% of the companies).

Technical assistance from the non-regulatory divisions of state agencies, provided that experts are working on the staff, can create increased demand for technical assistance by industry. Building on their interaction with many companies and focusing on detailed case studies, the agency can develop valuable technical and economic information from a neutral perspective that can serve to benefit the industry. Examples in other states, for instance in Massachusetts, have demonstrated that technical assistance programs run by non-regulatory agencies (e.g., Department of Environmental Management) can be managed cost-effectively.

As the demand by industry for the agency's technical assistance program is being created, a strategy should be developed that gradually transfers the state-run technical assistance program to the private sector.

A technical assistance program would have primarily two objectives. The first objective would be to reduce the technological risk and regulatory uncertainty confronting the electroplaters. The second objective would focus on augmenting the use of low-tech options for waste reduction, such as better housekeeping practices. Technological risk is most relevant with regard to more sophisticated process changes or recovery equipment, while low-tech practices pose little or no risk. It is likely that, due to the structure of the electroplating industry, different groups of platers would be attracted by these separate objectives. The small companies with only a few employees will probably be reluctant to install advanced recovery technologies. Reduction of technological risk will therefore not be relevent to them, and a technical assistance program focusing only on this issue will miss this target group. Medium to large electroplaters are more likely to respond to information that presents a thorough analysis of the performance of more sophisticated technologies.

A technical assistance program has to be connected to other incentives in the waste reduction arena to prevent counterproductive effects and to enhance the program from other perspectives. For example, the insurance industry could be one partner in this field. Although there are no insurance requirements for waste reduction, the firm might still derive insurance benefits from investments in waste reduction technologies. This would require (a) that the insurance industry distinguish between various levels of risk posed by companies operating with different hazardous substances and different production procedures, or (b) that the electroplaters decide to form insurance pools in which they determine their own strict requirements for insurance. With stricter disposal requirements under the landban provisions, insurance pressures might become more urgent, thereby stimulating waste reduction.

Another potential policy instrument is the matching grant, which offers the advantage of having applicants "buy into" the source reduction demonstration project.

The role of economic incentives has been minimized in the proposed demonstration project. The reason is that the barriers to adoption of waste reduction technology do not appear to be primarily economic in nature. (Economic factors in the marketplace have raised the costs of hazardous substances to such a level that adoption already makes sense in many or most cases. Of course, further economic incentives might have some additional effect, but the magnitude of the incentives, we expect, would have to be substantial, and perhaps punitive in nature.) For the demonstration project, we believe it is important to focus on what appears to be the dominant barrier, technological risk. Virtually every step in the proposed technical assistance program is geared to reduce the technical risks and regulatory uncertainty confronting electroplaters. However, if after expanding and refining the demonstration project, electroplaters do not participate or adopt waste reduction technology as expected, then economic incentives should receive strong consideration, perhaps as the focal point of the program.

B. Additional Options Beyond the Experimental Program for the Electroplating Industry[6]

(1) TECHNOLOGY TRANSFER

The technological and behavioral barriers in the electroplating industry can be significantly reduced through the implementation of a technology transfer program. Designed to demonstrate the capability of waste reduction technologies (WRT's), to illustrate the economic advantages and costs, and to diffuse the technology, this part of the program would consist of (a) a model demonstration plant, (b) field applications, and (c) workshops.

(a) A Model Demonstration Plant

The major barrier to the implementation of waste reduction technology is the skepticism of the electroplaters, which has been fueled by ineffective equipment in the past and seemingly unbelievable claims by the suppliers. Effective

[6]Not all of these options may be advisable for New Jersey. Together, they form a more general strategy that should be modified in any particular state according to the particular stage of development of electroplating technology and regulation in that state.

technology diffusion cannot occur until this skepticism is allayed.

A model demonstration plant would serve as an operating example of the effectiveness and applicability of waste reduction technologies. With the objective of reducing the technical risk associated with new technologies, the plant would contain waste reduction technology within an existing electroplating firm. With the equipment partially paid for by the state, the electroplating firm would be obligated to open the plant for inspection by other electroplaters. Developed through a cooperative effort by the state agency, the suppliers, and the electroplaters, the plant would not only demonstrate the technology, but also would reflect the economic savings that can be achieved.

This practical, "real world" demonstration of the technology would also serve as a marketing aid for the suppliers. By reducing the technical risks and illustrating the economic benefits, the demonstration project would generate an increase in the demand for the equipment. The creation of a market for WRT would then foster research into new, innovative technologies to reduce the production of toxic wastes even further.

In selecting technologies for the demonstration plant, the state should give priority to the substitution of less toxic baths and then work down the process line to the recovery technologies.

(b) <u>Field Applications</u>

The electroplating industry currently consists of many WRT's that have received substantial research and development, but have not been widely implemented. Further research (laboratory work) is certainly needed to extend the applicability of these technologies. Of greater need now, however, are scaled up implementation studies. In order to create a market for the WRT's, accurate information about (a) the technical effectiveness of the equipment, (b) the problems that can occur and the proper solutions, and (c) extensive economic analysis of the process, must be developed for a plant-size production line. By either funding research at the universities for internships at electroplating shops or hiring process engineers to perform the studies, accurate, independent information could be generated to be disseminated to the electroplaters.

(c) <u>Workshops</u>

Workshops should be organized in order to foster better communication between the state agency, electroplaters, and suppliers. The workshops should include publication of the (a) current regulations affecting the electroplating/metal finishing industry, (b) information about the current waste reduction technologies, and (c) economic details developed at the demonstration plants. The workshops should address both the advantages and the disadvantages of each technology, including the history of the equipment and modifications developed to overcome the problems.

(2) **REGULATIONS**

Given the observed barrier pattern, it is essential to develop additional incentives on the regulatory level to optimize the effectiveness of the incentives program and to increase the application of waste reduction technologies. Incentives on the regulatory level can be suggested in three different areas:

- (i) discharge and emission standards
- (ii) waste reduction requirements
- (iii) tax regulations

To design effective regulatory incentives requires sound information about the waste generation and emissions behavior of the targeted industry. Furthermore, a comprehensive analysis of state and federal regulations must be conducted to determine those regulations (environmental and others, such as tax regulations) which are counterproductive to the implementation of waste reduction technology. Because the regulatory process usually requires more time to develop, regulatory incentives cannot be immediately implemented.

(a) Discharge and Emission Standards

Stricter discharge and emission standards should be developed for the selected industrial segment (the electroplating industry) to promote the use of waste reduction technologies. Although many firms in this industry are not now in compliance, and enforcement of even stricter standards would probably force some companies out of business, the application of waste reduction technologies would improve their ability to comply with even stricter standards. However, these standards should be linked with technical assistance to provide information needed for investment in waste reduction.

In the electroplating industry, the small quantity generators (SQG) do not use wastewater treatment systems with metal precipitation, but rather discharge their metal-containing wastewaters indirectly or directly into the water. As a result, the large number of SQG require sticter regulation, which again would foster the use of WRT. SQG should also be ordered to report the amount and concentration of waste they produce.

(b) Waste Reduction Requirements

Two different approaches for developing waste reduction requirements are possible. One is reporting of the current waste reduction practices used by industry; the other one focuses on technology forcing by issuing technical performance standards. The states are authorized to develop their own questionnaires and reporting requirements for industry, which are in addition to the federal reporting requirements under RCRA and SARA Title III. To be able to utilize information from industry, it is advisable that the particular state be aware of the experiences of other states with regard to the reporting of their industrial waste reduction efforts.

Performance standards related to hazardous waste generation can function as an effective tool to promote the use of certain waste reduction technologies. Technology-based performance standards can be integrated into the permitting and re-permitting process.

One waste reduction option which has been discussed is to require an annual percentage reduction in hazardous waste generation, as well as a reduction in all affected environmental media. The efficacy of this concept, however, has been questioned because it does not permit companies the flexibility of achieving a higher percentage reduction in one year by installation of waste reduction equipment and then having no reduction to report in the next year.[7] However, allowing carry-forward credits for waste reduction would remedy much of the problem.

(c) Taxes

The tax system has actually impeded waste reduction activities to a certain extent. Well-intentioned tax advantages were created to stimulate investment in end-of-pipe treatment technologies. However, continued subsidization of those technologies through the tax system has retarded the diffusion of waste reduction technologies. In order to support WRT's, the tax structure needs to be revised, either by (1) eliminating end-of-pipe tax incentives or (2) creating equivalent ones, or preferably superior ones, for waste reduction technologies.

One problem, however, with traditional tax incentives, such as accelerated depreciation or tax write-offs or credits for capital investment, is that many waste reduction opportunities require minimal or no capital investment. For

[7] A related problem is that waste reduction performance standards may, in effect, serve to punish firms for having undertaken prior waste reduction initiatives.

example, most good housekeeping procedures and some process redesigns involve corporate expense but not new equipment. Therefore, tax incentives for waste reduction technologies must be finely-tuned to stimulate the full range of desired investments.

(3) **RESEARCH AND DEVELOPMENT**

Although many waste reduction technologies are currently available to reduce the production of toxic wastes in the electroplating industry, research is needed to expand the applicability of specific technologies. Improvement of plating bath substitutions or recovery technologies like reverse osmosis or electrodialysis are prominent examples. Because of the current lack of demand for WRT's, suppliers are not aggressively exploring new and innovative techniques, but rather are barely marketing their present products.

(4) **LOANS**

The implementation of waste reduction technologies is in several cases restricted by financial barriers. Many electroplating companies lack the financial flexibility to invest in capital-intensive recovery systems or in substitutions of plating baths. It may therefore be necessary to offer investment loans to companies. The elegibility requirements and application prerequisites will, however, need some time to be developed.

We suggest that the proposed investment loans be granted in all areas of waste reduction, with priority given to process changes and the less-diffused in-plant recovery technologies. The investment loans should be offered more for toxics use reduction and substitution than for recovery technologies. An additional option would be to restrict the loans mainly to small quantity generators.

(5) **DISCOURAGE CENTRALIZED TREATMENT PLANTS IN SOME INDUSTRIES**

Centralized treatment plants tend to discourage source reduction activities in industry. Having the option of bringing recyclable wastes to an off-site plant might induce some companies not to invest in substitution options or to use in-process recovery technologies. There are already several private companies which offer recycling services, and many more may not be advisable.

C. An Experimental Incentives Program for the Degreasing Process in New Jersey

Introduction

The analysis of the degreasing process was conducted in order to facilitate the development of an incentives program which promotes the implementation of waste reduction technologies. Note that we restricted our analysis to degreasers utilizing chlorinated hydrocarbons (a major user of which is electroplaters). Non-chlorinated hydrocarbons, such as mineral spirits, were not included primarily because these substances are generally not subject to environmental regulations.

The goal of the research is to suggest a demonstration project to achieve the following:

(1) reduction of environmental and health hazards of current industrial practice

(2) reduction of technical risk of implementing waste reduction technologies

(3) fostering of the private sector (suppliers and consultants) to compete in providing waste reduction technologies and managerial expertise and assistance

The suggested incentives aim to provide a comprehensive approach to stimulate investment in waste reduction technologies. The proposed incentive system is composed of the following elements:

(1) technical assistance[8]
(2) economic (financial) incentives
(3) regulatory requirements

Note that these elements may well overlap. For example, technical assistance, even if not subsidized, may provide economic benefits by lowering technical risks (which impose costs on the firm) and by reducing the risk of regulatory non-compliance (e.g., through fail-soft strategies). In addition, not all elements may be required during a specific phase of the incentives program. For example, it appears that some waste reduction technologies inure to the benefit of many (and perhaps all) degreasers who adopt them. For these firms, economic incentives may not be needed, or may be relegated to a secondary role, at least during the

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[8] Another potential element of the incentive system would be R&D assistance, in those cases in which R&D bottlenecks have been identified (and in which the important barrier is not diffusion of existing technology).

demonstration phase. Finally, as suggested above, different incentives may be deployed in different phases of the incentives program.

The set of incentives must have the proper balance of "carrots" and "sticks" to be effective. However, in terms of agency or private resources, there should be minimum concern with traditional measures of "programmatic efficiency" in the short run. The purpose of the demonstration project is to learn which incentives work and which don't, under which circumstances, and for what reasons. Therefore, the success of the demonstration program can be measured primarily by what is learned from it. The construction of a comprehensive, efficient program would be premature at this stage (but would be appropriate following the demonstration project).

A Technical Assistance Program

Because of the existence of waste reduction technologies which are currently available and profitable for use in the degreasing process, we tentatively propose to place the focus of a demonstration project on technical assistance. The structure of the proposed technical assistance program is outlined in the following discussion:

First step :	develop a profile of the users of the degreasing process in New Jersey in order to assess the need for technical assistance

Answer the following questions:

* Who are the suppliers to the industry?

* Which consultants do the degreasers refer to?

* To what technical information/assistance do the degreasers have access?

The agency, as part of the profile, should attempt to uncover any related source reduction technology for which R&D is not needed, but for which marketing is needed.

In addition, the agency needs to provide a screening for the safety of new chemicals introduced to promote source reduction. This particular agency function is perpetual (unless subsumed by some other state or federal agency); all other elements of source reduction may ultimately (or currently) be taken care of by the market.

If this profile indicates that technical assistance is needed (and the market is not supplying it), then proceed to the next step. Note that the suppliers and consultants may be either a good or a poor source of information to the firms (e.g., Monsanto and PCB's or end-of-pipeline engineering consultants). Indeed, a major reason for the state to provide technical assistance is that firms are being advised by the "wrong" suppliers and consultants.

Based on the expertise of inspectors from the New Jersey DEP, it appears that users of the degreasing process in New Jersey would benefit from technical assistance, particularly concerning non-sophisticated waste reduction practices.

<u>Second step</u> : design a workshop on the topic of waste reduction to assist consultants, suppliers, and degreasers

The workshop should be easy for New Jersey participants to attend (in terms of fees, location, and time). The participants would include degreasers, consultants, suppliers (of alkaline cleaners, distillation units, carbon-adsorption systems, refrigerated freeboard chillers, etc.), and related DEP personnel. A thorough demand analysis should be conducted in advance to make sure that the needs of the audience for particular information are included in the workshop. This could be done in the form of a telephone questionnaire to find out what consultants and degreasers would like to know in order to be more responsive to the possible implementation of waste reduction technologies. (However, in many cases the respondents themselves may not know the answers or may not believe it to be in their interest to tell you.) Also asking suppliers about the most frequent problems they face with their customers in distributing their products could be helpful in gaining a better understanding of the needs for education and information.

The workshop should address the various waste reduction options available and explain the advantages and consequences of an optimal plant design, taking into account the simultaneous implementation of the appropriate technologies.

It would enhance the effectiveness and popularity of the workshop (in the sense of the workshop being accepted) if it were organized with relevant professional associations, such as the National Association of Solvent Recyclers. This would present a good opportunity to cooperate with the respective associations to promote the application of waste reduction technologies.

The workshop should have two functions. On the one hand, it should focus on detailed technological descriptions of commercially available waste reduction technologies. Here, well-analysed case studies of companies which have already applied specific waste reduction technologies should be presented to the audience. The limitations of the technological options and their variability from firm to firm, as well as the advantages, should be discussed.

The second focus of the workshop should be to provide a detailed economic analysis of the benefits as well as the costs related to the implementation of a specific waste reduction technologies. Discussion of the economic effects should assist degreasers in conducting a comprehensive economic analysis of their plant (thereby eliminating mistakes caused by limited cost evaluation). The workshop should avoid general statements of the costs and benefits of waste reduction technologies. It should rather provide very specific technological and economic information. Finally, a multi-media approach in evaluating technological options should be stressed.

Several booklets need to be developed for the workshop and also for distribution among degreasers that present detailed technical and economic cost-benefit information for the individual waste reduction technologies.

<u>Third step</u> : conduct individual surveys at selected, manifested degreasers

Under the technical assistance program, interested individual firms should apply for a comprehensive environmental and engineering survey. Firms will be selected from among applicants for survey by the agency on the basis of their technical, economic, and managerial characteristics (and history) which suggest that such a survey might lead the firm to adopt source reduction technology. The agency will also attempt to select a variety of firms in terms of size, technology, and other characteristics (since firms are generally more responsive to related success stories). Note that these surveys involve substantially more than a compliance assessment conducted by an environmental engineer. Since the purpose of the survey is to suggest waste reduction options appropriate for the firm that may go beyond regulatory requirements, the skills of a process engineer conversant with the industry or a person experienced in industry processes from a source reduction perspective are a necessity.

It is likely that the survey will be conducted for a firm under some regulatory obligation. The agency can use the survey as a occasion to re-permit the firm. Other candidates for a survey would be those firms which would benefit from the reduction of existing compliance costs or those firms which could reduce their wastes sufficiently to be relieved of permitting requirements.

The agency should help to broker the technical assistance of qualified consultants in the area. One way of accomplishing this, while at the same time stimulating firms to apply for the survey, may be to subsidize the cost of the survey during the demonstration phase (i.e., charging the firm only a nominal fee but paying the consultant his usual, or some reasonable percentage of his usual, rate). Note, however, that qualified consultants may be difficult to locate, so that the agency may have to engage in a consultant screening or training process.[9]

The surveys should be of a multi-media character and should focus on technological as well as economic considerations. Multi-media waste reduction survey manuals developed by EPA should be improved upon (because they are currently geared too much to end of the pipe approaches) and then suggested to the degreasers for usage.

<u>Fourth step</u> : create a user tax on input solvents

Many firms have adopted waste reduction technologies, to some extent at least, because it is economically sensible to recover the undamaged solvent. In order to encourage other degreasers to adopt waste reduction technologies which currently are not economically advantageous to them, some type of tax on virgin solvents should be introduced. Such a tax would increase the effective price differential between the use of recycled solvent and virgin solvent and would also stimulate a switch to alkaline cleaners.

We note, however, that a front-end tax (normally a simple and direct tax instrument) would stimulate waste reduction technologies more effectively if it were imposed nationally, rather than just in New Jersey. The reason is that some firms would be willing to make their purchases out-of-state to avoid the tax, and prohibiting this practice would be difficult to enforce.

<u>Fifth step</u> : revise specification standards and rigorously enforce the regulations

Current regulations require the use of freeboard chillers even though, as our study has indicated, there are serious problems associated with this technology. Better control

[9] It may be possible to use the New Jersey university system to assist in these activities (e.g., use grants from Rutgers to educate professionals who might later serve as consultants).

could be achieved by requiring the use of roll covers on all sizes of tanks and by specifying, in the standards, exactly when the tanks are required to be covered.

Freeboard chiller regulations could also be improved by requiring larger freeboards on all tanks and introducing operating restrictions, in particular, the placement of a fan in close proximity to a degreasing unit (e.g., by hot workers during the summer). While these latter restrictions would be difficult to enforce, the issuance of guidelines, explaining the rationale behind the operating restrictions and indicating the hazards associated with solvents, might improve the degree of compliance.

To the extent possible, however, the use of covers, the placement of the degreasing equipment, and the placement of other equipment around the degreasing unit need to be rigorously enforced through the inspection process.

<u>Sixth step</u> : develop and conduct coordinated air and wastewater permitting procedures in the agency

One method of promoting the application of waste reduction technology is to restructure the permitting procedures in the agency for the firms selected to participate in the demonstration program.[10] Because all electroplaters are also degreasers, the permitting process for the wastewater treatment should be coordinated with the air permitting process for the degreasers.

The purpose of coordinated permitting here is not so much to prevent the transfer of pollutants among the different environmental media, since degreasing and electroplating are essentially independent processes. Rather, coordinated permitting would create economies of managerial attention for the electroplater/degreaser.[11]

The agency might also consider coordinating its permitting with the enforcement of OSHA regulations. The operational problems associated with freeboard chillers, for example,

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[10] In developing protocols for evaluating multi-media risks (to be applied to cross-media permitting), the agency may wish to adopt whatever protocols have been developed in the state for Superfund sites. (This is what is being done in Massachusetts.)

[11] However, we do not wish to minimize the serious complications involved in cross-media permitting, particularly because of the constraints imposed by associated federal statutes. For example, since federal law establishes air emission permits for the lifetime of the firm, the state may not be allowed to renew (or withdraw) air permits (except for new firms or by creating explicit state statutory provisions).

the agency and industry gain. Firms are able to reduce the costs associated with regulatory uncertainty (at least at the state level) and the agency is able to regulate more effectively.

Eighth step : refinement of the approach

The technical assistance program needs to be reevaluated after a certain period of its application. The evaluation of the technical assistance program should be an on-going process. This will be helpful for understanding the need for program modifications and refinements for broader application.

Ninth step : foster coordinated permitting

To promote coordinated permitting, the state may wish to develop a facility "masterfile" which provides a summary of all environmental activity of that facility (including media permits, fines, etc.) and a reference to the other file materials contained in the agency.

D. Lessons Learned from the Case Studies

As described at the beginning of the report, we chose two case studies for analysis: the electroplating industry and the degreasing process. We have designed experimental or demonstration programs for both those cases. In this final section we bring together in one place the lessons learned from the case studies to guide future research and experimental efforts.

1. The strategies for a particular industry or industrial process should be tailor made (a comparison of the recommendations for our two case studies reveals significant differences). This requires technical literacy on the part of the agency and/or its contractors. Because there are relatively few industrial processes and industries which are responsible for most of the hazardous waste problem, achieving sufficient familiarity with the relevant technology is well within the bounds of an agency's capabilities.

2. For the strategies, a mixture of instruments--technical assistance, regulation, and economic incentives--is needed. The mixture will differ according to industry structure, the state of technological development of production and control, and the regulatory status of the problem. In order to effectuate a successful strategy, a close relationship between regulators and those providing technical assistance

is required. All of their efforts need to be integrated toward a source reduction goal.

3. There are two significant market failures which could be corrected by agency incentives and programs: (a) the need to reduce technical risk or uncertainty for vendors and consultants so that they can be effective partners in the process, and (b) the need to promote the right kind of technological solutions (e.g., process redesign rather than add-on devices in some cases).

4. There are serious attitudinal problems in management which can be overcome by the agency providing technical assistance directly, and indirectly by educating industry's consultants who can work on changing management attitudes.

5. Trade associations and industry groups are important, but technical meetings in which researchers or academics interact with industry are essential. More information may be transferred in these meetings than at occasions in which industry talks to itself.

6. The role of the universities needs to be strengthened in two ways: (a) by providing a liaison between universities and industries, and (b) by enhancing the university's capabilities in process design and materials substitution, as opposed to traditional environmental engineering.

7. Coordinated enforcement in regulatory agencies is essential for two reasons: (a) there may be economies of scale for both the firm and the agency in coordinating different regulatory demands by the agency, and (b) there may be economies of scale in attracting managerial attention.

8. Mechanisms need to be developed to assist in training agency staff for both technical literacy and for increasing their receptivity to coordination of strategies to encourage waste minimization and source reduction.