1995125350

N95- 31771

ASSESSMENT OF POLLUTION PREVENTION AND CONTROL TECHNOLOGY FOR PLATING OPERATIONS

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ABSTRACT

The National Center for Manufacturing Sciences (NCMS) is sponsoring an on-going project to assess pollution prevention and control technology available to the plating industry and to make this information available to those who can benefit from it. Completed project activities include extensive surveys of the plating industry and vendors of technologies and an in-depth literature review. The plating industry survey was performed in cooperation with the National Association of Metal Finishers. The contractor that conducted the surveys and prepared the project products was CAI Engineering. The initial products of the project were made available in April, 1994. These products include an extensive report (ref. 1) that presents the results of the surveys and literature review and an electronic database. The project results are useful for all those associated with pollution prevention and control in the plating industry. The results show which treatment, recovery and bath maintenance technologies have been most successful for different plating processes and the costs for purchasing and operating these technologies. The project results also cover trends in chemical substitution, the identification of compliance-problem pollutants, sludge generation rates, off-site sludge recovery and disposal options, and many other pertinent topics.

BACKGROUND

The theme of this session is the evaluation of new environmentally friendlier replacement technologies for corrosion protection. The focus of this presentation is somewhat more retrospective, but we feel it is just as crucial to the session's purposes. Every old replacement technology began life as a new replacement technology. The best survived to become the established technologies of today, while back rooms and landfills are littered with the others' bones. A sense for what has historically worked and what has not may be as useful in assessing a new replacement's chances as are the usual brochures, specifications and testimonials in which each candidate comes clad.

Many corrosion protection processes involve electroplating. Environmental considerations have loomed increasingly large in the development of plating technologies for the past several years. In thousands of individual facilities throughout the country, many examples of pollution prevention techniques and pollution control equipment have been tried, and many have been accepted or discarded based on factors intrinsic to the technology, as well as factors peculiar to each individual shop.

The National Center for Manufacturing Sciences (NCMS) and the National Association of Metal Finishers (NAMF) have sponsored a project designed to capture the lessons learned across the industry, and to make that information available to the general public. The project involved a detailed survey of individual plating facilities, a thorough literature review, and input from technology suppliers. The purpose of this brief summary is to convey some idea of how the project was put together, and to give an overview of some of the key findings to emerge from the study. For those interested in specific details, the full report is now available as a four hundred page book, and the survey results are available on disk.[1] Some of these results were presented at the AESF-EPA Conference in January, 1994. The results have been revised, updated, and extended below.

A diagram showing the various stages of the project is provided in Exhibit 1. The assessment was conducted using three major sources of information and data:

(1) A mailed questionnaire-survey sent to approximately 2,000 electroplating and metal finishing plants (Users Survey).

(2) A mailed questionnaire-survey of approximately 60 vendors of pollution prevention and control equipment and off-site metals recycling services (Vendors Survey).
(3) A literature search that gathered approximately 600 articles, reports, conference papers and other sources of relevant information.

[1]For information contact the NCMS contractor, CAI Engineering at 703-264-0039.

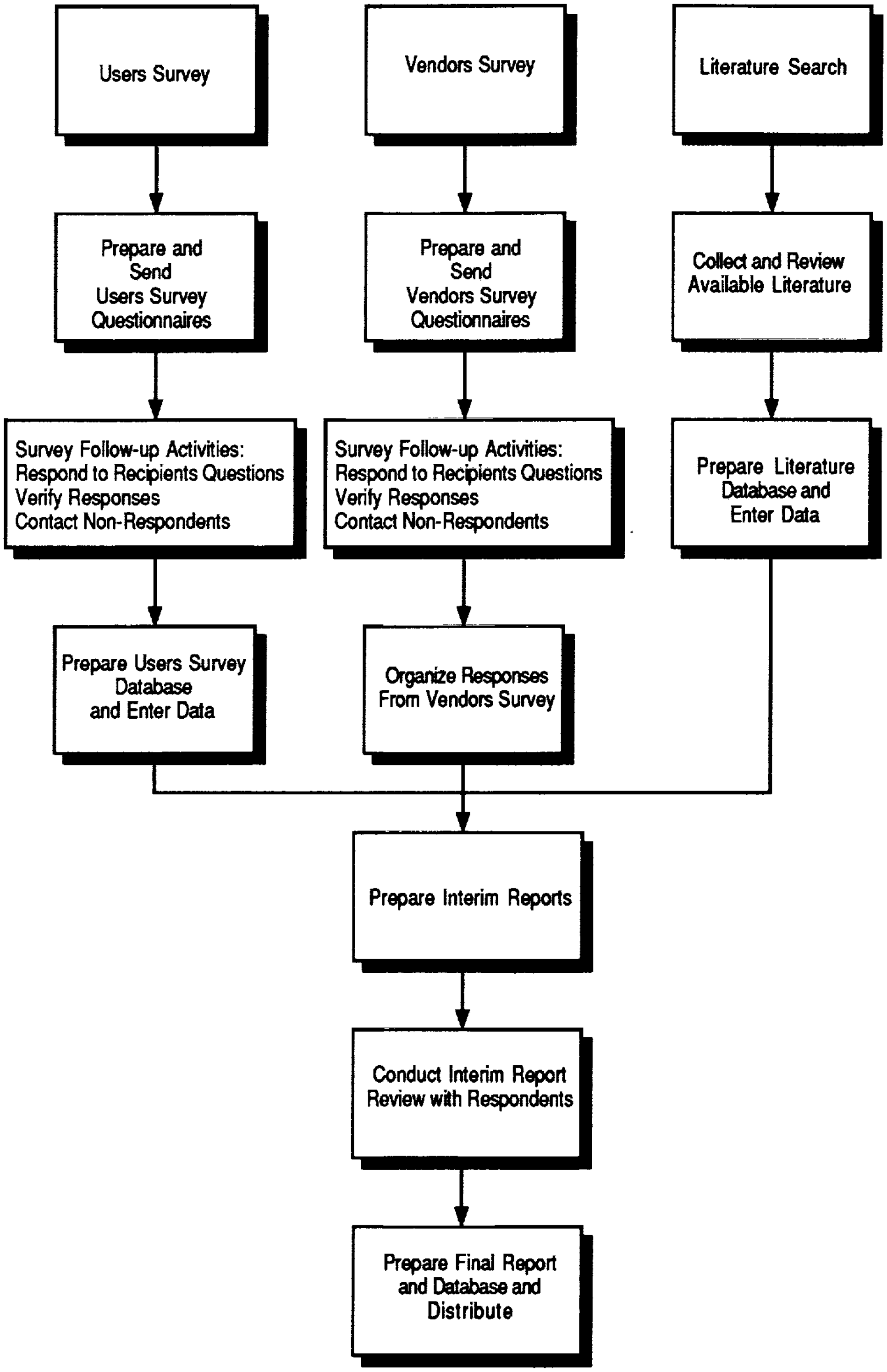


Exhibit 1.
Assesment of Pollution Prevention and Control Technology for Plating Operations
Overview of Project Activities

Using the collected materials, information and data, a set of seven Interim Reports was written covering the following topics:

- Interim Report No. 1: Overview of Project Results
- Interim Report No. 2: General Waste Reduction Practices
- Interim Report No. 3: Chemical Recovery
- Interim Report No. 4: Chemical Solution Maintenance
- Interim Report No. 5: Process Substitution
- Interim Report No. 6: Wastewater Treatment
- Interim Report No. 7: Off-Site Metals Recycling

The Interim reports were distributed to the respondents of the Users and Vendors Surveys and other interested parties. Based on comments received during the review process, the Interim Reports were revised and subsequently consolidated into a single final report. The report and Users Survey database are being distributed for NCMS by CAI Engineering. The reports and database will be updated once these results are disseminated and feedback is received. This will include additional data that will be accepted from new respondents to the Users Survey and Vendors Survey. Firms wanting to participate in updating these reports and database should contact the NCMS Project Manager.[2]

CHARACTERIZATION OF RESPONDENTS

The plating shops that responded to the Users Survey were diverse in terms of geographical location, size, the processes they employ and other factors. One general similarity of the respondents is that they mostly represent the job shop sector of the plating industry. Of the 300[3] initial respondents, 253 are electroplating job shops and 47 are captive shops. Distributions of other characteristics of the respondents are shown in Exhibit 2.

The geographical distribution of the respondents was relatively diverse, but concentrated in major electroplating regions. The majority of respondents (86%) are located in the Far West, Midwest and Northeast U.S. With respect to shop age, the average and median year that respondents commenced metal finishing operations was 1965. The range of commencement dates is 1867 to 1992. Approximately 18% of the respondents commenced metal finishing operations after August 31, 1982, the cut-off date where newer facilities are required to meet pretreatment standards for new sources (PSNS). The data show that the majority of the companies responding to the survey have 100 or fewer employees (86.8%). The average and median number of employees is 67 and 35, respectively. The range of employees is from 1 to 3,000.

METAL FINISHING PROCESS CHARACTERIZATION

Collectively, the respondents to the Users Survey operate 154 different types of metal finishing processes. The 25 most frequently found processes are identified In Exhibit 3 (excludes pre-plating, post-plating and stripping processes).

WASTEWATER AND DISCHARGE CHARACTERIZATION

The majority of the respondents to the Users Survey are indirect dischargers (i.e., discharge to a publicly owned treatment works, rather than directly to a stream, river or other water body). The percentage of shops that are either indirect, direct, both indirect and direct and zero discharge are shown in Exhibit 4. These data indicate that captive shops are more likely to be direct dischargers than are job shops. EPA estimates in 1984 indicated a similar trend (ref. 2).

The electroplating discharge rates (average daily flows) of the survey respondents vary from 0 gpd to 420,000 gpd (some higher discharge rates were reported for combined plating and non-plating industrial discharges). The average and median plating discharge rates for respondents were 34,600 gpd and 14,000 gpd, respectively (see Exhibit 2 for additional statistics regarding flow rates). Many shops indicated that they have made drastic progress in reducing wastewater flow rates, the most significant of which are the following:

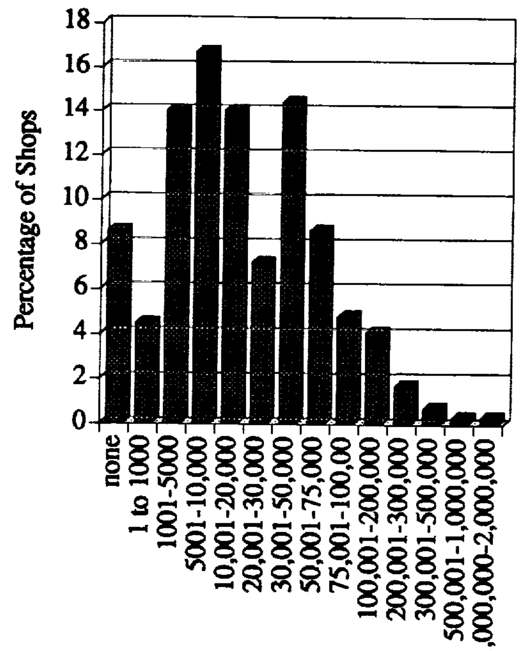
- PS 022[4]: from 140,000 gpd to 70,000 gpd (50% reduction since 1980)
- PS 036: from 52,700 gpd to 2,700 gpd (95% reduction since 1978)
- PS 059: from 90,000 gpd to 10,000 gpd (89% reduction since 1977)
- PS 118: from 232,630 gpd to 42,630 gpd (82% reduction since 1983)
- PS 139: from 127,000 gpd to 52,000 gpd (59% reduction since 1986)

[2]Paul Chalmer; NCMS; 3025 Boardwalk Drive; Ann Arbor, MI; 48108-3266; 313/995-4911.

[3]Data presented in this paper are based on the initial 300 responses. Additional responses are included in the final NCMS database and report.

[4]The names of respondents to the Users Survey are maintained in confidence by using a code sysem (PS stands for plating shop).

Average Plating Discharge Rate (gpd)



Company Size Distribution by Number of Employees

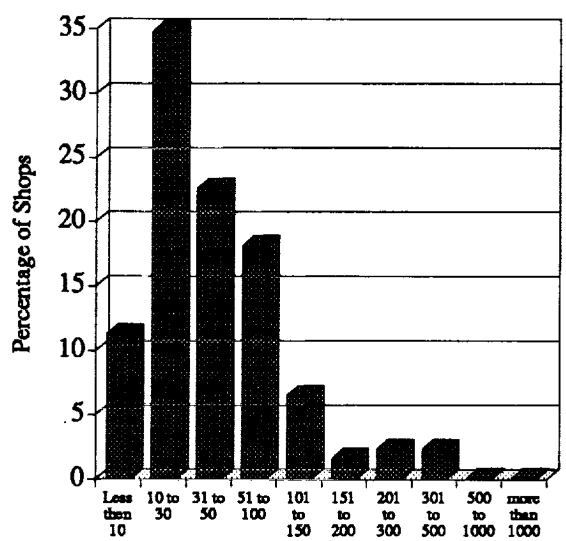
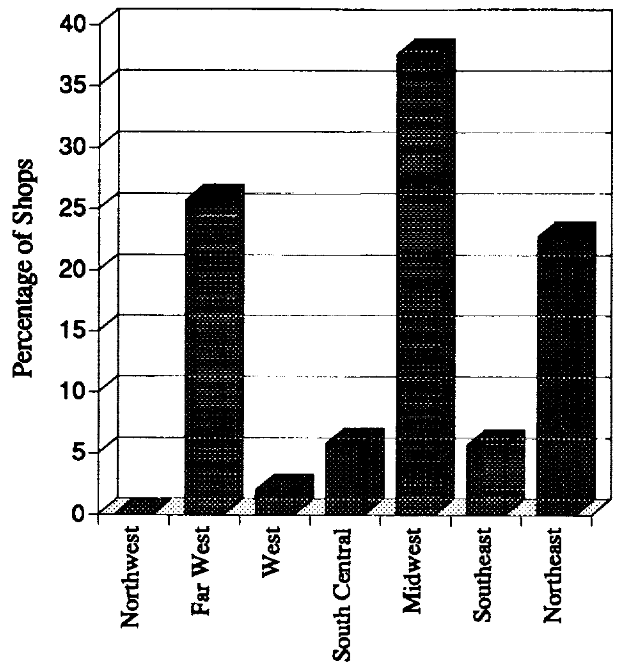


Exhibit 2.
Characterization of Respondents to the Users Survey

Geographical Distribution of Respondents



Shop Age Distribution
(year shop commenced metal finishing operations)

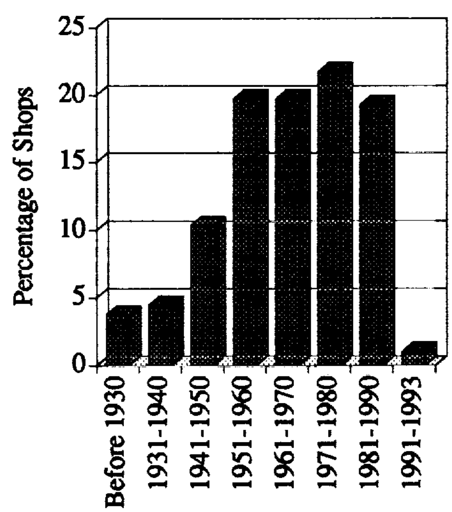


Exhibit 2.
Characterization of Respondents to the Users Survey (continued)

- PS 150: from 400,000 gpd to 100,000 gpd (75% reduction since 1986)
- PS 172: from 150,000 gpd to 70,000 gpd (53% reduction since 1975)
- PS 184: from 121,000 gpd to 11,000 gpd (91% reduction since 1982)
- PS 207: from 68,000 gpd to 18,000 gpd (74% reduction since 1986)
- PS 213: from 130,000 gpd to 50,000 gpd (62% reduction since 1985)
- PS 250: from 91,000 to 11,000 gpd (88% reduction, base year not given)
- PS 268: from 87,000 gpd to 17,000 gpd (80% reduction since 1987)
- PS 292: from 160,000 to 60,000 gpd (63% reduction since 1985)
- PS 296: from 1,900,000 gpd to 1,700,000 gpd (11% reduction, base year not given)
- PS 298: from 160,000 gpd to 90,000 gpd (70% reduction since 1990)

Exhibit 3.
The Twenty-Five Most Frequently Operated Metal Finishing Processes

Process Name	Percent of Shops Using Process	Average Volume of Solution per Shop*	Process Name	Percent of Shops Using Process	Average Volume of Solution per Shop*
1. Nickel (Watts) plating	42	4,102	14. Silver (CN) plating	25	465
2. Zinc (non-CN) plating	39	5,276	15. Chromate on cadmium	24	388
3. Chromate on zinc plate	39	1,594	16. Zinc phosphate	23	1,065
4. Chromate on aluminum	38	607	17. Tin-lead plating	21	256
5. Passivation (all types)	38	244	18. Gold (CN) plating	20	166
6. Copper (CN) plating	38	852	19. Bright dip of Cu/Cu	19	80
7. Cadmium (CN) plating	30	1,360	20. Copper (sulfate) plating	19	1,761
8. Electroless nickel plating	30	809	21. Black oxide	17	319
9. Decorative Cr (+6) plate	29	1,637	22. Brass plating	17	713
10. Tin (acid) plating	27	581	23. Hard coat anodizing	15	1,661
11. Nickel (sulfamate) plate	26	681	24. Zinc (CN) plating	15	4,221
12. Sulfuric acid anodizing	26	1,590	25. Chromic acid anodizing	14	814
13. Hard chromium plating	25	3,978			

*Often involves a multiple number of tanks per shop containing the same solution.

The respondents to the Users Survey are required to meet either CFR 413 (Electroplating Categorical Standards), CFR 433 (Metal Finishing Categorical Standards), or non-standard effluent limitations. Non-standard limitations are more stringent than the categorical standards for one or more pollutant parameters. Some of the non-standard limitations are written in terms of pollutant mass and flow rates (e.g., 0.37 lbs/day of chromium with a maximum flow of 40,000 gpd) rather than concentration limitations. The percentage of respondents that are required to meet each type of effluent limitation are as follows:

40 CFR 413: 28%
40 CFR 433: 8%
Non-Standard: 64%

In addition to concentration or pollutant mass discharge standards, 16% of the respondents indicated that they are also subject to aquatic-based effluent standards. These limits require that an industrial wastewater be sufficiently treated such that certain percentages of organisms (typically fish and water fleas) are able to survive in the effluent for a given time period.

The Users Survey asked platers to indicate the pollutant parameters for which they have compliance difficulty. A summary of their responses is shown in Exhibit 5.

DRAG-OUT AND RINSE WATER REDUCTION

For the typical electroplating job shop, the drag-out of process solutions and the subsequent contamination of rinse waters are the major pollution control problems. The NCMS report explains the basic principles of drag-out theory and explores the function and applicability of the various drag-out minimization techniques in use today. Because of the importance of drag-out and drag-out loss prevention, numerous questions in the Users Survey were related to this topic. The responses to these questions are statistically evaluated in the report and summarized in this paper.

The Users Survey asked respondents to indicate the methods they employ to reduce the formation or loss of drag-out and the usage rate of rinse water. A summary of their responses is presented in Exhibits 6 and 7. The most frequently used drag-out reduction methods are: allowing parts/racks to drip over process tanks; the use of drag-out rinses; reducing the speed of rack/part withdrawal; use of drip shields; and positioning the workpiece to minimize solution holdup. On the average, all of the drag-out reduction methods that are used by the respondents have been successfully applied. Some shops had specific problems with one or more methods (e.g., buildup of bath contaminants). These problems are discussed in the report along with potential solutions.

Exhibit 4.
Distribution of Respondents by Type of Discharge

Type of Discharge	Percentage of All Respondents with the Type of Discharge Indicated	Percentage of Job Shop Respondents with the Type of Discharge Indicated	Percentage of Captive Shop Respondents with the Type of Discharge Indicated
Direct Discharge	12.6%	10.8%	22.0%
Indirect Discharge	78.9%	80.6%	70.0%
Both Direct and Indirect	0.9%	0.7%	2.0%
Zero Discharge	7.5%	7.8%	6.0%

Exhibit 5.
Pollutant Parameters for which Compliance Difficulty was Reported by Respondents

Parameter	Percentage of Respondents Reporting Compliance Difficulty	Parameter	Percentage of Respondents Reporting Compliance Difficulty
Nickel	19	Lead	7
Zinc	19	Cyanide (amenable)	2
Chromium (total)	17	Chromium (+6)	2
Copper	12	Silver	2
Cyanide (total)	12	Total Toxic Organics	1
Cadmium	10		

Note: some shops listed two or more parameters.

The most frequently used methods of reducing water use involve the application of: flow restrictors; counterflow rinses; manually turning off water; and air agitation. As with drag-out methods, the rinse water reduction methods have been generally successfully, with the highest success ratings given to the use of flow restrictors and counterflow rinsing.

CHEMICAL RECOVERY TECHNOLOGIES

According the respondents of the Users Survey, chemical recovery technologies are most frequently purchased to (in order of frequency): help meet effluent regulations; reduce wastewater treatment costs; reduce plating chemical purchases; and to reduce the quantity of waste shipped off-site.

The Users Survey requested platers to provide detailed technical, performance and operating cost data for chemical recovery technologies. Also, during their survey, vendors were requested to provide technology descriptions, operating data and capital cost data. As a result of obtaining data from these two sources, plus the information from the extensive literature review, the NCMS report contains a substantial quantity of

Exhibit 6.
Summary of Users Survey Data Relating to Drag-Out Loss Prevention

Drag-Out Reduction Methods	% of Respondents Using Method	Success Rating (1 to 5)
Drag-out rinse tanks w/ rtn. of chem. to proc bath (manual)	61	3.8
Drag-out rinse tanks w/ rtn. of chem. to proc bath (auto.)	19	3.7
Drip tanks; w/ rtn. of chem. to proc bath (manual)	27	3.4
Drip tanks; w/ rtn. of chem. to proc bath (auto.)	7	3.2
Reducing speed of rack/part withdrawal (manual)	39	3.2
Reducing speed of rack/part withdrawal (auto.)	22	3.6
Allow rack/part to drip over plating tank (manual)	61	3.5
Allow rack/part to drip over plating tank (auto.)	25	3.8
Using a drag-in/drag-out arrangement (manual)	21	3.4
Using a drag-in/drag-out arrangement (auto.)	11	3.9
Fog/spray rinses installed over proc.bath (manual)	18	3.7
Fog/spray rinses installed over proc.bath (auto)	10	3.3
Air knives that blow off drag-out (manual)	2	3.1
Air knives that blow off drag-out (auto)	6	3.8
Drip shields between tanks	57	3.7
Lower bath concentrations	34	3.3
Increasing solution temperature	17	3.1
Using a wetting aqent	32	3.0
Positioning workpiece to minimize solution holdup	52	3.8
Average		3.3

Manual and automatic refer to the level of automation of the plating line.
The success rating is based on a scale of 1 to 5, with 5 being most successful.

Exhibit 7.
Summary of Users Survey Data Relating to Rinse Water Use Reduction

Rinse Water Reduction Methods	% of Respondents Using Method	Success Rating (1 to 5)
Manually turning off rinse water when not in use	66	3.6
Conductivity or pH rinse controls	16	3.2
Timer rinse controls	11	3.8
Flow restrictors	71	4.2
Counterflow rinses	68	4.2
Spray rinses	38	3.8
Air agitation in rinse tanks	58	3.7
Flow meters/accumulators to track rinse water	12	3.7
Reactive rinsing or cascade rising	25	3.8
Average		3.8

Exhibit 8.
Distribution and Ratings of Chemical Recovery Technologies

Process Name	ED[a]	EW	ATM EV	VAC EV	IX	MP	RO
Anodize, Chromic Acid	-	-	-	-	ND (1)	4.0 (2)	-
Anodize, Hardcoat	-	2.0 (1)	-	-	-	-	-
Brass	-	3.5 (2)	4.0 (2)	-	-	-	-
Cadmium, Cyanide	-	2.7 (29)	3.0 (4)	3.0 (3)	2.0 (4)	-	5.0 (1)
Cadmium, Non-cyanide	-	ND (1)	4.0 (1)	-	-	-	-
Chromate (Aluminum)	-	-	-	-	5.0 (1)	-	-
Chromium Etch	-	-	-	4.5 (2)	-	-	-
Chromium, Hard	-	-	4.3 (4)	-	2.0 (2)	4.1 (15)	-
Chromium, Decorative (Cr^{+6})	-	-	3.5 (11)	4.0 (5)	5.0 (3)	-	-
Chromium, Decorative (Cr^{+3})	-	-	5.0 (2)	-	-	4.0 (1)	-
Copper, Electroplating[b]	-	3.0 (15)	3.7 (4)	4.0 (1)	ND (3)	-	2.0 (1)
Gold, Electroplating[c]	-	4.0 (4)	-	-	4.0 (13)	-	-
Lead-Tin	-	-	-	4.0 (1)	-	-	-
Nickel, Electroplating[d]	1.0 (3)	4.0 (6)	4.1 (20)	4.0 (3)	3.8 (12)	-	1.0 (4)
Nickel, Electroless Plate	-	ND (1)	3.0 (2)	-	1.7 (3)	-	-
Seal, Nickel	-	-	-	-	-	-	4.0 (1)
Silver, Electroplate	-	4.4 (12)	2.0 (1)	-	-	-	-
Zinc, Cyanide	-	1.7 (7)	3.0 (2)	1.7 (3)	ND (1)	-	1.0 (1)
Zinc, Non-cyanide[e]	-	2.0 (7)	3.7 (9)	-	2.6 (7)	-	5.0 (1)
Zincate	-	-	4.0 (1)	-	-	-	-

[a]Technology key: ED=electrodialysis, EW=electrowinning, ATM EV=atmospheric evaporation, VAC EV=vacuum evaporation, IX=ion exchange, MP=meshpad mist eliminator, RO=reverse osmosis. Ratings are based on a scale of 1 to 5, with 5 being the most successful. Number of applications from the Users Survey is shown in parenthesis. "-" = no applications, ND = no data.
[b]Includes cyanide plate, cyanide strike and sulfate baths.
[c]Includes cyanide and non-cyanide baths.
[d]Includes bright, sulfamate, sulfate, Watts and Woods baths.
[e]Includes acid and alkaline baths.

information for the following chemical recovery technologies: electrodialysis, electrowinning, atmospheric evaporators, vacuum evaporators, ion exchange, reverse osmosis and mesh pad mist eliminators. A separate subsection of the report is devoted to each of these technologies. Within each subsection, the following are provided: technology overview; development and commercialization; applications and restrictions (with diagrams showing different potential configurations); technology/equipment description; capital costs; operating costs; performance experience; and residuals generation.

Exhibit 8 presents a summary of the chemical recovery applications covered by the Users Survey data. Exhibit 9 presents an example (vacuum evaporators) of the Users Survey data summaries contained in the report.

SOLUTION MAINTENANCE METHODS AND TECHNOLOGIES

Metal finishing solutions are subjected to a variety of forces that cause them to become unusable. The key contributing factors are: (1) depletion of bath chemicals; (2) chemical break-down of process chemicals or chemical side reactions; (3) contamination from impurities in make-up water, chemicals or anodes; (4) anodic/cathodic etching of parts and inert electrodes; (5) corrosion of parts, racks, bussing, tanks, heating coils, etc.; (6) drag-in of non-compatible chemicals; (7) buildup of by-products (e.g., carbonates); (8) breakdown of maskant, fume suppressant and wetting agents; (9) errors in bath additions; and (10) airborne particles entering the tank.

Solution maintenance replaces the practices of: (1) using a fresh chemical solution until it is degraded and replacing it with fresh solution or (2) decanting a

Exhibit 9. Partial Summary of Users Survey Data for Vacuum Evaporation (chemical recovery applications)

Plating Shop Code	Plating Solution Application	Manufacturer	Year Purchased	Capital Costs			Operating Costs ($/Yr.)			Savings					Use Code (3)	Satisfaction Level with Technology (4)	Future Decision (5)
				Equip.	Other	Total	Non-labor	Labor	Total	Bath Chem.	Treat. Chem.	Sludge Disp.	Other	Total			
034	Zinc (CN)	McDermid	1980	$35,000	$8,000	$43,000		$5,000	$5,000	$500	$200	$1,000	$2,500	$4,200	3	2	2
039	Zinc (CN)	Wastesaver	1975	$50,000	$4,000	$54,000	$9,000	$2,400	$11,400	$5,000				$5,000	2	1	2
082	Dec. Cr +6	Pfaudler (1)		$150,000	$25,000	$175,000	$50,000	$15,000	$65,000	$130,000	$115,000	$30,000		$275,000	1	4	1
088	Cd (CN)	Pfaudler (2)	1982	$23,000	$2,050	$25,050	$10,000	$6,000	$16,000	$9,900	$15,000	$5,000		$29,900	1	4	1
102	Cu(CN)	McDermid	1972												2	4	3
123	Sn/Pb	Calfran	1991	$60,000	$2,000	$62,000	$6,912	$14,560	$21,472	$214,700		$34,260		$248,960	1	4	1
124	Dec. Cr +6	Corning	1980	$108,210	$0	$108,210									1	4	1
125	Dec. Cr +6	Homemade	1985	$35,000	$10,000	$45,000	$15,000	$2,600	$17,600	$18,500				$18,500	1	4	1
125	Ni (Watts)	Homemade	1985	$70,000	$210,000	$280,000		$2,600	$2,600	$38,000				$38,000	1	4	1
132	Cd (CN)	Corning	1981												2	1	3
143	Cd (CN)	Water Vap	1992	$10,000	$500	$10,500	$3,000		$3,000			$500	$1,000	$1,500	1	4	1
196	Dec. Cr +6	Corning		$240,000	$25,000	$265,000	$10,000	$2,000	$12,000	$450,000	$15,000	$12,000	$18,000	$495,000	1	4	1
197	Dec. Cr +6	McDermid	1979	$44,646	$56,890	$101,536	$28,565		$28,565						1	4	1
197	Ni (Watts)	McDermid	1978	$41,521	$56,950	$98,471	$40,016		$40,016						1	4	1
197	Ni (Watts)	McDermid	1979	$54,172	$56,960	$111,132	$40,016		$40,016						1	4	1
213	Cr Etch	Corning	1988	$80,557	$0	$80,557									2	5	1
275	Dec. Cr +6	Corning	1984	$70,000	$6,500	$76,500	$10,000	$4,250	$14,250	$200,000	$200,000	$38,000		$438,000	1	4	2
280	Cr Etch	Corning	1990	$90,000	$8,000	$98,000				$16,400	$80,700	$10,000		$107,100	1	4	3
298	Zinc (CN)	Wastesaver	1991	$43,000	$29,000	$72,000	$15,600	$7,800	$23,400	$31,000	$13,000		$3,000	$47,000	1	2	2
	Average		*1983*	*$70,889*	*$29,462*	*$100,350*	*$19,842*	*$6,221*	*$21,451*	*$101,273*	*$62,700*	*$16,345*	*$6,125*	*$142,347*		*3.5*	

Exhibit 10. Partial Summary of Users Survey Data for Ion Exchange (bath maintenance applications)

Plating Shop Code	Plating Solution Application	Manufacturer	Year Purchased	Capital Costs			Operating Costs ($/Yr.)			Savings					Use Code (3)	Satisfaction Level with Technology (4)	Future Decision (5)
				Equip.	Other	Total	Non-labor	Labor	Total	Bath Chem.	Treat. Chem.	Sludge Disp.	Other	Total			
049	Cr Anodize	Kinetico	1990	$18,000	$1,000	$19,000		$1,200	$1,200	$2,000	$1,000	$10,800	$2,500	$16,300	1	5	2
067	Hard Cr	Eco-Tec	1993	$49,000	$3,000	$52,000	$9,000		$9,000						1	5	1
077	Hard Cr	Eco-Tec	1991	$60,000	$40,000	$100,000	$50,000		$50,000	√	√	√			1	4	1
131	Hard Cr	Eco-Tec	1975	$26,000	$3,500	$29,500	$10,000		$10,000						1	4	1
150	Hard Cr	Eco-Tec	1992	$65,000	$16,000	$81,000		$2,900	$2,900						1	4	1
165	Hard Cr	Eco-Tec	1987	$31,000	$12,000	$43,000	$6,912	$2,640	$9,552						1	5	1
191	Dec. Cr +3	Kinetico	1991	$34,121	$1,500	$35,621		$3,000	$3,000	$16,000	$1,000	$2,500		$19,500	1	5	1
198	Hard Cr	Aqua Line	1990	$10,000	$800	$10,800	$15,000	$1,000	$16,000	$2,000		√		$2,000	1	4	1
234	Hard Cr	Eco-Tec	1983	$17,000	$0	$17,000									2		3
244	Cr Anodize	Eco-Tec	1982	$14,647	$1,500	$16,147		$15,600	$15,600						2	1	3
273	CrO3 Cu Strip	ILL Water Treat	1987	$58,000	$0	$58,000	$3,000		$3,000			$500	$1,000	$1,500	2	2	3
	Average		*1987*	*$34,797*	*$7,209*	*$42,006*	*$15,652*	*$4,390*	*$12,025*	*$6,667*	*$1,000*	*$4,600*	*$1,750*	*$9,825*		*3.9*	

Notes:

(1) Purchased used..

(2) Purchased second hand, but unused.

(3) Use Codes: 1-currently operating; 2-not currently operating and no intension for future use; 3-not currently in use, but intend to use in future.

(4) Satisfaction levels 1 to 5, with 1=lowest and 5=highest (database also contains satisfaction levels for manufacturer's support).

(5) Future decision codes: 1-purchase the same technology from the same vendor; 2-purchase the same technology from a different vendor; 3-purchase a different technology; 4-do nothing.

(6) "√" indicates that a savings was realized, but not quantified.

(7) Average capital costs do not account for differences in purchase dates.

portion of a degraded solution and replacing it with fresh solution. In both cases, the spent solution is usually either treated on-site or transported to a treatment/disposal site. On-site treatment is not always possible because concentrated wastes may upset treatment facilities designed primarily for treating dilute rinse waters.

Two major categories of solution maintenance were identified during the project: preventative and corrective. Within the NCMS report, preventative solution maintenance refers to the practices that avoid bath contamination or involve monitoring and adjusting of solution chemistry. Corrective solution maintenance refers to the practice of removing contaminants from the bath, whether they are dissolved or particulate, organic or inorganic. Both preventative and corrective solution maintenance involve the use of methods, techniques and technologies. Methods and techniques are typically procedural in nature or low capital items that can be implemented quickly and have an almost immediate payback. Technologies are generally equipment packages that have a moderate to high capital cost and payback periods of one year or greater. Most preventative measures are either methods or techniques. However, some technologies such as an electroless nickel bath automatic replenishment system would also fall into this category. Corrective measures include both methods/techniques such as dummy plating and technologies such as microfiltration (ref. 1).

Within the NCMS report, the corrective technologies, which are generally less familiar to platers, are covered in detail. The methods of preventative and corrective solution maintenance that are commonly applied by plating shops (e.g., filtration) are more familiar to platers and therefore are covered less extensively. Exhibit 10 presents an example (ion exchange) of the Users Survey data summaries contained in the report. Other technologies covered by the report include: microfiltration, acid sorption, ion transfer, membrane electrolysis and diffusion dialysis.

SUBSTITUTE TECHNOLOGIES

The results of the Users Survey show that respondents have made significant strides in reducing or eliminating the use of chlorinated solvents, cadmium, cyanide and chromium. Sometimes referred to as the four Cs, these materials have been identified by EPA as key targets for control within the metal finishing industry. Approximately 60 percent of the respondents attempted material input changes that potentially reduce or eliminate the use of one or more of the four Cs or another pollutant problem. Based on the comments received from respondents, these changes were made in an effort to reduce the impacts of their processes on the environment and worker health, to help meet environmental regulations and to reduce operating costs.

Although most of the material input changes attempted by survey respondents have been successful, there have been some failures and in many cases, even with successful changes, there have been adverse production impacts. The NCMS report summarizes the status of change in these areas and conveys the attitudes and concerns of the respondents.

An example of a data summary regarding substitute technologies is presented in Exhibit 11. This exhibit shows that among respondents to the Users Survey, the number of solvent users has changed since 1980. In Exhibit 11, the shops are divided into three groups: (1) those in existence in 1980; (2) those established from 1981 to 1985 (inclusive); and (3) those established from 1986 to 1993 (inclusive). For the older shops, the number of solvent users remained approximately the same from 1980 to 1985 and then declined substantially from 1986 to 1993. In 1980, 53% of the shops used solvent and by 1993 only 39% used solvent. Therefore, 26% of the solvent users in 1980 have eliminated its use. For shops established from 1981 to 1985, the frequency of solvent use was below that of the older shops in 1985 and then from 1986 to 1993, the percentage declined similarly to the declining use rate of the older shops. Thirty-one percent of the shops established from 1981 to 1985 that originally used solvent have eliminated its use. The most recently established shops (1986 to 1993) presently have approximately the same percentage of solvent use as the shops established in 1981 to 1985.

END-OF-PIPE TREATMENT/SLUDGE DISPOSAL/RECOVERY

Various technologies are used by platers for end-of-pipe treatment. These technologies have been grouped during the NCMS project into conventional and alternative methods. Conventional treatment is a series of unit processes used extensively by industry that have provided reliable treatment for many electroplating operations (e.g., metals precipitation using sodium hydroxide and polymer). Alternative treatment methods are sometimes used by platers to reduce capital and/or operating costs or to improve pollutant removal efficiency.

The Federal electroplating and metal finishing pretreatment wastewater standards were developed by EPA by identifying commonly used treatment practices and determining their effectiveness by

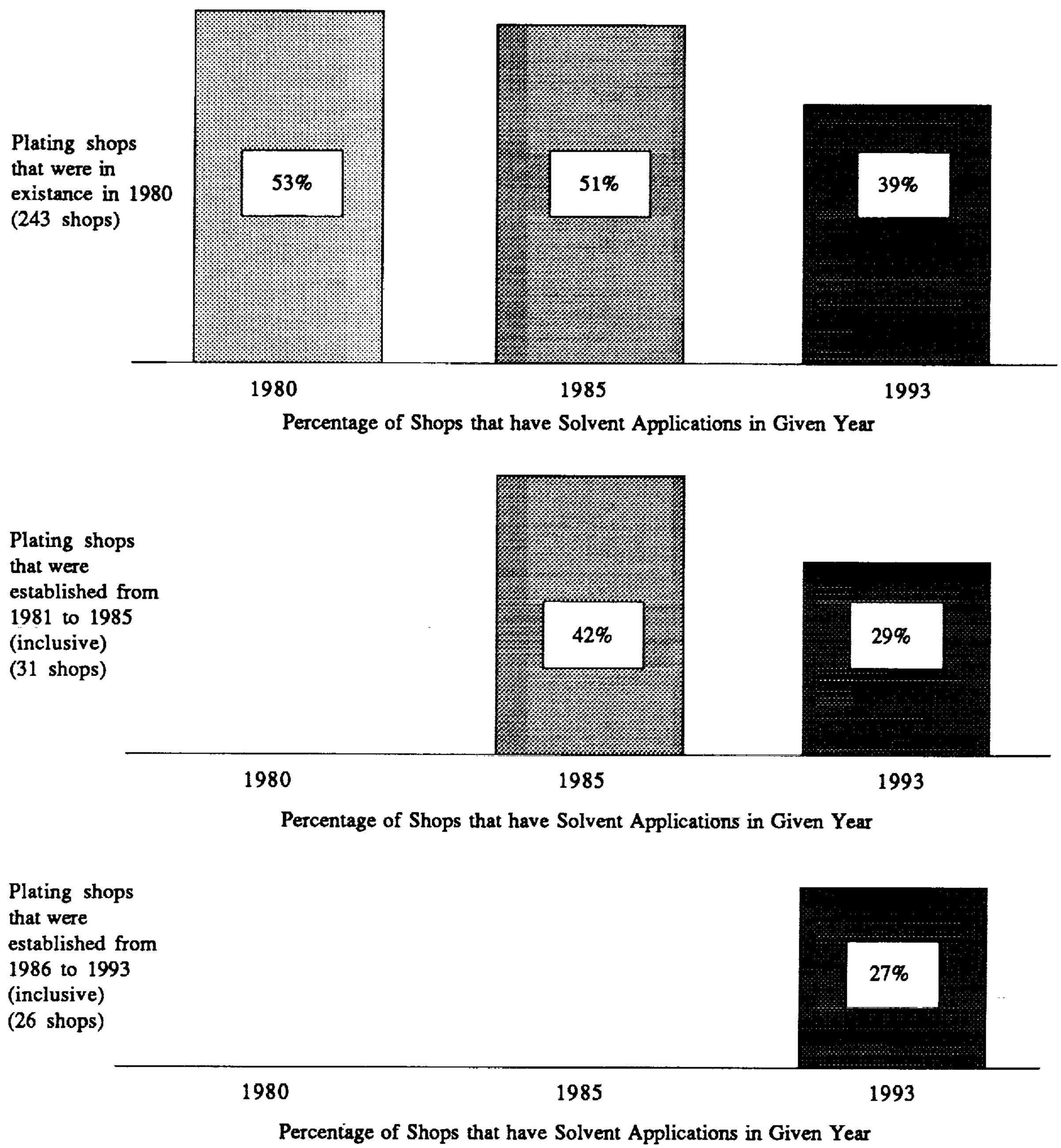


Exhibit 11.
Assessment of Pollution Prevention and Control Technology for Plating Operations
Distribution of Solvent Usage from 1980 to 1993 by Shop Age

collecting effluent data from well operated systems. Conventional treatment was selected by EPA as the standard system. Therefore, for most plating shops, use of conventional treatment will provide sufficient pollutant removal to meet discharge standards. There are two major exceptions to this rule. First, many plating shops are regulated by local discharge standards that are more stringent than the Federal standards and conventional treatment may be insufficient to meet these limitations. Second, the treatment systems selected by EPA for establishing the Federal standards were those systems that EPA determined to be "properly operating facilities." For example, EPA omitted facilities that: (1) did not have well operated treatment processes; (2) had complexing agents (e.g., non-segregated wastes from electroless plating); and (3) had dilution from non-plating wastewaters. As a result, some plating facilities may not meet the properly operated facility criteria used by EPA and may have difficulty meeting Federal standards using conventional treatment.

In cases where conventional treatment is insufficient to meet discharge limitations for a given facility, there are three basic choices for attaining compliance: (1) correct or upgrade the existing processes; (2) make internal changes (e.g., improve rinsing, add recovery, segregation of waste streams) to "normalize" the wastewater, (3) use conventional treatment plus additional treatment (i.e., polishing), and (4) use alternative treatment processes. Information on each of these methods is covered in the NCMS report.

One of the most frequent concerns of platers is the availability and cost of disposal for treatment process residuals (mainly F006 sludge). Respondents to the Users Survey generate an average of 160,000 lbs of sludge per year (median value is 50,000 lbs/yr) and spend an average of $27,300 per year for sludge disposal. The NCMS report provides data from each respondent covering sludge generation rates, the location of their disposal site, the distance that sludges are hauled, the solids concentration of the sludge, and the disposal charges. Many platers (33% of the respondents) are using off-site metals recyclers as an alternative to land disposal of their treatment residuals and spent process solutions. The NCMS report identifies the recycling companies used by the respondents, presents an overview of their recovery processes (provided by the recycling companies themselves), presents criteria for determining the applicability of off-site recycling, and compares the costs of recycling to land disposal.

SELECTED CONCLUSIONS DRAW FROM SURVEY RESULTS

The NCMS report contains such a wealth of information and data that a complete analysis of the results would take years to perform. One of the reasons for including a disk copy of the database with the report is to allow platers, vendors, researchers and other interested individuals the opportunity to perform their own analyses and develop their own conclusions. The following are conclusions drawn from several key areas of the survey results by the authors of this paper.

Pollution Control Technology Changes from 1975 to 1993

Pretreatment standards for the electroplating industry were first established in 1974, but it was not until promulgation of 40 CFR 413 on September 7, 1979 that Electroplating Categorical Pretreatment Standards became a reality. Several years later, EPA promulgated the Metal Finishing Categorical Standards (40 CFR 433). Prior to the existence of Federal standards, plating shops were regulated locally (if at all), presumably, with wide variation in effluent limitations and levels of enforcement. Most plating shops did not have treatment systems for cyanide destruction and metals removal. Approximately 12 percent of the surveyed plating shops that were in business in 1975 (excludes zero discharge shops) indicated that their initial treatment system was installed by that year. Exhibit 12 presents a breakdown of the data in five year increments. These data indicate that by 1985, after the compliance dates for Federal regulations, 70 percent of the surveyed plating shops had installed their initial treatment system (excludes zero discharge shops).

Exhibit 12. Distribution of End-of-Pipe System Installation Dates

Initial Treatment System Installed By:	Percent of Shops*
1975	16%
1980	32%
1985	70%
1990	95%
1993	98%

*Percent of shops in business by the date indicated. Excludes zero discharge shops.

Most initial treatment systems were installed between 1980 and 1985, although by 1985 there were still a substantial number of shops that had not installed their initial system.

Most plating shops installed conventional treatment to meet Federal regulations. Although it is difficult to assess exactly the respondents' data concerning end-of-pipe technology, it appears that an early trend occurred during the late 1970's and early 1980's when a significant percentage of shops attempted to utilize advanced technology in place of conventional treatment. These early efforts generally resulted in failure and the shops later resorted to conventional systems. One prominent example of this trend is the implementation of high surface area electrowinning as an end-of-pipe technology. Between 1979 and 1983, approximately 4 percent of the shops (excludes zero discharge shops) in existence installed this technology at an average cost of $66,360. Only one of these systems is currently operating and that unit was extensively modified by its user. Early failures such as these appear to have had a negative impact on advanced technology. No single technology has since emerged as a significant replacement for conventional treatment. In fact, changes in end-of-pipe methods have tended toward simpler technologies. Proof of this statement is that the most significant technology change with respect to end-of-pipe treatment since 1975 is the use of sludge dehydration equipment (i.e., sludge dryers) to reduce the volume of sludge shipped off-site (29 percent of the respondents have installed this relatively simple technology with approximately 80% purchased between 1988 and 1993). Approximately 10% of all the shops surveyed presently rely on non-conventional treatment methods (includes zero discharge shops). The most popular non-conventional end-of-pipe treatment methods (ion exchange, evaporation, and membrane technology) are covered in the NCMS report.

It should be noted that the majority of respondents to the Users Survey were job shops. More frequent use of advanced end-of-pipe technology may exist in other industry segments such as captive aerospace facilities.

Approximately 8% of the shops surveyed have attained zero discharge. These shops are generally smaller and less diverse than the shops with discharges. The average and median number of employees at the zero discharge shops is 16 and 15, respectively (for all shops the employee figures are: average = 67 and median = 35). Of the zero discharge shops, 58% are primarily hard chrome platers. The hard chrome process is one of the easiest to operate as a close-loop because of the high ratio of evaporation to drag-out (i.e., permits use of spray rinsing over the bath, drag-out recovery rinsing, etc.). The remaining zero discharge shops operate various metal finishing processes, including: cadmium, nickel and zinc plating; conversion coating; and aluminum finishing. Details of their metal finishing processes and pollution prevention and control technologies are contained in the NCMS database and summarized in the NCMS report.

Status of Pollution Prevention

Pollution prevention has emerged as an important method of attaining compliance and reducing operating costs. Widespread success has been achieved using simple methods and techniques that reduce drag-out losses and rinse water use. More than 90 percent of the shops indicated that they utilize these tools and have benefited from them. Although some shops have had great success with chemical recovery technologies, these have generally been much less frequently applied than drag-out and rinse water reduction efforts. The most successful of the chemical recovery technologies is atmospheric evaporation, which is generally regarded as the most simple to use. Bath maintenance technologies are less frequently used than are chemical recovery and have generally been less successful. Exhibit 13 shows ratings given by the respondents for some common pollution prevention methods.

Causes of Failure for Some Advanced Technology Applications

Many installations of chemical recovery technologies and advanced bath maintenance have not been successful (approximately 30 to 40 percent). The survey respondents indicate that failure is most frequently caused by: maintenance problems, misapplication of the technology (often due to ignorance on the part of manufacturer's representatives and/or the plating shop personnel), poor design, inability to purchase replacement parts (usually manufacturer went out of business), poor technical support by manufacturers, improper operation of technology by shop personnel, technically too complex for employees, chemical recovery caused a build-up of contaminants in plating bath, recovery process destroyed plating chemicals, recycled water was of insufficient quality, chemical product was insufficiently concentrated for return to plating bath, inadequate capacity, and high residuals generation.

Maintenance problems were the most frequent cause of system failure. The maintenance problems most often reported with advanced technologies are: low quality system components, mechanical problems with pumps and valves, damage to or fouling of components by plating chemicals, and excessive labor requirements for system cleaning. Exhibit 14 indicates the operational status of the chemical recovery and bath maintenance technologies purchased by survey respondents.

Exhibit 13. Ratings for Pollution Prevention Methods and Technologies

Method	Average Rating*
Good Operating Practices (all methods)	3.9
Drag-Out Reduction (all methods)	3.5
Rinse Water Reduction (all methods)	3.8
Chemical Recovery:	
Atmospheric Evaporators	3.8
Vacuum Evaporators	3.5
Ion Exchange	3.2
Electrowinning (all)	3.1
Electrowinning (excluding high surface area)	3.4
Electrodialysis (one data point)	1.0
Reverse Osmosis	3.0
Weighted Avg. for Chemical Recovery	*3.4*
Bath Maintenance:	
Microfiltration	–
Ion Exchange	3.9
Acid Sorption	4.3
Ion Transfer	3.5
Membrane Electrolysis	3.0
Diffusion Dialysis	–
Weighted Avg. for Bath Maintenance	*3.7*

Number of data points shown in parenthesis)
*(1 to 5 with 5 being the most successful)

Most Pressing Environmental Problems and Environmental Technology Needs

The respondents to the Users Survey indicated that their most pressing environmental problems were (percent identifying problem shown in parenthesis): increasing costs of compliance (73%); frequently changing regulations (55%); meeting effluent discharge standards (38%); eliminating the use of solvents (25%); meeting air emissions standards (24%); and lack of disposal sites (19%).

The environmental technology needs identified by the respondents were (percent identifying need shown in parenthesis):

- Alternatives to solvent cleaning/degreasing (12%)
- Better cyanide plating alternatives or controls (11%)
- Improved methods for water reduction, closed-loop processing, source reduction, recycling or zero discharge (9%)
- Better cadmium plating alternatives or controls (8%)
- Improved methods or more affordable end-of-pipe treatment (7%)
- Alternative to chromium metal finishing (includes all uses such as anodizing, plating and conversion coating) (6%).

Exhibit 14. Operational Status Of The Chemical Recovery And Bath Maintenance Technologies Purchased By Survey Respondents

Technology	% of Technologies That are Still Operating	Average Age of Operating Units (years)	Average Age of Non-Operating Units (years)	Age of Oldest Operating Unit (years)
Recovery:				
Atm Evap.	90%	5.4	6.1	18
Vacuum Evap.	74%	8.3	13.8	15
Ion Exchange	61%	6.5	5.4	18
Electrowinning	59%	5.5*	6.9	13*
Electrodialysis	0%	–	9.0	–
Reverse Osmosis	50%	4.0	9.3	6
Bath maintenance:				
Microfiltration	0%	4.4	1.0	–
Ion Exchange	73%	9.0	1.0	18
Acid Sorption	100%	4.9	--	15
Ion Transfer	70%	5.0	7.7	7
Membrane Electrolysis	60%	–	4.0	9
Diffusion Dialysis	–	--	--	–

*Excludes 43 year old homemade silver recovery unit that is still operating.

Future NCMS Survey Efforts

The initial NCMS project activities have established a benchmark assessment of pollution prevention and control technology for plating operations. The project products will assist platers in various ways, including: sharing ideas for drag-out and water use reduction; providing useful technology descriptions; providing an explanation of EPA's pollution prevention concept; summarizing cost and performance data from actual technology installations involving chemical recovery, bath maintenance and waste treatment; summarizing plater's experiences with alternative process chemicals that may reduce the hazardousness of the plating processes and the resultant wastes; and providing detailed data for off-site metals recycling options. This assessment has been made possible by the efforts of numerous platers, technology vendors and other interested parties. Hopefully, this industry will continue these efforts by participating in updates of the assessment. Each iteration of the assessment process will refine our technical knowledge and lead to more cost effective means of complying with environmental regulations.

References:

1. Cushnie, George, *Assessment of Pollution Prevention and Control Technology for Plating Operations*, National Center for Manufacturing Sciences, Ann Arbor, MI, 1994.

2. USEPA, *Guidance Manual for Electroplating and Metal Finishing Pretreatment Standards*, Effluent Guidelines Division, Washington, DC, 1984.