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Waste Reduction Through Material and Process Substitutions: Progress and Problems Encountered in Industrial Implementation

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ABSTRACT

This article presents eleven examples of successful material and process substitutions in the following areas: (1) replacement of chlorinated, caustic, or acidic cleaners and degreasers; (2) replacement of toxic metals; and (3) replacement of organic-based inks, paints, and solvents with water-based substitutes. Using these example cases, out both technical and regulatory constraints to the development of effective substitutes are discussed. Finally, ways are suggested to stimulate research and development to expand the utilization of these alternative technologies.

INTRODUCTION

In the fall of 1984, the U. S. Congress amended the Resource Conservation and Recovery Act (RCRA) in a number of significant ways that may have far-reaching effects upon many facets of society. The new RCRA amendments, by phasing out the land-disposal of various classes of hazardous wastes and by requiring industries to develop plans for waste reduction and toxicity reduction, provide substantial regulatory pressures for corporate leaders to implement technically and economically sound means of meeting the new environmental goals.

Some observers of environmental regulatory approaches see the RCRA amendments as further unnecessary meddling by the government in the industrial world's domain of providing goods and services for consumers in ways that are internationally competitive. Other observers see these amendments, if enforced according to their understanding of Congress' intent, as providing strong impetus for comprehensive emphasis upon a systems' approach to solving environmental and economic problems. The latter category of observers say that much of the regulatory emphasis of the past has provided only a medium-specific emphasis upon end-of-pipe pollution controls. In contrast, they see that while the RCRA amendments were ostensibly designed to minimize the generation and land "disposal" of hazardous wastes, the experience of some leading industries suggests that these amendments, coupled with increasing liability risks under CERCLA, OSHA, Worker's-Right-To-Know and Community-Right-To-Know, are making it increasingly sensible to use a systems' approach to the PREVENTION of the production and release of pollutants rather than a medium-by-medium, problem-by-problem approach to

POLLUTION CONTROL.

During the last ten years, leading industrialists around the world have documented successes that confirm the wisdom of placing primary emphasis upon the question of "how can we prevent or minimize the production of the pollutant?" rather than upon the question of "how can we dispose of our wastes?" In Europe, such approaches are termed, "Low and Non-Waste Technologies," "Clean Technologies," or "Environmental Technologies." In the U.S. and Canada, the terms "Pollution Prevention," "Waste Minimization," "Waste Reduction," and "Source Reduction" are used to refer to the approaches that utilize the preventative focus. The following citations document some of the experiences to date (1-19).

The industrial pollution prevention and waste reduction successes referred to in these publications have been found to occur in the following categories:

a. Improved housekeeping
b. Process modification through materials substitution
c. Equipment redesign

While much has been written about the role of each of these approaches and while all three approaches are frequently utilized at industrial facilities, this article focuses upon MATERIALS AND PROCESS SUBSTITUTIONS of a less toxic and/or less polluting component in the manufacturing process for the previously used material or process. The eleven examples which are presented herein illustrate replacement of chlorinated, caustic, or acidic cleaners and degreasers; replacement of toxic metals; and replacement of organic-based inks, paints, and solvents with alternative materials or processes. These brief discussions describe substitutions that have successfully reduced hazardous waste production.

1. Replace chlorinated with water-based degreasers.

In his article, "How to Meet Tough VOC Regulations," (20) Tilghman Fenstermaker cites the switch to chlorinated solvents as the alternative characterized by least difficulty and cost. Many state and local regulations exempt chlorinated solvents as a substitute for hydrocarbon solvents due to their low photochemical activity. For example, in 46 states, 1,1,1-trichloroethane is excluded from air quality regulations as described within the mandated State Implementation Plan (SIP) guidelines (nonexempt in MI, RI, NJ, and KY). (21) EPA guidelines are much broader, with only water, methylene chloride, and 1,1,1-trichloroethane exempted. (22) Chevron USA (23) and Carrier Corporation (24) have documented examples of substituting formulations based on 1,1,1-trichloroethane for other more toxic chlorinated solvents.

The use of 1,1,1-trichloroethane and methylene chloride seems to be an easy solution to the problem of reducing VOCs and other hazardous substances; however, there is concern in many quarters that halogenated solvents may be contributing to the disruption of the protective ozone layer. The EPA is in the process of preparing tough new standards that will regulate the use of almost all halogenated solvents. Work is also underway in The Netherlands to replace chlorinated solvents with water-based solvents in as many applications as possible.

New water-based cleaning solvents have been developed which, in many applications, can replace chlorinated and other organic solvent cleaners. Several companies have introduced new product lines which are non-petroleum, non-chlorinated replacements for organic solvents, solvent emulsions, and alkaline cleaners. In tests for removal efficiency of heavy greases, carbonized oils, gear lubes, grease buildups, oily deposits, tar, and bituminous deposits, the water-reducible cleaning solvents have outperformed most organic-based cleaners. These new cleaners are biodegradable and water soluble, producing no VOCs or hazardous waste.

These new water-based cleaning solvents can be used to break water-oil emulsions and therefore expedite resource recovery and waste reduction. The characteristics of these water-based cleaners make possible easy recovery of oils and simple separation of soil from the solvents. The formulations permit the discharge of used solvents to wastewater treatment plants.

The Hotsy Corporation, for example, provides high pressure hot water cleaning services to trucking and heavy equipment manufacturers, textile companies, metal finishing operations, and a wide variety of other manufacturing and process industries. In fact, Tom Martin of the Denver, North Carolina office says that "every industry in North Carolina is a prospect for us." Hotsy uses either water alone or with biodegradable chemicals such as a mild butyl-based cleaner in their operation. Frank Smith of the Knoxville office describes the system as being far superior to organic chemical cleaning with respect to efficiency and cleaning performance. The chemicals used in the system are cheaper and dilute farther than chlorinated solvents such as trichloroethane. Additionally, they produce no VOCs or hazardous waste.

One company which has successfully substituted water-based cleaners for organic solvent-based cleaners is the Hamilton Beach Division of Scovill, Inc. in Clinton, North Carolina. Scovill used 1,1,1-trichloroethane solvent to degrease the metal stampings in their small appliances manufacturing process. The company tested a water-soluble synthetic cleaner as a possible substitute for the 1,1,1-trichloroethane organic solvent degreaser. After some experimentation, they found the cleaner suitable for some of their applications and have been able to reduce their 1,1,1-trichloroethane use by 30 percent. The water-soluble cleaner is not suitable for all applications because it can corrode galvanized parts. Scovill reports an annual savings of $12,000 from this substitution. (25)

There are many other examples of effective solvent substitution for chlorinated degreasers and cleaners. Among them, Texas Instruments was able to eliminate its use of trichloroethylene (TCE) throughout its Attleboro operations. The substitute, an alkali cleaner used in a high-pressure process, actually improved finished product quality and reduced operating expenses. Electronic Molding in Providence, RI was able to substitute a water-based detergent for TCE in cleaning pins for use in electronic equipment. In New Hampshire, Moore Business Forms was able to eliminate the use of its organic degreaser in 90 percent of its cleaning operations. Instead, the firm uses water in a steam cleaning operation. (26)

2. Replace caustic metal cleaner with pneumatic system.

Vulcan Automotive Equipment Ltd. (Vancouver, British Columbia, Canada) remanufactures used automotive engines. The previously used cleaning process was modified by replacing the inorganic caustic cleaner with a pneumatic "aluminum shot" system. In this system, a high velocity stream of spherical aluminum shot is directed onto the engine blocks being cleaned. The abrasive action of the shot thoroughly and effectively removes all grime and rust. Furthermore, the engine blocks acquire an aluminum coating which is rust-resistent and which imparts an appearance of "brand new cast metal." This modification in equipment design resulted in substantial savings to the company due to decreased costs for raw materials, labor, and avoided hazardous waste management costs. The new aluminum shot system increased productivity, improved the final product, and provided an annual cost savings of $40,000 and a payback period of approximately two years. (27)

3. Replace caustic metal cleaner with high pressure hot water closed-loop system cleaner.

Chevron USA, Inc. maintains a petroleum product warehouse in Louisville, Kentucky. A shipping-drum reconditioning facility, in which used drums are cleaned and repainted for reuse, is operated on-site. Prior cleaning practices generated a complex hazardous waste stream composed of caustic, oil, water, and paint, which cost Chevron $50,000 annually to manage. A high-pressure, hot water cleaning system was installed to replace the caustic cleaning system. The new system is a closed-loop process which reuses the filtered cleaning water and also ensures recovery of oil removed from the drums and generates no hazardous waste. The system resulted in an annual savings of $80,000 with a 3-year payback period. (28)

4. Replace acidic metal cleaner with mechanical abrasion cleaner.

3M's microelectronics plant in Columbia, Missouri makes flexible electronic circuits from copper sheeting. Before use, the copper sheeting was previously cleaned by spraying it with ammonium persulfate, phosphoric acid, and sulfuric acid. This process resulted in the production of substantial quantities of hazardous wastes which were expensive to manage. An alternative equipment design was introduced to replace the chemical cleaning process. The new process features a machine with rotating brushes that mechanically cleans the metal using pumice. The use of the fine abrasive pumice generates a very small quantity of nonhazardous sludge which can be placed in a conventional sanitary landfill. This new method reduced the plant's annual hazardous waste production by 40,000 pounds. The new system also saved $15,000 in its first year, due to reduced raw material, hazardous waste management, and labor costs. (29)

5. Replace chromic acid bright dip with sulfuric acid/peroxide dip.

Stanadyne, Inc. in Sanford, North Carolina, which manufactures plumbing fixtures, has found a way to perform chromic acid bright dips with reduced waste generation. Brass and copper parts which had been brazed together were previously cleaned using a chromic acid bright dip, an operation which was a major hazardous waste producer. Stanadyne substituted a sulfuric acid/peroxide bright dip, which not only performs well but also produces much smaller quantities of hazardous waste sludge. (30)

6. Replace acidic methylene chloride paint stripping with pneumatic paint stripping operations.

The U.S. Department of Defense has documented many examples of physical process substitution (31). One particular case involves Hill Air Force Base in Ogden, Utah. Previously, the method of choice for aircraft paint stripping was an acidic methylene chloride solution which dissolved and loosened the paint. Plastic media pneumatic paint stripping has been successfully used for aircraft paint removal. In this process, old paint is removed with conventional sand blasting equipment using recoverable plastic beads. A dry waste of pulverized paint and plastic beads is produced, and the beads are reused. The previous caustic cleaning method produced 20,000 gallons of liquid hazardous waste per plane. The new pneumatic stripping method produces no liquid waste, only a small quantity of dry waste which can be safely managed in sanitary landfills.

7. Replace mercury with selective membrane.

ICI, at one of its plants in the United Kingdom, incorporated an FM 21 reverse osmosis (RO) membrane cell which does not entail the use of mercury for chlor-alkali production. This change resulted in a 30 percent reduction in energy requirements. It is more compact, thus requiring less production space; is easier to install and maintain; and allows for greater flexibility and control of the production process. Most importantly, the new membrane-based cell produces chlor-alkali with no mercury-containing hazardous waste.(32)

8. Replace cadmium-containing pigments.

Another substitution possibility is that of replacing a toxic substance with one less toxic while maintaining the same level of performance and production. One such area of material substitution is in the plastics industry, replacing cadmium-containing pigments with pigments that are less toxic. A report issued by the National Swedish Environment Protection Board (33) discusses the technical problems associated with finding substitutes for cadmium-containing compounds as pigments and stabilizers in different plastics as well as the time frames within which substitutes for cadmium in plastics can be expected to be forthcoming.

Approximately 80 percent of all cadmium pigments are used within the plastics industry, of which 85 percent are used in high volume plastics such as polyethylene, polypropylene, polystyrene, ABS, and PVC. The remaining 15 percent of the cadmium pigments are used in engineering plastics. It is possible, in most cases, to replace the cadmium-containing pigments in high volume plastics without any decrease in product quality; however, it is considerably more difficult to find substitutes in engineering plastics, such as polyamides, because of their higher processing temperatures. It is difficult to make generalizations regarding the possibilities of finding substitutes for cadmium in pigments. The demands on pigments vary between different plastics, processing temperatures, and products. Of crucial importance in finding substitutes for cadmium-containing pigments is the question of how much deviation in color and decrease in color quality will be accepted by the consumer.

The use of cadmium in Sweden for stabilization of PVC has been reduced by about 75 percent since the end of the 1970′s. Most cadmium stabilizers are currently used only in outdoor products. For certain flexible PVC products for outdoor use, it does not appear to be possible, at the present time, to completely eliminate cadmium without causing a substantial deterioration in quality. In PVC-coated fabric, on the other hand, it is usually possible to replace cadmium. Plasticol-coated steel sheet for outdoor use is still stabilized to some extent with cadmium stabilizers, since high demands are made on long-term stability and sunlight resistance. In other flexible PVC products for outdoor use, it has been possible to replace cadmium with, for example, zinc- or lead-containing stabilizers.

Substitution problems exist primarily in products of rigid PVC intended for long-term outdoor use. Certain types of tin stabilizers, primarily tin mercaptides and carboxylates, are regarded as promising substitutes from the technical viewpoint. In flexible products for indoor use, such as woodwork films, flooring, car upholstery, electrical cables, tubing, and hoses, it has been possible in most cases to replace cadmium. Substitutes in these applications can be zinc-containing stabilizers. There is no problem in replacing cadmium in rigid products for indoor use such as pipes, extruded sections, and phonograph records.

9. Replacement of organic-based paint with water-based paint in metal coating.

Emerson Electric Company of Murphy, North Carolina substituted a water-based anodic electrostatic immersion paint sustem for its organic solvent-based paint system in its production of small electrical appliances. As a result, the quality of the paint application has greatly improved, and annual productivity has increased by 1 million dollars. Down time for the new system has decreased 66 percent. The water-based system allows 99.5 percent recovery and reuse of the paint overspray. Consequently, raw material costs for paint have decreased by $600,000 per year. Instead of generating 3000 pounds per day of aromatic, chlorinated hazardous solvent waste and 70 pounds per day of paint solids, the company now generates only 150 pounds of non-reactive solvent per day, and only two pounds of paint solids per day. As a result of these changes, hazardous waste management costs have been reduced from $10,000 to only $300 annually. With the new paint system, personnel and maintenance costs have decreased by 40 percent, and worker exposure to organic solvents has been eliminated. (34)

10. Replace organic solvent-based coating with water-based coating in the pharmaceutical industry.

Riker Laboratories, one of 3M′s pharmaceutical plants in Northridge, CA, replaced the organic solvent coating for medicine tablets with a water-based one.

Different spray equipment was installed in the coating machine to accomodate the new coating medium. The pumping mechanism, tubing, and control systems were also modified. Because the switch was from organic solvents with a higher volatility than water, the heating capacity of the dryer had to be increased so that the tablets would dry properly. Special tests proved the stability of the product, the U.S. Food and Drug Administration approved it in time to meet the effective date of the new environmental regulations, and thus productivity was maintained and costly pollution control equipment was not needed.(35)

Although the original incentive for the change was California's VOC regulations, Riker received unexpected benefits from its modification. The firm saved $15,000 annually in solvent costs and $180,000 in pollution equiment which would have been required had they not changed to the water-based system. Additionally, Riker avoided liquid waste disposal costs, worker exposure to solvents, and future long term liability under CERCLA.

11. Replace organic-based ink with water-based ink.

Rexham Corporation in Greensboro, North Carolina substituted waterborne inks for the traditional alcohol/acetate-based inks in their manufacturing and printing of specialized product labels. There were initially several technical problems with the substitution, but, for many applications, operator retraining was sufficient to achieve excellent product quality with water-based inks. This change resulted in reduced spent solvent volume and air emissions of solvents. The substitution did result in decreased printing speed and cannot be used if gloss is required in the final product.(36)

CLEO WRAP of Memphis, Tennessee is the largest U.S. producer of Christmas gift wrapping paper. The company uses rotogravure printing with seven high-speed and two low-speed presses. Frequent ink changes and press cleanups using organic solvents led previously to the generation of large amounts of "ignitable" hazardous wastes and large quantities of VOC's. After five years spent in implementation, CLEO WRAP completed the conversion from organic solvent-based inks to water-based inks.

Annual hazardous waste disposal cost savings alone will exceed $35,000. Conversion to water-based inks eliminated land disposal requirements and solvent vapor air emissions, providing a safer worker environment. The cost of new equipment was only $3,500, including a steam cleaning tank for cleaning print cylinders and a waste dilution and disposal tank. The ink change resulted in the elimination of all solvent storage, below and above ground, and consequently a reduction in fire insurance premiums and a new status as a small hazardous waste generator.

However, the conversion to water-based inks involved a long pioneering effort with many interrelated modifications. The conversion necessitated that all printing cylinders had to be replaced with those having shallower etchings; all printing plant personnel had to be retrained to work with water-based ink technology; and ink suppliers had to be persuaded to develop a full range of water-based ink colors which did not exist in 1978, when the conversion was initiated.

Amko Plastics in Cincinnati, Ohio is a manufacturer of specialty plastic bags used by retail stores, industrial packagers, and promotional advertisers. Its manufacturing processes include flexographic printing, polyethylene film extrusion, injection molding, and bag manufacturing. In its efforts to comply with "best available technology" when installing three new printing presses in 1983, Amko decided to switch to a water-based ink system.

However, conversion from solvent-based inks to water-based inks was not an easy task; many procedural as well as manufacturing changes were necessary to facilitate the conversion. One challenge was to make everyone throughout the company--printing press operators, ink department personnel, sales representatives, administrative clerks, supervisors, and managers--aware of the commitment and involvement which would be required for successful implementation. Printing press and polyethylene film modifications were necessary because of the poor quality of early water-based inks and their significantly slower evaporation/drying rate. The ink distribution system, printing plate materials, and press cleanup also had to be modified.

Despite the technical challenges of the switch, some advantages have resulted. Water's slower evaporation rate and resultant smaller viscosity fluctuation make it easier to hold consistent color throughout a press run. Though the cost of water-based inks is frequently higher in cost per pound than alcohol-based inks, a higher yield can be expected because water-based inks contain more pigment per pound of finished inks. The management reports "a noticeable improvement in the quality of ambient press room air due to the drastic reduction of solvent vapors." (37)

Regulatory Constraints to Substitution Efforts

The previous two examples (CLEO WRAP and Amko) particularly highlight some of the technical difficulties of material or process substitutions. Substitution is not appropriate for every firm, and the decision to make a process change does not guarantee its success. As described in the Amko example, extensive procedural and manufacturing changes may be required. Financial, attitudinal, and time commitments may be more extensive than initially anticipated.

In addition to its technical problems, Amko continues to encounter difficulties as a direct result of inequitable Clean Air Act regulations and uneven enforcement of existing regulations on its competitors. Makrauer states:

> One competitor, located in Indiana, operates nine presses which are subject to absolutely no regulation since they were installed prior to 1980. This competitor is installing two new presses, which will have control devices, but is subject to no regulation requiring it to either convert to water-based inks or install control devices on its existing nine presses. In a personal conversation with one of their division officers, I was told, "Because of high unemployment in this area, local officials are afraid to do anything which might negatively affect employment."
>
> The EPA had not even heard of another large competitor, located on Long Island, New York. In a personal conversation with one of their vice-presidents, I asked, "Have you used any water-based inks?" "No," was the reply. "What do you do about getting permits when you install a new press?" I asked. "Oh, we don't get permits," he responded. "In our area, if you do not vent your press exhaust outside your building, you do not have to get permits." In a conversation with a representative of the New York Division of Air, an Amko attorney was told that, if there was no venting, no permit would be required and no EPA regulations would apply, because EPA regulations did not apply to inside air, regardless of the source.
>
> And, yet another competitor on Long Island paid fines of $5,000 on April 1, 1985, $10,000 on October 1, 1985, and $15,000 on April 1, 1986. They are claiming compliance with exempt solvents which, incidentally, have raised serious concerns within the industry about their potential toxicity and carcinogenicity.(38)

So, while Amko has spent over two million dollars on its compliance efforts, one competitor paid total fines of $30,000 and four others spent nothing whatsoever.

Another problem relates to the quality of currently available water-based inks. Because only a few firms have requested that suppliers develop and improve water-based inks with a commitment to completely converting from alcohol- to water-based inks, research expenditures, while significant, have not been as great as they would have been if all flexographic printers had put pressure on suppliers to develop a water-based system. Amko believes that the development of improved water-based inks is directly proportional to the number of printers whom the EPA forces to come into compliance with water-based inks.

A second problem relates to customer acceptance. Lower gloss levels and less vivid colors cause some customers to refuse products printed with water-based ink, turning instead to competitors who print with alcohol-based ink, out of compliance with EPA regulations. This problem might be alleviated by consistent EPA enforcement against all printers in the industry; if forced to choose between control devices and water-based inks, most printers would probably choose water-based inks. Consequently, the number of competitors whom consumers could turn to to print with alcohol-based inks would be significantly reduced.

A third problem is the 20 to 25 percent increased production costs of printing with water due to slower printing speeds with the water-based inks. Even after a successful conversion, water-based ink printing currently results in increased costs in the form of longer set-up and wash-up times, increased metal anilox roll maintenance, increased scrap rates, and slower production runs resulting from slower drying speeds. Other firms who have done virtually nothing to comply with EPA regulations have experienced neither these costs nor the cost of control devices.

The inequitable regulations and uneven enforcement which companies encounter have extended effects which may negate the original intent of the regulations: (1) if only a few companies comply, there is no stimulus for suppliers to engage in R&D to improve the alternative technology; (2) there is no incentive for customer acceptance of water-based ink products if some companies are allowed to operate out of compliance; and (3) companies who comply with regulations incur the added cost of implementation while their competitors do not. Makrauer feels that the EPA's enforcement scheme is not well served by permitting technological innovators such as Amko to suffer competitively and economically as a result of uneven enforcement. (39)

CONCLUSIONS

The eleven examples which have been presented illustrate that material and process substitutions <u>can</u> be effective. Replacing chlorinated and non-chlorinated organic solvents with alternative solvents and waterborne coatings results in minimized VOC emissions, reduced hazardous waste disposal costs, improved worker safety, and reduced explosion risk. Replacement of caustic and acidic metal cleaning systems with abrasive and mechanical cleaning approaches can, in many cases, almost completely eliminate waste generation. Finding a less toxic substitute or a physical process to replace toxic metals such as cadmium and mercury eliminates or reduces the problems of CERCLA liability and RCRA compliance.

These process changes have the potential not only to bring the firm into compliance with environmental regulations but also to enhance productivity and product quality. However, there are several constraints which inhibit the development and implementation of waste reduction strategies. Inequitable regulations and uneven enforcement discourage compliance by stifling research and development of alternative technologies, slowing customer acceptance of compliance products, and inflicting an unbalanced implementation cost on firms who do comply.

Caldart and Ryan (40) have developed an excellent model of the motivation and mechanism which characterize an effective regulatory policy to encourage production process change. Another stimulus for the development of waste reduction technologies would be for government and industry to work together in (1) <u>identifying</u> problem areas in need of safer substitutes, (2) <u>prioritizing</u> these research needs, and then (3) <u>providing financial support</u> in these areas for research teams drawn from academia, industry, and government sectors to develop and test new and safer materials and methods. The Dutch are pioneers in this area; Dutch government and industry give extensive financial support for the development of safer alternatives, relying on that as a vehicle towards achieving their environmental goals rather than upon regulations alone to be the driving force. The combination of governmental and industrial support of academic and industrial research to develop and test these alternative technologies, coupled with greater consumer acceptance of alternative materials, could be a practical paradigm for the United States.

REFERENCES

1. Campbell, M. and W. Glenn, Profit from Pollution Prevention, Pollution Probe Foundation, Toronto, Ontario, 1982.

2. Chazelon, J.C., Les Techniques Propres Dans L'Industrie Francaise, La Mission Technologies Propres de la Direction de la Prevention des Pollution du Ministere de l'Environment, Paris, 1982.

3. Compendium of Lectures on Low- and N Waste Technology, National Authority for Environment Protection and Nature Conservation, Budapest, 1983.

4. Compendium of Low- and Non-Waste Technology, United Nations Economic Commission for Europe, Geneva, and Switzerland, Vol.'s I-VI, Geneva, 1982, 1983, 1984.

5. Environmental Protection Technologies, Deutsche Forschungs - und Versuchsanstalt fur Luft-und Raumfahrt, Koln, West Germany, 1984.

6. Higgins, T., Industrial Processes to Reduce Generation of Hazardous Waste at DOD Facilities, Department of Defense Environmental Leadership Project Office, Washington, D.C., 1985.

7. Huisingh, D. and V. Bailey, eds., Making Pollution Prevention Pay, Pergamon Press, New York, 1982.

8. Huisingh, D., L. Martin, H. Hilger, and S. Thesen, Profits of Pollution Prevention, North Carolina Board of Science and Technology, Raleigh, NC, 1985.

9. Huisingh, D., L. Martin, H. Hilger, and N. Seldman, Proven Profits from Pollution Prevention, Institute for Local Self-Reliance, Washington, D.C., 1985.

10. Kauders, R. and U. Ousko-Oberhoffer, Austrian Non-Waste Technologies, Schriftenreihe der Arbeitgemeinschaft Unwelfschutz der Arbeirgeberverbande und der ORL-Osterreichischen Gesellschaft zur Reinhaltung der Luft, Wein, Austria.

11. Recycling '85: Turning Waste into Resources, Clean Japan Center, Tokyo, 1985.

12. Royston, M., Pollution Prevention Pays, Pergamon Press, Elmsford, New York, 1979.

13. Sarokin, D., W. Muir, C. Miller, and S. Sperber, Cutting Chemical Wastes: What 29 Organic Chemical Plants Are Doing to Reduce Hazardous Wastes, INFORM, Inc., New York, 1985.

14. Tavlarides, L., Process Modifications for Industrial Pollution Source Reduction, Lewis Publishers, Inc., Chelsea, MI, 1985.

15. Van den Akker, F., Low Pollution Process Technology in The Netherlands, Ministry of Housing, Physical Planning, and the Environment, Leidschendam, The Netherlands, 1986.

16. Vogel, G., 1984 Recycling = Moglichkeiten und Grenzen der Abfakkrerwertung, Servicebetriebe der Hochschulerschaft an der Wirtschaftsuniversitat, Wein, Austria, 1984.

17. Waste Abatement, Reuse, Recycle, and Reduction Opportunities in Industry, Environment Canada, Kingston, Ontario, 1984.

18. Huisingh, D. and J. Aberth, "Hazardous Wastes: Some Simple Solutions," Management Review, 75, 46 (1986).

19. Huisingh, D., L. Martin, and J. Aberth, Toward Pollution-Free Manufacturing, American Management Association Management Briefing, New York, 1986.

20. Fenstermaker, T., "Air-Dry Compliance Coating Chosen for Painting Large Air Conditioners," Products Finishing, 48, 69 (1983).

21. Dombrowski, S., "Specialty Solvents: The Safe Alternative," Industrial Finishing, 62, 55 (1986).

22. Carlsten, R. and P. Fisher, "New Technology Coatings Meet Low-VOC Requirements," Industrial Finishing, 62, 31 (1986).

23. "Chevron Meets VOC Regs with 1,1,1," Industrial Finishing, 59, 14 (1983).

24. Dinunzio, J., "Air-Dry Compliance Coating Chosen for Painting Large Air Conditioners," Products Finishing, 48, 69 (1983).

25. Huisingh, et al., Proven (1985) 41.

26. Ratzkin, A., Personal correspondence to D. Huisingh, RICOSH Committee on Occupational Safety and Health, November 21, 1986.

27. Huisingh, et al., Proven (1985) 239.

28. Ibid, 221.

29. Ibid, 165.

30. Ibid, 117.

31. Higgins, 3-4.

32. Fisher, J.C.D., "The Implementation of Cleaner Technologies," presented at the conference on Low- and Non-Waste Technologies: Theory and Practice (October 8-9, 1985). Zell Am See, Austria.

33. Haag, M. and I. Jedvall, Cadmium in Plastics: Possibilities of Substitution, National Swedish Environment Protection Board, Solna, 1985, 39.

34. Huisingh, et al., Proven (1985) 143.

35. Ibid, 83.

36. Ibid, 63.

37. Makrauer, G., "VOC Compliance in Flexographic Printing with Water-Based Inks," presented to the National Air Pollution Control Association, June, 1986.

38. Ibid.

39. Ibid.

40. Caldart, C. and C. Ryan, "Waste Generation Reduction: A First Step Toward Developing a Regulatory Policy to Encourage Hazardous Substance Management through Production Process Change," Hazardous Waste and Hazardous Materials, 2, 309 (1985).

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