

Identification of Pollution Prevention and Accident Prevention
Technology Opportunities for use in Supplemental Environmental Projects

by

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Submitted to the Department of Chemical Engineering
in Partial Fulfillment of the Requirements for the Degree of

Master of Science in Technology and Policy

at the

Massachusetts Institute of Technology

September 1997

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Abstract

Pollution Prevention (PP) is generally recognized as the preferred strategy to address environmental problems linked with industrial activity. The US Environmental Protection Agency (EPA), through a combination of various regulatory and incentive mechanisms, can influence the adoption of PP. This thesis (a) argues that the term PP in the Supplemental Enforcement Projects context should clearly include Accident Prevention (AP) goals and (b) proposes a methodological approach for the identification of promising PP technologies for possible inclusion in SEPs, that can maximize the environmental benefits of SEPs.

Part I establishes the conceptual framework and clarifies the relationship between AP and PP in the SEP context. This clarification may have significant impact in the environmental strategies of EPA, because currently AP technologies are not actively promoted by the EPA as part of SEPs, although they clearly meet the criteria of PP SEPs. Part II describes the screening criteria and proposed screening methodology in the identification of high-priority industrial sectors/industrial processes and product lines. These high-priority areas present a high potential for tangible environmental benefits if PP technologies are implemented. Moreover, the methodology offers a practical strategy for future application in the construction of pollution-oriented inter-sector prioritization schemes. Part III demonstrates an application of the search methodology in the identification of eight SIC-specific and four general-purpose PP technologies, that are suitable for promotion by the EPA through the SEP mechanism. Part IV presents policy recommendations for enhancing the effectiveness of the PP and AP initiatives of the EPA. These recommendations concern the scope of the PP SEPs, the proper information content that PP-related material should possess, and the ways that the PP technology prioritization methodology can be extended to AP technologies.

Several key conclusions emerged from this research. First, the working definition of PP in the context of SEPs should use language that explicitly encompasses AP. Second, there exists a number of sectors/processes/product lines with high environmental burden where proven PP technologies are available; EPA should actively promote their inclusion in SEP agreements. Finally, the coherent prioritization methodology for the identification of PP technologies that was developed in that thesis can be easily extended to the prioritization of AP technologies.

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Acknowledgments

I wish to express my thanks to Professor Nicholas Ashford of the Technology and Policy Program who gave me the opportunity to undertake this research and who has been a source of intellectual and moral support as well as a trusted advisor during my three years at MIT.

This research would not have been possible without the financial support of the Office of Enforcement, U.S. Environmental Protection Agency through a cooperative agreement (Grant No. CR 819086-01-2).

To my parents, I thank you for your continued interest, encouragement, and support throughout my academic life. Finally, for her patience, emotional support, and the joy she has brought into my life, I would like to thank Maria.

Σας ευχαριστω απο καρδιας !

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1.0 Introduction

The Pollution Prevention Act of 1990 identified Pollution Prevention (PP) as the preferred method of environmental management and control ahead of recycling, treatment and disposal. Consistent with this view, the US Environmental Protection Agency (EPA) has geared its enforcement program towards incorporating PP conditions into enforcement settlements whenever feasible.

Over the last five years, EPA has found that PP Supplemental Environmental Programs (SEPs) are a very useful tool to promote PP. Experience shows that it is the violating firms that are coming up with proposals about specific PP technologies; EPA does not offer a portfolio of proven PP technologies that can be promoted through SEPs. Additionally, EPA does not have a clear-cut and coherent methodology for prioritizing its PP preferences when dealing with various industrial sectors, processes or product lines.

The purpose of this thesis is to identify new or unexploited PP technologies that offer significant opportunities for environmental improvement in specific industrial sectors/processes/product lines that could be the focus of PP SEP initiatives. To accomplish that goal the following tasks were undertaken:

- (1) identification of major or serious sources of pollution associated with specific industries, industrial processes and product lines where the dominant technology in widespread use has remained essentially unchanged over the recent past.
- (2) identification of promising PP technologies in industrial processes and product lines that could offer significant improvements in environmental benefits, with special emphasis on multi-media improvements.
- (3) identification of those problem industries, industrial processes, and product lines--with special emphasis on small and medium size enterprises (SMEs)--which are in special need of technical information and assistance regarding PP solutions and whose access to this information or assistance from trade associations, in-house expertise or R&D departments, or connections with universities and research institutions is limited.
- (4) the development of criteria related to both EPA and firm concerns and characteristics for successful inclusion of specific technologies and technological approaches into SEPs and injunctive relief settlement agreements. These criteria include both behavioral and economic factors.
- (5) identification of those technologies that show particular promise for more widespread adoption in or transfer to specific industrial processes or product lines through SEPs and injunctive relief settlement agreements.

The major objective of the thesis was to uncover major Pollution/Accident Prevention Opportunities (PP/AP) that have both:

- significant potential for multi-media pollution/accident prevention benefits in 5-10 industrial sectors/industrial processes/product lines, especially sectors dominated by small or medium size enterprises, and
- features that make favorable their inclusion in enforcement settlements, e.g. relatively proven technologies, limited implementation horizon and significant capital expenditure.

The thesis sought to address *Gradual Releases* of pollutants with *Pollution Prevention* (PP) strategies, while *Sudden and Accidental Releases* would be addressed by *Accident Prevention* (AP) strategies. The relationship between PP and AP in the SEP context, is of great importance and needs to be clarified. Part I of that thesis, apart from describing the conceptual framework through the definition of central concepts (such as PP and SEP) explains why the working definition of PP should include AP. Part II describes the screening criteria and proposed screening methodology in the identification of high-priority industrial sectors/industrial processes and product lines, i.e. it addresses the five tasks described above. Part III demonstrates an application of the search methodology in the identification of eight SIC-specific and four general-purpose PP technologies, that are suitable for promotion by the EPA through the SEP mechanism. Part IV presents policy recommendations for enhancing the effectiveness of the PP and AP initiatives of the EPA. These recommendations concern the scope of the PP SEPs, the proper information content that PP-related material should possess, and the ways that the PP technology prioritization methodology can be extended to AP technologies.

PART I: “CLEANER” TECHNOLOGY OPPORTUNITIES IN THE SEP CONTEXT

2.0 Supplemental Environmental Projects (SEP) [1]

2.1 Background

In [1] a typical enforcement settlement is described as follows:

“Enforcement settlements negotiated by EPA have three major features: injunctive relief, penalties and SEPs. Injunctive relief (i.e. the specific actions that the violator must take to return to compliance) assures that the violation is corrected and that the violator complies with all applicable environmental laws and regulations. Penalties deter the specific violator, as well as other potential violators, from future noncompliance. SEPs provide some “extra” environmental and health benefits to the public”.

2.2 Definition of SEP

SEPs are environmentally beneficial projects which a defendant agrees to undertake in settlement of an environmental enforcement action, but which the defendant is otherwise not legally required to do. “Environmentally beneficial” means that the SEP must improve, protect, or reduce risks to the environment or to the public health.

The cost of the SEP is a mitigating factor in establishing an appropriate settlement penalty to be paid by the defendant.

2.3 Categories of SEPs

The revised SEP policy of EPA, issued on May 4, 1995, permits the following seven categories of allowable projects [1]:

- (1) **Pollution Prevention:** these SEPs reduce the generation of pollution through source reduction; e.g. raw material substitutions, process redesigns or even product reformulations.
- (2) **Public Health:** these SEPs provide diagnostic, preventive and/or remedial aspects of human health care related to actual or potential damage to human health caused by the violation; e.g. medical examinations of potentially affected persons.
- (3) **Pollution Reduction:** these projects reduce the amount and/or toxicity of any hazardous substance, pollutant or contaminant that is released into the environment by a means that does not qualify as pollution prevention; e.g. the installation of more effective end-of-process control or treatment technology.
- (4) **Environmental Restoration and Protection:** these SEPs may be used to restore natural (ecosystem) or man-made (building) environments.
- (5) **Assessments and Audits:** these projects can be PP assessments, site assessments, environmental management systems audits or compliance audits.
- (6) **Environmental Compliance Promotion:** these projects provide technical support to other members of a regulated community so as to help these members maintain compliance with the applicable regulatory and statutory requirements.

(7) Emergency Planning: such a SEP provides technical assistance to state or local emergency planning and response organizations.

As stated in the introduction, the PP SEPs are the most desirable from the Agency point of view and hence EPA provides special incentives to encourage such projects. First of all, PP is one of the five (EPA-determined) factors that can mitigate the final penalty for the violator, the other four are: (a) the benefits to the public or environment at large, (b) innovativeness, (c) environmental justice and (d) multimedia impacts.

Moreover, PP SEPs, to the extent that they perform well on several of the agency determined mitigation factors, may receive the highest mitigation percentage of 100%. That is, the penalty could be mitigated one dollar for each dollar spent on the SEP.

2.4 Nexus Requirement

The revised SEP policy requires that there must be a distinct “nexus” or relationship between the violation and the proposed project; i.e. the SEP must remedy or reduce the probable overall environmental or public health impacts or risks to which the violation at issue contributes or reduce the likelihood that similar violations will occur in the future. The nexus may be either “vertical” or “horizontal”. A vertical nexus exists when the SEP reduces the emission of a pollutant to a medium that are the same pollutant and medium addressed in the violation. A horizontal nexus exists when the SEP involves either (a) relief for different media at a given facility or (b) relief for the same medium at different facilities.

3.0 The relationship between Accident and Pollution Prevention in the SEP Context

In the Pollution Prevention Act of 1990 and specifically in PPA § 6607 (b) (7) the Act requires that each owner of a facility required to file an annual toxic chemical release form under the section EPCRTKA § 313 for any toxic chemical shall include with each such annual filing a toxic chemical source reduction and recycling report for the preceding calendar year. In this toxic chemical source reduction and recycling report should include “(7) *The amount of any toxic chemical released into the environment which resulted from a catastrophic event, remedial action, or other one time event, and is not associated with production processes during the reporting year*”. A toxic chemical is defined as one listed on the Toxics Release Inventory (TRI).

Based on the above requirement, failure to report an accidental release creates the opportunity for an AP SEP, i.e. a project that addresses sudden and accidental releases of TRI pollutants to the environment. From our analysis it is clear that the PP Act provides ample opportunities for both PP and AP SEPs; however, the experience shows that AP SEPs are very infrequent (if they exist at all). In a personal communication, Mr. Peter Rosenberg of the US EPA Office of Enforcement and Compliance Assistance made it clear that AP projects should in principle be acceptable SEPs. However, AP SEPs are not really promoted by the EPA. This is probably due to the lack of specificity in the language of the SEP policy. A new revision of the SEP policy that will state clearly the suitability of AP projects for SEPs would address this shortcoming.

The promotion of AP technologies through SEPs is very important as it consists one of the very few regulatory incentives for the corporate world to move towards inherently safer technologies. Although inherent safety and pollution prevention are very similar concepts (both attempting to prevent the *possibility* of harm, from accidents or pollution respectively, by eliminating the

problem at its source) the pattern of their adoption by the corporate world is very different. Firms are embracing PP for three main reasons: (1) the use of the current practices of waste treatment and pollution control is very costly, thus the adoption of PP technologies has tangible economic benefits, (2) the Superfund Act (SARA Title III) created joint and several liability for environmental damage due to industrial releases of toxic substances and (3) the Emergency Preparedness and Community Right to Know Act (EPCRA) has provided the public with the information that revealed large inventories and emissions of toxic substances. This information is provided through the pollutant release data that the firms submit on their Toxics Release Inventory (TRI) reports. Evidently, there exist both economic and informational mechanisms that are shifting the firms towards PP [2].

On the other hand, there are no economic nor informational mechanisms promoting AP. First, the firms do not pay the full social costs of accidents to the workers or to the public and also, since the accidents are rare stochastic events cannot be easily observed or calculated, that they possess lower informational "content"/charge. It is thus important that at least one mechanism, i.e. the SEPs, promotes those inherently safer technologies [2].

4.0 Identifying the Universe of PP/AP Opportunities

The first step was to identify the Industrial Sectors/Industrial Processes/ Product Lines that present both serious pollution problems and significant potential for improvement. This potential is defined by technological options that either exist in full operation in other areas (requiring diffusion or incremental innovation for their adoption) or exist only in bench scale/pilot plant scale thus requiring a largely innovative response).

The first historical integrated effort to map PP (though not AP) opportunities across different industry types is found in an 1986 OTA report [3]. There OTA presents the opportunities for: 1) operations changes, 2) in-process recycling, 3) process changes, 4) input substitution and 5) end product changes, across different industry types.

The methodology developed in that thesis builds on the OTA approach; however, the research is extended so as to cover:

- accident prevention opportunities
- industrial process and product lines in addition to industrial sectors.

Table A1 of the Appendix presents, for comparison purposes, other methodological approaches to prioritization [4]. They focus predominantly on a substance-specific hazard/risk analysis, and only secondary --if at all-- on technological opportunity criteria. This thesis does not make use of these data.

The only scheme that is close to a technology/opportunity-focused approach is [5], where the purpose is: *"to identify a short list of industries or industrial segments or even generic technologies, that present: the most significant environmental problems or risks, and the most significant opportunities for waste reduction"*.

However, this multi-attribute approach of the EPA Risk Reduction Engineering Laboratory (RREL), does not address accident prevention. With reference to the PP area, the technologies ultimately identified through the screening mechanism did include some found in RREL

publications, although not all in the RREL list were suitable for the SEP enforcement implementation approach.

These methodological distinctions having been explained, the thesis now proceeds with more detailed discussion of the chosen approach, which begins by identifying both (1) pollution/accident problem areas and (2) stagnant technology.

4.1 Pollution/Accident Problem Areas

Strategies focusing on problem pollution identified:

- *Specific Industries*, based mainly on SIC classification. Of interest were pollution problems that a large number of firms within the SIC is facing. For example, all the Metal Finishing Industry (SIC 3471) is characterized by high concentration of metals in the waste streams; thus the existence of a technological strategy addressing this problem represents a widespread beneficial potential for this SIC.
- *Specific Industrial Processes*. These processes were encountered in many *different* industrial sectors, and in each of them the process used (= practice) and the resulting environmental problems are essentially the same. For example, the electroplating process which is the most problematic process concerning the Metal Finishing Industry (SIC 3471) is also encountered in various others industrial sectors. The automobile industry (SIC 347) in particular, is using extensively electroplating procedures in auto-parts manufacturing. Therefore, the locus of the electroplating process is much more wide than can be assigned by a rigid SIC-oriented prioritization scheme.

At this point it is useful to distinguish Primary, Secondary and Ancillary processes. In [4] these terms are defined as follows:

“a primary process is one that defines the product and yields its key functional property(s) (e.g., metal casting in the case of a steel bolt); a secondary process is one that is not primary to the function of the product but serves a supplemental function (e.g., the metal plating of the part which provides a non-corrosive or esthetically-pleasing finish), and ancillary processes are cleaning, degreasing, defluxing and similar operations which are often necessitated by the choice of primary and secondary processes (e.g., use of a chlorinated organic solvent to remove an oil-based metal cutting fluid).”

Applying these definitions to our example, electroplating in a job shop comprises the primary (core) technology in use, while it is a secondary technology in automobile manufacturing. Obviously, secondary processes are not unimportant, but industry may be more benefited in undertaking innovation in core technology than in secondary or ancillary technologies. This is because core technology innovation may offer many different kinds of benefits in addition to reduced need for pollution control, such as reduced material and water costs and energy conservation.

Although [6] indicates that most SEPs in PP that were included in settlement agreements involved diffusion in secondary/ancillary processes, one important conclusion was that enforcement could be used to prod the firm into considering innovation in the core (primary) technology.

- *Specific Product Lines.* In this case, in spite of the fact that the pollution profile of a particular industrial sector does not present major pollution concerns, a specific product line in that sector imposes high pollution loads may exist. A typical example of this is found within Pharmaceuticals (SIC 2834): The most of the world's production of LiAlH_4 is consumed in the production of cimetidine (an ulcer medicine of SmithKline Beecham), with obvious consequences for the waste stream. The existence of an alternative raw material (or intermediate) that would dictate a different synthetic pathway would contribute in the significant reduction (or the complete phase out) of the LiAlH_4 used in the specific product line [7].

4.2 Stagnant Technology

The technological stagnation concept is very important because such a stagnation can be a good indicator of the opportunities for PP/AP. Sectors/processes characterized by stagnation are an obvious choice for regulatory intervention encouraging technological progress. Although it may be the case that no innovation is possible in the area, in the vast majority of the cases the potential for progress is huge (at least in the form of simple technological diffusion) and the stagnation must be attributed to the lack of willingness (i.e. culture and attitude) and/or capacity (i.e. skill and knowledge) of the firms concerned.

Regulatory mechanisms, and enforcement settlements involving penalty mitigation in particular, represent the ultimate opportunity for progress PP/AP-wise for these “laggard” firms or technologies.

On the other hand, industrial sectors which are by nature dynamic and innovation-driven, where success is mainly based on extensive R&D expenditures, are not likely to need the direct interference and leverage from the Office of Enforcement and Compliance Assurance (OECA). In the case of these firms, EPA needs to provide clear goals and a clear time-horizon; the firms themselves are likely to be able to undertake the appropriate technological advances.

On that point, it reserves repeating that this thesis seeks to address both the gradual and the sudden releases of pollutants. The Sectors/Processes/Product lines that represent opportunities for PP may be distinct from the Sectors/Processes/Product lines that exhibit AP potential. This is explained by the fact that firms may be innovation-driven to prevent pollution but not accidents. To elucidate this idea, the Organic Chemicals Industry (SIC 286) and the Petroleum Refineries (SIC 291) serve as characteristic examples. These sectors are, economically speaking, very dynamic; they include many big firms with extensive in-house expertise and high R&D expenditures; and they base their success on frequent innovations either in their end products or their processes. Nevertheless, all this innovation is focused on the utility of their marketable products and they tend to neglect -or at least not to promote at comparable rates- innovation in inherent safety in their processes/product lines [8]. Because of this, the enforcement mechanism can leverage innovation in AP technologies even in areas that would normally considered not in need of technical assistance or regulatory prodding.

It must also be emphasized that the concept of stagnation is very difficult to quantify in a general manner (i.e. based on Statistical/Census data); this is because *economic* stagnation, although easily quantifiable, may not be indicative of *technological* stagnation.

Having identified a number of problem areas and stagnant technologies ripe for change, the next step was the identification of candidates according to criteria related to the SEP/enforcement requirements. This is discussed in the next chapter.

5.0 Prioritization Criteria Related to Enforcement Concerns Regarding SEPs.

This part focuses on the subset of the high potential industrial sectors/processes/product lines identified previously with the following characteristics:

1. Technically implementable PP/AP technologies successfully addressing the specific problems of these sectors/processes/product lines *that already exist*.
2. PP/AP technologies that are also suitable for inclusion in enforcement settlements.
3. Those PP/AP technologies that can offer multi-media improvements, including worker-protection.

The term “technically implementable” in the first criterion means that any specific technology to be proposed/promoted is either in industrial use in some other sector/application (thus requiring diffusion or incremental innovation for widespread adoption) or at least is proven and accepted in *pilot plant scale* (requiring innovation). In any case, the scientific and engineering principles are well-defined and broadly understood. It is undeniable that *bench-scale* technologies are not yet suitable for inclusion in enforcement settlements as their risky implementation is insupportable both for the firm and the agency.

It is neither unexpected nor a negative consequence that the finally chosen technologies will be more diffusion than innovation oriented. On the contrary, it is compatible with the nature of the SEPs and the mindset/culture of the people that will be called to implement them [9]. Nevertheless, even if diffusion of proven technologies is the only mechanism of PP/AP to be effectively promoted, this is a huge improvement if put in the perspective of the very recent past [9].

Other attributes of a technology, in addition to the relatively low risk of technical failure, that makes it suitable for inclusion in SEPs and/or Injunctive Relief are the following.

- the implementation period of the SEP is of the order of one year (typical duration of agreements of that kind)
- the implementation of the technology should involve a sizable capital investment on the part of the firm, in order to qualify for a penalty mitigation agreement.

A third characteristic, is that there be multi-media (MM) benefits resulting from the promoted technology. The term medium may refer to: (1) water, (2) air, (3) waste stream, (4) worker exposure (i.e. occupational health and safety).

The emphasis on the MM-benefits does not mean that one should overlook any single-medium technologies with very significant beneficial effects. The emphasis on MM benefits is justified by two reasons:

- Any sound PP strategy must avoid media-shifting technologies. That is, although technologies may seem to cope very efficiently and cost-effectively with a single-medium pollution/accident problem, they may actually shift the problem to another medium, e.g. reduce emissions by adopting a process that is hazardous for the health or safety of the workers [10].
- The MM benefits can include non-obvious economic advantages, making a PP/AP strategy more economically attractive than initially/superficially perceived.

If the firm is focusing on one-dimensional solutions, then Pollution Control (PC) may appear better/cheaper an alternative than PP; but if a multi-media strategy is adopted then PP becomes much more attractive and frequently is more economic than PC.

This is expressed mathematically below, where C represents cost, and i any of the four media defined earlier in this section:

Even if: $C_{PP} \geq C_{PCi}$, i : any medium

it may be that: $\sum_i C_{PP} (\equiv C^*_{PP}) \leq \sum_i C_{PCi}$

By C^*_{PP} we define a single comprehensive technological change that addresses all the environmental concerns simultaneously.

6.0 Identifying the Weak and Needy Areas

The third task was to identify those problem industries/industrial processes/product lines which are in special need of technical information and assistance regarding PP/AP solutions, especially where their access to this information or assistance from trade associations, in-house expertise or R&D departments, or connections with academia is limited.

With regard to PP solutions special emphasis is given to small and medium-size enterprises (SMEs). This is because in the universe of SMEs the subset that meets the above stated limitations is very extensive and, subsequently, the potential for regulatory leverage (through enforcement agreements) for PP-oriented technological progress is also extensive.

On the other hand, in the areas of: (i) acute events (sudden releases) (AP) and (ii) MM-oriented PP solutions, the culture and the capacity of larger firms *may* be such that they are favorable targets for enforcement leverage. This lies in the fact that either the firm's or the overall sector's culture is oriented towards secondary prevention and/or single-medium approaches. It is generally difficult to come up with very precise/measurable criteria that can serve as rule of thumb in the identification of the needy firms. In the case of AP where the cultural attributes are of major importance, the classification needs to be based on a case-by-case examination.

The SME concept however is a bit more amenable. An adequate set of criteria that a company must meet to qualify for an SME, are related to: (1) Access to capital, (2) Number of employees, and (3) The geographical spread of its market.

The criteria that an Industrial Sector should meet to be characterized as of special SME interest are the following:

1. *Distribution of Establishments by Facility Size*, that presents more than 50% small and medium facilities, i.e. facilities with less than 100 employees.
2. *Limited access to capital*. This can be determined from the *Capital Expenditures to Labor Cost Ratio*, the *Profitability/Solvency/Financial Leverage Ratios* or the *Market Growth Rate* (We were not able to find such data for all the 4-digit SIC sectors we analyzed).
3. *Geographic Distribution of Establishments* characterized by high proportion of Rural vs. Urban establishments and/or high concentration of establishments in the 5 States with the higher industrial activity with regard to the specific sector (We were not able to find such data for all the 4-digit SIC sectors we analyzed).

* * *

The general approach for choosing candidate industrial sectors, industrial processes and product lines has been discussed in this section. In PART II of this thesis, this general prioritization methodology is operationalized and used for the identification of industrial sectors, industrial processes and product lines suitable for use within the SEP framework.

PART II: DESCRIPTION OF THE PRIORITIZATION METHODOLOGY - APPLICATION IN THE IDENTIFICATION PROMISING POLLUTION PREVENTION TECHNOLOGIES FOR INCLUSION IN SEPS.

7.0 Description of the Screening Mechanism

7.1 General Discussion

Figure 1 presents in flowsheet format, the screening approach used for identification of suitable technologies to be included as SEPs in enforcement agreements. In Phase I sector-related criteria are used to identify the Industrial Sectors with high PP potential; also a set of generic problematic processes frequently met in many SICs was identified. Phase II identifies specific PP technologies that can address the key environmental problems found in the SICs and in the generic processes identified in Phase I.

The reader will notice that the screening mechanism is PP-focused and does not explicitly contain AP-related criteria. This was not intentional. As PART IV explains in detail, currently there are no AP technology databases/case study compendia available on which a screening mechanism can be applied. In PART IV, this thesis addresses the issue of constructing a meaningful AP technology database and explains how the PP screening mechanism developed in this chapter can be extended to AP. Nevertheless, throughout the PP screening procedure great care was given into ensuring that no PP technologies were chosen that deteriorate the safety characteristics of the process/product line in which they are to be used.

The screening procedure is as follows:

7.2 Phase I - Addressing the Tasks 1 & 3

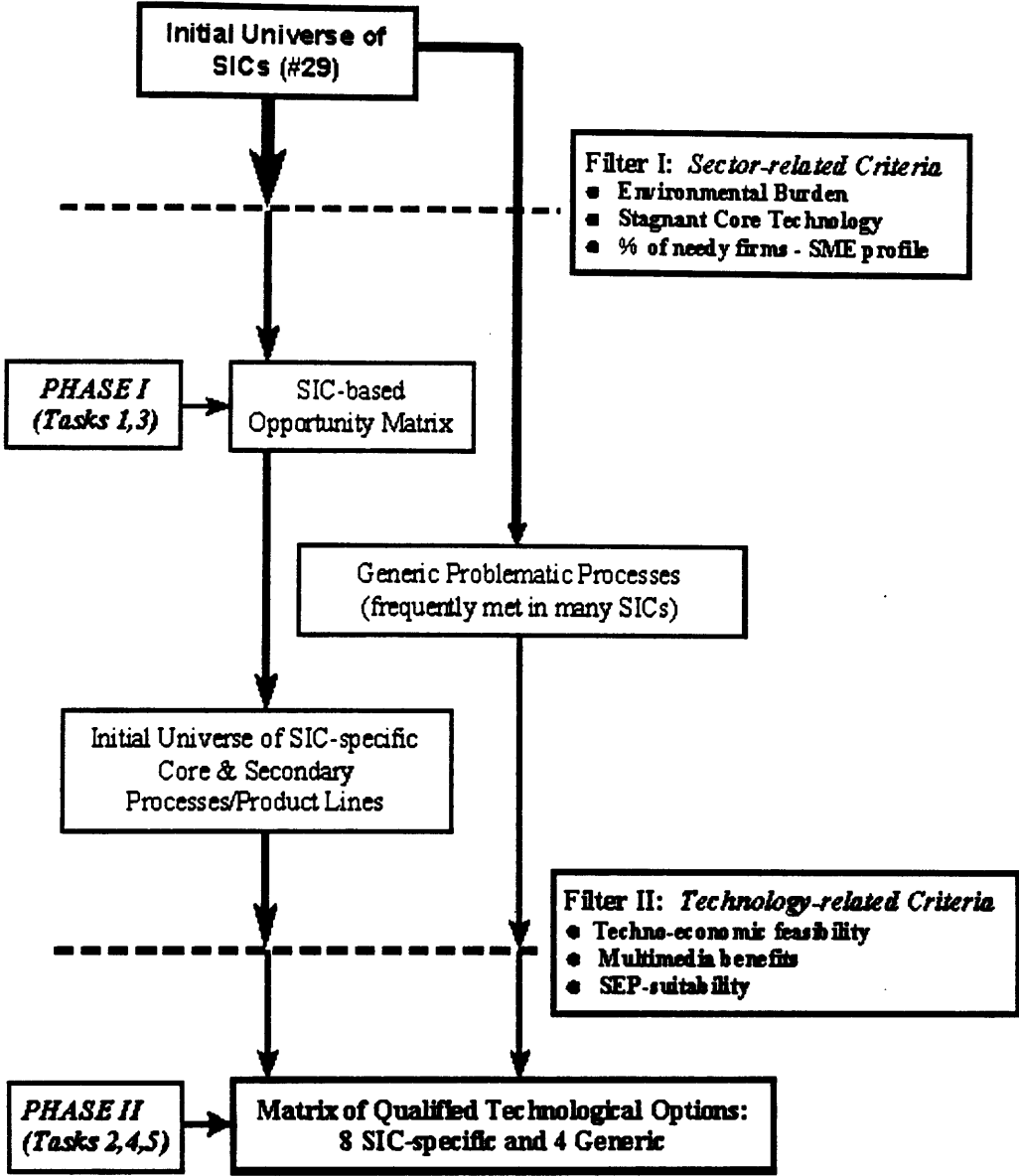
7.2.1 *Identification of Industrial Sectors with high PP potential*

Preliminary Analysis: An extensive set of industrial sectors or sub-sectors, that are considered in the literature as the most closely linked with environmental problems is identified[3]. As the number of the sectors that was investigated in prior work was generally chosen arbitrarily, these choices did not constrain this work.. The Standard Industrial Classification system (SIC) was the most convenient base for the selection of sectors. However, the SIC system is an economy-oriented system with only secondary technological considerations; thus the initial universe of industrial sectors of interest will contained a “mixture” of 2-, 3- and 4-digit SIC codes.

The first step was to gather data on the 29 SICs (-Industrial Sectors) most commonly mentioned in the literature [3,5,11] as problematic. The data needed here are general/synoptic sector-profiles on hazard/risk, on industrial/market structure and on compliance performance (this last type of data was not available for that thesis).

Filter I: This filter (consisting of three subfilters) was applied to 29 Sectors to find the 8-10 most suitable for further investigation. The subfilters were: environmental burden, technologic stagnation and percentage of (allegedly) needy firms. More specifically:

FIGURE 1: The Screening Mechanism



- **Subfilter Ia: Environmental burden of the industrial sector**

Problematic sectors were identified based on:

(1) The 1992 TRI Data [12]. The criteria related to TRI were:

(a) The absolute amount of TRI releases and transfers.

(b) The ratio of (1) monetary Value of Shipments to (2) the total pollutant production, as measured by the total TRI releases and transfers (VSRT). Sectors with low VSRT ratios might be classified as “environmentally inefficient” and thus may become targets for diffusion of PP technologies.

(c) The ratio of (1) Value Added by manufacture to (2) total TRI Releases and Transfers (VART). Low scores in that ratio imply environmental inefficiency and or that the sector is in a commodity business. The later attribute, is related to the level of needy firms in the sector (third subfilter); companies in commodity businesses may not have the financial resources and the technical expertise to achieve superior environmental performance.

(2) Secondary, qualitative criteria on environmental burden:

(a) Existence of pollutants classified as critical in EPA initiatives such as the 33/50 Program, the Common Sense Initiative and the Waste Minimization National Plan. [5,11,13,14].

(b) The appearance of a sector in at least one EPA publication [4,11,14,15,16], where it is characterized as a major polluter.

(c) The frequent appearance of a sector in NGO reports, where it is characterized as a major polluter [17-19]

(3) Enforcement Data from the EPA *Integrated Data for Enforcement Analysis* (IDEA) System. The following criteria are potentially important:

(a) Inspections per Facility per Year (IFY): high IFY ratios indicate an existing compliance problem.

(b) Inspections per Enforcement Action (IEA): low IEA ratios are a proof of major compliance problem.

The IFY and IEA data are currently available at a high level of aggregation in the 16 volumes of [20], unfortunately it was not possible to obtain more detailed enforcement data from the EPA OECA and thus these criteria were not utilized.

- **Subfilter Ib: Technologic Stagnation**

Information on the *core technologies* used in the 29 sectors is gathered. If these core technologies are *stagnant* over the last 10-15 years, then the probability for the existence of PP opportunities increases significantly, and the sectors meet the “technologic stagnation criterion”.

The quantitative criterion for technologic stagnation is the Average New Capital Expenditures (ANCE). Low ANCE levels indicate high priority SICs. Low new investments in a sector mean either that there are no new technologies to invest on or that the economic performance of the sector is not optimal. Both explanations indicate stagnation and lack of dynamism; thus both a need and an opportunity for regulatory leverage exists.

For qualitative information about technological stagnation, we relied upon:

- ◆ Recent PP technical Handbooks [21,22]
- ◆ SIC profiles prepared by EPA [20, all the 16 vols.].
- ◆ OTA publications [3,23]
- ◆ Interviews with experts [EPA Reg. 1, EPA HQs, EPA DfE, NEWMOA, TURI, MA OTA, Academia].

- **Subfilter Ic: Percentage of needy firms - SME profile**

The existence of moderate to high percentage of Small and Medium-size Enterprises (SMEs) is the key indicator of high percentage of needy firms. The main source of Information is the Census of Manufacturers data, and the criterion used was the *Establishment Size Distribution*. That is, in the qualifying sectors more than 50% of the facilities should have personnel of less than 100 employees.

Other, qualitative criteria, generally used for that purpose include [7,11]:

- ◆ production characteristics (i.e. labor-intensive sectors are generally SME-dominated and possess limited access to capital); and
- ◆ market concentration (i.e. the less concentrated the market in a specific industrial sector, the more important is the role of SMEs in the sector).

7.2.2 Identification of Processes and Product Lines with high PP potential: (i) in the sectors already identified in Phase Ia, and (ii) in their own right.

For the “qualified” industry/industrial sectors detailed information on the technologies in use was acquired. Data for all these three categories were gathered: core (primary), secondary and ancillary technologies. Also, data on the main product lines within these industrial sectors were gathered. The technologies/product lines of interest are the ones that impose environmental burdens. These burdens may be either under current EPA scrutiny/regulation or they may consist an anticipated future economic concern due to stricter regulation [enforcement data from the EPA IDEA system and regulatory publications].

The problematic technologies/product lines may be either SIC-specific or generic. The *industry-specific* problems relate to core-technologies and product lines. The *generic* technologies are likely to be secondary or ancillary technologies encountered in more than 3-4 SICs. These

generic technologies may have the highest potential for environmental benefits because they are easier to implement and can be considered in the context of many SICs. The ease of implementation lies in the fact that they are, in general, less sophisticated and they do not affect critical procedures/parts of the firm's life, i.e. they are not the "core" technologies.

Generally the technologies identified were not different than the ones discussed in the Appendix [24], so no further description of them in this stage is needed. The screening procedure for Phase II, where the final set of recommended technologies from the extended list created in Phase Ib is derived, is described in Chapter 7; while the results of the application of the screening methodology are presented in Chapter 8. In PART III, detailed technology profiles are provided.

7.3 Phase II - Addressing the Tasks 2, 4 & 5

The initial universe of technological options, as has already been explained, consists of two parallel groups: the industry-specific and the generic options. This division is kept throughout this second stage of screening. In the flowchart in Figure 1, this is presented as two parallel flows of technologies passing through the same Filter II. This filter consists of three subfilters that are explained below.

- **Subfilter IIa: Techno-economic feasibility**

Only technologies that were already proven and implemented at least at the pilot level were accepted. These technologies should also have reasonable payback times (e.g. less than five years). The main sources of information have already been cited under Subfilter Ib. Other sources are:

- ◆ Electronic Databases: UNEP ICPIC and EnviroSenSe.
- ◆ OTA fact sheets. We have reviewed over 40, with successful PP cases mainly drawn from New England.
- ◆ Publications related to the Design for the Environment initiative [25].
- ◆ NEWMOA, TURI and NGO compendia of PP successes, publications from CMA and from other Industrial Alliances [26-28].
- ◆ PP technologies that have won the Governor's Award for Toxics Use Reduction [14].

- **Subfilter IIb: Multi-media environmental benefits**

The multi-media benefits may refer to: (i) water, (ii) air, (iii) waste-stream or (iv) worker exposure (occupational safety & health). A general discussion on the importance of multi-media benefits was provided in Chapter 5, while the sources of relevant information are the ones cited under subfilter IIa.

- **Subfilter IIc: SEP-suitability**

The criteria described in Chapter 5 are operationalized, as follows:

- (1) The promoted technology should be economic but not very profitable. i.e. the environmental project should not have a significantly positive NPV without the penalty mitigation (assuming that the discount rate used appropriately accounts for the project-

specific risk). If the technological option has an extremely positive NPV, the firm should be eager to undertake it anyway.

(2) The promoted technology should call for significant capital so that a penalty mitigation would be of value. Although the cut-off level is arbitrary, preference should be given to significant projects in utilizing scarce EPA compliance resources and attention. In this thesis, a level of \$25,000 was chosen so as to give a wide variety of different options

(3) The horizon of implementation of the project should not be longer than 18 months. This is because the EPA attorneys and case attorneys are likely to deem inappropriate for the SEP process any project of longer duration. It is worthwhile mentioning that information on project duration is not always available in the PP literature; neither it is always meaningful since implementation periods may be very much firm-specific (i.e. depend on how much effort and resources a firm wants to devote in a project).

(4) As an extra criterion to ensure a certain level of comfort for EPA with the promoted technology, only technologies that are at least somewhat known to EPA are chosen. Obviously, this does not mean that the Office of Enforcement and Compliance Assurance should be already using/promoting these technologies but that the technologies should either have been

- ◆ mentioned/researched by the EPA ORD or RREL, or
- ◆ recognized with a Governor's award or
- ◆ found/mentioned in a reliable domestic or international database (e.g. Enviro\$en\$e, UNEP ICPIIC, etc.).

8. Application of the Screening Mechanism

The ultimate purpose was to come up with ~ 8 SIC-specific and 4 generic PP technologies that can be used in SEPs.

First, 8 SICs for detailed investigation were selected; this was achieved using the literature sources (especially [5]) and quantitative criteria introduced and discussed in Chapter 7.

The actual procedure used was the following: The 29 4-digit SICs most frequently indicated in various reports and EPA initiatives ([3],[5],[11]) are identified. The complete data set we used in the screening is presented in Table IIB, which can be found in the next page. The sectors were ranked according to the first four criteria presented in Table IIA. Ideally, the two enforcement-related criteria (the fifth and sixth criteria) should be also used, but the relevant data were not available for this study.

Table IIA: Description of the Criteria in use				
Criterion	Descriptor	Explanation	Source	Other Comments
R+T	Total TRI Releases and Transfers (<i>in M lb.</i>)	↑ (R+T) ⇒ ↑ priority on the SIC (<i>major environmental burden</i>)	1992 TRI Data	
VSRT	Value of Shipments over total TRI Releases and Transfers (<i>in \$/lb.</i>)	↓ VSRT ⇒ ↑ priority on the SIC (<i>environmental inefficiency</i>)	1987 Census & 1992 TRI Data	
VART	Value Added by manufacture over total TRI Releases and Transfers (<i>in \$/lb.</i>)	↓ VART ⇒ ↑ priority on the SIC (<i>a. environmental inefficiency and/or b. commodity business</i>)	1987 Census & 1992 TRI Data	
ANCE	Average New Capital Expenditures; (<i>NCE in \$ per establishment</i>)	↓ ANCE ⇒ ↑ priority on the SIC (<i>sign of: stagnation, lack of dynamism, both a need and an opportunity for regulatory leverage</i>)	1987 Census of Manufacturers	
IFY	Inspections per Facility per Year	↑ IFY ⇒ ↑ priority on the SIC (<i>a. indication of existing problem b. opportunity for leverage</i>)	IDEA	Data not available for this study
IEA	Inspections per Enforcement Action	↓ IEA ⇒ ↑ priority on the SIC (<i>a. proof of major compliance problem b. opportunity for the implementation of a SEP</i>)	IDEA	Data not available for this study
* In the case of Service industries we use the value of receipts instead of the value of shipments				

Table IIB: The complete data set

SIC	Descriptor	Rank Listic	Rank Other	SIC Range	NoE	%SMEs	R	T	R+T	VS	VA	NCE	VSRT	VART	ANCE	IFY Ratio	IEA Ratio
3471	Electroplating	1	[1], [9]		3451	97.4	18	67	85	3,867	2,634	140	45	31	40,626		
2821	Plastics, resins and elastomers	2			480	74.8	214	328	542	26,246	10,873	1,247	48	20	2,598,333		
2869	Industrial Organic Chemicals N.E.C.	3			699	72.1	781	722	1,503	41,812	17,526	1,986	28	12	2,841,059		
285	Paint Industry	4	[1]	2851	1428	91.0	23	132	155	12,702	6,221	275	82	40	192,647		
371	Automotive manufacturing/assembling	5	[1], [9]	0-7	4438	79.8	98	169	267	205,923	66,367	6,578	771	248	1,482,267	0.4	13.3
3674	Electronics/semiconductors	6	[9]		853	49+	6	20	25	19,795	13,429	1,921	780	529	2,251,817		
2911	Petroleum Refining	7	[9]		308	54.4	104	737	840	118,186	14,219	2,035	141	17	6,607,143	2.0	6.1
2879	Pesticides	8			277	91.3	101	119	220	62,997	3,832	234	286	17	845,126		
2752	Commercial printing, lithographic	9			24984	97.3	14	5	19	32,832	18,232	1,539	970	82	61,579		
7216	Dry cleaning plants	10			21257	99.8	NA	NA	NA	3,997	NA	NA	NA	NA	NA		
2819	Inorganic Chemicals N.E.C.	11			662	84.1	596	335	931	13,220	7,538	506	14	8	764,502		
2491	Wood preserving	12			540	62.5+	2	5	7	2,170	553	44	318	81	81,667		
753	Automotive repair shops	13			114601	100.0	NA	NA	NA	26,664	NA	NA	NA	NA	NA		
2621	Paper mills	14			282	23.0	122	44	166	28,918	14,024	2,760	174	85	9,786,879		
2754	Commercial printing	15	[9]		332	87.0	38	10	47	3,060	1,534	176	65	32	528,614		
261	Pulp mills	16		2611	39	28.2	137	50	188	4,314	2,281	231	23	12	5,928,205		
226	Textile dyes and dyeing	17			648	78.2	4	4	9	7,042	2,321	173	799	263	266,358		
2893	Ink manufacture	18			504	97.2	35	7	42	2,392	985	38	57	23	75,198		
2834	Pharmaceutical preparations	19			732	75.3	44	109	153	32,094	23,884	1,471	209	156	2,009,699		
2891	Adhesives and sealants	20			714	93.4	9	14	23	4,678	1,996	112	201	86	156,443		
271	Newspaper publishing	21		1,3,4,7-9	9091	91.8	0	0	0	31,850	24,311	1,523	78,229	59,712	167,495		
2865	Coal tar crudes, dyes and pigments	22			186	65.6	191	166	357	8,859	3,414	379	25	10	2,036,559		
372	Aircraft and parts	23			1622	76.4	32	34	66	77,304	40,803	2,536	1,176	621	1,563,564		
311	Leather tanning & finishing	24		3111	344	60+	8	14	23	2,219	747	28	99	33	80,523		
2753	Engraving & plate printing	25	[9]			NA	0	0	0	NA	NA	NA	NA	NA	NA		
331	Iron & Steel		[9]	2,3,5,6,7	1127	67.9	128	487	615	51,815	20,486	1,668	84	33	1,479,769		
334	Secondary smelting and refining of Non-Fe metals			3341	398	91.2	12	268	280	4,431	947	63	16	3	157,286		
335	Rolling, drawing and extruding Non Fe metals			1,3,4,5,6,7	1069	60.5	51	248	299	33,282	10,332	989	111	35	925,444		
336	Non-Fe castings (foundries)			0-9	1689	87.6	8	63	70	6,315	3,395	195	90	48	115,512		

Notation:	Source:
NoE = Number of Establishments (in K)	1987 Census of Manufacturers
%SME = % Establishments with <100 employees	1987 Census of Manufacturers
R = Releases (M lbs)	1992 TRI Data
T = Transfers (M lbs)	1992 TRI Data
IFY = Inspections per facility per year	IDEA
IEA = Inspections per Enforcement Action	IDEA
VS = Value of Shipments (M \$)	1987 Census of Manufacturers
VA = Value added by manufacture (M \$)	1987 Census of Manufacturers
NCE = New Capital Expenditure(M \$)	1987 Census of Manufacturers
VSRT = VS/ (R+T) in '87\$/'92lbs	1987 Census & 1992 TRI Data
VART = VA/(R+T) in '87\$/'92lbs	1987 Census & 1992 TRI Data
ANCE = NCE/(NoE) in \$/establishment	1987 Census of Manufacturers

In the case of Service industries we use the value of receipts instead of VS, VA

For each criterion, one point was given to each of the top-8 SICs. These results are presented in Table IIC.

Criterion/ Rank	R+T	VSRT	VART	ANCE
1	2869	2819	334	3471
2	2819	334	2819	2752
3	2911	261	2865	2893
4	331	2865	2869	311
5	2821	2869	261	2491
6	2865	3471	2911	336
7	335	2821	2879	2891
8	334	2893	2821	334

From the results of Table IIC, Table IID - which shows the cumulative scores of the overall top-8 SIC's - is constructed

SIC#	Score	Rank
334	4	1
2869	3	2
2819	3	3
2821	3	4
2865	3	5
2911	2	6
261	2	7
3471	2	8

The SICs of Table IID were then screened for SME-dominance; i.e. sectors in which less than 50% of their establishments have less than 100 employees were discarded. That way, SIC 261 -- Pulp mills, was eliminated as a non-SME dominated sector. (As we can see in Table IIB, only 28% of the facilities in SIC 261 have less than 100 employees).

The final target group consisted of the 7 remaining SICs of Table IID and the SIC code 285 (the Paint Industry). The latter, while not having very high scores in our prioritization mechanism, was deemed very important in [5] and in [29]. The final target group is presented in Table IIIE.

Sic #	Descriptor	Explanation
334	Secondary smelting and refining of Non-Fe metals	Table IID
2869	Industrial Organic Chemicals N.E.C.	Table IID and [3]
2819	Inorganic Chemicals N.E.C.	Table IID
2821	Plastics, resins and elastomers	Table IID and [3]
2865	Coal tar crudes, dyes and pigments	Table IID
2911	Petroleum Refining	Table IID
3471	Electroplating	Table IID and [3]
285	Paint Industry	[3] and [27]

The creation of Table IIE, completed **PHASE Ia** of the screening procedure. **PHASE I** (see Figure 1) is concluded by acquiring information on PP technologies relevant to these sectors and on generic technologies frequently encountered in the literature survey. For the targeting of generic technologies there exists no quantitative method; thus the identification of such technologies was based on the literature survey and the relevant EPA report.

In **PHASE II** the set of the technology-focused criteria presented in Section 7.1.1 was used in order to analyze the technological options identified in **PHASE Ib**; then, a small set of 8 SIC-specific and 4 generic technologies was identified. This small set of technologies possesses all the features needed for successful inclusion in PP SEPs.

Table IIF summarizes the SIC-specific technological options which are promising candidates for PP SEPs. Table IIG summarizes the generic technological options which are promising candidates for PP SEPs. In PART III, the detailed profiles of the 12 chosen technologies are presented.

TABLE IIF: SIC-Specific Technologies

SIC	Process/ Product line Description	Technological Options	Locus of change	Techno- economic Feasibility	PP Benefits	Capital Expenditure	Time horizon	Data Source
334	Lead smelting	Use of an improved design mold eliminates the cutting process and results in less scrap to be smelted	Primary Process change	*Readily available * Payback <18 months	↓ air emissions ↓ scrap, lead energy	\$ 100,000	<12 months	UNEP ICPIC
2869	Batch organic chemicals manufacturing	Ultrasonic cleaning system replaced the use of solvents and caustic	Ancillary Process	* in use * fast payback	↓ water pollution ↓ worker exposure	\$ 36,000	Unclear { < 18 months}	UNEP ICPIC
2819	Hydrochloric acid production	Installation of an acid gas adsorption system	Secondary Process	* in use * fast payback	↓↓ wastewater ↓ Hydrochloric acid, chlorate compounds	\$ 250,000	4 months	INFORM
2821	polypropylene production	Vinyl Acetate (VA) recovery system	Adjunct to the Core Process	Payback <2.5 yrs	↓ 30% of the hazardous (ignitable) VA stream	\$ 1,300,000	13 months	EPA RREL
2865	Manufacturing of plasticizers	Recycling of distillation overhead waste and installation of on line analyzers to reduce by-products	Primary Process - equipment modification	* Fully implemented * Payback ~ 8 yrs (no liability reduction savings considered)	↓ 13% in hazardous waste (mixed organic chemicals)	\$ 500,000	Unclear	UNEP ICPIC
2911	Petroleum refining	Installation of an oily water treatment unit to remove insoluble emulsified oil from the desalter wash water	In-process recycling in a primary process	*In use *Payback ~ 3 yrs	Complete removal of emulsified oil ↓ in sludge generation	\$ 60,000	N/A	API
3471	Surface finishing of fabricated metal products	Installation of an aqueous cleaning system eliminates the use of TCA	Ancillary process	* Fully commercialized * Payback =1.4 yrs	Elimination of TCA emissions	\$ 80,000	N/A	UNEP ICPIC
285	manufacturing of colorants	Installation of additional mill chambers and pumps to reduce the frequency of cleaning and the amount of purge generated.	Ancillary process modifications	*In use *Payback < 1yr	43% reduction in the amount of resinous and water waste generated	\$ 25,000	< 1 yr	ENVIRO SENSE

TABLE IIG: Generic PP Technologies

SIC Range	Process/ Product line Description	Technological Options	Locus of change	Techno- economic Feasibility	PP Benefits	Capital Expenditure	Time horizon	Data Source
34-35- 36-37	Vapor degreasing	Use of an aqueous wash system instead of TCA	Secondary Process	Payback 2.5-3 yrs	Eliminates the heavily toxic TCA in air emissions and in the waste stream	\$ 464,000	Unclear {probably < 18 months}	RREL paper
34-35- 391	Metal plating	wastewater purification and metal recovery	Primary or Secondary Process	Payback 3 yrs	↓↓↓: metal hydroxide sludge, usage of chemicals ↓: water usage	\$120,000	< 18 months	PP News
28-35- 36-37	Paint removal	Use of a cryogenic process for paint removal from steel structures, substitutes the use of acids or pyrolytic oven	Secondary Process	* Payback < 1.5 yrs * patented technology	No acids, no liquid wastes, improved worker safety conditions, decreased solid wastes	\$ 235,000	Unclear {probably < 18 months}	UNEP ICPIC
285-34- 35-36-37	Painting of metal parts	Substitution of solvent based paint with powdered paints	Secondary Process	Payback < 1 yr	Minimized emissions and worker exposure to organic solvent (TCA and mineral solvent vapors)	\$383,000	Unclear {probably < 18 months}	UNEP ICPIC

PART III. DETAILED DESCRIPTION OF THE IDENTIFIED TECHNOLOGIES

In the description of technologies discussed below, features of the existing processes/product lines/technologies as well as options for change that we have identified as worthy of promotion, are found in bolded text.

9.0 SIC-Specific Options

Technological Option #1 - SIC 334

Pollution Prevention technology in the secondary lead processing in a Manufacturer of Starting, Lighting, and Ignition (SLI) Batteries

The facility operates one, two, or three 8-hour shifts and employs 220 people. In 1993, they sold 231,000 batteries.

Facility operations can be divided into six main steps: (1) conversion of scrap lead into cast panels, (2) conversion of virgin lead into lead oxide powder and paste, (3) pasting and curing of panels, (4) container formation of batteries, (5) tank formation of batteries, and (6) laboratory analysis and process controls. The battery making process begins on two parallel tracks: the facility recovers lead from used batteries that are collected and brought to the facility, scrap lead is recycled and then cast into grids, and virgin lead is mechanically converted into a powdery lead oxide, which is used to make a paste. These separate feeds merge at the grid pasting machine where the paste is pressed into the grids. Pasted plates are cured and then take one of two paths to become battery elements: tank formation or container formation. These processes convert the paste into active material that will electrically charge and discharge throughout the useful life of the battery. In tank formation, this process takes place in large tanks whereas in container formation, the cured plates are assembled and formed in the battery case itself.

To make the lead oxide paste, lead oxide powder is mixed with de-ionized water, sulfuric acid, and organic expanders. One recipe makes a positive plate, while a slightly different recipe makes a negative plate. The pasted plates then move on a conveyor belt through a drying oven. After pasting and drying, the plates move into a curing chamber for about 48 hours to convert the remaining lead into lead oxide.

Existing Pollution Problems

(1) waste acid from the used batteries that are cracked to recover lead is disposed of on-site, (2) uncovered lead slag and dust piles, (3) excessive energy used in smelting ovens, curing rooms, and the tank formation process, and (4) excessive wastewater generation in the grid pasting and washing processes. **In addition, over 2,500 kilograms of lead oxide paste is spilled and feed into the smelting process each day, using virgin lead where scrap lead would suffice. Finally, several technological problems (e.g., the outdated lead oxide mill and lack of a moisture analysis oven) increase raw materials use and adversely affect battery quality.**

Pollution Prevention Opportunities

Overall, this assessment identified nineteen pollution prevention opportunities that could address the problems identified and produce significant economic benefits for the facility. If implemented, these opportunities could save over \$1,531,206 (US) in the first 12 months for an investment of \$ 522,500 (US).

The pollution prevention strategy is premised on the belief that addressing sources of waste and pollutants also improves the company's economic position by reducing operating costs and improving product quality. In this case, product quality is increased by (1) increasing the lead oxide particle size by buying a liquid atomization mill, (2) increasing the moisture content of the paste recipes, (3) increasing the curing temperature, humidity, and air circulation, (4) analyzing the moisture content of the pasted plates on-site, at the oven, (5) monitoring the smelting oven temperature and adjusting to the optimal level, (6) curing larger batches of pasted plates, and (7) utilizing cadmium sticks in the laboratory to measure cell voltage.

The following is a list of the opportunities for pollution prevention recommended for the facility and presents the environmental and product quality benefits, implementation cost, savings, and payback time for each. Because the quantities of pollution generated by the facility and possible pollution prevention levels depend on the production level of the facility, all values should be considered in that context.

Conversion of Scrap lead into Cast Panels--Smelting--Options included

- **Buy temperature monitoring instrument to adjust oven which reduces toxic emissions and slag and reduces energy costs. Costs \$1000 provides a financial benefit of \$1000 per year. Thus it has a pay back period of one year.**

Casting Panels--Option included:

- **Purchase improved design mold which reduces waste, lowers energy use and eliminates steps in the process. The cost is \$100,000 (US). Financial benefit and payback period is incorporated in plate cutting.**

Conversion of Virgin lead into lead oxide powder and paste-- Options included:

- **Purchase a liquid lead atomization mill - improves efficiency and reduces emissions of lead oxide powder. The cost is \$200,000 (US) which provides quality improvements.**

Pasting and curing Panels: Cutting-- The options identified included:

- **Eliminate the cutting process which reduces scrap and saves lead and energy. The cost is \$100,000 with a financial benefit of \$70,956 per year and a payback period of less than 18 months.**

Tank formation of plates: Eliminate the process --saves water and natural gas, reduces worker exposure to acid and lead dust, reduces volume of waste water and improves battery quality. The cost is \$100,000 with a financial benefit of \$693,000 per year and therefore a payback period of less than three months.

Implementation Status

The facility has already implemented many of the low/no cost. In addition, the facility has begun to implement several capital intensive changes. For example, it has placed an order for boost charging equipment (\$ 100,000) and requested price quotes for a liquid lead atomization mill (\$240,000).

Source: The UNEP ICPIIC database

Technological Option #2: SIC 2869

Ultrasonic reactor cleaner reduces waste generation and cuts energy costs, in an industrial organic chemicals manufacturer.

A Chemdet Sonic Cleaning system is now used at 3 M to clean batch reactors, replacing the old process of filling the reactor with caustic or solvent and boiling the solution for one or two days. Cleaning chemicals are pumped under pressure through a twin-nozzled rotating spray head to break down the waste. Then, caustic or solvent is sprayed under 600 lb. pressure to complete the dissolution and flush the vessel clean.

Material/Energy Balance and Substitution

FEEDSTOCKS: Solvent, caustic

WASTES: Spent solvent, caustic, containing adhesives, resins, polymers

MEDIUM: Liquid

Economics

CAPITAL COST: \$36,000

OPERATION/MAINTENANCE: Reduction in labor costs not reported

SAVINGS: \$575,000 in first year, from labor, materials and machine costs

PP Benefits

FEEDSTOCK REDUCTION: Reduced requirements for solvent and caustic not reported

WASTE PRODUCTION: 1,000 tons/yr. of water pollutants were eliminated

IMPACT/PROBLEMS: Installation of the Chemdet system for cleaning the reactors has eliminated the need to fill the 4,000 8,000 gallon reactors with solvent and caustic, which greatly reduces the amount of spent solvent generated.

Source: The UNEP ICPIC database

Technological Option #3: SIC 2819

Closing of evaporation ponds and introduction of an acid gas adsorption system in the production of hydrochloric acid

In 1987 Dow Chemical introduced a process change in the Pittsburg, California plant. The process change involved the installation of an acid gas adsorption system, that eliminated the need to send brine to evaporation ponds. This process change which called for a capital expenditure of **\$250,000** reduces caustic waste by 12,000,000 lb./yr. and hydrochloric acid waste by 160,000 lb./yr for a payback period of less than 2 months. {Note: Many SMEs that will use such a process, will incur longer payback times because the volumes of wastes they handle and thus the level of cost reductions they will enjoy are much smaller}

Previously, the wastestream of hydrochloric acid gas, formed by the reaction between chlorine and organic compounds, was scrubbed with caustic, forming brine: a portion of this brine was sent to evaporation ponds while the rest was used to produce chlorine gas through electrolysis. Now, the hydrochloric acid is first scrubbed with water and then caustic. This stepwise method salvages a portion of the hydrochloric acid waste stream so that it can be reused as a raw material elsewhere in the plant or sold as a product. It also avoids the formation of sodium chlorate compounds that precluded the in-process recycling of the spent caustic stream. Further, less caustic is needed to convert the remaining hydrochloric acid to brine, and all the brine is used as raw material to produce chlorine gas.

Source: " Environmental Dividends: Cutting More Chemical Wastes", INFORM 1992

Technological Option #4: SIC 2821

Recovery and reuse of vinyl acetate in the production of polypropylene

The Union Carbide Seadrift Plant is located along the southeast Texas coast approximately 130 miles from Houston, Texas. The plant, one of Carbide's largest, employs close to 1,300 people. The plant produces ethylene, glycols, amines, solvents, polyethylene, and polypropylene.

Seadrift's largest waste stream is a residue that contains high concentrations of vinyl acetate (VA) along with heavier components such as poly oils. It is characteristically ignitable, making it hazardous under RCRA. At its peak, this waste stream averaged over 5 million pounds per year.

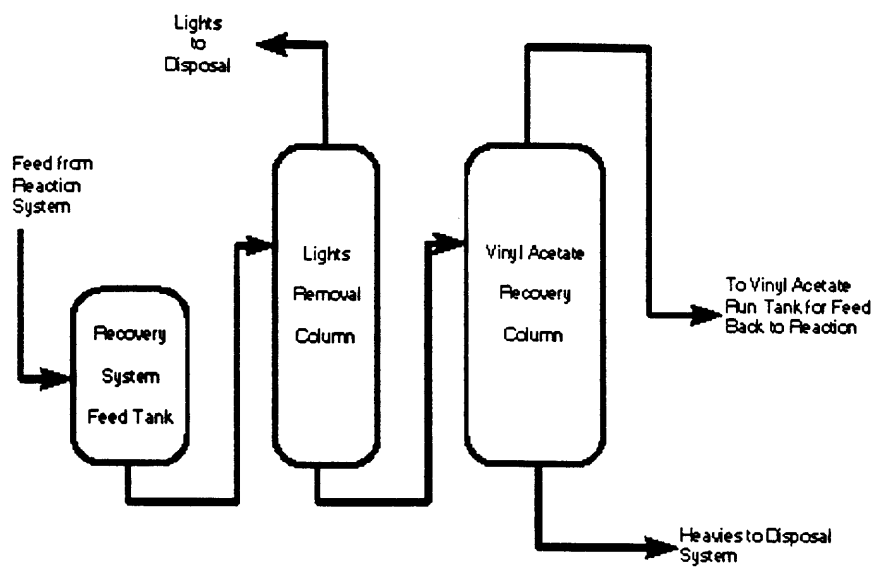
In late 1987 the plant installed a VA recovery system on their High Pressure 2 Polyethylene Unit. This recovery system began full-time operation in 1988. The project installation cost of this recovery system was approximately \$1.3 million and took 12 months to complete. After the first full year of operation, documented raw material efficiency improved 10%. This resulted in a savings of \$570,000. The volume of the hazardous waste stream was decreased by 1.4 million pounds during this reporting period. No additional manpower was added to operate the recovery system. Operational costs for the new equipment, such as utilities and maintenance, have been minimal. Over the three year period of its operation the recovery system has resulted in reported savings of approximately \$2 million.

The vinyl acetate system is closed-loop recycle (see flow diagram on next page). The residue is taken from the reaction system purge column and various entrainment separators to the Recovery System ("Lights" Column Feed Tank), which operates at fairly low pressures and temperatures below 100 C. In the feed tank some of the dissolved lights (ethylene and propylene) are sent to a vent gas suction system. An inhibitor is also added at this point to prevent the VA from polymerizing.

The residue stream is then fed to the Lights Column where the bulk of the dissolved ethylene and propylene are taken out. This column contains a number of trays with an integral upward-draft condenser. The column operates under 20 psi and below 100 C.

The lights from the Lights Column go to the Flash Tank for disposal via thermal treatment and the heavies (vinyl acetate and poly oils) go to the Vinyl Acetate (VA) Recovery Column. The VA Recovery Column contains 21 trays below 20 psi and below 150 C. The column takes refined VA as an "overhead" make at a reflux ratio of approximately 2. The recovered vinyl acetate is therefore able to be used as a raw material in the original process.

Improvements were made to the recovery system during 1989 which resulted in another 10% increase in efficiency. The calandria was revised to provide better fluid dynamics and heat transfer. Modifications to recycle piping improved recovery during start-up, shutdown, and reactor upsets. Closer attention to product scheduling and operating parameters (such as base temperature) have also allowed for improvements with no additional capital investment. The control panel display has been modified to show operators the cost savings in a graphic way to encourage optimization.



- 1) Feed and Make Rates Vary With Reactor Product
- 2) Operating Conditions Vary With Reactor Product
- 3) Major Equipment Only is Illustrated

SEADRIFT PLANT

Simplified Flow Diagram
Vinyl Acetate Recovery System

Source: Union Carbide, Seadrift Plant

Source/Citation: Mr. Henry Ward, Union Carbide Health, Safety and Environmental Affairs, 39 Old Ridgebury Rd., Danbury, CT 06817 (through an EPA RREL compendium of PP case studies)

Technological Option #5: SIC 2865

New solvent recovery process in the manufacturing of plasticizers results in reduced quantity of waste generated.

Manufacturing processes were modified to reduce the quantity of hazardous waste generated by 13%. Process modifications include: additional recycling of distillation overhead waste, installation of on line analyzers to reduce the production of by products, better control of chemical reactions to improve yield.

Case Study Summary

The manufacture of plasticizers, such as phthalic anhydride or phthalic esters, generate the following listed wastes: K015 (still bottoms from the distillation of benzyl chloride), K023 (distillation light ends from the production of phthalic anhydride from naphthalene), and K024 (distillation bottoms from the production of phthalic anhydride from naphthalene). Approximately 5 million lb./yr. of these wastes were generated at this plant. Some wastes were incinerated, and some were landfilled both on site and off site.

Scale of Operation: This facility has more than 100 employees, and more than 1000 tons of waste were manifested between 1981-1985.

Stage of Development: Fully implemented

Level of Commercialization: This information is not available
Results of Application: 13% reduction in the quantity of hazardous waste generated

Investment cost: \$500,000 (1987)

Cleaner Production Benefits

Economic Benefits: \$78,000 annual savings in treatment/disposal costs.

Liability reduction: Reduced liabilities by reducing the quantity of hazardous waste generated

Regulatory compliance: Regulatory compliance is easier with a **13% reduction in the quantity of listed hazardous waste generated at this plant.**

Waste and/or Emission Description

Physical state: Liquid, solid

Composition: Mixed organic chemicals

Description: K015, K023, K024

Cross Industry Application: Organics manufacturing

Source: "A Study of Hazardous Waste Reduction and Recycling in Four Industrial Groups in New Jersey", Environmental Resources Management, Inc, April 1987 {through UNEP ICPIC}

Technological Option #6: SIC 2911

Installation of an oily water treatment unit to remove insoluble emulsified oil from the desalter wash in a petroleum refining process

Introduction

A West Coast refiner has a desalter producing 13,675 tons per year (TPY) of oily water containing approximately 6.3 weight percent oil and 0.1 weight percent solids which would ordinarily be discharged to the refinery wastewater system. If allowed in the wastewater system, the oily water forms sludges and emulsions that would have to be removed and disposed.

Description of Waste Minimization Practice

As part of original construction, the refiner installed an oily water treatment unit downstream of the desalter. The purpose of the unit is to remove insoluble oil from desalter wash water containing emulsified oil. The figure on the next page is a simplified flow diagram of a typical system.

The oily water stream from the desalter is contacted with 1647 tpy of naphtha and a surfactant chemical. The water-oil-solvent stream is mixed in an in-line, low-shear mixer and proceeds to the main separator vessel, where an electrostatic field is established to maintain a sharp hydrocarbon/water interface and to assist in the separation process. The separation occurs because of density differences between the two phases.

The distillate solvent oil extracted from the water exits the top of the main separator and is sent to crude oil storage. Oil-free water (12,800 tpy) is discharged from the bottom of the vessel and proceeds to the refinery disposal system.

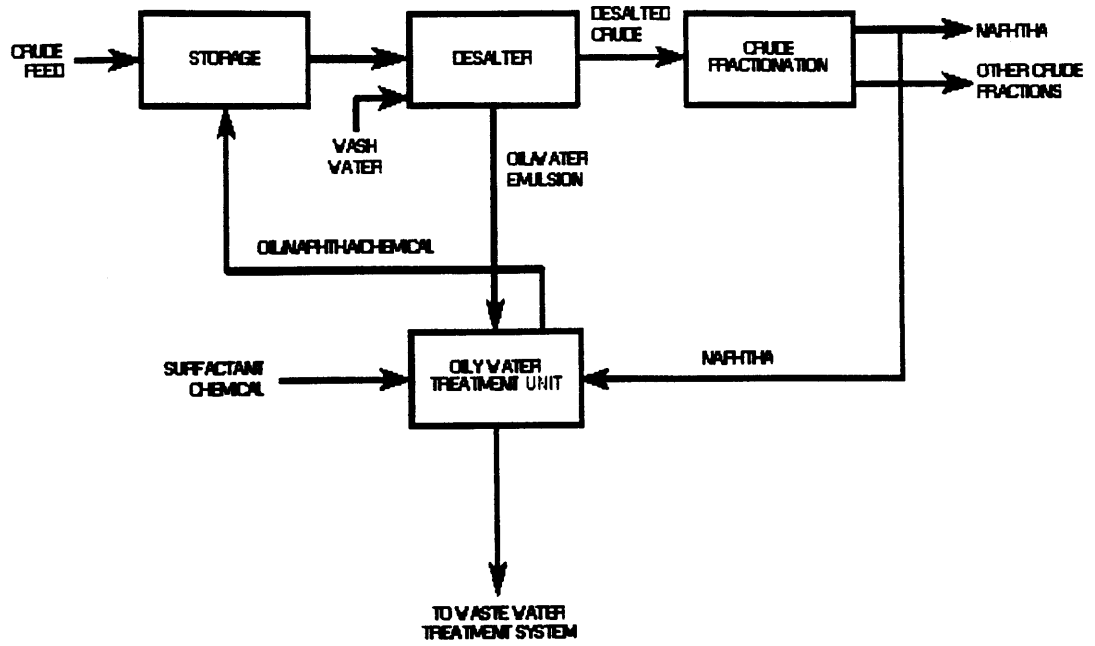
Effectiveness

The oily water treatment unit removes approximately 862 tpy of oil. Treated wastewater typically contains 100 to 500 ppm oil and grease and 25 to 200 ppm solids. Assuming an API separator sludge composition of 70% water, 20% oil, and 10% solids, sludge generation is reduced by at least 122.4 tpy. At a nominal \$200/ton disposal cost, annual disposal cost savings would be \$24,500/year. The user reported initial difficulties with the mixer supplied with the treatment unit, and installed an in-line mixer to replace the original equipment. Aside from this modification, the unit has operated for nine years with very little maintenance. The long-range effectiveness of this system appears to be good.

Costs

The capital cost of the oily water treatment unit is approximately \$60,000. Naphtha use amounts to 525,600 gallons per year and naphtha is recovered. Approximately 730 gallons per year of surfactant chemicals are used (1979 average cost for surfactant chemical was \$10.93/gallon). Electrical power consumption for this unit is not known.

Deoiling of Desalter Effluent



Source: "Waste Minimization in the Petroleum Industry - A compendium of practices", API Publication 849 30200

Technological Option #7: SIC 3471

1,1,1 Trichloroethane (TCA) is eliminated from the production process by aqueous based cleaning at a fastening parts manufacturing facility.

Cleaner Production Class: improved operating practices, substitute less toxic raw material
Industry Class: surface finishing, cleaning, and coating

SIC Code: 3400, fabricated metal products, 3471, electroplating, surface finishing

PP Technology Category: The PP technology involved initially reducing TCA use and finally eliminating its use by installing aqueous cleaning systems.

Case Study Summary

Process and Waste Information: This facility manufactures nails, staples, and the tools to drive these fasteners. The fastening tools are made of aluminum, magnesium and carbon steel. To produce these fastening parts, grinding, milling, drilling, lathe working, heat treatment and metal finishing operations are employed. Prior to many of these operations, parts are cleaned in a cold application using TCA. TCA was being discharged in the wastewater at levels twice as high as the allowable limit. Absorbents used around the machine tools also showed levels of TCA that prevented disposal in the regular trash. The company decided to attempt to eliminate the use of TCA from the manufacturing of fastening tools.

A task force identified potential causes of excessive TCA cleaning wastes: too much availability of cleaners, unnecessary dumping of TCA, lack of operator awareness, and unnecessary parts cleaning. Initially, the firm reduced the number of cleaning stations from 37 to 27. Costs associated with dumping of cleaners were made the responsibility of each department. Operators were surveyed to identify TCA use and determine opinions for alternatives.

PP Opportunities:

The selected pollution prevention measure was to use a heated tank with liquid agitation, contingent on the necessary chip removal and oil removal systems. In the machine maintenance areas, two mineral spirit cleaners were installed and the company is in the process of installing aqueous-based cleaning systems. At the time of this writing, they had installed 13 aqueous washing systems and two (2) mineral spirits cleaning systems. They expect to have a total of 15 aqueous systems, which are centralized within departments which will replace 37 former TCA locations.

Other process implementation, in addition to the processes for reducing TCA, included treating soapy water by oil separation and in house pH neutralization. Also, a precision grinder was replaced by an older piece of grinding equipment which does not require virgin material. A "procedure" (not further described) was also recommended that would prevent the spoilage of coolants.

Scale of Operation: Approximately 6500 gallons per year of TCA were used. No other measure of the scale of operations was provided.

Stage of Development: The PP technology is in the implementation stages, all equipment is not yet fully installed.

Level of Commercialization: The technology is fully commercialized

Material/Energy Balances and Substitutions:

Material Category	Quantity Before	Quantity After
Waste Generation:		
1,1,1 trichloroethane	400 ppb in waste	not detectable water discharge
Feedstock Use:		
1,1,1 trichloroethane	6500 gallons	0
Water Use:	N/A	N/A
Energy Use:	N/A	N/A

Economics

Investment Costs: The anticipated capital expenditures during 1990 1991 on this project are \$80,000. This includes costs for aqueous cleaning systems, waste water collection equipment, and equipment installation.

Operational & Maintenance Costs: \$15,000 in utility costs are required for heating and pumping aqueous fluids. There is an extra electrical cost associated with heating and pumping aqueous cleaning fluids equal to \$15,000 per year. TCA cold cleaning had no utility cost.

Payback Time: With an approximate annual savings of \$56,500 and \$80,000 in capital costs, the pay back period is approximately 1.4 years.

Cleaner Production Benefits

A net savings of \$7,000 is expected from reduced disposal costs, since the disposal costs in 1988 were \$9,000 and they expect that the cost for disposal of separated oils will be \$2,000. In addition, the annual cost saving associated with the disposal of absorbents no longer contaminated with TCA is \$34,000.

A net savings from replacing virgin TCA and aqueous cleaners will be \$7,000. This was calculated from the difference in the 1988 cost of virgin TCA (\$27,000) and the 1991 costs for aqueous cleaning solution (\$20,000).

Other processes implemented, in addition to the processes for reducing TCA, included treating soapy water by oil separation and in house pH neutralization. The annual savings from segregation and in house treatment are \$20,000. The savings from changing to an older grinder lead to an annual savings of \$1,200 from reuse of the coolant. The annual savings from preventing spoilage of coolants are \$1,300.

Overall, the potential savings from eliminating TCA is approximately \$56,500 per year

There are also regulatory advantages that cannot be directly quantified. Permit concerns associated with TCA discharge were greatly diminished by successfully negotiating with the regulatory agencies to tie the metal finish discharge into the nearby town sewer system. The company will no longer have to report under SARA for TCA which will save considerable time. Finally TCA air discharges will be eliminated. This may be especially important since TCA has come under intense scrutiny and regulation because of its ozone depletion and air toxics potential.

Citation: American Electroplaters and Surface Finishers Society, Inc., and the Environmental Protection Agency; "12th AESF/EPA Conference on Environmental Control for the Surface Finishing Industry"; January, 1991; pp. 165 181.

Technological Option #8: SIC 285

Plasticolors, Inc has developed and implemented a waste minimization program which reduced waste generation by 43% during its first plan year.

Clean Technology Category

Process raw materials modification and **process modifications** were undertaken by Plasticolors, Incorporated, to implement their goal of waste minimization.

Case Study Summary

Plasticolors, Inc. manufactures dispersions, additives and colorants. In early 1990, the company began a waste minimization program to reduce the amount of waste generated and to reuse materials when possible without affecting product quality. The amount of **resinous and water waste** generated during the twelve months prior to their waste minimization program (WASTEMIN) was 556,100 pounds. **During their first plan year** it was 315,478 pounds, a **reduction of 43%**. Overall production during this time decreased by 17%. In addition, 12,227 pounds of solid waste (office/computer paper and cardboard) was sent out for recycling rather than a landfill where it had previously been sent.

All areas of Plasticolors' operation have been involved in the WASTEMIN project. All employees have received various degrees of training and education regarding the proper segregation, collection, reuse and/or disposal of residual materials and their associated costs. Segregation and separation of flammable materials from combustible materials, and pourable from thick liquids prior to disposal, has been a common practice for many years. However, Plasticolors' Waste Minimization Team has also begun segregating material for reuse in the manufacture of new or existing products.

Initially, Plasticolors' waste reduction program consisted of **collecting and reusing resins. These resins were used to purge out sandmill chambers and related equipment between product runs.** This material was identified, collected and stored for use in the next batch of material to be made. Production scheduling was also incorporated into this process so that the colors being processed were in the proper sequence. **Two additional mill chambers and pumps were purchased to reduce the frequency of cleaning and, consequently, the amount of purge generated. Plasticolors' largest reduction in generated waste has come from the production area.** The lab has also been involved in the WASTEMIN project. The lab revised their procedures, collects smaller quality control samples and retains samples.

The pollution prevention techniques concerning minimization and/or reuse of resinous and water waste were conceived, developed and implemented by the Waste Minimization Team. This team was made up of employees from all areas of the company, from line employees to office managers. The team utilized the talents, abilities and input of all the employees. The seven member team was charged with accomplishing a first year 25% waste reduction. These reduction techniques have been used since their implementation. The technology and processes incorporated by Plasticolors were not commercially available.

Economics

Investment costs

Two sandmill chambers, pumps and associate equipment \$24,556

Operating and Maintenance costs

Waste Minimization team

(comprised of seven members meeting weekly) 350 hours \$5,968

Employee Training

(Procedural and awareness) 140 hours \$2,387

The payback period was less than one year. The total investment during the plan period of October 1, 1990, to September 30, 1991 was \$32,911. Using the previous twelve months as a baseline, the net savings were \$83,480 of which \$55,656 was divided among all employees as a waste minimization bonus. This amounted to each employee receiving a check for approximately \$500.

Cleaner Production Benefits

The reduction in waste and its associated costs had a positive financial impact on Plasticolors. Additional resources are now available for use in other growth oriented areas of their business. The reduction has also had a positive impact on Plasticolors' team concept of doing business and it reinforced efforts to involve operators and technicians in the problem solving process. Plasticolors has strengthened its relationship with the local community in which it is located.

Source: Case found in EnviroSenSe: {<http://es.inel.gov/techinfo/case/comm/plastico.html>}

10. Generic Technological Options

Generic Technological Option #1: Vapor Degreasing
{SIC-range = (34, 35, 36, 37)}

Use of an aqueous wash system eliminates completely the use of 1,1,1 TCA in degreasing

The full of description of the technology is given in the following attachment

Source: Case was provided by the RREL and the Center of Clean Products of the University of Tennessee

DEMONSTRATIONS OF ALTERNATIVES FOR VAPOR DEGREASERS

Dean Manke - Center for Clean Products Rupy Sawhney - Department of Industrial Engineering University of Tennessee 327 South Stadium Hall Knoxville, Tennessee 37996-0710 (615) 974-8879

INTRODUCTION

The "Cleaner Technology Demonstrations for the 33/50 Chemicals" is a cooperative agreement project between the Center for Clean Products and Clean Technologies and the U.S. EPA. Though originally designed to support the 33/50 Program, the results of this RREL-funded research will have a broad range of applications within industry and offer pollution prevention benefits beyond the 33/50 goals. The overall objective of this project is to evaluate substitutes of the 33/50 chemicals in order to encourage reductions in their use and release within specified priority use clusters. Priority use clusters, identified in the "Product Side of Pollution Prevention: Evaluating Safe Substitutes for the 33/50 Chemicals" report, are products and/or processes that consume a significant fraction of the 33/50 chemicals (1). The first evaluation, presented here, focused on the metal and parts degreasing priority use cluster and specifically substitutes for solvent degreasing processes that eliminate the use of the chlorinated degreasing solvent dichloromethane, tetrachloroethylene, 1,1,1-trichloroethane, and trichloroethylene. In this study the Center for Clean Products worked directly with an industry partner to demonstrate substitute feasibility and to gain actual industrial information. Calsonic Manufacturing Corporation (CMC) is aggressively pursuing less polluting alternatives to solvent degreasing and agreed to participate as the Center's industrial partner to demonstrate solvent degreasing substitutes. CMC manufacturers automotive parts included heaters, blowers, cooling units, motor fans, radiators, auxiliary oil coolers, and exhaust systems. Over the past four years, CMC had evaluated and implemented a number of environmental improvements to completely eliminate 1,1,1-trichloroethane (TCA) from their degreasing processes. This research focused on two of these improvements: an aqueous wash system which replaced five vapor degreasers of the radiator manufacturing line, and a no-clean processing alternative (i.e., application of an evaporative lubricant which does not require cleaning for subsequent processing) which eliminated two vapor degreasers of the condenser manufacturing line.

METHODOLOGY

The technical, environmental, economic, and national impact evaluations performed for the aqueous wash system and no-clean alternatives employed at the CMC facility had the following specific objectives: 1. technical evaluation o evaluated the substitutes' effects on process and product performance as compared to the solvent degreasing processes 2. environmental evaluation o evaluated the releases and off-site transfers of the 33/50 chemicals in the production process compared to the substitutes' chemical releases and transfers 3. economic evaluation o evaluated the costs, traditional and nontraditional, of the substitutes as compared to the 33/50 chemicals 4. national evaluation o evaluated and compared the overall life-cycle national environmental impacts of replacing the 33/50 chemicals with the substitutes. Data required to perform the technical, environmental, and economic evaluations were collected from CMC through data request tables, site visits, and interviews with CMC employees. Data request tables, completed by CMC employees and during site visits, allowed for the collection of process information including capital costs, operating and maintenance costs, utilities consumption, and production data. Questions concerning generation rates and disposal costs of waste (hazardous and non-hazardous) and wastewater accompanied the data request tables, as well as questions concerning permitting requirements. Tables and questions were directed at operations both before and after the process changes. Site visits and interviews allowed Center staff to become familiar with the day-to-day operations of each CMC manufacturing line of interest. This information was used to extend the traditional economic evaluation by using activity-based cost accounting. Activity-based cost accounting specifically identifying the frequencies, durations, costs, and possible chemical emissions for every activity required to operate and maintain the solvent degreasers and alternative systems. Direct manufacturing activities, as well as indirect support activities (e.g., paper work, waste management, supervision) were identified and included in the evaluation. These evaluations of CMC, supplemented by on-line databases and literature sources, were used to estimate the national environmental impacts that could occur if entire industrial sectors replaced solvent degreasing systems with the alternatives.

RESULTS

For this study, process and product performance were used as the two parameters to evaluate the technical feasibility of the alternative cleaning systems. As part of a continuous manufacturing line, the cleaning process (or

no-clean alternative) has the potential to influence both of these parameters. Process performance was defined as the rate of production. Product performance was based on the part reject-rate per unit of production, which was determined from the leak test records of every unit manufactured. The production and part reject-rates when the solvent degreasing processes were on-line were used as the baseline for comparisons with the alternative processes. Production rates and part reject-rates were both established through historical records and employee interviews. Evaluation of this data revealed that the production rate of either process line (radiator or condenser) was not affected by the change to the alternative system. Neither was the part reject-rate of the condenser line, both before and after the process change to the no-clean alternative. The part reject-rate for the radiator line, however, did significantly decrease after the aqueous wash system was installed. By implementing the aqueous wash system, and through the efforts of a Radiator Task Force established by CMC, the leak detection rate of the radiator line was decreased nearly 77 percent. Though the alternative processes eliminated TCA releases and transfers from the radiator and condenser process lines, other chemical releases and transfers resulted from their implementation. Therefore, it was necessary to evaluate multiple media (land, air, and water), as well as hazardous and nonhazardous wastestreams, to capture the full impact of the changes to the alternative processes. Air releases and off-site transfers, reported to the 1992 Toxic Release Inventory (TRI), were the predominant releases and transfers of TCA from CMC's manufacturing facility. Table 1, below, summarizes these releases and transfers, and shows how they decreased over the past four years. TRI only requires facilities to report total releases and transfers of a chemical, not process-by-process releases or transfers. Therefore, specifically identifying the contribution to the overall reductions from either the radiator or condenser process lines was not possible. However, chemical use records for these process lines, and employee interviews establish the following estimates: 1. the radiator process line, consuming 250,400 lb. of TCA for solvent degreasing in 1990, released 115,000 lb./yr. in 1990, 86,800 lb./yr. in 1991, and 0 lb./yr. in 1992; and 2. the condenser process line, consuming 88,500 lb. of TCA for solvent degreasing in 1992, released 75,500 lb./yr. in 1992, and 0 lb./yr. in 1994. The implementation of these alternatives eliminated this consumption of TCA and the releases and transfers associated with its use.

The implementation of the aqueous wash system for the radiator line, however, generated an 8,400 gallon/day water wastestream. Treated at an on-site pretreatment facility, this wastewater represents a significant waste management change. A nonhazardous, oily wastestream, skimmed from the surface of the aqueous wash reservoirs, was also a newly generated wastestream of the aqueous wash system. The no-clean alternative, by applying an evaporative lubricant to eliminate the need for parts cleaning, generated a new source of volatile organic compound (VOC) emissions to air. Based on lubricant consumption records, and assuming 100 percent evaporation, approximately 4,000 pounds/year (1.7 pounds/day) of volatile organics are emitted to the air from this alternative process.

TABLE 1. CMC TRI-REPORTED RELEASES AND TRANSFERS OF TCA

Year	TCA Air Emissions (lb./yr.)	Percent Change	TCA Off-Site Transfers (lb./yr.)	Percent Change
1990	425,758	--	233,530	--
1991	194,822	-54.3	338,826	+45.0
1992	176,239	-9.4	208,345	-39.0
1993	89,448	-49.8	194,875	-5.5
1994*	88,800	-25.3	109,000	-44.1

* Values estimated from eleven months of TCA purchase records and trends of previous years

The traditional economic evaluation, results of which are presented in Table 2, indicated return on investments in as little as 0.3 years (CMC-determined RI for the condenser line). The activity-based costs accounting economic evaluation had not been complete at the time of this abstract publication. However, initial review of the activities recorded during site visits to CMC identified significant differences in the required activities between the solvent degreasing processes and those of the alternative systems. These differences centered around two operations: one being the activities required to manage toxic chemicals and toxic waste; the other was the costs associated with the treatment of the aqueous system's wastewater. These results will be available by the time of the presentation, and copies of the methodology and results will be available.

TABLE 2 - COMPARISON OF SPECIFIC TRADITIONAL COSTS

Costs	Radiator		Condenser	
	Degreasers	Aqueous System	Degreasers	Evap.Lubs.
Capital Investment	not avail.	\$463,585	not avail.	\$44,000
Chemical Costs	\$182,460	\$21,400	\$87,040	\$4,720
Waste Disposal	\$20,000	\$12,430	\$13,735	\$0

Chemical releases and transfers occur through out their life cycles: from their production, use, and disposal. Significant changes in these emissions can occur if entire industrial sectors were to implement alternatives to solvent degreasing similar to those of CMC. Therefore, a life-cycle, multi-media approach to the national environmental impact evaluation was used to capture the overall environmental impacts of the alternatives.

Production facility releases and transfers of the chlorinated degreasing chemicals, in TRI reporting year 1992, totaled 1,286,823 lb. An estimated 34 percent of the chlorinated solvents produced in the U.S. were used in solvent degreasing applications in 1992 (2). Using a life-cycle approach, some fraction of the production emissions may be attributed to solvent degreasing: 34 percent to the production releases, establishing the potential upper boundary, equaled 440,000 lb. The EPA estimates that 24,500 solvent degreasers were operational in 1992 within the US (3). These solvent degreasers consumed approximately 440 million pounds of chlorinated solvents. Based on this information, the EPA also established a 1992 air emission baseline from these 24,500 solvent degreasers at 283.5 million pounds (4). Eliminating the use of chlorinated chemicals in solvent degreasing processes would greatly reduce or eliminate these emissions, both associated production releases and transfers, as well as the use and disposal releases and transfers. Phase-out regulations for TCA will reduce the use and releases/transfers of TCA regardless of the degree of which these alternatives are implemented. The alternatives to solvent degreasing also have life cycle environmental releases and transfers. Aqueous detergents may include in their formulations surfactants, saponifiers, chelators, corrosion inhibitors, and stabilizers. Specific examples from each of these additive classes were analyzed. Disposal of the water wastestreams may have significant effects on publicly owned treatment works (POTW). The POTW infrastructure of the nation was evaluated, and the potential impact the aqueous wash systems have on the infrastructure was established. A similar life-cycle approach was used to evaluate the mineral-spirits- based evaporative lubricants.

CONCLUSIONS

A significant number of studies are being conducted, or have been completed, which evaluate the effectiveness of cleaning alternatives. These studies primarily focus on one of the four evaluations performed in this study; little integration of all potential issues is attempted. This cooperative agreement with EPA expands the existing knowledge of alternatives to solvent degreasing by integrating technical, environmental, and economic issues, as well as addressing the life-cycle attributes of the alternatives on a national scale. The technical feasibility of CMC's process changes has proven to be positive. Significant reductions in toxic chemical releases and transfers were a result of the process changes, while other wastestreams were generated which required different management schemes. The traditional economic evaluation of this study did not reveal any unique conclusions. However, the activity-based cost accounting method did identify the costs associated with managing toxic chemicals and wastes, costs normally absorbed by the company as overhead. Finally, the national impact evaluation identified the importance of a life-cycle approach to evaluate pollution prevention projects. Though the alternatives evaluated in this research eliminate chlorinated chemical emissions, there are new wastestreams and constituents that must be addressed.

REFERENCES

1. Product Side of Pollution Prevention: Evaluating Safe Substitutes of the 33/50 Chemicals, EPA/600/R-94/178, U.S. Environmental Protection Agency, Office of Research and Development, September 1994.
2. Product Side of Pollution Prevention: Evaluating Safe Substitutes of the 33/50 Chemicals, EPA/600/R-94/178, U.S. Environmental Protection Agency, Office of Research and Development, September 1994.
3. National Emission Standards for Hazardous Air Pollutants: Halogenated Solvent Cleaning -Background Information Document, EPA-453/R-93-054, U.S. Environmental Protection Agency.

Generic Technological Option #2: Zero-discharge metal plating systems
{SIC-range = (34, 35, 391)}

In process wastewater purification and metal recovery in the metal plating process at a jewelry manufacturing SME.

The full of description of the technology is given in the following attachment

Source: The technology was presented in the Spring 1993 issue of the Pollution Prevention News

Case Study

Moving Towards Zero

Our approach to solving pollution prevention problems in this country is showing a gradual shift from end-of-pipe controls to front-end reduction of strategies. The next logical step? Closing the loop entirely. As innovations at the Robbins Awards Co. of Attleboro, Massachusetts show, getting rid of pollution is not some environmental pipe dream; the company's closed-loop production system proves that reduced use and zero discharge of toxics are technically feasible objectives that can translate into significant savings.

Robbins is a medium-sized company that designs and manufactures custom jewelry and awards. Production of these goods involves a metal plating process famous for high levels of

pollution; the process is chemical intensive, requires high volumes of water, and produces huge quantities of wastewater residuals.

Robbins zero discharge system, installed in 1988, involves two subsystems: wastewater purification and metal recovery. These two units have reduced the company's water usage by 48 percent, chemical usage by 82 percent, and production of metal hydroxide sludge by 99.8 percent, from 4,000 gallons per year in 1986 to seven gallons in 1988.

Installation of the system cost the company \$120,000, plus \$100,000 for a new wing to house the units. Overall savings average \$71,000 per year; the investment was repaid in full after three years.

A combination of factors spurred Robbins to explore the zero discharge option. A 1985

study of the Ten Mile River identified Robbins as one of the river's major polluters. As a result, the State's Office of Technical Assistance (OTA) held a series of pollution reduction workshops. OTA's message convinced Robbins' environmental manager, Paul Clark, to substantially reduce the company's water usage, from 12 to 15,000 gallons per day to only 2,500 gpd.

Then in January 1987, EPA and state officials announced strict new pollution restrictions based on the 1985 report. In addition, MassPIRG filed a lawsuit stating that Robbins had violated its wastewater discharge permit limits repeatedly from 1981 to 1987, translating into 2,500 violations, with potential fines of up to \$30 million. (MassPIRG put

the suit on hold while Robbins made the transition to closed-loop production, and dropped the case after the company demonstrated that it had achieved zero discharge in 1988.)

As Clark explored the feasibility of a closed-loop system, pollution control suppliers told him, "it can't be done." The state OTA agreed to visit the company, and came up with specific ideas on how a closed-loop system might work. Now it was up to Clark to convince top management that the closed-loop system was the most cost-effective way to bring the company into compliance with the strict new discharge requirements. The numbers were clear, but the system had never before been tried. Senior managers agreed to Clark's proposal with some hesitation, but have since become forceful advocates of toxics use reduction. "Companies have to become effective in dealing with

environmental issues," says Robbins' Executive Vice-President John Bradley. "The ones that don't are going to be paying huge fines and penalties - they won't be in business by the year 2000."

Other companies are showing growing interest in the Robbins approach. Crucial ingredients to Robbins' success include technical support from the state, a citizens' group threatening legal sanctions, strict federal requirements, and an innovative, persistent advocate for change within the company. According to Bradley, the major hurdle to overcome is fear of risk. "Upper management has to be flexible," he says. "They can't shut anything out just because it hasn't been done before."

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This article is reprinted from **The What Works Bulletin**, a bimonthly publication highlighting outstanding environmental action. **What Works** is published by The Environmental Exchange, a national nonprofit organization accelerating environmental action by sharing information about what's working to protect the environment. To exchange information about successful environmental initiatives, contact The Environmental Exchange, 1930 18th Street N.W., #24, Washington, DC 20009; Tel: 202-387-2182.

Generic Technological Option #3: Paint Removal

SIC-range = (28, 35, 36, 37)

A cryogenic process for paint removal from steel structures, using liquid nitrogen instead of acids or pyrolithic oven.

Cleaner Production Principle: Material substitution

Description of PP Application:

The process for paint removal is based on liquid nitrogen's ability to quicken cooling. The differing rates at which the material of the structure and paint coat contract results in cracks in the paint. By means of mechanical action the paint coat is then removed. The resulting solid waste can be used for the production of plastic objects. The objects to be treated are placed in a tank containing liquid nitrogen (-196 °C); the removal process can be realized in a continuous and completely automated plant. Conventional processes utilize acid dripping or pyrolitic ovens and produce pollutants. Liquid nitrogen, chemically inert, is already in the atmosphere and can be obtained at low cost. This type of process **does not produce liquid waste**. **The solid waste that is produced can be recovered and utilized** to produce plastic objects. Existing plant capacity is 2500 Kg/h of objects to be treated. The technology has been fully implemented and in operation since 1990. It is covered by a **patent**.

Economics: Referring to 2.500 Kg/h of treated objects the investment cost is \$220,000 to \$250,000. Payback time is 1/1.5 year.

Advantages: In addition to the benefits outlined above, nitrogen is a comparatively low cost raw material and the objects processed by this technology have a life span five times longer compared to those produced by other processes. Although this process has a high productivity until 3.000 Kg/h, this is not a constraint for an SME.

Source: The UNEP ICPIIC database

Generic Technological Option #4: Solvent Substitution in Paints
{SIC-range = (285, 34, 35, 36, 37)}

Substitution of solvent based paint with powdered paints minimizes organic solvent emissions.

Cleaner Production Class: substitute less toxic raw material

Industry Class: surface finishing, cleaning, and coating

Clean Technology Category: This clean technology scheme involves the utilization of powdered paints instead of solvent based liquid paints.

PROCESS AND WASTE INFORMATION: A fixture manufacturing facility in Landskrona, Sweden utilized a mineral oil based cutting oil for metalworking. Manufactured components were then degreased using trichloroethylene solvent. **Solvent based paints were utilized in the final finishing of parts.** The use of powdered paints results in reduced organic solvent vapor emissions and reduced operating costs.

SCALE OF OPERATION: 400,000 pieces/yr.

STAGE OF DEVELOPMENT: Clean technology is fully implemented.

LEVEL OF COMMERCIALIZATION: Clean technology is fully commercialized.

MATERIAL BALANCES:

Material Category	Quantity Before	Quantity After
Waste Generation:		
Trichloroethylene vapor	N/A	5 tons/yr. less than before
Mineral Solvent vapor	N/A	30 tons/yr. less than before
Wastewater	N/A	N/A
Feedstock Use:	N/A	N/A
Water Use	N/A	N/A
Energy Use:	N/A	N/A

COSTS: Investment for system for powdered painting was \$383,000. No other investment costs provided. Operating costs for powder painting is \$415,800/yr less than for solvent based painting. Thus the Payback for painting system changeover investment was less than 1 year.

PP BENEFITS: New processes minimizes organic solvent emissions, costs associated with solvent purchase and waste disposal greatly reduced. Further, workplace exposure to solvents is prevented. In addition, new system facilitates continuing compliance with air pollution standards.

SOURCE: Siljebratt, Lars et al; Förebyggande miljöskyddsstrategi och miljöanpassad teknik i Landskrona, etapp 2. ISSN 0281 5753 {From the UNEP ICPIC database}

PART IV: POLICY RECOMMENDATIONS FOR ENHANCING THE EFFECTIVENESS OF PP SEPs AND PROMOTING AP SEPs

11.0 PP SEPs - Conclusions drawn from the application of the proposed prioritization methodology

11.1 Overview

After going through the prioritization exercise described in Part II, valuable conclusions can be drawn concerning the availability of sound PP technologies that can be used in enforcement, the scope of the relevant PP technologies, and the information needed for a sound choice of technologies. Sections 11.2, 11.3 and 11.4 address these issues.

11.2 PP SEPs -Current performance and future opportunities

There is no doubt that PP SEPs are a successful environmental strategy and their importance is appreciated by the agency [1]. This is evidenced by the fact that EPA revised its SEP policy so as to promote PP SEPs by increasing the breadth of acceptable PP projects and by relaxing the nexus requirements. However, EPA needs to be more proactive in the negotiation of such agreements by having a clear idea of appropriate PP technologies worth of adoption for PP SEPs [8].

The main value of this research, aside from identifying 12 specific technologies that can be promoted through SEPs, is that it gives EPA a useful framework for prioritizing future actions, comparing technology options, and optimally allocating its scarce human resources.

As far as future opportunities are concerned, the Internet is creating significant opportunities for cost-effective and timely dissemination of PP information and the agency should fully integrate the new medium in its PP strategy. In [30], the above ideas are summarized as follows:

“As we have already indicated, we believe that the Internet possesses the highest potential to become the main platform of dissemination of environmental information. This is because the Internet is much more convenient and user-friendly than the modem-accessed bulletin boards that do not possess a GUI environment, it offers the ability to link to guide the interested “client” to other sources of information, it is feasible to combine multimedia (e.g. informational videos or interactive flowcharts) and powerful data search facilities (for efficient database queries) and it seems that the users are increasing with such high rates that very soon, the connection to the Web will be such a cheap and easily implementable activity that even the most unsophisticated SMEs will be able to afford. In this light, we propose that EPA OECA post all the promising PP technology profiles, such as the ones that our research identified, in a web-page in the EnviroSense site, probably in a section called “PP technologies suitable for SEPs”.

In addition to the opportunities provided by the Internet, EPA needs to use its (internal) enforcement databases in the PP technology prioritization process. As discussed in Section 7.2.1, enforcement data from the IDEA database could significantly enhance the efficacy of the prioritization process. The authors’ experience trying to access this database shows that IDEA is a closed and isolated system that minimally --if at all-- contributes to the current strategic targeting process for PP SEPs.

11.3 Quality assessment of the PP technologies sources

The experiences of the author concerning the quality of the data on PP technologies, both in the framework of this thesis as well as in past research ([10], [30]) shows that the quality of the publicly-available information leaves much to be desired. Many of the PP cases found in the major PP Clearinghouses/databases such as PIES, EnviroSenSe and the UNEP database, do not have an easily absorbable format and do not contain vital information on issues such as the worker health and safety aspects of the promoted technologies. For example, [10] finds that:

(a) Many of the case studies identified from the above-mentioned databases completely lack information regarding the interactions of human beings with the production processes, materials, or products. Process engineers generally do not consider workers or jobs as part of the production process. From a worker health perspective, this is a serious problem that must be solved if risk shifting from the environment to people is to be limited.

(b) No information is given regarding the physical or economic context for the processes. It is very difficult to know what the processes in the PIES system or in the UNEP -ICPIC database actually looked like with respect to the physical space in which they were located, the degree of automation, the quality and maintenance status of the equipment, engineering controls, or administrative practices used to run the processes including shift work. From an industrial hygiene perspective, it is well-known that the actual conduct of the processes described in these case studies can vary considerably depending on the economic context and physical surroundings of the workplace. For example, chemical manufacturing performed with using practices that range from manual reactor vessel charging, mixing, packaging, and maintenance to process steps that are almost completely enclosed and automatic. The same process under these different conditions could have very different implications for worker health.

(c) Limited information is given regarding the physical form of the substances at certain stages in the process so that should a worker be exposed, the physiologic route of entry can not be adequately anticipated. The physical form of substances can occasionally be determined by knowing process specifications such as temperature and pressure but these process specifications are not given consistently. Information is lacking about the manner in which materials are added to a process, maintained, stored and disposed.

11.4 Enhancing the information content and scope of PP technology data sources

The shortcomings identified in Section 11.3 pose some major concerns for the efficacy of the PP SEP mechanism, since the dissemination of PP information through the above mentioned databases is a central part of the EPA PP SEP strategy. This thesis advocates the use of a new format for the PP technology profiles which, if adopted, will ensure optimal choices that do not cause media shifting from gradual pollution to sudden and accidental releases. This format was first introduced in [10] and is presented in Table IVA. EPA needs to implement such a format in all PP-related publications.

Table IVA: Proposed Format for PP Technology Profiles

Note: [Corresponding sections in the UNEP data-bases are in square brackets]

1. NAME OF THE TECHNOLOGY [Headline]
2. DATA-BASE(S) WHERE THE TECHNOLOGY IS FOUND
3. NARRATIVE/TECHNICAL DESCRIPTION OF THE TECHNOLOGY
[Description of Cleaner Production Application]
 - General description
 - Substances involved: physical form, toxicity/hazard profile
 - Work practices: exposure potential profile including duration and frequency
 - Equipment: degree of sophistication, reliability, maintenance level assumed
 - Process: degree of automation, batch vs. continuous, temperatures and pressures utilized
4. ORIGIN/OWNERSHIP OF THE TECHNOLOGY [Contacts]
5. SECTORS IN WHICH THE TECHNOLOGY ARE OR MIGHT BE USED [ISIC] AND LOCUS OF THE TECHNOLOGICAL CHANGE (Primary, secondary, or ancillary process/technology) [Description of Cleaner Production Application]
6. IMPORTANCE OF THE TECHNOLOGY TO NATIONAL/EU INDUSTRIAL CONCERNS
 - economics of the technology per se [Economics]
 - economic importance of the process/product line with which the technology is associated
7. ENVIRONMENTAL PROBLEMS ADDRESSED (& IMPORTANCE OF THE TECHNOLOGY FOR GOVERNMENT ENVIRONMENTAL INITIATIVES) [Advantages]
 - pollutants and media involved
8. ENVIRONMENTAL PROBLEMS NOT ADDRESSED [Constraints]
 - pollutants and media not addressed
9. CHANGES IN OCCUPATIONAL RISKS (HEALTH AND SAFETY) BROUGHT ABOUT BY IMPLEMENTATION OF CP/PP TECHNOLOGY [Constraints]
 - accident and exposure profiles of both old and new technologies/approaches
10. MISSED OPPORTUNITIES TO IMPROVE WORKER HEALTH AND SAFETY
(Other choices that would have addressed the environmental concerns but would also have improved worker risks; or additional approaches that could be used along with the newly implemented CP/PP technology)

12.0 Linking PP and AP - Expansion of the Reach of the PP SEPs

12.1 Overview

As shown in Chapter 3, the statutory language and the regulatory definition concerning PP are broad enough to ensure that sudden and accidental releases (and thus AP strategies) can be addressed through the currently available SEP framework. Moreover, Chapter 3 explains the economic and behavioral reasons that make the SEP framework a desirable and highly needed vehicle for the promotion of AP technologies. The linkage between PP and AP having been established, this thesis proceeds by proposing an AP technology prioritization mechanism and policy recommendations concerning EPA's AP SEP strategy. Specifically, Section 12.2 shows how the methodology developed in PART II can be extended to AP technologies, while section 12.3 identifies policy measures that the EPA needs to find in order to promote AP.

12.2 Extension of the PP Prioritization Methodology for AP technologies

The filters developed in the prioritization of PP technologies in PART II of that thesis can be used, with minor changes, for AP technology prioritization as well. With regard to Figure 1 and to Sections 7.2 and 7.3, the changes needed are the following:

(a) In the sector prioritization Subfilter Ia, the TRI data should be substituted by data on accident events, misses or even near misses. Such data can be found in various databases, which are described in detail in the Appendix of [8]. The most relevant databases in the SEP framework are the ARIP (Accidental Release Information Program) and the AHE (Acute Hazardous Events) databases. Both these information sources are internal EPA systems that possess a wealth of accident-related data on all economic sectors.

(b) As far as Filter II is concerned, this can be used as is, provided that the MM-benefit definition includes inherent safety concerns.

From the above, becomes clear that the informational infrastructure and the methodology for AP technology identification is already in place, what we are really missing is a rich pool of AP technology profiles from which the EPA or firms might choose suitable AP SEPs. Section 12.3 argues that EPA needs to take the initiative in addressing this problem.

12.3 Regulatory Responses to the need of promoting AP technologies

As explained in Chapter 3, AP technologies are equally important but less likely to be implemented than PP technologies for a variety of reasons. Also, the experience gathered during this research shows that even if the EPA or a firm in violation of the environmental law wanted to consider AP SEPs, there are no relevant technology profiles readily available to initiate / facilitate such a process. Thus, EPA needs to take specific actions addressing the identified shortcomings. These actions can be summarized in the following four recommendations.

First, EPA needs to make available both to SEP negotiators and to interested firms an extensive universe of AP technology profiles. The most efficient way to achieve that is by expanding the already available PP Clearinghouse databases (such as PIES, EnviroSenSe etc) to include descriptions of accident prevention/inherent safer technologies.

Second, EPA needs to leverage more its accident-related databases (ARIP and AHE) in targeting industrial sectors for enforcement control. Since the agency is already using rather successfully the TRI data for targeted PP-related enforcement control, one can safely assume that the extension to AP-related controls would not pose any particular difficulty.

Third, the agency must expand the technology descriptions of the installed base of PP technologies so as to include their inherent safety features. The adoption of the technology profile format proposed in Section 11.4, would be very helpful to that end. Such an expansion would have a double benefit: (a) it will improve the chances of AP projects being implemented and (b) it will ensure that no unacceptable trade-offs between AP and PP is taking place through the implementation of PP SEPs.

Fourth, reiterating the conclusion of the analysis of Chapter 3, EPA needs to revise the language of the SEP policy to include and encourage the use of AP technologies in enforcement settlements.

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Appendix: Historical and Ongoing Efforts at Prioritizing Opportunities for (both gradual and sudden) Pollution Prevention.

A. The 1986 OTA Report on PP

US Congress Office of Technology Assessment: "Serious Reduction of Hazardous Waste" [A1], Washington DC, 1986. Project Director: Joel S. Hirschhorn.

This report, an introduction to the Pollution Prevention concept (Waste Reduction in the terminology of the period), is a coherent presentation of PP opportunities in the industrial sector. As this attempt of mapping the universe of PP opportunities is similar to our project, we will describe it in some detail.

The OTA report covered essentially all the industrial sectors, ranging from mature/stagnant to innovation-driven and from large-scale manufacturing of consumer-goods to job-shop processing. The PP opportunities are classified in the following categories: (i) Operations Changes, (ii) In-process Recycling, (iii) Process Changes, (iv) Input substitution and (v) End-product changes. Some of the most promising sectors identified in this report were;

- a. Paints (SIC 285), presenting opportunities in all five categories.
- b. Automobiles (SIC 371), presenting opportunities in all five categories
- c. Electroplating (SIC 34), presenting opportunities in categories (i)-(iv).

B. The EPA 33/50 Program [A2, A3]

Purposes:

- (i) Target 17 chemicals and reduce their national aggregate releases by 33% by the end of 1992 and by 50% by the end of 1995.
- (ii) Encourage PP activities to achieve those goals.

System Description:

The 17 chemicals were chosen from the TRI pool using as criteria,

- production and environmental releases volume
- toxicity to humans
- potential for reducing releases through PP practices.

The selection process was qualitative. Each EPA office used its own ranking criteria to evaluate the TRI data. The chosen 17 target chemicals were the ones with the highest aggregated "scores".

System Evaluation:

The **pros** of the program from the perspective of designing a useful prioritization scheme are,

- (i) its focus on multi-media releases: air, surface water, POTW discharge, on-site land, off-site transfers.
- (ii) its focus on the PP-potential concept.

while as **cons** we consider,

- (i) the risk/hazard oriented approach, (as opposed to technological opportunity approach), and
- (ii) the resulting qualitative prioritization scheme adopted.

C. The EPA Common Sense Initiative [A4]

This is a relatively new EPA program, announced in mid July 1994, targeting “a cleaner environment at less cost to industry”. This is to be achieved through the establishment of a new approach to the environmental problems that seeks to change the attitudes both within EPA and in the whole community. Specifically, this new effort adopts an industry-by-industry, as opposed to a pollutant-by-pollutant, environmental strategy. It also promotes the extended participation of all the stakeholders (Government, Industry, NGOs, local communities) in the decision-making process. EPA acknowledges the limited potential of end-of-pipe technologies and the need for promotion of the PP model; moreover, the agency commits itself to the promotion of innovative solutions through flexible regulation.

The participating Six Industrial Sectors in the Common Sense Initiative are:

- Automobile assembly (SIC 371)
- Computers and Electronics (SIC 367)
- Iron & Steel (SIC 331)
- Metal Plating & Finishing (SIC 34)
- Petroleum Refining (SIC 2911)
- Printing (SIC 275)

These sectors were chosen because they:

- a. demonstrated willingness to participate
- b. have significant contribution on the US Economy (14% of GDP)
- c. have significant impact on the environment
- d. face a broad array of regulatory changes
- e. represent a broad array of American businesses (from highly-concentrated & sophisticated to SME-dominated).

We believe that the overall approach is correct/sound and shares the same rationale/reasoning with our approach, although the focus is rather different. Since this program was initiated quite recently, any effort to assess its success would be premature.

D. The EPA Design for the Environment (DfE) Initiative and the “Green Chemistry” movement.

As we consider that the “Green Chemistry” movement presents significant technological opportunities pertinent to our research objectives, we attempt here a relatively detailed discussion. The main topic of the discussion is the EPA DfE initiative, although other institutions such as the National Science Foundation (NSF) and the American Chemical Society (ACS) are also actively engaged in that endeavor. As an introductory note we have to underline the fact that DfE is primarily concerned with basic research in scientific areas pertinent to PP and to PC where the methods and the technologies have been essentially stagnant for years. Thus it is unlikely that one can identify suitable PP opportunities for current inclusion in enforcement settlements. Nevertheless, the whole movement towards environmentally benign chemical processes has such an enormous long-term potential that we cannot afford to overlook/ignore it.

The General Principles of DfE: DfE is a program initiated by the EPA's Office of Pollution Prevention and Toxics with main objective to facilitate information exchange and research on PP. Specifically the program aims at [A5, A6]:

- a. Changing general business practices to provide incentives for PP efforts.
- b. Working with businesses (large and small) and trade associations in specific industries to evaluate the risks, performance and costs of alternative chemicals, processes and technologies. (Current research focuses on sectors of printing, dry cleaning, aerospace, video film industries.)
- c. Helping individual businesses undertake environmental design efforts.

The underlying idea [A7] is that, the most known synthetic reactions were primarily based on the merits of product yield, with little or no regard for the toxic nature of the raw materials, catalysts, solvents, reagents, by-products, or impurities. Thus, there is high probability that other synthetic pathways will prove optimal now that the "constraints" have expanded in order to account for environmental and occupational hazards.

Moreover, it is now realized [A8] that there is enormous ground for improvement not only for commodity chemicals manufacturing (a sector typically considered stagnant technology-wise) but also for fine & specialty chemicals. The explanation is that the development of organic synthesis products is the domain of synthetic organic chemists, the latter tend to use classical stoichiometric processes and multiple-step pathways rather than catalytic steps (unlike chemical engineers and surface scientists). Examples of widely used stoichiometric reactions are various aromatic substitutions (halogenations, sulfonations, Friedel-Crafts acylations) and oxidations with dichromate and permanganate. It is also argued [A7, A8] that the isolation and purification of organic acids is currently entailing more neutralization reactions that are really needed; the ultimate result is an increased environmental burden in the form of salt by-products. The issues linked with the non-catalytic approach is lack of "atom selectivity" and "atom utilization", disproportionate amounts of inorganic salt by-products and aqueous waste.

The DfE response to the above described problems is the promotion of research in the following areas: Aqueous solvent-based reactions, ambient temperature reactions, just-in-time in-situ generation of toxic intermediates, chiral catalysis, artificial enzymes and built-in recyclability. [A9]

Non-DfE efforts in the same context of "Green" (i.e. environmentally benign) chemistry include research efforts with already proven -at bench scale- results focus on salt-free catalytic technologies with high atom utilization, such as catalytic oxidations and carbonylations. These technologies exhibit both Pollution and Accident Prevention potential. PP-wise, they contribute to waste stream minimization and they diminish the use of functional groups such as halogens, SO_3H , NO_2 . AP-wise the use of new catalysts such as zeolites, superbases and biocatalysts can diminish the industrial use of many hazardous and/or toxic chemicals; namely, phosgene, dimethyl sulfate hydrogen chloride, chlorine and bromine.[A8].

The most significant research efforts that we identified within the framework of "Green Chemistry" are the following:

- (1) EPA and National Science Foundation (NSF) Partnership [A7, A10].
 - i. Union Carbide and M.D. Donohue & J.L. Geiger (Chem. E. Dept. Johns Hopkins). Research on supercritical CO₂ (SCCO₂) in spray painting applications to reduce VOCs.
 - ii. J. DeSimone, University of North Carolina at Chapel Hill: study of SCCO₂ as medium for dispersion polymerization.
 - iii. C.L. Czecaj & K.A. High, Oklahoma State University and Phillips Petroleum: Elimination of side reactions in the production of sulfoane. (Sulfoane is an important chemical used in pulp delignification and electroplating baths).
 - iv. G. Epling, University of Connecticut at Storrs, is working on the replacement of toxic metal-based catalysts (Cd, Pb, Hg, Ni, Cr) by clean sunlight driven reaction centers such as dye-molecules.
 - v. G.A. Kraus, Iowa State University at Ames, is working on photochemical alternatives to Friedel-Crafts reactions. The objective is to eliminate Aluminum Chloride and toxic solvents from the production of commercial chemicals such as Ibuprofen and doxepin.
 - vi. J. Frost, Purdue University, has substituted the toxic substance benzene by quinic acid in the production of hydroquinone (photographic development agent) and benzoquinone (which is the base for many industrial chemicals).
 - vii. J. Tanko, Virginia Polytechnic Institute and State University., is investigating the use of SCCO₂ in free radical reactions (halogenations primarily) used in the production of many drugs and polymers.
 - viii. O.L. Chapman, UCLA, has developed an innovative process that converts xylenes to styrenes in a single step as opposed to the current process that in a multi-step process utilizes benzene, ethylene and involves catalytic alkylations and dehydrogenations.
- (2) Mark E. Davies, Chem. Eng. Professor at Caltech, and an expert on catalysis, has done a comprehensive presentation of the current situation in environmentally benign catalytic Chemistry at the ACS meeting in San Diego, 1994. [A11]
The main areas that he covered with specific applications, applications on which we are still trying to gather more detailed information, were:
 - ◆ Zeolite catalysis
 - ◆ Substitution of strong acids (HF, H₂SO₄) by sulfated oxides and heteropoly acids
 - ◆ Replacement of traditional caustic catalysts by superbases (M-MOH-Al_xO_y where M: Li, Na, K, Cs, Rb).

E. Recent EPA efforts on Identification and Prioritization of PP Opportunities.

"Industrial PP Opportunities for the 1990's", by I.J. Lisic, Waste Minimization, Destruction and Disposal Research Division, Risk Reduction Engineering Laboratory, EPA Office of Research & Development, Aug. 1991. [A12]

1. **Objective:** Identify a short list of industries or industrial segments that present both (a) the most significant environmental problems or risks and (b) opportunities for significant waste reduction.

2. Methodology:

(a) Based on the Standard Industrial Codes (SIC) classification system they applied to their *PP potential criteria* to a fairly large number of industrial sectors (175 two-, three- and four-digit SICs). Their criteria are presented in Table A2 and the list of industrial sectors in Table A3. The various sectors were evaluated based on the scores given by 25 PP experts from academia, state PP programs and contractor personnel. The scores are presented in Tables A4 and A5 classified by 4-digit and 2-/3-digit SIC respectively. The highest priority sectors were:

- Electroplating (SIC 3471)
- Plastics, resins and elastomers (SIC 2821)
- Industrial Organic Chemicals not elsewhere classified (SIC 2869)
- Paints, varnishes and lacquers (SIC 285)
- Motor vehicles and equipment (SIC 371).

(b) Based on the results of the previous part they chose 17 industries for further investigation. The sources of information in that stage were: Industry trade associations, academic researchers, local government officials, and a literature survey within the EPA PP Information Clearinghouse (PPIC). The result of their investigation was the identification of specific technologies with substantial PP benefits in these industrial sectors. An annotated summary of their findings in these 17 sectors is presented below. We give a more detailed presentation of the sectors that have the specific characteristics we are seeking for in our own research, i.e. stagnant technology and many needy firms with neither access to R&D nor sophisticated technological expertise. In addition to the industry-specific technologies, they also identified 13 generic technology improvements that are critical for any effective PP strategy. These are presented in Table A6.

3. Industry Profiles:

1. Textile dyes and dyeing (SIC 226)

The ongoing trend is to switch to more environmentally benign dyes, e.g. from azo- to triazine-based reactive dyes. Significant confidentiality and proprietary issues prevent the transfer of this technology within the sector. There exists enormous potential for reduction in water use and waste-water generation. The option of solvent finishing for example, in the case of wool fabric degreasing, is identified as a very promising PP technology already proven outside the US. Dye recovery and recycling also exhibits significant potential and calls for high capital expenditure. Overall the sector seems suitable for regulatory-leveraged PP success.

2. Wood preserving (SIC 2491)

This industry has made significant improvements the last years introducing new environmental-friendly technologies. Clearly the sector does not meet the criterion of technological stagnation and thus we do not consider it a target in our project.

3. Pulp and paper (SIC 26)

This is a slow-moving, very capital-intensive sector with long-established core technology. Currently, the serious environmental problems have to do with bleaching, de-inking (for paper recycling), reduction of wastewater generation. The use of pulp byproducts as raw material in thermoplastics manufacturing may prove an interesting PP strategy with multi-media and multi-sector benefits. This option as well as other R&D efforts within the sector will be highly leveraged by “external” regulatory incentives.

4. Printing (SIC 27)

The sector is fully compatible with our research objectives because it is dominated by SME's and characterized by stagnant technology.

The most promising cited technologies are:

- ◆ the Toray waterless offset plate system
- ◆ dry-printing (xerography) that eliminates the use of solvents
- ◆ diffusion of silver-recovery systems, (well documented technology)
- ◆ extensive automation that will reduce the amount of ink, solvents and scrap-paper (this option is an ideal candidate for SEP agreements since it calls for significant capital investment).

5. Chemical manufacture (SIC 281)

Although the sector is active in PP efforts, the potential for further improvement is huge since SIC 28 remains a very significant polluter.

As far as it concerns Organic Chemicals (SIC 286), the most significant opportunities for environmental benefits lie in the areas of:

- ◆ Solvent substitution
- ◆ optimization of multi-product/process operations using sophisticated computer models that include waste minimization in their objective function. This opportunity is more suitable for medium or large facilities.
- ◆ improvements in catalytic efficiency. This is a critical issue as we have already mentioned in the “DfE - Green Chemistry” part of our report. The ORD report mentions the following specific processes; (i) production of diisocyanates without phosgene as an intermediate (J. Cusumano, Catalytica); (ii) use of zeolite-supported catalysts for ammonia production (J. Landford, Texas A&M); (iii) selective zeolite supports for aromatics production and isomerization (V. Weckman, Mobil).

In the case of Inorganic Chemicals (SIC 281), the sector is characterized by stagnant established technology and no economic incentives for process change in the form of diffusion or minor innovation of already known technologies. Thus, it is clear that the role of regulation/enforcement may become the critical factor for environmental progress both in specific subsectors such as the chloralkali industry - SIC 2812 (where the Hg-free membrane techniques are progressing slowly) and generally within SIC 281. As an example of the latter case we would mention in-process recycling and product recovery technologies; in these cases the rate of diffusion of modern techniques such as reverse-osmosis and ion-exchange is not satisfactory.

6. Plastics (SIC 2821)

The sector is characterized by product-specific tailor-made processes and proprietary technologies. However, some opportunities with wide applicability were identified:

- ◆ Recovery or even substitution of blowing agents (methylene chloride and fluorocarbons).
- ◆ Enhanced recycling of scrap plastic using “compatibilizers”

7. Pharmaceuticals (SIC 283)

The sector is comprised of very sophisticated firms with high R&D expenditures and state of the art technologies. Moreover, these firms are already operating under very stringent quality standards and strict regulations. We see no ground for the enforcement mechanism to leverage PP in that sector, as we do not discern neither stagnation nor the existence of a regulation-leverage point.

8. Paint Industry (SIC 285)

The report identifies many promising technologies in manufacturing processes, in product reformulation and/or substitution. Specifically, the report mentions the following opportunities:

a. Manufacturing process:

- ◆ computerized production schedule to effect maximum reuse of residues and solvent washings.
- ◆ improvements in kettle design and materials of construction to minimize stickage.

b. Product reformulation:

- ◆ conversion to non-solvent and low-solvent or high-solids coating systems, that results to VOC reduction.
- ◆ electrostatic painting and powder coating with thermal or high energy (i.e. gamma or UV). The EPA leverage is considered critical for the adoption of these innovative technologies.
- ◆ use of “exempt” (i.e. non-regulated organic) solvents such as the natural vernonia oil, or water based paints and coatings.

- ◆ use of high pressure CO₂ either as a transport medium or solvent substitute. According to the EPA report, the Agency has already acquired experience with a specific technology of that kind, namely the UNICARB process, while several researchers like Johns Hopkins' Dr. Donahue are already developing similar technologies.

c. Product substitution: A key area of progress is the repainting of surfaces. Currently, the removal of rust and biological growth is accomplished via solvent stripping or caustic stripping. Environmental-friendly options in that area include sand blasting, high-energy aqueous stripping systems, the use of sodium bicarbonate and laser stripping.

9. Ink manufacture (SIC 2893)

The main PP opportunities lie with proper production scheduling (also the case with paint industry) and product reformulation (transition from solvent-based to water-based inks). The latter issue is complicated because the printing industry (mainly the lithographic segment) which is the end-user of these products do not have at the moment the appropriate printing systems to switch to environmentally benign inks. The report gives no specific information on the issue and thus we cannot comment further before reviewing other pertinent literature [A13].

10. Petroleum Industry (SIC 291)

The main issues in the petroleum industry have to do with accidental releases, for example the prevention of oil spills. PP-wise there are no special opportunities; i.e. there is ground for PP benefits but these benefits will be accomplished rather by generic than by tailor-made technological options. For example, the identified needs for improved separation practices and for H₂SO₄ and spent catalyst recovery can be classified as generic technological needs.

11. Steel Industry (SIC 331)

This is a sector where enforcement leverage may have a critical role. The U.S steel industry is characterized by economic depression and technologic stagnation and thus, lacks both the incentives and the capacity to implement PP strategies. That is the sector neither has technological expertise (as the R&D expenditures are relatively low and decreasing) nor the economic incentives (the price competition is fierce, there exists a grave dumping problem from non Western producers and there are no projections for substantial market growth in the near future) to implement PP strategies. The main identified PP opportunities have to do with the recovery of pickling acids. A case study carried out by Versar for EPA is mentioned. In that study the spent HNO₃/HF pickle acid is neutralized in two stages to yield CaF₂ which is recycled to the furnace.

12. Non-ferrous metals (SIC 333-334)

The EPA report identified significant PP opportunities in many areas within this sector.

- a. In pyrometallurgical processes (smelting) exist significant opportunities for: the elimination of metallurgical coke, the secondary recovery of precious metals (Ag, Au) from smelter residues [A14] and the prevention of Arsenic oxide formation [A15].

b. In casting processes, sand can be recovered from the sand mold waste stream using the KHD Humboldt process. Using that technique the ferrous metal is removed magnetically and the organics are destroyed at elevated temperatures.

13. Metal finishing (SIC 347)

The main PP opportunities in the sector are the following:

- a. Non-cyanide plating of metals (Ni, Cd).
- b. Improved recoverability and reuse of cyanide-containing plating baths, e.g. removal or conversion of the inorganic salts formed during the bath's life. This can be achieved through various evaporative technologies.
- c. Improvement in the ancillary operations, which account for 50% of the generated waste sludge. These improvements may be in the acid washes, cleaners, brighteners or phosphating agents.

14. Electronics/semiconductors (SIC 3674)

The environmental problems that the fabrication segment of this industry is facing, are similar to those of other industries (mainly electroplaters). Hence, the sector does not possess any specialized PP interest to us, since its pollution problems will be addressed by generic technologies.

15. Automotive manufacturing/assembly (SIC 371)

The EPA report argues, and we tend to agree, that the industry does not possess particular interest for tailor-made PP initiatives or EPA leverage because of the generic technologies it uses and the huge resources and in-house expertise of the auto-manufacturers.

16. Laundries/dry cleaning (SIC 721)

This sector is characterized by a large proportion of SMEs and difficulty to monitor the pollution generated. The main identified PP opportunities are:

- a. reduction of residual solvents in still bottoms and in filters via
 - ◆ distillation for solvent recovery
 - ◆ use of carbon adsorption units to remove solvents from the filters. A technique of that kind, microwave heating, is currently under development by Ontario Power.
- b. volume reduction of contaminated wastewater through heat recovery and wastewater reuse.

17. Automobile repair shops (SIC 753)

The reasons that make the particular sector attractive for targeting are that these shops represent source of waste and the market structure is SME dominated. The major pollutants encountered (i.e. VOCs, chlorinated solvents, metal contaminants, H₂SO₄) impose significant risks that are targeted in many EPA initiatives. Specific PP opportunities include:

a. coating applications (electrostatic painting, dip coating): the objective is to reduce VOC emissions and particulates via

- ◆ the introduction of Low pressure/high volume spray guns
- ◆ development of new harmless technologies, namely high solids paints, solvent substitution by supercritical CO₂, ultrasonic activated and hot melt coatings.

b. degreasing: the objective is to reduce or eliminate the use of hydrocarbons (either chlorinated or not) via either aqueous cleaning or blasting with solid particles.

4. Critical generic technologies: The most suitable generic PP technologies for promotion through the Enforcement mechanism are the following:

a. VOC control (recovery technology): the target chemicals are solvents that must be either recovered effectively or substituted through product reformulation. The problem is so widespread that affects essentially all the manufacturing SICs.

b. Oil-water separations: the objective is to achieve higher rates of in-process recycling. The specific sectors that will directly benefit from advances in this technology (e.g. in emulsion breaking) are the metal working/machining sectors (that extensively use cutting fluids) and the refineries.

c. Metal degreasing: the objective is, as a first step, to enhance solvent recovery rates and, ultimately to substitute solvents by aqueous or physical degreasing techniques (e.g. ultrasonics, sandblasting). Although the electroplating industry has particular interest in this technology, the application could be diffused to essentially every sector that is related with metal processing and parts manufacturing.

d. (Strong) Acid recovery: The most promising technology in this area is the electrodialytic bipolar membranes [A16]. The Steel Industry is the sector that will benefit directly by advances in this technology (pickle liquors); nevertheless, the chemical, dye and explosives sector can also reap significant benefits from the strong acid (i.e. H₂SO₄, H₂FO₃, HNO₃, H₂ClO₃) recovery technologies.

5. System Evaluation:

We believe that the prioritization scheme used in this effort is very important although it is not without weaknesses. It is the first prioritization methodology that does not adhere to a strictly risk/hazard oriented approach; in fact 11 out of the 12 criteria in use are not risk-related. Instead, the prioritization mechanism focuses on economic, technical and organizational issues. With respect to that aspect, the approach shares the same rationale with the Technological Options Analysis we proposed in previous work [A17]. Moreover, the report studies a wide range of industrial sectors creatively/flexibly using the SIC classification system.

However, the prioritization scheme does not consider the issues of multimedia impact of the proposed technologies, a factor that can prove critical for the widespread adoption of PP strategies. In addition, neither the specific targeting criteria nor the input data-needs of the prioritization system are defined clearly. As a result, the scheme may not yield reproducible results and cannot be used for re-evaluation of the inter-sector ranking without recourse to new extensive interviews.

Overall, we believe that the 1991 ORD PP prioritization methodology has the right rationale and strategic objectives, but could be improved by a clearly stated and easily quantifiable "scoring" system. In our approach we adopted a similar methodology but we introduced some clear-cut, easily-measured criteria.

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Table A1 Existing Screening, Ranking and Prioritization Schemes [Source: A2]

<u>System</u>	<u>Agency/Office</u>
Arizona Waste Minimization Project Screening Process	EPA Office of Waste Programs Enforcement (Region IX)
Chemical Use Clusters Scoring Methodology	EPA Office of Pollution Prevention and Toxics
EPA 33/50 Program Targeting Process	EPA Office of Pollution Prevention and Toxics
EPA Regional Comparative Risk Ranking Program	EPA Office of Policy Planning and Evaluation
Existing Chemicals Screening Program	EPA Office of Pollution Prevention and Toxics
Industrial Pollution Prevention Opportunities for the 1990's Screening Process	EPA Office of Research and Development
National Corrective Action Prioritization System (NCAPS)	EPA Office of Solid Waste
Nonhazardous Industrial Waste Targeting and Pollution Prevention Project	Minnesota Office of Waste Management
Numerical Hazard Ranking Scheme for Waste Scheduling	EPA Office of Solid Waste
Risk-Based Enforcement Strategy (RBES)	EPA Office of Health and Environmental Assessment
Superfund Hazard Ranking System (HRS)	EPA Office of Solid Waste and Emergency Response
Toxics Release Inventory (TRI) Environmental Indicators Methodology	EPA Office of Pollution Prevention and Toxics
Toxics Release Inventory Risk Screening Guide	EPA Office of <u>Pollution Prevention and Toxics</u>

Table A2: The set of Prioritization Criteria used in the ORD 91 Report [Source A12]

CRITERIA USED IN MAKING SIC SELECTIONS/PRIORITIZATIONS
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1. Importance of the industry to nation or society.
2. Significance of all or certain waste streams in toxicity, volume or both.

Large frequency of small and mid-sized firms that would benefit from government participation.
4. Significant benefits that would be derived from waste minimization efforts that reduce toxicity and/or volume.
5. Waste minimization is not expected to adversely impact product quality or marketability.
6. Waste minimization would offer cost benefits, at least in the long run.
7. Waste minimization in this industry would be readily transferable to other industries.
8. Industry has exhibited an interest in waste minimization.
9. Waste minimization appears to be technologically achievable.
10. Industry would benefit from government involvement because of lack of direction, capital, or technical sophistication.
11. Industry would be receptive to waste minimization studies.
12. The industry will not be viable in the long run without massive changes.

Table A3. List of the 175 SICs considered in the ORD '91 Report [Source: A12]

LIST OF 175 STANDARD INDUSTRIAL CLASSIFICATION CODES CONSIDERED

Industry	SIC	4-etc	3-etc	2-etc
Cash grains	911	10	10	17
Field crops	913	19	19	-
Beef cattle feedlots	0211	15	15	27
Broiler, fryer and Roaster chickens	0221	12	12	-
Crop harvesting, by machine	0722	0	0	0
Extraction of Pine Gum	0843	0	0	0
Copper ores	1021	36	36	127
Lead and zinc ores	103	46	46	-
Gold Ores	1041	11	23	-
Silver ores	1044	14	-	-
Bauxite mining	1051	0	0	-
Anthracite mining	1111	0	0	0
Bituminous Coal mining	1211	10	10	10
Crude petroleum/gas extraction	1311	19	19	19
Crushed & broken stone	142	0	0	0
Construction Sand/Gravel	1442	0	0	-
Potash, Soda, and borate minerals	1474	0	0	-
Phosphate rock mining	1475	0	-	-
Building Construction	15	37	37	37
Highway & Street Construction	161	0	0	0
Meat packing plants	2011	14	27	27
Poultry dressing plants	2016	13	-	-
Canned fruits/vegetables	203	0	0	-
chop suoy, canned	203	0	-	-
Grain mill products	204	0	0	-
Beverages	208	0	0	-
Wool woven fabric mills, cotton	221	14	14	100
Dyeing & finishing Textiles	226	07	07	-
Wool Textile Goods	229	7	7	-
Logging camps/contractors	241	0	0	126
Sawmills, planing mills	242	6	6	-
Millwork, veneer, plywood	243	11	11	-
Food preserving	2491	104	109	-
Particleboard	2492	3	-	-
Furniture and fixtures	25	15	15	15
Pulp mills	261	91	91	209
Paper mills	2621	100	100	-
Paper coating and gazing	2641	10	10	-
Sanitary paper products	2642	0	-	-
Newspaper publishing	271	02	02	410
Periodical publishing	272	01	01	-

Commercial printing, lithographic	2732	125	207	-
Engraving and plate printing	2733	69	-	-
Commercial printing, gravure	2734	93	-	-
Alkalies and chlorine	2812	56	250	1732
Inorganic pigments	2816	55	-	-
Inorganics, Not Elsewhere Classified	2819	139	-	-
aluminum compounds	2819	-	-	-
catalysts, chemical	2819	-	-	-
chromium compounds	2819	-	-	-
glauber's salt	2819	-	-	-
hydrochloric acid	2819	-	-	-
hydrofluoric acid	2819	-	-	-
mercury compounds	2819	-	-	-
silum	2819	-	-	-
phosphates	2819	-	-	-
potassium compounds	2819	-	-	-
propellants	2819	-	-	-
rare earth salts	2819	-	-	-
sodium compounds	2819	-	-	-
Plastics, resins, elastomers	2821	106	164	-
acetate, cellulose	2821	-	-	-
ABS resins	2821	-	-	-
coal tar resins	2821	-	-	-
diisocyanate resins	2821	-	-	-
epichlorohydrin bisphenol	2821	-	-	-
epoxy resins	2821	-	-	-
ion exchange resins	2821	-	-	-
melamine resins	2821	-	-	-
nylon resins	2821	-	-	-
phenolic resins	2821	-	-	-
polyesters	2821	-	-	-
polyethylene resins	2821	-	-	-
polystyrene resins	2821	-	-	-
polyurethane resins	2821	-	-	-
polyvinyl chloride resins	2821	-	-	-
Silicone resins	2821	-	-	-
Synthetic rubber	2822	17	-	-
Cellulosic man made fibers	2823	23	-	-
Other synthetic fibers	2824	10	-	-
Biological products	2831	20	147	-
Medicines/botanicals	2833	15	-	-
Pharmaceutical preparations	2834	04	-	-
Soaps and other detergents	2841	10	23	-
Soaps and cleaning, polishing	2842	4	-	-
Perfumes, cosmetics, toilet prep	2844	1	-	-
Paints, finished lacquers	285	192	192	-

Table A3 List of the 175 SICs considered in the ORD '91 Report [Source: A12]

Cum and Wood chemicals	2861	3	33	-	Total cans	341	22	27	484
Coal tar crudos, dyes, pigments	2863	80	-	-	Total shipping barrels	34200	5	-	-
Industrial Organics, not elsewhere	2869	250	-	-	Total forgings and stampings	346	7	7	-
acetic acid	2869	-	-	-	Electroplating, anodizing	3471	201	377	-
acids, organic	2869	-	-	-	Coating, engraving, NEC	3479	96	-	-
alcohols, industrial	2869	-	-	-	hot dipping	3479	-	-	-
chemical warfare gases	2869	-	-	-	plastic dipping	3479	-	-	-
chlorinated solvents	2869	-	-	-	galvanizing	3479	-	-	-
ethylene glycol	2869	-	-	-	Ordnance (ammunition)	348	26	26	-
fluorinated hydrocarbon gases	2869	-	-	-	Misc. Fabricated products	349	47	47	-
laboratory chemicals, org.	2869	-	-	-	Household appliances	361	23	23	197
Nitrogenous fertilizers	2873	15	163	-	Cathode ray TV picture tubes	3672	21	174	-
Phosphatic fertilizers	2874	22	-	-	Semiconductors	3674	133	-	-
Pesticides	2879	124	-	-	Motor vehicles and equipment	371	104	104	257
Adhesives and Sealants	2891	82	220	-	Aircraft and parts	372	73	73	-
Explosives	2892	12	-	-	Jewelry, precious metals	3911	24	24	24
Printing Ink	2893	04	-	-	Pipe Lines, except natural gas	46	0	0	0
Chemicals, Not Elsewhere Classified	2899	40	-	-	Electric services	4911	31	31	119
Petroleum Refining	2911	144	144	144	Gas Production/distribution	492	4	4	-
Paving and Roofing Materials	295	20	20	-	Water supply	496	7	7	-
Tires and Inner Tubes	301	52	52	81	Sewerage systems	4932	26	73	-
Reclaimed Rubber	303	4	4	-	Refuse systems	4933	49	-	-
Fabricated Rubber Pds. NEC	3049	0	0	-	Steam supply	496	2	2	-
Misc. Plastic products	3079	17	17	-	Groceries & Related pds, wholesale	514	10	10	10
Leather Tanning and finishing	311	71	71	71	Gasoline Service Stations	534	46	46	46
Flat Glass	321	10	10	10	Eating and Drinking Places	581	0	0	0
Glass and Glassware	322	0	0	32	Federal Reserve Banks	601	0	0	0
Glass pds from purchased glass	323	0	0	-	Power laundries, family & commercial	7211	11	209	209
Structural Clay products	325	0	0	-	Linon supply	7213	10	-	-
Vitreous China fixtures	3261	0	0	-	Diaper Service	7214	0	-	-
Concrete, gypsum, & plaster pds	327	12	12	-	Dry cleaning plants	7216	121	-	-
Wreaste, asbestos, misc. minerals	329	20	20	-	Industrial laundries	7218	67	-	-
Blast furnaces	3312	3	84	163	Photographic studios, portrait	722	0	0	-
Electrometallurgical pds	3313	11	-	-	Research & Development labs	7391	31	31	31
Steel wire drawing	3315	20	-	-	Photofinishing labs	7393	0	-	-
Cold rolled steel sheet	3316	21	-	-	Automotive repair shops	753	102	102	102
Steel pipe and tubes	3317	21	-	-	Car Washes	7542	0	0	-
Gray iron foundries	3321	15	15	-	Heating/Air Conditioner repair	7623	53	53	53
Primary smelting - copper	3331	41	193	-	Hospitals	804	20	20	27
Primary smelting - lead	3332	60	-	-	Medical and Dental laboratories	807	7	7	-
Primary smelting - zinc	3333	23	-	-	Colleges, universities	822	21	21	21
Primary production of aluminum	3334	44	-	-					
Primary smelting - NEC	3339	17	-	-					
Secondary smelting - NEC	334	29	29	-					
Rolling, drawing of nonferrous	335	10	10	-					
Non-ferrous foundries	336	32	32	-					

Table A4: Industry prioritizations according to the ORD 91 Report [Source: A19]

SIC	Descriptor	Rank
3471	Electroplating	1
2821	Plastics, resins and elastomers	2
2869	Industrial Organic Chemicals N.E.C.	3
285	Paint Industry	4
371	Automotive manufacturing/assembling	5
3674	Electronics/semiconductors	6
2911	Petroleum Refining	7
2879	Pesticides	8
2758	Commercial printing	9
7216	Dry cleaning plants	10
2819	Inorganic Chemicals N.E.C.	11
2491	Wood preserving	12
753	Automotive repair shops	13
2621	Paper mills	14
2754	Commercial printing	15
261	Pulp mills	16
226	Textile dyes and dyeing	17
2893	Ink manufacture	18
2834	Pharmaceutical preparations	19
2891	Adhesives and sealants	20
271	Newspaper publishing	21
2865	Coal tar crudes, dyes and pigments	22
372	Aircraft and parts	23
311	Leather tanning & finishing	24
2753	Engraving & plate printing	25

Table A5: Aggregated Industry prioritizations based on 2- & 3-digit SICs [Source: AIZ]

INDUSTRY PRIORITIZATIONS BASED ON 3- AND 2-DIGIT SICs

SIC	3-Digit SIC Descriptor	Ranking	SIC	2-Digit SIC Descriptor
347	Coatings/Engraving	1	28	Chemicals
286	Ind. Org. Chemicals	2	34	Fabricated metal pdts
282	Plastics/syn. rubber	3	27	Printing, publishing
275	Commercial printing	4	33	Primary metals indust.
281	Ind. Inorg. Chemicals	5	37	Transportation equip
289	Misc. Chem. Products	6	26	Paper
333	Prim. Smelt-non-ferrous	7	36	Electrical/electronics
285	Paints, varnishes	8	72	Personal services
371	Motor vehicles	9	29	Petroleum refining
721	Laundry & cleaning	10	10	Metal mining
367	Electronic components	11	24	Lumber & Wood products
287	Agricultural chemicals	12	49	Elect, gas & sanitary services
283	Drugs	13	22	Textile Mill products
291	Petroleum refining	14	75	Auto repair
249	Misc. wood products	15	31	Leather products
753	Auto repair	16	30	Rubber products
261	Pulp mills	17	76	Misc. repair services
226	Dye & finish-textiles	18	55	Auto dealers/service
267	Paper mills	19	15	Building construction
331	Blast furnaces, steel	20	1	Agri. pdts.-crops

Table A6: List of 13 generic technologies with high PP potential [Source A12]

VOC control (recovery technology):
CFC substitutes
Oil-water separation
Improved seals for pumps and valves
Equipment modifications
Improved operational testing (process baths, etc.)
Small scale recovery for recycling
Inventory control techniques
Metal degreasing:
Acid recovery:
Boiler waste reduction
Adsorption systems for regeneration and recovery
Industrial process scrap metal waste reductions