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**OVERVIEW OF WASTE MINIMIZATION
ISSUES, APPROACHES AND TECHNIQUES**

by

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**OVERVIEW OF WASTE MINIMIZATION ISSUES,
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ABSTRACT

The paper provides a discussion of the recently proposed EPA definition of waste minimization (WM), along with discussions of issues such as dilution and dewatering, and how to measure WM progress. Incentives to minimize waste are described, with special emphasis on economics. An overview of the key elements of WM planning is provided. A conceptual checklist of source control approaches is given, together with examples of specific techniques.

Introduction

Historically, the development of processes has shown a trend toward more efficient utilization of material inputs owing to increases in demand, competitive pressures, and technical progress. The striving toward higher yields, higher levels of by-product utilization, more automation, and more sophistication of production process control has undeniably been an integral part of industrial progress¹. As progress has been made toward these goals, wastes flows have been reduced.

The benefits of reducing pollution at the source have long been recognized². However, as an explicit project goal, waste minimization (WM) has not been practiced widely, especially prior to 1976 when the Resource Conservation and Recovery Act (RCRA) was passed. From that point on, WM has experienced an ever-increasing level of recognition in the industrial and regulatory community, most notably since the passage of Hazardous and Solid Waste Amendments to RCRA in 1984, which have resulted in dramatic increases in the cost of waste disposal.

Why Minimize Waste

There are several good reasons for minimizing waste generation. First of all, WM is a desirable environmental goal. Second, it is a way to reduce a firm's liability for future problems associated with the land disposal of hazardous wastes. Third, current regulatory requirements, such as the certification requirement (Item No. 16 on the Universal Hazardous Waste Manifest) and the biennial reporting requirement, force generators, at the very least, to address the issue. Fourth, although EPA's Report to Congress⁶ has not recommended performance standards, waste management standards, or changes to the existing RCRA requirements (under Section 3002 and 3005), it is possible that such requirements may eventually emerge.

However, as disposal costs skyrocket, the most powerful incentive to minimize waste is economic. Unlike most environmental projects centered around end-of-pipe treatment, source reduction and recycling can often be justified on purely economic grounds. Table I presents statistics on payback periods based on 28 published WM cases where economic data was provided. As seen, more than 80% of these cases have payback periods of less than 3 years which is indicative of high profitability.

Analysis of the profitability of WM projects utilizes the same methods or criteria that are applicable to all projects: a "do nothing" base option is compared to other alternatives. Following the derivation of incremental capital and operating costs, one can estimate the payback period, the internal rate of return, or the net present value for an alternative and base option. However, WM projects involve different cost elements that must be considered. Table II lists readily identifiable avoided cost elements which generally enter the determination of incremental operating cost. Of these, the cost of raw materials, operating labor, utilities, maintenance costs, and disposal fees are usually dominant. It must be noted that assumption of constant disposal cost may be over-conservative and too penalizing for the project. A more realistic assumption is to allow for growth in the disposal fees over the project lifetime.

In addition to the cost elements which can be quantified, there are also intangibles that enter a project feasibility analysis as shown in Table II. Some of these elements favor WM projects, e.g. future liabilities, public relations, and land disposal restrictions; others work against WM projects, such as the risk of detriment to product quality. These intangible elements can enter the analysis in two ways. First, the hurdle rate, such as the minimum required rate of return or maximum payback period, can be adjusted. This was the case with a boiler modification project undertaken by the Nashua Corporation, where a 5-year payback was considered

adequate in view of potential future liabilities¹⁰. Second, one could attempt to estimate the cost of a single penalizing occurrence (e.g. being identified as a responsible party for a hazardous waste site cleanup) and multiply it by the estimated probability of this actually happening. The first approach, i.e. hurdle rate adjustment, is considered more practical by the authors.

Definition of Waste Minimization

At present, there is no universally recognized definition of waste minimization. Terms such as waste reduction, source reduction, waste elimination, waste avoidance, pollution prevention and others have been used interchangeably to define activities aimed at reducing the quantity and/or hazard of process effluents.

A complete review of the various definitions that have been offered is outside the scope of this paper. However, to appreciate the variety of proposed classification schemes and definition frameworks, the reader is referred to such sources as proceedings of the 1985 Woods Hole conference on WM³, a recent study by the U.S. Congress' Office of Technology Assessment (OTA)⁴, EPA's 1986 Report to Congress on WM⁶ and the associated technical support document⁵, and the monograph published by the Government Institute⁷, among many others.

The working definition of WM used by EPA in its recent Report to Congress⁶ encompasses the majority of elements proposed or used by others. The classification framework of EPA's definition is presented graphically in Figure 1.

WM is viewed as consisting of three components: 1) source reduction, 2) recycling, and 3) treatment. Of these three elements, source reduction clearly is the most preferable approach in terms of environmental considerations. As described by OTA⁴, recycling and treatment are "waste management" options, i.e. they address how to deal with the waste after it is generated. Source reduction, on the other hand, is preferred because it addresses ways to avoid or reduce the generation of waste at its source. Recycling is preferred to waste treatment because reusing or reclaiming waste material reduces the amount of waste that ultimately must be disposed. The functional hierarchy for exploration of WM alternatives, thus, is source reduction, followed by recycling, which in turn is followed by treatment. This hierarchy was recognized by EPA in 1976⁸.

Source reduction encompasses two elements: product substitution and source control. Product substitution, as an option, applies more to the consumer than to the waste generator. This is exemplified by substitution of reinforced concrete pilings for treated wood pilings, which avoids waste generated in the wood treatment process.

Source control, a term attributed to Chevron⁹, relates to in-plant activities undertaken by the waste generator. Source control has three elements:

- o alteration of input materials
- o alteration of technology
- o alteration of the human (procedural and/or organizational) aspects of the production process.

Each of these three elements is broken down into further detail in Figure 2.

Any attempt to rigidly classify an extremely diverse field will probably be flawed. An act of substituting a powder coating for a solvent-based paint will be viewed as input material substitution (source control) by the applicator, but also as an act of product substitution by the paint manufacturer. An act of product conservation, e.g. use of proper tire maintenance to reduce the tire replacement

frequency, does not fit neatly into the proposed classification scheme; it would be viewed as most akin to product substitution. Other overlaps or "gray" areas are present. For example, it is not possible to distinguish between source reduction and recycling in the case where carbonates are removed from spent cyanide plating solutions in order to extend solution lifetime. In spite of present shortcomings, the definition does provide a good starting point for the discussion and ensuing iteration.

Question of Waste Treatment, Dilution and Dewatering

It is useful to address the question of whether waste treatment should be considered as a valid WM component. The language of EPA's definition of WM in Figure 1 does not explicitly recognize treatment as an element of WM; however, such recognition is given implicitly. The EPA's Report to Congress⁶ states that "waste minimization includes the concept of waste treatment, which encompasses such technologies as incineration, chemical oxidation and others." Indeed, it would be difficult to argue that treatment such as incineration or biooxidation is incapable of "reduction of total volume or quantity of hazardous waste" or of "reduction of toxicity of hazardous waste or both so long as the reduction is consistent with the goal of minimizing present and future threats to human health and environment⁶." The statutory language (HSWA, Section 1003(a)(6)) provides for inclusion of treatment as part of WM activity, but EPA recognizes that such inclusion must not be interpreted as giving treatment the weight equivalent to recycling or, moreover, to source reduction, which is the most desirable WM element.

Both the OTA and EPA studies correctly recognize that the reduction of waste toxicity by dilution and of quantity by dewatering (or more generally, by the removal of inert components) are not valid WM activities. A word of caution is in order, however. The act of using more dilute plating solutions to reduce dragout would constitute a valid source control approach, in the opinion of the authors, whereas the act of diluting the dragout by excessive rinsing would not. Also, if a dilution or dewatering step is necessary to render the resulting waste recyclable or treatable, then such a step must be viewed as an integral, necessary part of the recycling or treatment operation, both of which are viable WM measures.

How to Measure Waste Minimization Progress

To monitor the progress of WM activities, an appropriate measure of waste generation rate is needed. The specific or relative waste generation rate based on pounds of waste constituents of concern per unit of production appears to be the most suitable approach. Production can be measured using mass output (tons/year), discrete output (number of parts/year or ft² painted surface/year) or any other conveniently defined production unit or index. Alternatively, waste generation could be measured in terms of input material consumption rate per unit production to include all losses, e.g. evaporation as well as solid waste streams. ASTM's committee D-34 on hazardous waste disposal has initiated the effort to define standards to measure waste minimization¹⁵.

Multimedia Approach

When developing waste minimization programs, it is important to consider whether reducing waste in one medium will transfer the problem to a different environmental medium. Consider the removal of volatile organic compounds from an air stream using carbon beds. Steam regeneration of the activated carbon followed by regenerant vapor condensation can result in generating a non-recyclable solvent-water mixture, which translates the problem into the domain of hazardous waste disposal and/or wastewater treatment and disposal.

This example demonstrates the necessity to consider all pollution media, i.e. air, water and solid waste, when planning or executing waste minimization programs. The fact that WM is currently being driven by RCRA should not imply that the efforts must be centered around RCRA hazardous waste. OTA's report⁴ presents this argument in a very eloquent fashion.

The Management Approach to Waste Minimization

The key element necessary of the successful waste minimization program includes:

- o top-level organizational commitment;
- o financial resources;
- o technical resources; and
- o an appropriate organization, goals and strategy (or plan).

The commitment of senior management is the first element that must be in place. Efforts to establish the other elements can follow. The organization of WM efforts varies; at least two approaches are currently in use. One approach relies on delegating the total responsibility to the individual plants with progress monitored at the corporate level. In the second approach, individual plants are assisted by an independent expert task force. Organizational structure adopted should promote communication and feedback from the participants - in this regard, it would be useful to evaluate the applicability of structures used in previous years for energy conservation programs.

Some firms set quantitative WM goals. For example, DuPont is currently reviewing a 5% per year corporate waste reduction goal¹¹. Other firms are more qualitative in their goal setting³.

A WM strategy often consists of first establishing an efficient materials and waste tracking system. Priority setting--which plant to address first and which waste to address first--often follows. At this point, difficulties arise about what to do next. In our view, an important next step is to conduct a waste minimization audit. However, there is disagreement about what these audits should be focused on and how they should be conducted.

In the OTA's view⁴, the waste audits should focus only on source reduction and should encompass an extremely broad range of objectives, including material/waste identification, analysis and tracking, identification of sources, priority setting, analysis and selection of waste (source) reduction techniques, economic analysis and evaluation of progress and success. No specific procedure for developing and screening WM options is offered by OTA, however.

Other views also tend to favor a very broad approach in which the goals can include environmental compliance, information transfer and even liability definition¹¹. In our view, the scope of the waste audit should be considerably more narrow and oriented toward two principal goals:

1. Generating a comprehensive set of WM options following the hierarchy of source reduction first, recycling second, and treatment last.
2. Screening the evolved options to select those which deserve an in-depth evaluation of technical and economic feasibility, or which merit immediate implementation.

There are frequent situations where an a priori focus (i.e. which waste first) does not exist before the commencement of the audit activities. In such cases, the focus has to be established as part of pre-audit activity.

The audit should be waste-stream-oriented in order to produce a list of specific options for additional evaluation or direct implementation. The options development and screening process is an exercise in creative engineering and critical examination of plant operations and their control.

The procedure for conducting a waste audit, as originally proposed by the authors¹³, is currently being evaluated and refined under a program sponsored by EPA's Hazardous Waste Engineering Research Laboratory. Six separate audits have been performed to date in various facilities. In addition to options development and screening, preliminary economic feasibility analyses were also performed. Some of the results will be presented in a paper given at this APCA conference¹⁴.

The Engineer's Approach to Waste Minimization

The key question that must be asked at the outset of WM investigation is "why is this waste present?" An engineer must establish the primary cause(s) of waste generation before attempting to find solutions. Understanding the true cause is critical to the success of the entire investigation. Listings of typical sources of waste generation along with operational or design-related causes are available^{5,13}. Once the causes are understood, solution options can be formulated. As presented in Figure 2, the source control investigation should focus on 1) changes in input materials, 2) changes in process technology, and 3) changes in the human aspect of production. Illustration of all these source control approaches are given in Figures 3, 4 and 5.

Input material changes (see Figure 3) can be classified into three separate elements:

- o purification
- o substitution
- o dilution

Purification of input materials is performed in order to avoid the introduction of inerts or impurities into the production process. Such an introduction does result in waste because the process inventory must be purged in order to prevent the undesirable accumulation. Examples of purification of feed materials to lower waste generation include the use of deionized rinse water in electroplating or the use of oxygen instead of air in oxychlorination reactors for production of ethylene dichloride.

Substitution is the replacement of a toxic material with one characterized by lower toxicity or higher environmental desirability. Examples include using phosphates in place of dichromates as cooling water corrosion inhibitors, or the use of alkaline cleaners in place of chlorinated solvents.

Dilution is a minor component of input material changes and is exemplified by use of more dilute plating solutions to minimize dragout.

Input material alterations seem to have more application potential with respect to auxiliary (as opposed to principal) raw materials.

Technology changes relate to alteration of a physical plant. The following components are distinguished (see Figure 4):

- o process changes

- o equipment, piping or layout changes
- o changes to process operational settings
- o additional automation
- o energy conservation
- o water conservation

Process changes are alterations of the existing processing scheme. Approaches include alternate (low waste) process pathways, waste concentration, and alteration of reaction parameters. Alternate process pathway approaches are illustrated by such examples as the chloride vs. sulfate route to titanium dioxide, a counter-current rinse or wash sequence in parts cleaning, or a switch from solvent-based finishes to powder coatings. In essence, an alternate process pathway leads to the same or similar product using a less wasteful process route.

Waste concentration can help to reduce waste volume by recovery of a valuable waste component and recycling it to the process or by rendering the entire stream recyclable. Examples include an increase of heavies concentration in purification columns, a secondary recovery of solvents from viscous still bottoms and evaporation of rinse water in order to return the concentrate to the electroplating bath.

Alteration of reaction parameters is of key importance and encompasses catalyst improvements, changes to reactor design and changes to reaction control or operation. An increase in catalyst selectivity decreases the amount of undesirable reaction byproducts. Examples include an improved fixed bed catalyst for oxychlorination in ethylene dichloride production and an improved ammoxidation catalyst for acrylonitrile synthesis. Reactor design can affect waste generation, as was the case with the allyl chloride reactor in Dow's Freeport, Texas facility where a design change resulted in a vastly decreased rate of tar formation. Also, reactor control can affect the byproduct generation rate. Examples include the use of rapid quench to limit thermal (non-catalytic) reactions and the use of optimum temperature trajectory or reagent addition strategy in batch reactors.

Equipment, piping or layout changes relate to those improvements where the existing process route is not affected. Examples include the use of canned or magnetic-driven pumps to eliminate pump seals and the associated leakage, the use of bellows-sealed valves to eliminate leaks through the packing or the use of conservation vents on storage tanks.

Changes to operational settings involve adjustment of equipment operational settings without modifying the equipment. Examples include the use of lower atomizing air pressure for paint spraying or a lower height of a liquid curtain in a curtain coater to reduce air emissions.

Additional automation helps to pre-empt or limit inadvertent releases and off-spec product generation. It is of special importance in batch or discrete operations where the level of direct human involvement is higher than in continuous processes.

Energy conservation is not considered as important to source control as other elements discussed; however, its applicability is demonstrated by an example where a lower flash steam generation (e.g. due to better steam trap maintenance) results in lower cooling water requirement which, in turn, lowers the cooling tower blowdown and the associated treatment sludge production.

Water conservation reduces waste generation because less water used generally results in limiting the carryover of organic or inorganic waste precursors into a treatment system in a dissolved or entrained form. This is exemplified by situations where water is used to wash away the soluble impurities from the organic product - excessive water washing results in increased product loss.

Procedural and/or institutional changes consist of improvements in the ways people affect the production process. Also referred to as "good operating practices" or "housekeeping", this area includes the following elements:

- o procedural measures
- o loss prevention
- o waste segregation
- o personnel practices
- o material handling improvements

Procedural measures relate to alteration of routine process control and monitoring procedures. This includes proper scheduling of batch operation, implementing an efficient waste and material tracking system, use of periodic mass balances and waste audits, and process documentation. Making the production unit or department directly responsible for the costs associated with disposal of their waste is another example of procedural measure.

Loss prevention practices include improvements to quality control to lower off-spec batch generation, preventive maintenance programs and spill prevention control and countermeasure (SPCC) plans.

Waste segregation is essential in enhancing the recyclability of wastes such as solvents and in decreasing the amount of hazardous waste by accumulating the non-hazardous waste separately.

Personnel practices entail interaction between management and employees and may include closer supervision, operator training programs, and programs designed to increase awareness such as newsletters or awards. Management initiative is a necessary initiating component for such programs.

Materials control and handling improvements include the introduction of control systems for material purchasing, limiting the number of different types of materials, such as solvents, that are used in similar applications, and increasing the size of containers which helps to cut down on the total wetted surface and resulting residuals.

Good operating practices are of particular importance to discrete or batch processes characterized by a higher degree of human involvement as compared to highly automated continuous processes.

Summary

Increasing disposal and raw material costs, coupled with the increasing awareness of the benefits of WM, provide a strong driving force to reduce waste generation. In addressing the issue of how to minimize, emphasis should be given to source reduction, with recycling next and treatment last.

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Table I. Payback periods of waste minimization projects.

Payback Period (years)	Analyzed Cases	Percent
1	15	54
1 - 2	6	21
2 - 3	2	7
3 - 4	3	11
4	<u>2</u>	<u>7</u>
Total	28	100

Table II. WM project cost elements and intangibles.

AVOIDED COST ELEMENTS

Raw materials

Direct labor, utilities and maintenance costs

Disposal fees

Generator fees/taxes

Transportation

Onsite waste storage & handling

Pre-disposal treatment

Permitting and recordkeeping

Emergency preparedness and site cleanup contingency

Pollution liability insurance

INTANGIBLE COMPONENTS

For WM

Human health & environment

Future liability

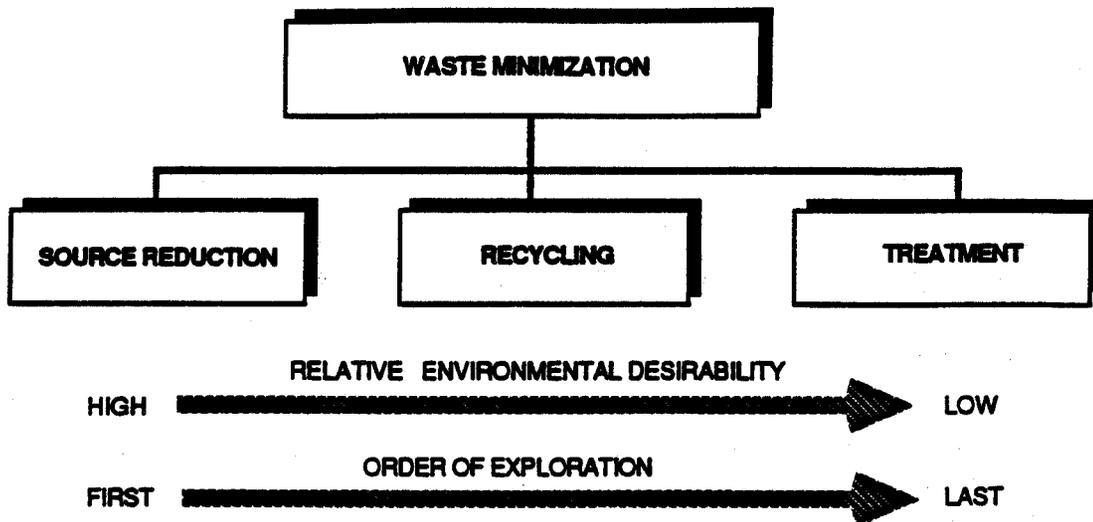
Public relations

Land disposal restrictions

Against WM

Risk to product quality

Unforeseen expenditures



WASTE MINIMIZATION

The reduction, to the extent feasible, of hazardous waste that is generated or subsequently treated, stored or disposed of. It includes any source reduction or recycling activity undertaken by a generator that results in either (1) the reduction of total volume or quantity of hazardous waste or (2) the reduction of toxicity of the hazardous waste, or both, so long as such reduction is consistent with the goal of minimizing present and future threats to human health and the environment (EPA's Report to Congress, 1986, EPA/530-SW-86-033).

SOURCE REDUCTION

Any activity that reduces or eliminates the generation of hazardous waste at the source, usually within a process (op. cit.).

RECYCLING

A material is "recycled" if it is used, reused, or reclaimed (40 CFR 261.1 (c) (7)). A material is "used or reused" if it is either (1) employed as an ingredient (including its use as an intermediate) to make a product; however a material will not satisfy this condition if distinct components of the material are recovered as separate end products (as when metals are recovered from metal containing secondary materials) or (2) employed in a particular function as an effective substitute for a commercial product (40 CFR 261.1 (c) (5)). A material is "reclaimed" if it is processed to recover a useful product or if it is regenerated. Examples of recovery of lead values from spent batteries and regeneration of spent solvents (40 CFR 261.1 (c) (4)).

TREATMENT

Any method, technique, or process, including neutralization, designed to change the physical, chemical, or biological character or composition of any hazardous waste so as to neutralize such waste or so as to render such waste non-hazardous, safer for transport, amenable for recovery, amenable for storage or reduced in volume. Such term includes any activity or processing designed to change the physical form or chemical composition of hazardous waste so as to render it non-hazardous (RCRA, Subtitle A, Section 1004(34), PL-98-616).

Figure 1. Components of waste minimization, their hierarchy and definitions.

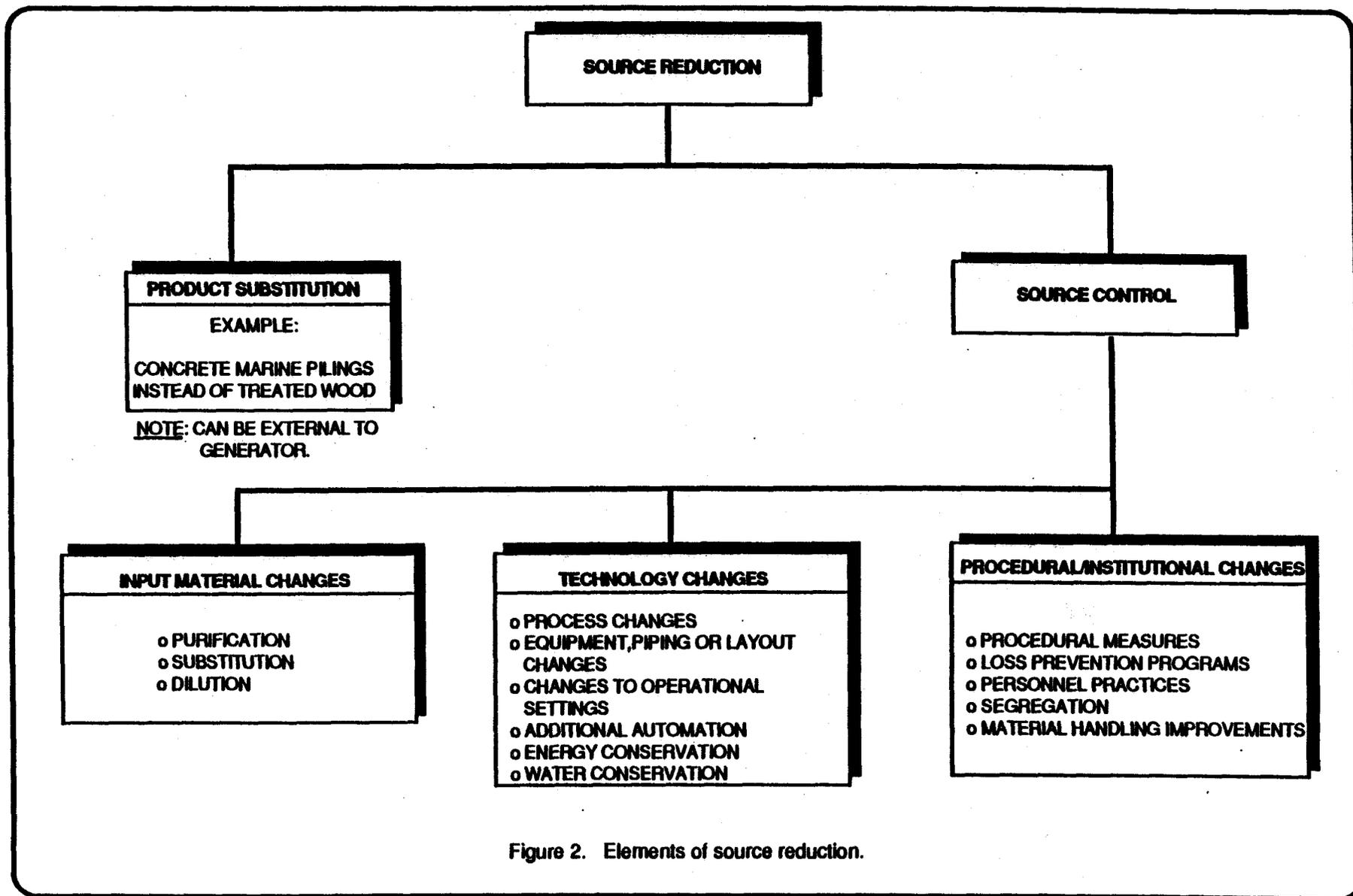


Figure 2. Elements of source reduction.

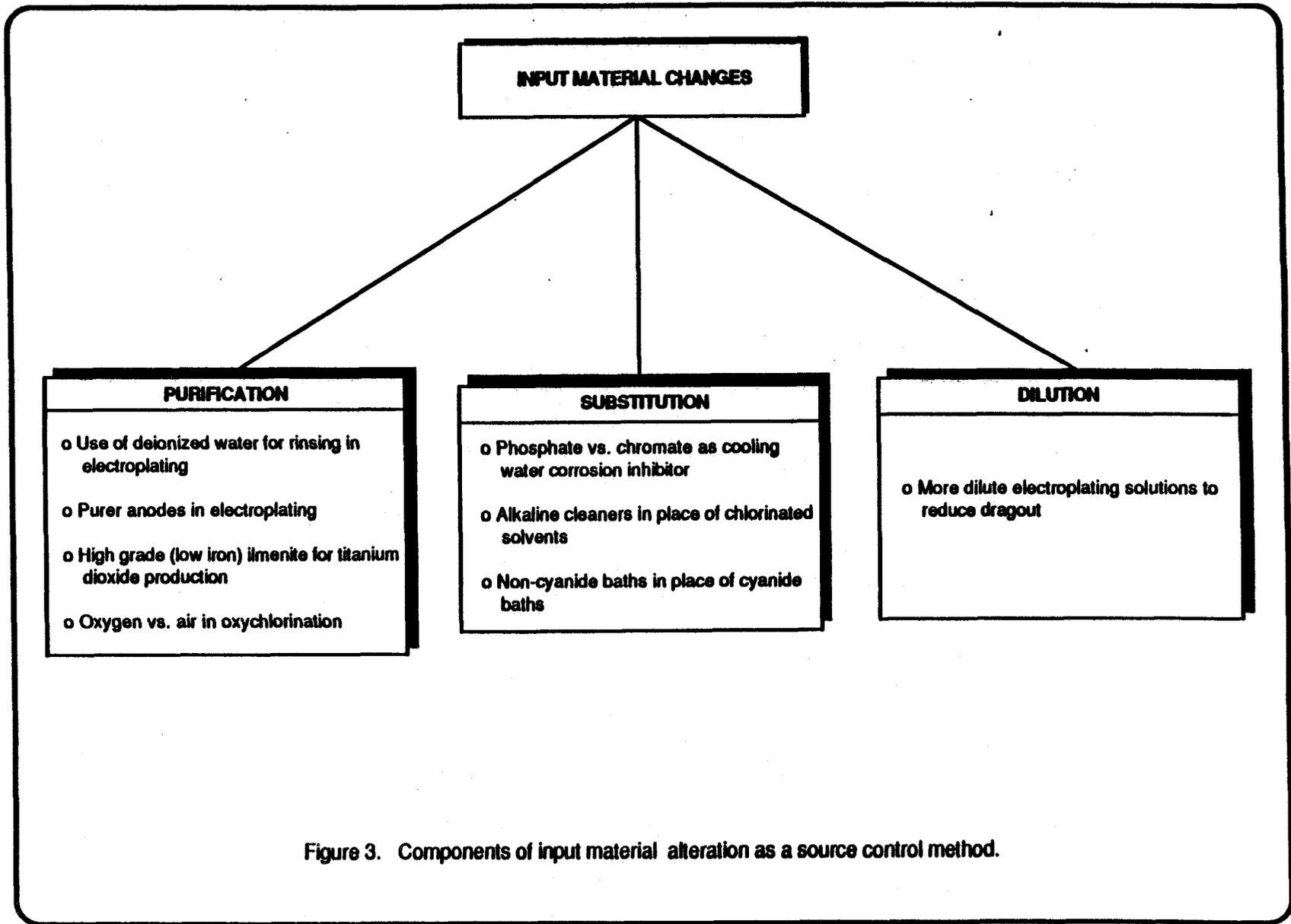


Figure 3. Components of input material alteration as a source control method.

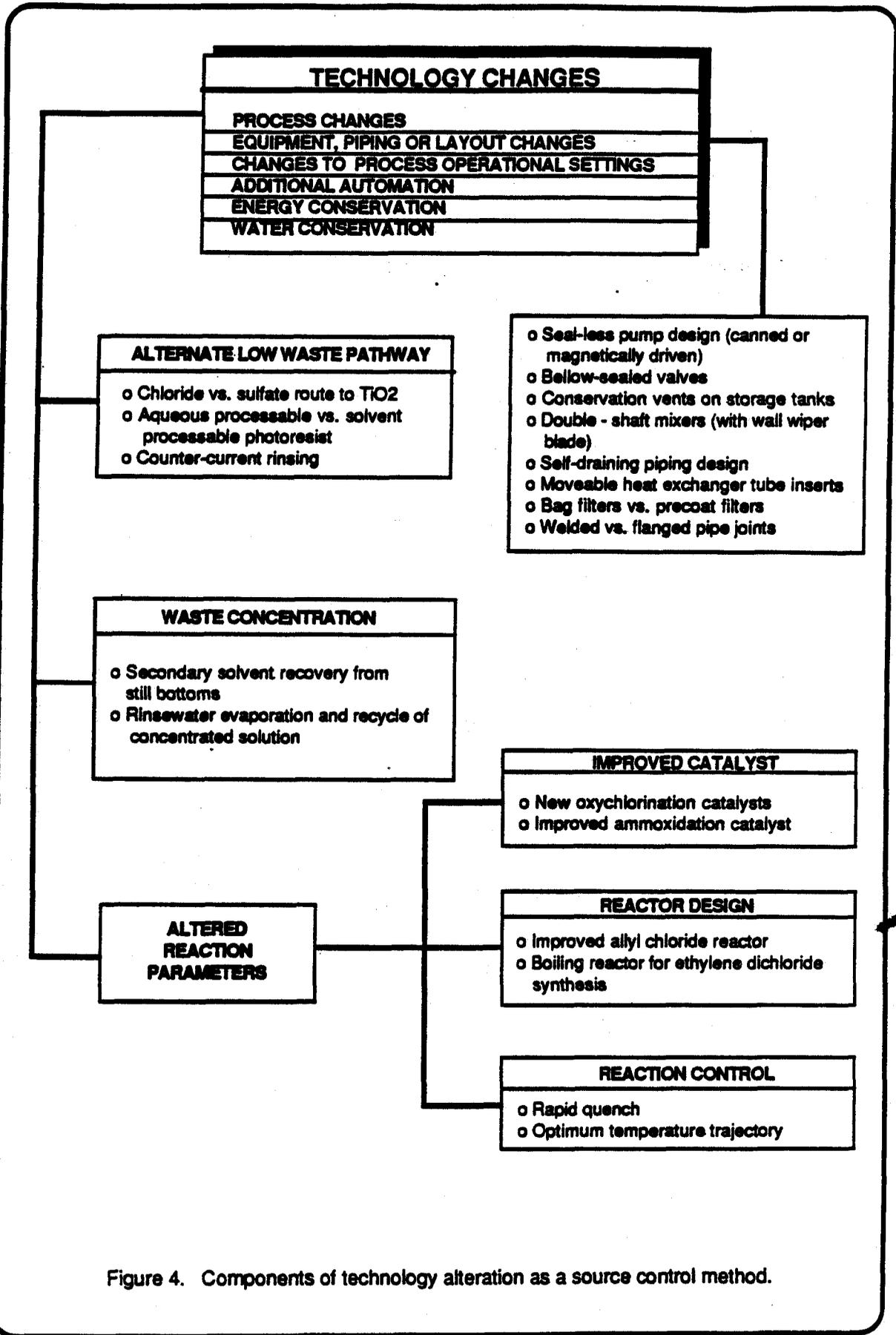


Figure 4. Components of technology alteration as a source control method.

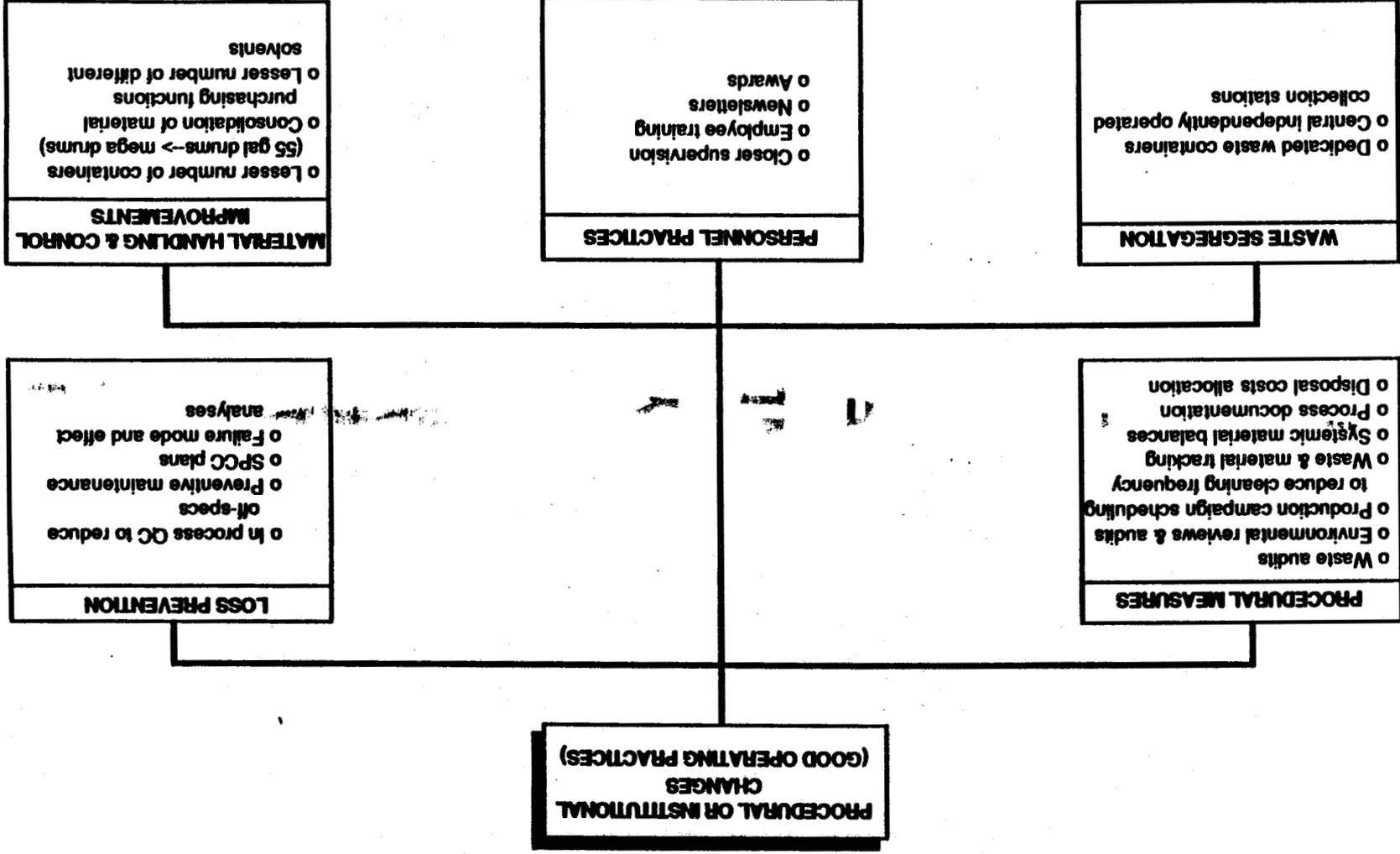


Figure 5. Procedural or institutional changes as a source control method.