

Issues in Facility-Level Pollution Prevention Measurement

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ABSTRACT

Issues in developing measures of pollution prevention at the process-level and facility-level are reviewed, based on existing literature. Pollution prevention can be measured based on changes in waste or changes in materials use. The measurement can be further be adjusted to account for changes in production or may be left as an absolute measure, but choosing an accurate index may be difficult. A range of data sources may be appropriate to support measurement of pollution prevention, including a full facility mass balance, reported TRI data and facility materials tracking systems. After process-level pollution prevention measures are obtained, they can be aggregated across the facility to provide a facility-wide measure of pollution prevention. Several schemes to account for the varying hazard potential of different chemicals are described, but more research in this area must be done.

INTRODUCTION

Pollution prevention (P2) is widely acknowledged to be the preferable strategy for environmental protection. But once a company implements a pollution prevention measure, it will want to know what kind of waste reduction and cost savings have been realized from that effort. Others have taken on the task of trying to evaluate pollution prevention to assess progress towards state goals of waste reduction or to compare industrial sectors and to evaluate TRI pollution prevention measurements (1, 2, 3). Our focus in this article is to draw on the literature to describe the various issues which must be considered in developing pollution prevention measures for an individual process (e.g. a painting line, or circuit board etching process in which some P2 measures have been taken) and aggregating those measures to the entire facility-level. The article reviews the decisionmaking stages of developing a pollution prevention measurement for a given facility and process. These stages include consideration of goals of the P2 measures; data needs and data sources; calculation of measurement based on changes in waste or changes in materials use; adjusting the measure to account for changes in production; aggregation of measures for an individual process across the entire facility; and possible adjustment of measures to account for varying hazard potential. The major issues that will need to be resolved within these stages of developing pollution prevention measurement for a facility include:

- Choosing appropriate data relative to the process and pollution prevention activity being measured.
- Evaluating data quality and appropriateness of data for particular measurement objectives.
- Deciding whether to measure changes in quantities of waste generated or changes in quantities of raw materials required by a process.
- Calculating the changes in waste resulting from pollution prevention activities. Measurements can be made as absolute change in waste quantity or as waste quantity change adjusted for variations in production. Measures of absolute changes in waste may be appropriate to address community concerns or to assess progress towards reduction goals; adjusted measures may give a better picture of chemical use efficiency.
- Choosing an activity index that correlates well with the wastes in question. Failure to find an appropriate unit for adjustment can lead to meaningless measures. Also, most formulas for adjusting pollution prevention measures assume a linear relationship between the adjusting factor and waste generation, but it is not clear that this is usually the case.
- Aggregating pollution prevention measurements across different processes within a facility. Aggregation can lead to inaccuracies where the adjustment factors are not the same.
- Accounting for the varying degrees of hazard between different wastes reduced at a facility. There is not yet a widely-accepted system for scoring wastes reduced by hazard potential, but failing to address the issue implicitly assumes that all waste reduction is equivalent, where in reality, equal reductions in quantities of highly toxic substances and less-toxic ones are not equivalent from a human health or environmental protection perspective.

WHY MEASURE?

There are many reasons to measure P2 at a process or facility level. Uses for pollution prevention measurement might be to demonstrate progress towards various goals. These include

- Internal corporate goals
- Goals of a voluntary program like the EPA's voluntary 33/50 Program in which companies pledged to try to reduce emissions of 17 targeted chemicals by 33 percent by 1992 and 50 percent by 1995 (4)
- Statewide goals. For instance, Maine has instituted a mandatory P2 goal of 30% by 1998 (2)

A facility is likely to also want to assess the cost-effectiveness of the pollution prevention efforts they have made in order to evaluate whether they are worth expanding. To do this, they will need to first measure the quantity of waste they have reduced and then attach cost information. Pollution prevention measurements may also be aimed at showing the public that a facility is making progress towards protecting the community's health, or to show good corporate citizenship.

SOURCES AND CHOICE OF DATA FOR P2 MEASUREMENT

A P2 measurement system could be the result of a comprehensive effort in P2 opportunity assessment and prioritization of these opportunities. In such a situation, inputs and outputs would be known for each process and changes in quantity could be accurately tracked based on mass balance or materials accounting. For instance, Olbina and Dolnicar approach P2 by first quantifying the parameters of industrial production and waste generation and introducing cost information so that the quantities of raw materials and wastes in the original system is well-characterized before making a decision of what wastes to target with P2 (5). Saminathan et al. describe a system of measuring waste minimization and process optimization which requires constant monitoring of materials flow, process conditions and waste generation (6). Pojasek and Cali also suggest that an optimal measurement system would incorporate process flow diagrams, inputs, losses and outputs based on information from existing manufacturing, production, accounting and compliance systems (7).

Despite the precision offered by a measurement based on a full-scale facility materials accounting or mass balance, a measure of pollution prevention may not require such elaborate detail. Warren and Craig recommend that measurement systems be simple wherever possible (8), and the EPA also recommends choosing the simplest measurement method that still meets that objectives of obtaining the measure (9).

Often firms implement P2 measures based on less than a full-scale systems analysis of their facility. Staff trying to develop a measurement for a P2 measure may find that she or he is lacking data (9). For instance, baseline data against which to compare waste generation figures, or cost information for the process under investigation may not be available. Greiner points out that if the pollution prevention effort that a manager is trying to measure has already been implemented and baseline data had not been collected, then choices for measurement indexing units will be limited to those for which the company has historical data (10). This can be a significant constraint since many different kinds of data are not tracked on a regular basis. In that case, the data will have to be estimated or a less-detailed measurement will have to be developed.

Facility-level Toxics Release Inventory Data

Use of existing reported TRI data to measure P2 may be advantageous because it does not require new data collection. The facility is also likely to have measured or estimated TRI data about emissions and wastes in the time period before a particular pollution prevention method was implemented, thus allowing comparisons of emissions and waste. However, the TRI only covers a limited number of substances of the thousands of industrial chemicals in use, does not cover the entire universe of generators, and questions have been raised about the accuracy of the data (11). The TRI is also subject to reporting thresholds that may limit its usefulness to compare waste between two years (2). For instance, if facility slightly exceeds the threshold for a chemical in one year, it would report all its emissions and wastes of that chemical in that year. If it falls slightly under the threshold in the following year, it is required to report none of its emissions and wastes of that chemical. If the facility's pollution prevention measurements relied only on TRI data, it would report a reduction of 100% for that chemical while actually the reductions were considerably smaller. TRI (or any measurement system that assesses only change in wastes)

also cannot account for those quantities of toxics incorporated into the product itself. Hearne provides the hypothetical example of a facility that reformulates half of the cleaning solutions it manufactures so that they no longer incorporate toluene, but continues to use toluene in other formulations. If the majority of the facility's waste is in the form of fugitive emissions from storage tanks, valves, and connections of transfer equipment, then the waste will remain essentially unchanged, and a pollution prevention measurement based on that waste will give no credit to the company for having reduced toluene in its product (12).

Finding/Developing Other Data Sources in a Facility.

Data to feed into a P2 measurement method can also come from other sources in the facility, and can be measured directly or estimated (13). For instance, Rooney suggests using engineering data and accounting loss estimates as well as emissions data, thus incorporating all process losses (14). Zosel suggests using the materials accounting concept to calculate wastes and fugitive emissions that are difficult to measure directly (15). An alternative approach for approximating waste reductions comes from the American Petroleum Institute, which suggests that rather than measuring wastes or materials use in individual processes, that a surrogate measure may be used to estimate pollution prevention progress (16). Specifically, changes in quantities of a particular indicative wastestream like specific sludge production in oil refining may be a good surrogate for pollution prevention effectiveness for the entire facility because so many other processes eventually feed into it.

A P2 measure may need to account for changes in use of a raw material or a process input (see below). This kind of data can often be obtained through facility inventory systems or from data reported under state laws requiring materials use data like New Jersey and Massachusetts. Such materials use information has also been suggested as a supplement to national TRI reporting requirements (17). The state of Massachusetts collects process-level data materials use data, and this reported information may also be a good source for data to feed into P2 measurement. Other reports of facility-level use, or internal inventory and tracking systems may not provide enough detail to identify changes in materials use by a single process if many different processes use the material of interest. In that case, the quantities may need to be estimated, or data disaggregated to provide process-level information (7).

Data Problems and Data Choice

It is important to ascertain not only what is being measured, but also how accurate the measurements need to be for their intended use (18). If the expected pollution reductions are smaller than the error in the measurement data, then it will not be possible to obtain significant pollution prevention measures because of the error in the data. A related issue arises when the basis of a waste accounting or estimation method changes and reductions/increases may appear in waste figures that do not reflect actual changes in physical wastes and emissions (known as "paper changes") (1). In that case, any measurement system seeking to compare between 2 years of releases to ascertain the effectiveness of a pollution prevention measure will be inaccurate. If it is known that such paper changes have occurred, then use of other data that have been unaffected (like purchasing and inventory records) will be more appropriate.

A second issue arises with respect to the timing of the measurements. It would not be effective

to try to measure the effects of a solvent recovery system that was only operating for one month out of a reporting year by using reported TRI numbers for that entire year. Nor would it make sense to try to measure in the first year a pollution prevention good-maintenance and good-housekeeping education program that is expected to take two years to show results.

Thirdly, if the objective of the measure is to benchmark the facility's pollution prevention performance against other facilities, then the metric chosen will have to allow comparisons, either by using comparable units to those used by other facilities or by expressing reductions as a percentage of previous levels of chemical waste or chemical use.

The way that the measurement results are collected and reported must also be tailored to be responsive to overall decisionmaking needs (19). For instance, a facility in a Clean Air Act non-attainment area whose objective in implementing P2 is regulatory compliance for VOC emissions will need information about total reductions in quantities of VOCs resulting from P2 measures in order to be able to evaluate the effectiveness of those measures and possibly to communicate this to regulators and the public. A facility that is implementing P2 as part of overall efficiency improvement efforts must express its measurements relative to a per unit to answer questions about the effect P2 measures have had on quantity of raw materials used or quantity of waste generated per product unit and on the costs of implementing the measures as well as the avoided costs of materials and wastes.

CALCULATING A P2 MEASURE

P2 may be measured by assessing change in the quantity of waste from a process at a facility. This may be especially appropriate where the cost of waste disposal or treatment is the primary driver for P2 efforts, and the objective of the measurement effort is to determine whether or not costly waste generation has been reduced.

The P2 measurement may also be based on changes in the quantity of raw materials or inputs required for a process. This is known as a use-based measure. There are several advantages to a use-based metric for process-level and facility-level pollution prevention measurement. It provides a more direct measure of materials use efficiency than a metric based only on waste (20). A materials use measure also provides a better tool for targeting improvements in worker safety and accident prevention, since these two concerns are more related to quantities of the chemicals being handled on site than to quantities of waste generation and emissions.

It has been suggested by researchers investigating national pollution prevention measurement that, in a given facility, the measures of pollution prevention obtained using use-based data may differ from those obtained from using waste data (21). If such a discrepancy occurs, an evaluation of the data quality, uncertainty, and applicability to the individual process should be done to determine which measure is more accurate.

Selecting an Adjusted or Flat Measure of P2

Having surveyed the available data and data quality needs and determined the probable uses and audience for the measurement study, the next step in developing a measurement of P2 in a process is to calculate changes in the waste or materials use from that process. This measurement can be made as either an absolute change between two time periods, or it can be

adjusted to account for those changes that occur as the result of changes in production rate rather than any inherent change in the way a product is produced (also known as "normalization" or "indexing").

Uses For Unadjusted Pollution Prevention Measurement Metrics

Pollution prevention can be measured as an absolute reduction in waste over time or it can be adjusted to reflect variations in waste-generating activity over time (8). The unadjusted measure is represented simply as one of the following:

$$\text{Waste reduced/increased} = \text{Waste}_{\text{time2}} - \text{Waste}_{\text{time1}}$$

or

$$\text{Waste reduced/increased} = \text{Use}_{\text{time2}} - \text{Use}_{\text{time1}}$$

Measuring absolute pollution levels in year x or absolute change between two years can help a facility target reduction efforts (22). For instance, if most processes in a facility have shown reductions in waste generation, an absolute reduction measure will allow efforts to be directed towards the one or two processes that do not show reductions. An absolute measure is likely to be more relevant than an adjusted measure if a facility is responding to community concerns. Community groups are usually more concerned with total quantities of a substance to which they are exposed than about production efficiency because adverse health effects depend on total levels of exposure. An absolute measure of reduction in use of a particular chemical is also relevant to overall spill and release and worker exposure concerns on the theory that the more that is handled, the greater the risk of mishap and exposure. A measure of absolute change in chemical waste or use over time will have to be used where none of the adjusted measures discussed in the next section are appropriate (23).

Normalizing Data to Account for Activity

Although there are important uses for an absolute measure of chemical or waste reduction between two years, that measurement may also mask important trends in chemical use that a well-chosen measure which accounts for variations in production would highlight (24). Process-level measurements, termed "micro-scale" measurement by Stephan et al., tend to focus attention on the effectiveness of pollution prevention in controlling losses from the manufacturing process, and for this purpose need to account for production levels (25). The TRI requires facilities to develop and report an "activity index", and it is widely recommended that pollution prevention measures be normalized to account for production (23,7).

Measures of P2 normalized for production are often found by calculating an activity index, I , as follows:

$$I = Q_1/Q_0$$

where Q_1 is the production level or activity level in the current year, and Q_0 is the production or activity level in the previous year. The measurement of P2 is then calculated as

$$\text{Normalized P2} = (W_1 - W_0 * I)$$

where W_1 is quantity of waste in the current year and W_0 is the quantity of waste in the previous year. This provides a measure of the difference between the actual levels of waste in the current year and the projected amount of waste from previous year (27).

As described above, "Chemical Use" may be substituted for the "Waste" variable in the

formulas. A throughput ratio can also express waste relative to production. Throughput ratio is defined as:

$$(Q_w + Q_c + Q_o) / Q_w$$

Where: Q_w = quantity of a chemical generated as waste

Q_c = quantity of the chemical consumed

Q_o = quantity of the chemical incorporated into the product.

(27). A lower throughput ratio shows a more efficient incorporation of raw materials into product rather than lost as waste. A comparison of throughput ratios can show whether a P2 effort has improved the efficiency of the process. There may, however be a tendency to attribute efficiency improvements to P2 efforts when other factors may have been at work (8).

Choosing an Indexing Unit

A major initial measurement design challenge is to identify production or activity factors that correlate well with the wastes being measured. If an inaccurate or inappropriate factor is chosen, the measurement results can be meaningless or misleading (16, 22). A facility may look 'greener' or less green depending on what index it chooses to use (28). It is easiest to find a well-correlated factor when a chemical is used in a single production process to make a uniform product, with chemical use and waste carefully metered (10). It becomes more challenging when the unit of product is not homogeneous. For instance, a plating operation may plate parts of many different sizes and shapes, all of which use different amounts of plating solution and all of which drag out different amounts of plating solution. The literature does not provide extensive evaluations of the accuracy of various indices as correlated with chemical use or emissions. One study examined a limited number of facilities in New Jersey and concluded that a significant number of the activity indices they reported were not reliable (12). One approach that has been tested is a statistical tool which uses regression analysis to correlate various potential adjustment factors to chemical use and identify the one most associated with changes in waste generation for a substance (10).

Appropriate normalizing factors are process and facility specific (28). Some examples of production-based normalizing factors include the following, which would be plugged into one of the equations above as the "output" variable:

- Number of units produced (26), e.g. number of mufflers manufactured;
- Throughput of a material to be processed, e.g. crude oil processed in a refinery (16);
- Gallons of bulk product produced, e.g. gallons of coating (14);
- Unit representing technological content of a product rather than a physical measure of product (29), e.g. computer speed and memory produced.
- Number of production hours (28), e.g. labor hours on a degreaser (10).

Research characterizing accurate normalizing factors for various common processes would be helpful to provide guidance to individual facilities that do not have the resources to devote to choosing appropriate units of normalization.

It has been suggested that economic measures, like number of number of production employees or total value added could be an appropriate normalization factor (see, e.g., 30, 26, 31), but it is not clear that these factors correlate well with use or waste generation of any

particular chemical. Washington State's pilot pollution prevention measurement study pointed out that sales prices may fluctuate strongly, even within a given region, leading total revenues to be an inaccurate adjusting factor for waste reduction (28). The study also compared the activity index reported on TRI forms to other normalized indices of waste for several facilities and concluded that the number of employees is not a good activity factor in a highly mechanized industry, but that number of production employees might be meaningful. The literature leaves unaddressed the issue of whether different indexing factors might vary in their correlation to different wastes or material uses, and whether this introduces inaccuracy into a process-level measure which seeks to assess reductions of multiple chemicals.

A second major challenge in developing a meaningful measurement index arises from the underlying assumptions of the typical adjusted waste reduction formula. The purpose of indexing waste generation to production level is to separate the changes in waste generation due to pollution prevention activities from changes due to variations in production level. The typical adjusted pollution prevention measurement assumes that, for a given process, the production function for chemical use is linear and that change in activity level leads to a directly proportional change in waste or materials use at all levels of production, represented as line A in Figure 1. Under this assumption, if a pollution prevention measure were implemented, it would lead to a new production function, represented as Line B in Figure 1, for which all levels of production would lead to lower waste generation. However, the waste-generation vs. production relationship might not be linear, as in the case where higher levels of production lead to greater materials use efficiency, shown as the ratio W/P (Figure 2). In that case, an increase in production to level P_1 would lead to a decrease in the waste-generation per unit product ratio W_1/P_1 without any pollution prevention changes being made to the process. Thus, a facility that had made no pollution prevention changes would be able to report reduced waste per unit product, and facilities that had implemented pollution prevention might show more reductions in waste generation per product than those created by the pollution prevention methods alone. These "apparent" pollution prevention improvements would be lost if production returned to its original level, P_0 .

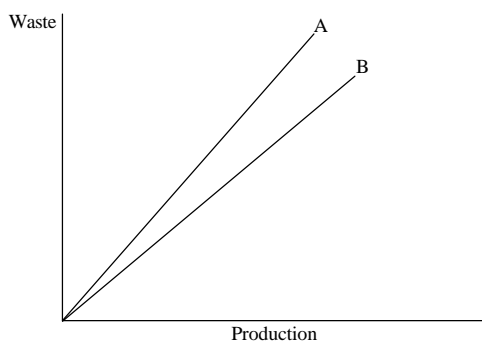


Figure 1 Line A is a linear waste vs. production function. Line B represents the waste vs. production function for the same process after pollution prevention has been implemented. At any level of production, the waste per unit product, W/P , is constant. $W_A/P_A > W_B/P_B$.

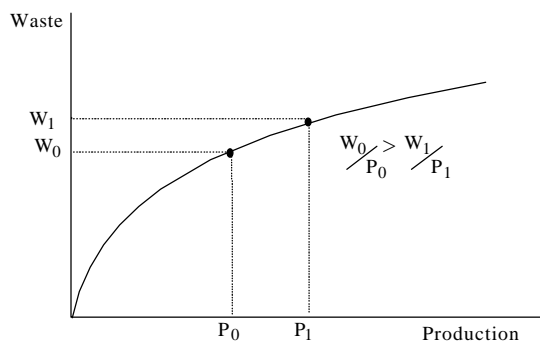


Figure 2

The waste per unit production ratio W/P is lower at higher levels of production (W_1/P_1) than when production is a P_0 . The improved ratio is due to the shape of the waste vs. production function for this process rather than due to pollution prevention activities.

A final issue in choosing a unit for an adjusted measurement arises when one attempts to measure change in waste or use resulting from pollution prevention in product design. Stephan et al. describe a methodology for assessing such change, but warn that it is valid only where the functional unit remains the same in the redesigned product (25). In the case of new product design, it is difficult to measure pollution prevention because there is no data for emissions or use before the change was implemented (23).

Aggregating Pollution Prevention Measures Across Processes

As already described in this paper, a facility-wide figure showing total reductions in waste or materials use may not effectively reflect the effects of P2 on a process. The changes may be instead due to changes in production or activity. Observation of significant P2 reduction in one smaller process may be lost when aggregated with waste data from larger processes. Thus simply adding the absolute changes in waste or materials use for each process across the facility may not provide an accurate measure of P2.

Aggregating measurements of process-level pollution prevention across the facility for each chemical affected by a pollution prevention effort poses its own set of problems. If the reductions in a particular waste per unit output in several different processes within a facility are aggregated, a level of important detail can be lost. Unless the processes within a facility are homogeneous, units of waste reduction from different processes are likely to be indexed by different production or activity factors (20). For instance, one facility may know that it has reduced its toluene waste by 0.75 pounds per tons of wire cleaned, and it may also know that it has reduced its toluene waste by 0.05 pounds per square foot of metal painted. The two figures cannot simply be added because the resulting measure then will change depending on the unit or normalization chosen for each process regardless of any changes in waste.

A common method of obtaining a facility-wide P2 measurement is to index the total quantity of waste (i.e. all releases and transfers) reported for a TRI chemical by a single activity index. If the reported chemical is used in more than one process, the TRI Form R instructions recommend calculating the index based on a weighted average. The same issues of accuracy in selecting an index that were described above are implicated in this strategy. Further, observation of P2 reductions may be lost in the overall facility-wide data, as described above. A resolution to this problem would be to report out the reductions per unit activity for each process or system for which pollution prevention was implemented rather than attempting to aggregate them into one measure. If it is necessary to assess overall progress towards a corporate goal, then each individual process reduction measure could be assessed against a corporate reduction goal and the results used to target improvements. In a situation where comparative measures across similar facilities are desired, one possible solution is proposed by the Pollution Prevention Frontiers mechanism which uses maximization of the sum of chemical use per chemical waste (i.e. an efficiency of materials use measure rather than waste per unit product measure) across similar facilities (20).

Is it Possible or Useful to Weight Measures by Relative Impacts?

The preceding section suggested that it is difficult to accurately aggregate measures of change in use or waste for a particular chemical across processes. In this section, we suggest that

it is even more difficult to aggregate measures of change in use or waste of different chemicals within a process or across processes. In reviewing the results of pollution prevention measurement for two processes, a decisionmaker may not be able to easily evaluate a reduction in air releases of two diverse releases, like assessing a reduction in a hazardous air pollutant versus a reduction in releases of cadmium in wastewater. In order to make a meaningful evaluation, the manager will want to have some way to assess the different impacts of substances on human health and the environment, including differences in their effects depending on the media to which they are released. From a business perspective, the evaluation will also have to include such factors as costs and other corporate guidelines.

There are a variety of models that attempt to predict the ecological or human health impacts stemming from industrial activity, but current methods of evaluating these impacts are still incomplete, and they may be data-intensive and costly (32). There have also been attempts to create ranking or scoring indices which would incorporate the toxicity and environmental fate of chemicals (see, e.g., 33). An expert systems approach may also be used to assess chemical hazard. In such a system, emissions are grouped into classes (like ozone-depleters or acute human health hazards) and weighted according to expert assessment of their risk (34, 30, 26).

The above discussion refers to assessing differing impacts of process wastes in the context of a pollution prevention measurement system. But a pollution prevention measurement system is normally part of an overall concern for environmental quality. It will be important eventually to address not just changes in process wastes, but changes in the entire life-cycle impact of the product from of cradle to grave. This is a far larger undertaking than most of the pollution prevention measurement literature has undertaken to date. Future attention to concepts and tools from the field of life-cycle assessment may allow managers and researchers to begin to assess these effects.

CONCLUSION

Pollution prevention measures must be carefully designed to address the information needs of the audience and to be consistent with the system being measured. Data needs must be assessed for accuracy and availability, and the uncertainty of the data considered in light of the expected magnitude of change being measured. If the data is to be normalized for production, the units of output must be carefully chosen so that they correlate with waste generation or throughput.

Significant questions in this area remain, however, as to how to handle situations in which measures are being normalized but in which production-waste functions are not linearly related. Likewise significant questions remain about how to accurately aggregate normalized measures from different processes, and how to aggregate measures of reduction of wastes with disparate environmental impacts.

FIGURES

Figure 1: Line A is a linear waste vs. production function. Line B represents the waste vs. production function for the same process after pollution prevention has been implemented. At any level of production, the waste per unit product, W/P , is constant. $W_A/P_A > W_B/P_B$.

Figure 2: The waste per unit production ratio W/P is lower at higher levels of production (W_1/P_1) than when production is at P_0 . The improved ratio is due to the shape of the waste vs. production function for this process rather than due to pollution prevention activities.

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