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Eco-labels and Eco-Indices. Do they Make Sense?

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ABSTRACT

Life Cycle Assessments (LCA) of complex systems, such as vehicles and vehicle components, are based on the quantification of the energy, wastes, and emissions associated with the material production, manufacturing, use and end of life of the product. However, the volume of information needed to provide a comprehensive assessment of the environmental burdens is large and complicates the decision process in choosing among alternatives. For this reason people have attempted to simplify the information by collapsing it into a single index, which essentially assigns a score to a product of being “good” or “bad”. Even though such an approach looks attractive to the decision-makers that want simple answers based on meaningful data, the results may be misleading.

INTRODUCTION

Increasingly, consumers, shareholders, customers and designers amongst others are demanding information about the environmental implications of products and services. The problem, however, is that the volume of information needed to provide a comprehensive description of environmental performance is large. This is thought by many to be unacceptable as the results can only be interpreted by a small number of trained scientists and engineers. There is therefore a desire to simplify the results by compressing them into a single index, which essentially assigns a score to a product, or, in the extreme, an eco-label, which essentially says 'good' or 'bad'.

In response to this demand, various groups have developed a variety of different approaches to measure environmental performance. If all of these different approaches gave the same or similar conclusions, then there might be less disquiet. Unfortunately, this is not so and in practice it is possible to find a technique that will give almost any desired conclusion. To the non-scientific observer this leads to confusion and disillusionment.

Even a cursory examination of the approaches developed to measure environmental performance suggests that there is still considerable disagreement about what needs to be measured and how to use the results of any measurements.[1,2,3,4] The reason for the disagreement appears to stem from an attempt to satisfy too many different needs in a single analysis. Not only are these different approaches trying to summarize a number of totally unrelated environmental problems, but they are also trying simultaneously to summarize corporate, plant, product and materials performance.

Protocols for measuring these different types of environmental performance have been widely discussed.[5,6,7,8] Everything from worker safety to minute quantities of toxic water pollutants has been suggested

[1] Lehni, M. *Measuring and reporting corporate eco-efficiency*. Report for the World Business Council for Sustainable Development (WBCSD), Geneva, 1998.
[2] Lehni, M. *WBCSD Project on eco-efficiency metrics and reporting: state-of-play report*. World Business Council for Sustainable Development (WBCSD), Geneva, 1998
[3] *Measuring eco-efficiency in business*. National Round Table on the Environment and the Economy (NRTEE), Ottawa, 1997.
[4] DeSimone, L. & Popoff, F. *Eco-efficiency: the business link to sustainable development*. MIT Press, 1997.
[5] White, A. & Zinkl, D. Green metrics: *A global status report on standardized corporate environmental reporting*. CERES Annual Conference. Boston, Massachusetts. 1998.
[6] *Measuring environmental performance: A primer and survey of metrics in use*. Global Environmental Management Initiative (GEMI), 1997.
[7] Ranganathan, J. *Sustainability rulers: Measuring corporate environmental and social performance*. World Resources Institute, Washington DC, 1998.
[8] Allenby, B. *Eco-efficiency indicators discussion paper*. World Business Council on Sustainable Development (WBCSD), Geneva, 1998.

as a potential measurement indicator.[9] Since every company considers its situation unique, it tends to tailor proposed measurements to fit its specific needs. This has resulted in little consistency in measurement indicators. The confusion is further compounded by the fact that many proposed measurement systems have also tried to combine measures of corporate, product, and material performance in a single system. Unfortunately, the mixed bag of economic, physical, and social measures are difficult to interpret and have produced few if any uniform reporting formats that allow valid comparisons between organizations or products. Furthermore, many of the techniques appear to go beyond the limits of objective scientific and technical information. Should decision-makers unwittingly use these techniques they may accidentally make things worse rather than better.

We address these limitations in a case study that is based on the LCA emissions obtained during the paint process.

The Historical Context

Much of the technical information underpinning eco-indicator models is derived from life cycle assessment (LCA) studies or, more commonly, life cycle inventories (LCI). In many cases the use of LCI data in eco-indicator models represents a misuse of the results usually arising from an ignorance of the proper meaning of the information. The origin of this ignorance can be better understood by examining the reasons why LCA's first came into existence.

Until the mid 1960's, most industrial decisions were based on economics tempered by social and political considerations. Environmental considerations were usually limited to compliance with local and national pollution regulations. However, the 1960's saw the gradual emergence of an embryonic green movement and the start of the world modeling exercises which eventually became public in a number of seminal documents.[10,11,12] Some companies, aware of this work, realized how little they really knew about the wider implications of the processes they operated. A few started to collect information and one of the earliest was that carried out by Harold Smith at ICI.[13]

One factor, which really concentrated the industrial mind, was the Oregon Bottle Bill.[14] The late 1960's saw the introduction of one-trip steel and aluminium cans, which displaced the more traditional returnable glass bottle. At the same time plastic bottles were also beginning to appear. The environmental movement now had sufficient support that it managed to have legislation passed which directly affected the way certain industries could operate. The Oregon experience received worldwide attention and showed that industry could no longer ignore environmentalism.

One by-product of this experience was the need to be able to compare one beverage delivery system with another. Simply comparing the energy to manufacture the different types of containers was no indication of the overall effect of the different production, use and disposal systems. The result was an examination of extended systems stretching from the extraction of raw materials from the earth through to the final disposal of these materials back into the earth. These were the first cradle-to-grave studies.

At the time, the emphasis was on energy use and especially fossil fuel use because these were the parameters that had been highlighted by the world modeling exercises. This concept of describing the physical behavior of industrial systems that covered the operations of many companies and were potentially global in extent was new and produced new insights into the way industrial society behaved.

From a technical viewpoint, it is important to recognize two characteristics of this type of work.

(a) The results were intended to describe the physical flows of materials and energy. They were aimed at complementing the economic, social and political considerations that had long driven industry by providing objective physical descriptions. They were not aimed at displacing these other considerations.

(b) Because the emphasis was on energy, aggregating the data was physically meaningful because the aggregated result represented the global physical energy resources that had to be extracted from the earth in order to drive the system.

In the 1980s the technique was extended to air emissions, emissions to water, and a more detailed treatment of solid wastes. The calculation method employed was identical to that which had been used for fuel resources so the inventory methods presented no new problems. However, the extension to these additional parameters did lead to a number of new problems when it came to interpreting the inventory results:

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9 *Measuring environmental performance: A primer and survey of metrics in use*. Global Environmental Management Initiative (GEMI), 1997.

10 Meadows, H.M., Meadows, L.M., Randers, J & Behrens, W.W. *The limits to growth*. Pan Books, 1972.

11 The Ecologist (edited). *A blueprint for survival*. Penguin, 1972.

12 Hubbert, M.K. *Resources and man*. W H Freeman & Co, 1969.

13 Smith, H. Transactions of the World Energy Conference. Section 18E, 1969.

14 State of Oregon Legislation, 459.810-459.890. 1972.

Many of the new parameters included in the analysis did not cause global problems. Some (such as toxics) were highly localized. Others (such as SOx, which causes acid rain) were regional in effect. Yet others such as CO_2 (a greenhouse gas) were truly global. Thus, although it is possible to calculate aggregated results for all parameters, it is extremely doubtful whether the aggregation of some of these parameters yields results of any physical significance. Consequently some of the aggregated results cannot be interpreted in the same way as those parameters that are truly global in extent.

In 1990, the first SETAC[15] conference took place in Vermont. As a toxicological organization, it is hardly surprising that the emphasis was on the air and water emissions of industrial systems rather than on energy and materials flows which had been the predominant drivers up to that time. There were two effects of this conference.

(a) It introduced the term *life cycle assessment*.

(b) Because of the publicity achieved by the conference and its proceedings[16] it led to a large number of new workers moving into the field. Many of these new workers did not have a science or engineering background so that the scientific content of some LCA work is suspect.

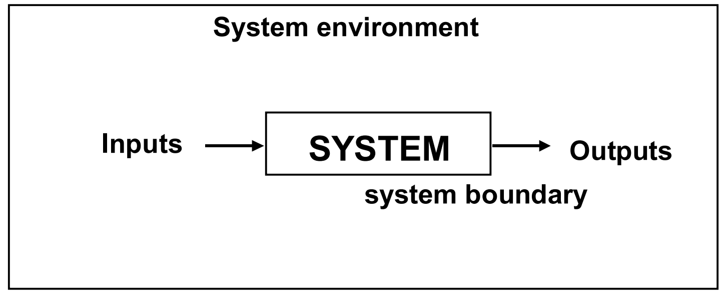
Interestingly, by the late 1990's, things seem to have come full circle because there is a reawakening to the fact that energy use, the starting point for this work, is still a problem that has not gone away. Moreover, by far the greatest proportion of all air emissions arises from the production and use of fuels.

Production Systems

Many of the problems that have arisen in measuring and comparing environmental performance arise from the confusion between systems and products. Although industry is primarily concerned with *products,* it is the *production system* that is of importance in this type of analysis. An industrial system is defined as any collection of operations which, when acting together, perform some defined function. Here it is the emphasis on the function that is important because the basic property that must be defined before any of the fine detail, is the function of the system.

If the function of the system is defined, then it is possible, in principle, to identify those operations that are needed to achieve this function. This provides the essential ideas that are basic to understanding the meaning of any results. Figure 1, for example shows schematically a system enclosed by a box. This interior box represents the *system boundary* and separates the *system* from the *system environment*.

Figure 1. Simple Schematic Diagram of a System



A number of attributes follow from these simple definitions:

1. Inventory calculations are concerned solely with a quantitative description of the flows of inputs and outputs across the system boundary. In that sense they are neutral since they are simply trying to describe these flows in as unambiguous a manner as possible.

2. The system environment acts as the source of all the inputs and the sink for all the outputs.

3. There is no restriction on the types of system that may be defined. In the industrial sphere they may be simple production processes(gate to gate) or they may be increasingly extensive, ranging from eco-profiles (cradle to gate) or complete life cycles (cradle to grave). The factor that differentiates these different types of systems is the nature of the inputs and outputs. A simple production process will usually take in materials that have already been processed and carry out further processing. An eco-profile will start with raw materials in the earth and follow all processing operations up to the production of some product at the factory gate ready for dispatch to another plant for further processing. A true life-cycle starts with raw materials in the earth, follows all processing, use and disposal operations so that the only output are wastes returned to the earth.

4. It is very important to recognize that the property, which identifies a true LCI, is an input of raw materials from the earth and an output only of wastes back into the earth. Any system, which does not exhibit this property, is not a true life cycle.

5. The characteristics of any two systems can only be compared when the two systems perform the same function. Comparisons between systems, which perform different functions, are meaningless. Thus a system whose function is to produce steel cannot be compared with a system whose function is to produce PVC. It is

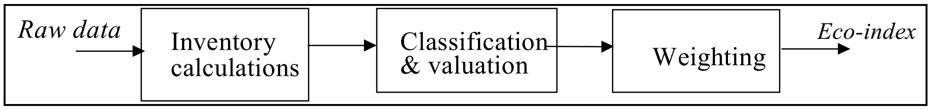
[15] Society of Environmental Toxicology and Chemistry.

[16] *A technical framework for life-cycle assessment*. SETAC Foundation, January 1991.

meaningless therefore to compare steel and PVC on the basis of the characteristics of two systems, one of which produces 1 kg of steel and the other produces 1 kg of PVC; the steel system can never produce PVC and vice versa.

6. The input side of an industrial system provides a description of the resource input needed to operate the system and the output side provides a measure of the potential pollution aspects of the system.

Figure 2. Stages in the Production of an Eco-Index



The importance of recognizing that all descriptions are based on systems cannot be over emphasized. The major problem is that almost all workers in this field pay lip service to the concept but then proceed to talk about products. The ISO committee working on ISO14041 exacerbated the problem; to achieve a consensus on definitions they introduced the confusing term *product-system*. To avoid problems, it is probably wiser to understand the difference between product and system rather than use this mixed term. For a complete life cycle, a system performs a function while a product is simply a materials flow within the system. Inventory data refer to the behavior of the system.

Using Inventory Data

The output from life cycle inventory calculations is a set of parameters, each of, which describes some facet of the behavior of the system examined. As inventory calculations have been refined, the number of parameters has increased. Typically, there might be 300 or more different parameters in the final aggregated data set listed under the various headings such as fuel use, raw materials use, emissions to air, emissions to water and generation of solid waste. Others, such as land use may also be incorporated.

As noted earlier, in the days when this type of work was concerned with a single parameter (energy) there were few problems of interpretation because energy was measured in common units (MJ or Btu), the fuels themselves were usually interchangeable and the environmental implications were global.

Even when the analysis progressed to multiple parameters, and until the advent of eco-indices and their equivalents, this data set was regarded simply as a compilation of information from which the user selects those parts that are needed to address specific problems. Thus if the intention is to examine the greenhouse gas implications, the users would select CO_2, CH_4, N_2O, etc. from the air emissions set and ignore the rest of the data.

Two factors, however, pushed towards the development of eco-indices or their equivalent. First there was a feeling that the number of parameters was so large that they were unmanageable, especially when used in applications such as the design process.
Secondly, there was the understandable desire to have some simple form of summarizing all of this information so that the intelligent layperson could get some idea of the overall environmental implication of the system.

The three stages needed to produce any form of eco-index are shown schematically in Figure 2. First the raw data collected from the various companies within the system are combined in the inventory calculations. Secondly, in the classification and valuation stages, the inventory data are grouped together and summed in an appropriate manner so that each of the grouped data sets describe some environmental facet of the system. Finally, these grouped data sets are multiplied by some weighting factor and summed to give an overall index.

It is important to recognize that in carrying out this three-stage procedure, there will be potential errors at each stage of the process and these will be carried through to the final index. Furthermore, since stages 2 and 3 involve multipliers, the effect of these errors will usually be magnified. It is, therefore, important to examine each of the three stages in turn to see what errors and omissions are likely to occur.

Problems with Inventory

The primary problems with inventories as applied to the production of indices relate to accuracy and completeness.

Much has been written about the accuracy of inventory data and much of it is extremely muddled. Fundamentally, the raw information for inventory calculations is provided by industrial operations. If we assume that industry is not deliberately supplying false information, then we need to consider how accurate the information is likely to be.

On the input side, the information of fuels, energy and raw materials is usually based on inputs that have been paid for. In principle, this should provide accurate information but at a practical level, factors such as stock changes and losses mean that few industries would ever claim that their data are better than about 5%.

On the output side, the amount of information is dependent on the level of pollution monitoring. In general, the better the monitoring, the greater the emissions usually appear. In many cases, emission data are simply not measured and has to be estimated. The techniques for estimating emissions vary not only from country to country but also from plant to plant. It is therefore impossible to assign any sensible accuracy figure to most pollution data and in general, the best that is possible is to compare the data from a number of similar plants to see if they are reporting wide variations. If wide variations occur then the problem needs to be followed up with individual plants.

There is a belief amongst some inventory practitioners that any spread in data when a number of plants is examined, is due to random variations, which can be manipulated statistically. This is not the case. Most of the differences between plants result from actual physical differences in plant performance arising from factors such as age of plant, level of maintenance, whether operated on a continuous or a shift basis, and so on.

It is very important to recognize that life cycle inventories are simply a compilation of those quantitative parameters for which data are available. If the data are not available and cannot be estimated, then they will not appear in the final results. Furthermore, there are some important environmental parameters, which cannot be quantified. Properties such as biodiversity and aesthetics cannot be quantified and so do not appear in the final results table. It is therefore incorrect to assume that the inventory table provides a complete environmental picture.

Characterization Problems

Characterization involves identifying those parameters that contribute towards a specific environmental problem and once identified, valuation is the process of quantifying the contribution that the identified parameters make. The problems that arise in this area are concerned with the spatial extent of the environmental problem and the difficulties in quantifying the contribution of the parameters.

Environmental problems can be global (e.g. greenhouse effect), regional (e.g. acid rain) or local (e.g. noise). It has already been noted that the overall results of an LCI may be global in extent, depending on the participants in the system. Most metal processing systems are global because ore concentrates and bulk metals are traded internationally. In general, therefore, the overall results of an LCI can only be applied to global problems. It is misleading to apply them to regional or local effects. If data are available for the component unit operations within an LCI, then it is possible to select those operations lying in a particular region. For example, if we wished to explore the incidence of acid rain in Scandinavia, data would be required on the emission of the relevant gases in the UK and Poland, since these are the principal sources of the offending gases. Emissions of acid rain gases in North America or Australia would be irrelevant in this example.

For localized pollution problems, such as noise or the emission of toxic gases, which produce only localized effects, it is doubtful whether LCI's give any new insights compared to the monitoring information that would be used to satisfy local pollution regulations.

The unrestrained use of overall LCI data in all problems is incorrect. The user of any LCI data must follow standard scientific practice and demonstrate that the data to be used in any effect does in fact possess physical significance. If this cannot be proved then the data should not be used.

Valuation Problems

Once an environmental problem is selected for attention it is usually easy to identify which parameters are involved. Combining the data sets for these parameters can, however, pose some problems.

Some data sets can be readily combined. For example, the Intergovernmental Panel on Climate Change (IPCC) produces tables of values for global warming potentials of different gases.[17] These can be used to convert the total loading of the relevant gases to CO_2 equivalents. Not only does this provide the appropriate weighting factors but it also converts all of the units to a common base.

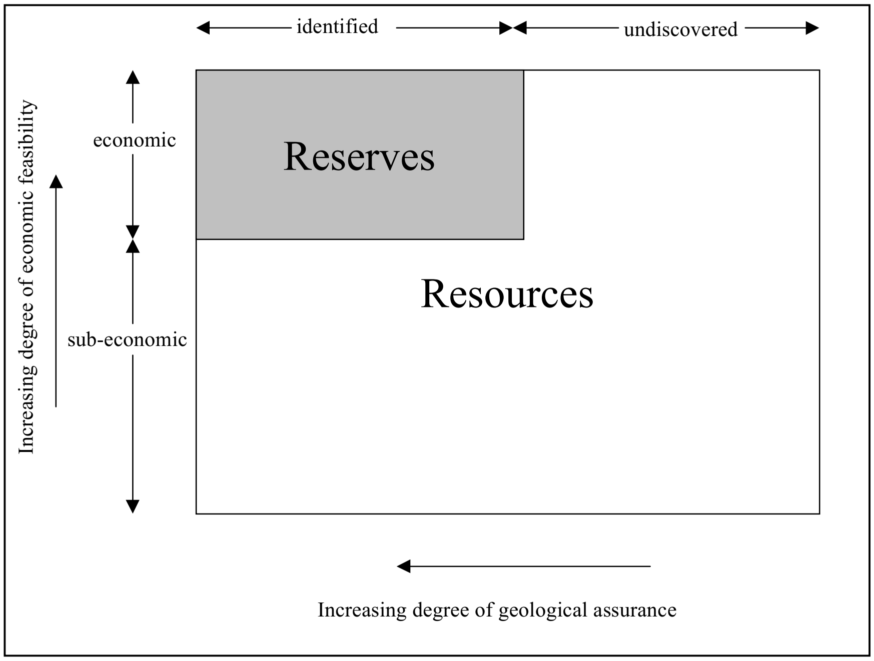
There are, however, some instances where the conversions are erroneous. For example, it is often proposed that raw materials resources should be referred to the rate of depletion of reserves. This attractive idea suffers one major drawback: reserves of any raw material change with time. The reason for this was neatly summarized by McKelvey.[18] He proposed that a graph should be plotted of economic feasibility against geological assuredness as shown in Figure 3.

From this it is clear that the reserves of any raw material (the shaded portion of Figure 3) are determined by a

[17] Houghton, J.T.,Jenkins, G.J. & Ephraums, J.J. (eds.) *Climate change - The IPCC scientific assessment*. ISBN 0-521-40360-X. Cambridge University Press, 1990.

[18] McKelvey, V.E. Approaches to the mineral supply problem. Technology Review, pp 13-23, March/April 1974.

Figure 3. The McKelvey Diagram



deposit of the material being identified and being economic to extract. Thus, as the price of a raw material increases or as further supplies are discovered, the reserves will increase. Similarly as price falls, then reserves fall. Thus, using reserves as a base against which to measure depletion of raw materials is extremely uncertain and time dependent.

Weighting Problems

Although the problems identified above will all influence the final result, by far the most serious problem arises with the final weighting factors. In converting a set of valuations into an index, it is necessary to assign multiplying factors, which indicate their relative importance. Assigning these weighting factors implies that it is possible to make sensible judgements about the relative importance of effects such as global warming, acid rain and fossil fuel use.

It is critically important to recognize that there is no scientific way in which such value judgements can be made. These judgements are entirely subjective.

Limitations of Eco-Indices

Eco-indices and eco-labels already exist and are in use. This does not however imply that they have any meaning nor does it mean that they cannot be misleading. To judge their value as a means of providing a summary of environmental performance, it is important to recognize that there is a world of difference between having a full data set available and then simplifying it and having only an index or, in the extreme, an eco-label. Many of the strongest proponents of eco-indices know what the full data-set looks like and can guide their judgement accordingly. In contrast, many of the users of eco-indices do not even know what a full data set would look like. Consequently their judgements are based on the index alone and if the index is wrong, so are their judgements.

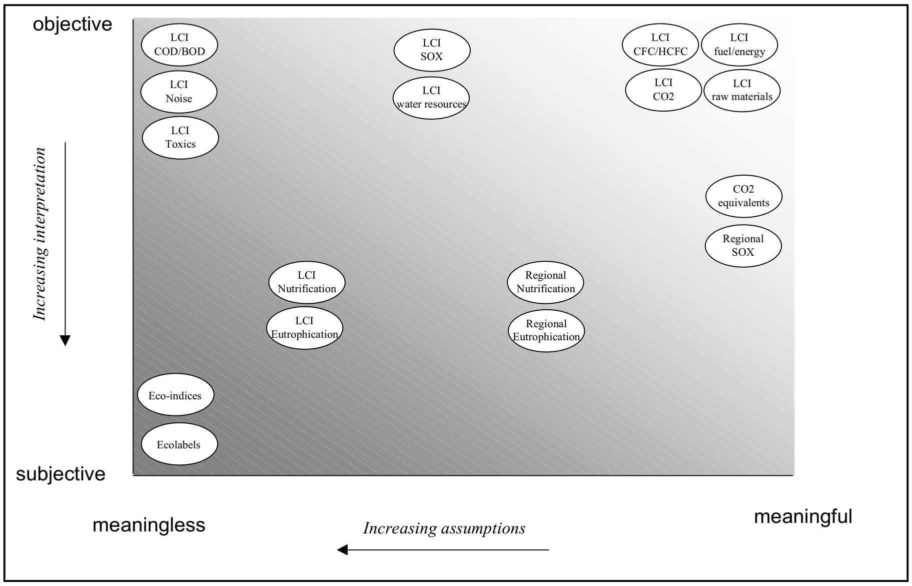
The validity of any environmental index depends in part on the starting data and in part on the way in which the data are manipulated to derive the index.

It is often claimed that the starting data are objective and therefore meaningful. But is this true? Pure LCI data can be regarded as objective within the limitations of data collection and analysis. However, although the aggregated data for globally significant parameters such as energy use, raw materials consumption and carbon dioxide emissions can be immediately interpreted and related to environmental effects, others, such as aggregated local values of COD, noise and toxic chemicals possess no physical significance and so are meaningless except in the unusual case when the complete life cycle occurs at a single geographical location. This is illustrated in Figure 4. Thus, objectivity of data is no guide to the meaning of any parameter.

Manipulating LCI data can take two forms: selective aggregation and direct interpretation. To illustrate selective aggregation, Figure 4, for example, shows that the LCI data for SOx, one precursor for acid rain, is only partially meaningful. The reason for this is that an emission of SOx in Australia, for example, is of little consequence to the formation of acid rain in Scandinavia. If, however, the data for those unit operations within the full life cycle and which occur in one geographical location are aggregated, then the regional aggregate of SOx becomes more meaningful than the corresponding LCI data, as shown in Figure 4. However, the process of selective aggregation implies invoking some subjective judgements in deciding which operations to include in the aggregate.

To illustrate direct interpretation, the greenhouse gases could be combined to produce carbon dioxide equivalent. Such a procedure is based on well-founded science and so, although subjective judgements are being applied, the result is still meaningful.

Figure 4. Schematic Diagram Relating Objectivity to Meaning



In contrast, interpreting the localized data that are aggregated to give eutrophication potentials, for example, requires the application of significant subjective judgements to inappropriate LCI data. As a consequence, there is a loss of meaning and an increase in subjectivity ratings. If the starting data for such an interpretation were subjected to selective aggregation before the interpretation was carried out, the results would have more meaning as shown in Figure 4.

Eco-indices and eco-labels can only be produced by the application of significant subjective judgements, especially at the weighting phase, and these judgements are frequently applied to the full LCI data set. As a consequence, they appear in Figure 4 with a high subjectivity rating and a very low meaning.

Indices are only intended to provide a relative measure of environmental performance for one item versus another. This information provides no insights into what caused the problem nor does it facilitate a likely solution. However, if data for individual parameters are kept separate, then it is likely that a design professional will not only be able to see which designs produce fewer impacts, but will be able to highlight which parameters are affected so that specific choices can be made. For example, if the goal of the designer is to reduce CO_2 by 10% due to some regulatory pressure, an index is of little use. In an index, the CO_2 value is just one contribution and therefore its overall contribution is diluted. In most indices there is no way to determine the absolute contribution of any one parameter.

Solving design problems using eco-indices system tacitly assumes that there is only one problem – lowering environmental impacts. However, the truth is there are numerous problems. Every system has a number of conservation problems associated with individual natural resources, as well as pollution problems associated with numerous air emissions, water effluents, and solid wastes. There is no scientific method that can relate the importance of one impact to another.

Keeping environmental objectives separate facilitates solutions on two fronts. First, each problem is addressed rigorously without modifying the original scientific data. This allows a designer to know the exact measure of the environmental problem. Secondly, it avoids making inaccurate decisions. Because there are numerous types of environmental issues associated with a production system, it is unlikely that any one design will simultaneously provide a solution to all environmental problems. More often than not, there are tradeoffs. As one factor is lowered (e.g. CO_2), another may be increased (e.g. solid wastes). To meet specific company objectives, the design professional needs to see which factors are being lowered and which are not.

Take for example a company with objectives, in order of priority, to reduce by 10% acid rain, greenhouse gases, and solid wastes. If the company produces electricity using coal, it may reduce SOx emissions by implementing flue gas desulphurisation. However, although this reduces SOx, it increases CO_2 emissions. A single index would not identify this tradeoff. The index may show a reduction over all parameters in the index, but in reality there may actually be an increase in those parameters of most significance to meeting company objectives. Alternatively, if data on individual factors are kept separate, then the designer is provided with some options on how to solve the problem. Flue gas desulphurisation is needed to reduce SOx emissions so that solutions for CO_2 and solid waste reductions can be sought in other parts of the system.

We illustrate the limitations of eco-indices in the following example, which is based on the paint process of an automobile. We address the emissions released during the manufacturing of paint formulations and different paint process-scenarios and discuss which aggregated emissions provide meaningful results.

Case Study: Life Cycle Environmental Assessment of Paint Processes

Among all manufacturing processes that take place in the production of a vehicle, the painting operation contributes most to the direct environmental emissions. As government environmental regulations become more stringent, the painting operations are subject to tighter emission standards, which has lead to the consideration of new paint technologies. A transition from solventborne to waterborne to powder paint coatings has been observed over the past decade to reduce plant volatile organic compound (VOC) emissions.

In our study we compared three scenarios:

(1) solventborne primer - waterborne basecoat - solventborne clearcoat, which is considered the baseline,
(2) powder primer surfacer - waterborne basecoat - solventborne clearcoat,
(3) powder primer surfacer - waterborne basecoat - powder clearcoat.

Within scenario (2) we looked at two different colors, white and pewter as well as two powder primer formulations, acrylic and polyester.
In Table 1 we introduce the nomenclature of each scenario.

For the purposes of this study it is assumed that each scenario operates in a greenfield plant. The automotive paint process consists of five stages:

(1) The phosphate pretreatment cleans the metal and prepares is for painting.
(2) The electrodeposition primer, called ELPO by GM plant engineers and E-coat by non-GM automotive companies, provides corrosion protection to the metal.
(3) The primer surfacer serves as a filler and provides a smooth surface for the topcoat (basecoat and clearcoat) that gives the color and the shine to the autobody.
(4) The basecoat provides the color and consists of an organic chemical formulation that includes color pigments and modifying additives to enhance the chemical properties of the paint that prevent it from UV breakdown.
(5) The clearcoat is a nonpigmented, i.e color free, application that provides the gloss, clarity and durability of the metal finishes.

The boundary conditions of this study do not include the phosphate and the ELPO processes. The main reason is that the primary scope of the study attempts to address the impact of switching from solventborne paint formulations to powder based ones, assuming that the phosphate and the ELPO processes are identical for all scenarios. The vehicles being studied are sport-utility-vehicles (SUVs), in this case Chevy Blazers. We do not consider the fate of the painted vehicle body at the end of its lifetime. The reason is that there are no quantifiable processes that account for the separation of the paint from the metal in the shredder. Often the paint is never separated from the parts and the metal is treated with the paint on it.

The results of the analysis provide the energy and water requirements as well as the air, water and solid waste emissions per job, during the production of the materials and during the paint operation.

The LCA results presented in this analysis have been obtained by using the Boustead software, which is a state-of-the-art life cycle assessment tool developed by the Boustead Consulting Ltd. Because the LCA of some of the raw materials was not included in the software's database we amended the database to incorporate those materials using material composition and processing information from technical publications, product literature, and direct contact of the manufacturers.

The LCA of each paint formulation and process takes into consideration the following points:

The LCA of the environmental emissions of *each paint formulation* includes those associated with:

- the mining and production of each of the raw materials,
- the production of energy required to mine and produce the raw materials and the final product,
- the mining of fossil fuels required to generate the necessary electricity and heat to run the

mining and chemical manufacturing processes, and

- transportation of the raw materials to the manufacturing plant.

The environmental emissions for each process are assessed by considering:

- the air, water, and solid emissions generated from each process,
- the energy and emissions associated with the production of raw materials required for the production of electricity and natural gas.
- the emissions generated from the production of energy (electricity and natural gas) required to run the capital equipment for each scenario.

Table 1. Scenarios

Scenarios	Primer	Basecoat	Clearcoat
1	*Primer Solventborne* **SP1:** (Acrylic)	*Waterborne Basecoat* **WB1:** White (Polyester)	*Solvent Clearcoat* **SC1:** (Acrylic)
2	*Primer Powder* **PP1:** (Acrylic) **PP1:** (Acrylic) **PP2:** (Polyester)	*Waterborne Basecoat* **WB1:** White (Polyester) **WB2:** Pewter (Polyester) **WB1:** White (Polyester)	*Solvent Clearcoat* **SC1:** (Acrylic) **SC1:** (Acrylic) **SC1:** (Acrylic)
3	*Primer Powder* **PP2:** (Polyester)	*Waterborne Basecoat* **WB1:** White (Polyester)	*Powder Clearcoat* **PC2:** (Acrylic)

Figure 5 shows the capital equipment attributed to the paint process of scenario (1). Similar schemes have been developed for the other two scenarios.

Findings

In this case study we can differentiate the emissions that are attributed to the manufacturing of the materials and those to the paint process.

The LCA of each paint formulation, solventborne or powder, consists of all subsequent LCAs for each raw material that is involved in the synthesis of the final product. For this very reason, the aggregated environmental emissions associated with the final product have to be considered carefully with respect to the valuation scheme presented in Figure 4.

Atmospheric Emissions

In the case of atmospheric air emissions associated with the chemical manufacturing of the paint formulations, as presented in Figure 6, aggregate values for CO (carbon monoxide), NOx (nitrogen oxides), SOx (sulfur oxides), PM (particulate matter), and VOC (volatile organic compounds) present a meaningless result, from the perspective of examining environmental impact.

This is because the mining, chemical synthesis and transportation of the raw materials to the chemical plant that manufactures the final product, are operations that have local or regional environmental impacts. Thus, the sum of all local emissions, which are occurring in many different locations, as presented in Figure 6, has little or no useful meaning.

However, the air emissions from the paint process as presented in Figure 7, are more meaningful. This is because here we can differentiate atmospheric emissions that are associated with the plant operations and those with the production of electricity outside the plant but which are also local or regional.

- The SOx emissions are exclusively generated during the production of electricity, outside the plant.
- The CO, NOx, PM and VOCs emissions are generated during both the paint process inside the plant and the production of electricity outside the plant. The plant contribution to NOx and CO emissions is due to the combustion of natural gas useful for heating.

Figure 5. Processes for Scenario 1: SOLVENT – WATER - SOLVENT

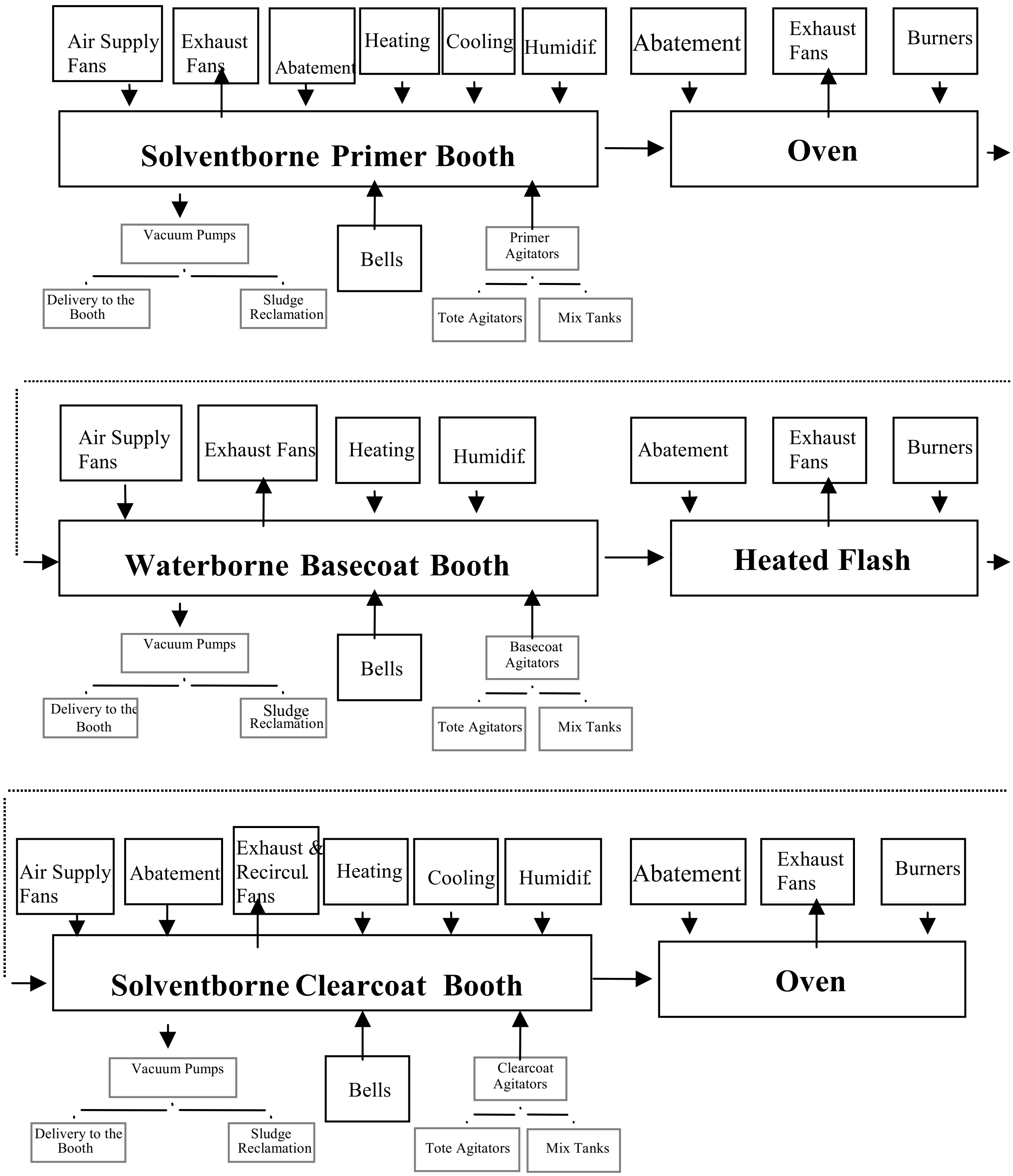

Air Supply Fans
Exhaust Fans
Abatement
Heating
Cooling
Humidif.
Abatement
Exhaust Fans
Burners
Solventborne Primer Booth
Oven
Vacuum Pumps
Delivery to the Booth
Sludge Reclamation
Bells
Primer Agitators
Tote Agitators
Mix Tanks
Air Supply Fans
Exhaust Fans
Heating
Humidif.
Abatement
Exhaust Fans
Burners
Waterborne Basecoat Booth
Heated Flash
Vacuum Pumps
Delivery to the Booth
Sludge Reclamation
Bells
Basecoat Agitators
Tote Agitators
Mix Tanks
Air Supply Fans
Abatement
Exhaust & Recircul. Fans
Heating
Cooling
Humidif.
Abatement
Exhaust Fans
Burners
Solventborne Clearcoat Booth
Oven
Vacuum Pumps
Delivery to the Booth
Sludge Reclamation
Bells
Clearcoat Agitators
Tote Agitators
Mix Tanks

Figure 6. Atmospheric Emissions Released During the Manufacturing of the Paint Formulations in Different Scenarios per Job

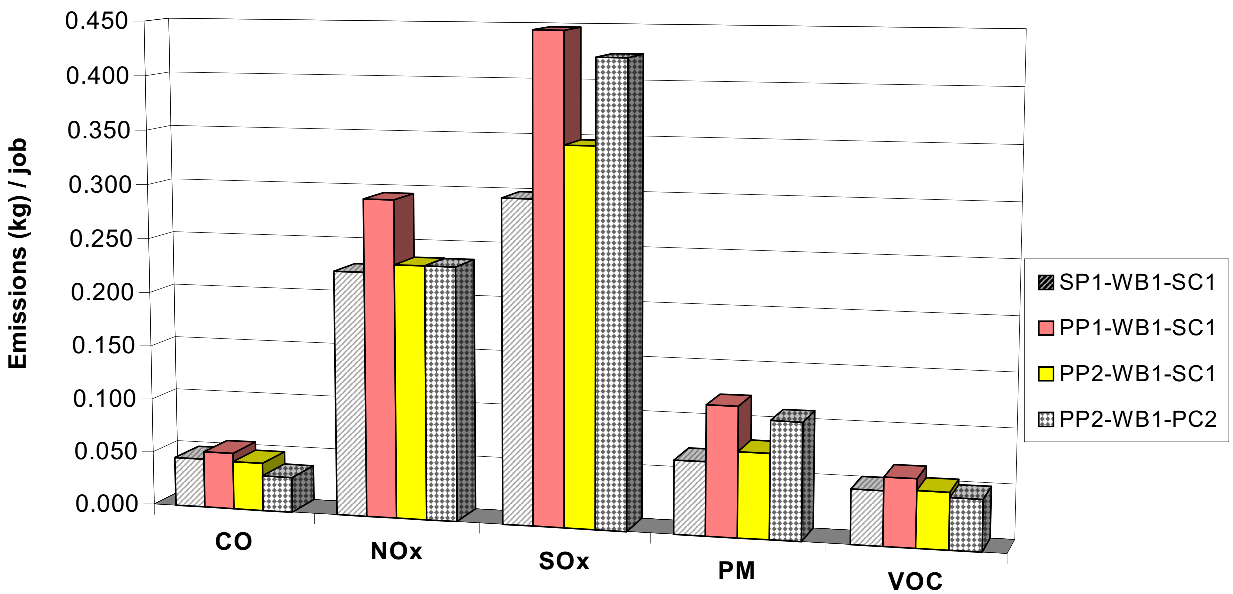
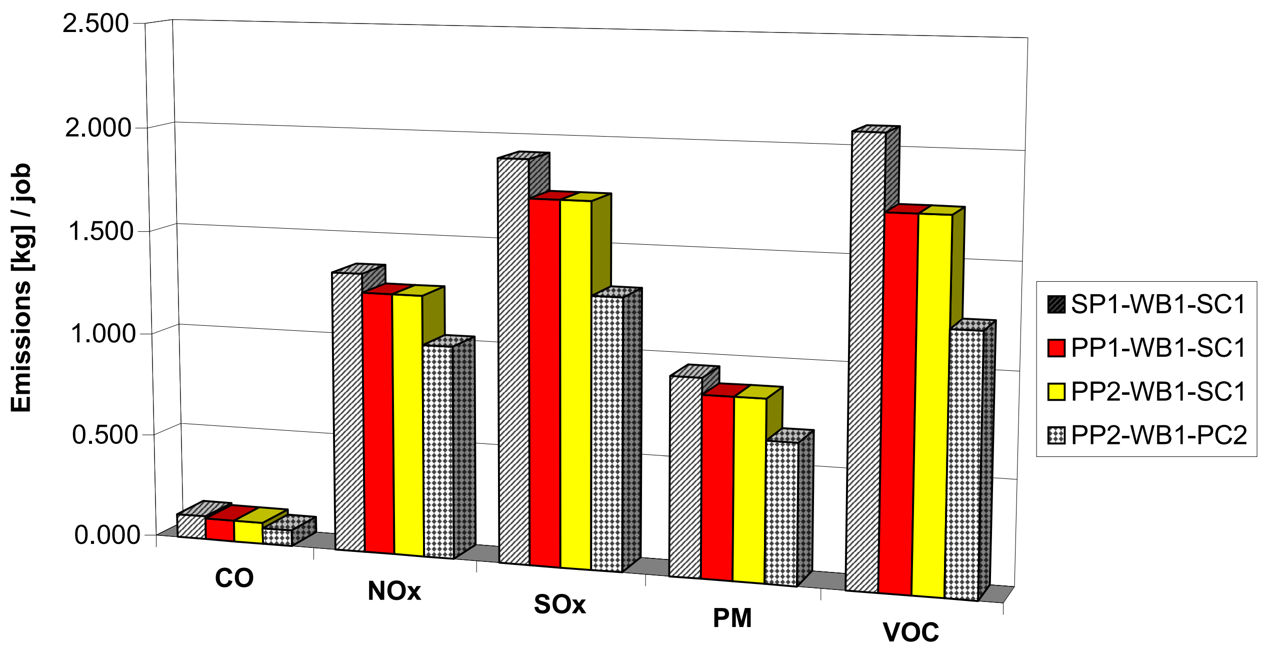


Figure 7. Atmospheric Emissions from the Paint Processes in Different Scenarios



In this case the atmospheric releases are well defined according to the geographic location of the emissions and the associated impacts can be determined accordingly. Overall, the sum of the atmospheric emissions from the materials production and processes, can have little meaning for species with a significant contribution from the paint manufacturing stage whereas total carbon dioxide emissions (CO_2) can be considered favorably due to their global impact characteristics.

Water Emissions

For water emissions, the following categories were examined. These are defined by the Boustead database as follows:

Total solids: materials left after evaporation and drying the sample.
Suspended solids: materials removed from a sample filtered through a standard glass fiber filter.
Dissolved solids: the difference between the total and suspended solids.
Hydrocarbons and Dissolved Organics: compounds containing carbon and hydrogen in various combinations, found especially in fossil fuels. Because of government and industrial interest in fossil fuels and its conservation issues, hydrocarbons are reported separately from other organic compounds.
BOD_5: a measure of the amount of oxygen utilized or consumed in the biochemical oxidation of organic matter in five days.
COD: a measure of the amount of oxygen required to oxidize all compounds in water, both organic and inorganic.

Figure 8 presents the water emissions for the materials and processes. Due to graphic space limitations the nomenclature of the scenarios changed slightly. SWS corresponds to SP1-WB1-SC1, P1WS to PP1-WB1-SC1, P2WS to PP2-WB1-SC1 and PWP to PP2-WB1-PC2. As Figure 8 shows, the majority of the emissions are attributed to the industrial synthesis of the materials.

As mentioned previously, because there are numerous types of environmental issues associated with a production system, it is unlikely that any one design will simultaneously provide a solution to all environmental problems. More often than not, there are tradeoffs (e.g. solid wastes).

Figure 8 is simply a graphical representation of the inventory data. The value lies in being able to identify the different contributions. However, if this information were represented as a single index and, if we assume that the individual contributions were equally weighted, then the results would be represented as a single bar for each of the paint systems. Presented only with such single bars and with no knowledge of the different contributions, it is difficult to see what use could be made of the data other than simply to compare the sizes of the bars.

Sludge emissions

The results indicate that for the manufacturing of the two colors, white and pewter, the energy requirements are approximately the same, 467 and 449 MJ per job respectively. However, the water emission values for all the above mentioned categories, but the suspended solids, are higher for the pewter color. In the solid waste emissions, the sludge generated by the white painted vehicle is 57, 62 and 99% higher than that generated from the pewter painted vehicle for scenarios (1), (2) and (3) respectively.

As a result the choice of color with respect to their environmental impacts does not present a clear-cut selection choice.

CONCLUSION

Eco-indices and eco-labels were introduced with the laudable aim of summarizing environmental information in an easily digestible form. As currently practiced, they cannot be regarded as of any great use in serious environmental debates and should only be used with extreme caution.

ACKNOWLEDGMENTS

We are thankful to Ron Williams and Steven Cadle of General Motors Research and Development Center for their useful comments.

Figure 8. Total Water Emissions

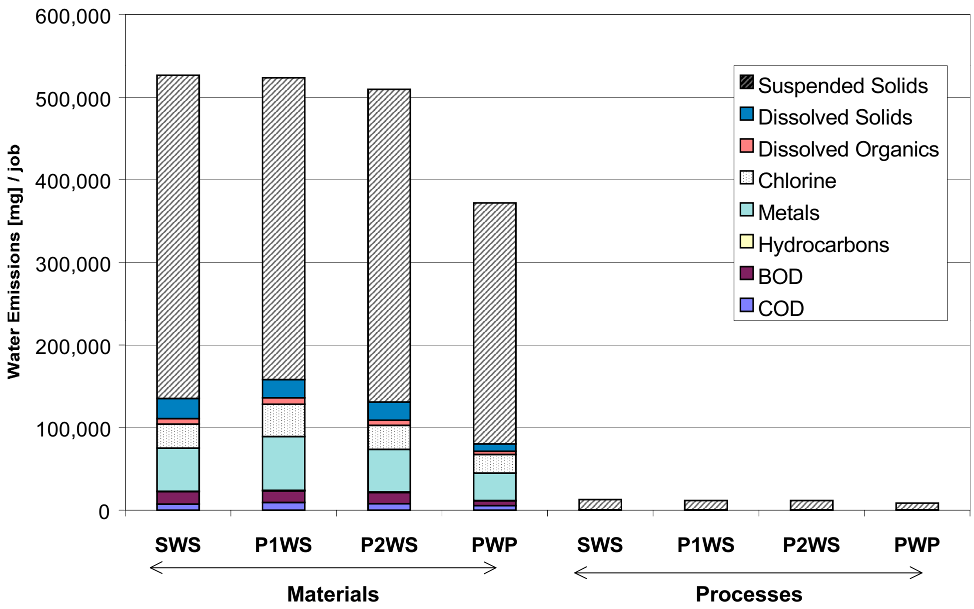


Figure 9. Sludge Generated per Job from the Paint Process