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International Sustainability Stories: Enhancing Good Practices

"El saber de mis hijos hará mi grandeza"

4. EVALUATING CLEANER PRODUCTION INTERVENTIONS IN A MEDIUM SIZE COMPANY

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1. Introduction

Based on case studies in Brazil waste minimization programs and CP practices could generate promising results in reducing pollution at low costs (CETESB, 2002); however, medium-size industries are hindered from implementing the practices due to various attitudinal, organizational, technical, and economic barriers. In São Paulo, Brazil, educational initiatives that describe the environmental and financial benefits of CP are encouraged by CETESB (Environmental Sanitation Technology Company), which is the state environmental agency that monitors CP projects within companies and shares the data with other companies to explain the benefits (CETESB, 2002). Projects monitored by the CETESB have a good chance of success because companies that volunteer to participate can improve their environmental performance, increase innovation, and have access to the CETESB's advisors; however, several initiatives are still adopted without this type of support, resulting in improvements that are not properly documented and therefore do not effectively encourage companies to incorporate elements of CP in their routine procedures. Moreover, most large-scale industry reports remain unpublished due to confidentiality.

The adoption of environmentally sound technological solutions based on scientific research is another relevant strategy that should be addressed. To accomplish the necessary changes, academic results and insights can be integrated into the industry, and based on the sets of experiences, it would be easier to restructure concepts and principles. Most of the initiatives in Brazil regarding CP are still dependent on academic groups that share the concepts with their communities. The group from Paulista University promotes the International Workshop Advances in Cleaner Production every two years (www.advancesincleanerproduction.net). This multi/interdisciplinary forum was designed for the exchange of information and research results on technologies, concepts, and policies based on CP and was conceived to assist the desired transition to a sustainable society. This group has also developed a series of theses, dissertations, articles, and books on environmental concerns (Carvalho, 2015; Di Salvo, 2015; Oliveira, 2015; Lupinacci, 2015; Coelho, 2014; Tassinari, 2013; Mariano, 2013; Sevegnani, 2013; Demétrio, 2012; Di Augustini, 2012; Frugoli, 2012; Simões, 2012; Demétrio, 2011; Vendrametto, 2011; Frimaio, 2011; Ferreira, 2011; Lima, 2011; Faro, 2007; Giannetti et al., 2011a, 2011b, 2013a, 2013b, 2013c, 2015; Almeida et al., 2011, 2012, 2013a, 2013b, 2013c, 2015; Agostinho and Ortega, 2013; Agostinho and Siche, 2015; Agostinho et al., 2013, 2015; Mariano et al., 2015; Di Augustini et al., 2015; Frugoli et al., 2015; Frimaio et al., 2011; Giannetti and Almeida, 2006; Giannetti et al., 2016).

It is known that cleaner technologies and practices are diffusing comparatively slowly in general despite the benefits that have been documented in systems in which they have been implemented (Giorgio et al., 2009). It is also argued that the implementation of CP programs is no guarantee of continuity in environmental progress in itself unless management systems are used to ensure that the activities are continuous and systematic (Zwetsloot, 1995), and it is critical to measure the results of CP practices. Identifying appropriate indicators that address both the productivity and environmental aspects of a system is still a challenge. The indicators should not only enable the estimation of the CP practices suitable for a product or process and comparisons with other equivalents but also the quantitative measurement of improvements of the existing process or product, which would facilitate the development of new products.

In this context, the need for using appropriate methodological tools to correctly assess the real environmental costs and benefits of any practice, support decision making, and identify where improvements need to be made is acknowledged. The use of performance indicators within medium-size enterprises can help monitor and compare the environmental-economic improvements systematically as a first step toward a more complex evaluation; however, environmental-economic improvement is a rather general term that can include raw material and energy use, aspects that affect worker health and safety, discharges to air, water, and land, including solid waste for landfill disposal, and the environmental impact of products during use and disposal (Roberts, 1996). Thus, there are several approaches to determining the optimum level between economic and environmental aspects. One is to perform an impact assessment to evaluate the most environmentally benign system among the design alternatives (Shonnard and Hiew, 2000; Nielsen and Wenzel, 2002). A second approach is based on process integration methodologies for final comparative assessments (Bagajewicz, 2000; Rossiter and Kumana, 1995; Alva-Argaéz et al., 1998; Telukdarie and Haung, 2006; Erol and Thorming, 2005).

The present chapter analyzes the use of resources in a non-cyanide alkaline industrial system with chromate conversion coating located in São Paulo, SP,Brazil. The process change to the organo-metallic technology aims to provide environmental benefits due to the non-use of chrome. To assess the potential technology change, emergy accounting was used for a quantitative environmental assessment to compare two different processes used for metal fastener coating. The emergy corresponding to the damage to human health or the number of years of life lost due to the emission of chromium to water was also evaluated.

A case study that describes the experiences of a medium-size company that adopted different CP concepts as tools for environmental management in a joint action with the researchers of Paulista University is presented. CP concepts were used to achieve the reduction or elimination of hazardous materials used as raw materials for the production process. In addition, the changes in the input materials would also eliminate the generation of hazardous waste during the production process. Due to the need to substitute the toxic input by imposition of the costumers, the company intended to apply CP concepts to replace the existing technology. Technology change is a well-known strategy used by CP practitioners, and it refers to modifications in the process and/or equipment to increase production efficiency and reduce waste and emissions. These changes can range from small, low-cost options to the replacement of processes that involve large capital investments. A technology assessment was conducted using emergy accounting to evaluate the efficiency and the disavantages of each technology. An evaluation of the environmental services used to dilute the release of toxic substances in the effluent was also performed.

An example of the application and evaluation of CP options (good operational practices, material and raw material changes, technological modifications, and product change) is presented to motivate product manufacturers to prioritize environmental performance and assessments and their products and services equally as well as to save manufacturers substantial time and efforts during their first attempts to implement CP actions.

2. Emergy Accounting

Emergy accounting was used to evaluate the company in the case study, as it provides strong scientific-based indicators that can assess several aspects of the company's performance.

Emergy is the available energy of one kind previously used up directly and indirectly to make a service or product. Its unit is the solar emergy joule, sej. (Odum, 1996). Emergy's logic of memorization rather than conservation is different from other energy-based analyses (Brown and Herendeen, 1996). An emergy synthesis separates renewable (R) from non-renewable inputs (N) and local (I = N + R) from external inputs (F). These distinctions allow for defining several emergy-based indicators that can support decision making (Brown and McClanahan, 1996) (Figure 4.1).

Emergy indicators (unit emergy value [UEV]) and emergy yield ratios (EYR) include the aspects of environmental sustainability issues regarding resource use, its origin, and process efficiency in converting inputs into outputs. The total emergy per unit of product or service (UEV expressed in sej/unit) is a measure of global efficiency. The less emergy needed to produce a given amount of product, the more efficient (in relation to the biosphere) the system will be.

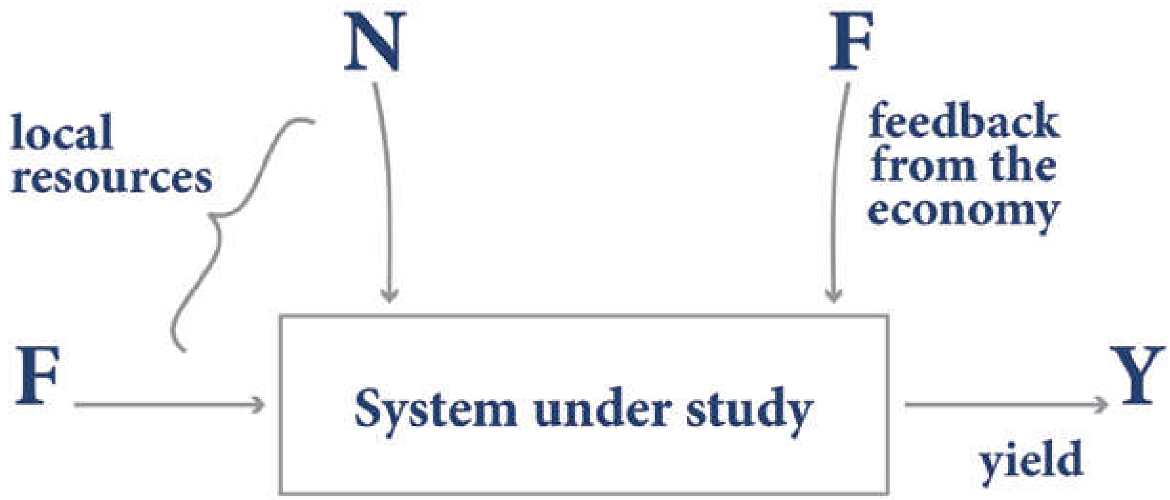

Figure 4.1 Three Arm Energy System Diagram. R (renewable resources), N (non-renewable resources), F (feedback from the economy), Y (yield).

EYR is the ratio of total emergy (Y = R + N + F) to the emergy purchased from the market (F). This index shows the efficiency of the system in the use of the available local resources.

Emergy accounting allows for the conversion of all contributions received by the production system (metals, energy, oil, money, and even information) on a single basis of measurement: the solar energy joule (sej). Systems under study can be compared regarding efficiency in resource use, productivity, environmental burden, and global sustainability.

The evaluation procedure applied is performed according to the following steps:

- Definition of the system under study to set the boundaries for investigation;
- Study of the context in which the system is inserted and execution of the mass balance;
- Elaboration of energy flow diagrams;
- Elaboration of emergy tables with data collected;
- Emergy Indicators Calculation;
- Discussion for future management actions and decision-making.

3. The Case Study of the Medium-Size Metal-Finishing Company

The application of sacrificial coatings onto steel and other ferrous substrates has long been established as an effective and reliable standard of the industry for corrosion protection. Due to its low cost, zinc has been used as the predominant coating. Approximately 30% of the zinc used by the automotive industry is used for coatings, which allows manufacturers to warranty their vehicles up to 12 years against corrosion. In 1996, 494,000 metric tons were used by the automotive industry globally, which was 6.6% of 1996's total global zinc consumption (Johnston, 1999).

The application of zinc electroplating is evident in everyday life and ranges from cars to the fasteners that hold their parts together. The automotive and fastener industry are two of the largest consumers of zinc electroplated goods (Johnston, 1999).

Most developments in this area focused on improving corrosion resistance and process optimization (Chettry, 1999). There are several different processes available for the electrolytic application of zinc. The zinc cyanide system was the original process used to electroplate zinc; however, these systems are being replaced with the advent of alternatives that avoid the use of hazardous substances, such as cyanides. Acidic chloride-based zinc plating processes provide brightness that competes with nickel-chrome plating, and they are quite conductive, leading to high plating efficiency, which saves energy and increases productivity. Sulfate-based systems also operate at acidic pH and are employed when a bright deposit is not required. There is also a non-cyanide alkaline version of zinc plating that is used, especially in the fasteners industry.

The corrosion resistance of plated zinc is enhanced by treating it with a conversion coating, which can remarkably increase its corrosion resistance. These conversion coatings are applied to zinc-plated surfaces through immersion in solutions containing chromate or dichromate ions. Another benefit of conversion coating is that it will give the article color, from an almost colorless to blue to yellow, green, and black. Yellow conversion coatings are popular due to their ability to resemble brass and can be found on all types of fasteners.

Environmental aspects of the zinc plating industry, as well as the metal finishing industry in general, have been a focus of attention, such as the development of low-wastewater discharge systems (Cohen and Overcash, 1995). Environmental issues associated with Cr(VI) are well-documented, and the search for alternatives is the subject of extensive research and development in the zinc-plating industry (Hadley et al., 2002); however, several commercial systems still employ conversion coatings based on hexavalent chromium salts to achieve the desired corrosion resistance.

Recently, organo-metallic coatings were suggested by the automotive industry as an environmentally friendly solution to replace zinc-coating processes and as an alternative to avoid the harmful consequences related to the use of conversion coatings based on Cr(VI). The technology for organo-metallic coatings was developed in the U.S. in the mid-1960s. The company responsible for this development, which is now part of a large chemical conglomerate, was originally known as Diamond Shamrock Co. In the early 1990s, Geomet water-based technology and Zintek solvent-based technology was provided to the market. It should be noted that there is a lack of relevant scientific publications in relation to organo-metallic coatings because both are patented products, and such technology is held by few companies.

In 2007, the company in study expressed a strong wish to replace the zinc-coating process with an organo-metallic process. The process currently used by the company is the electroplating bath with alkaline cyanide-free zinc deposition process and a conversion layer that uses Cr(VI). The company intends to gradually substitute the current process with the water-based organo-metallic coating process (Geomet).

4. Emergy Accounting for the Medium-Size Metal-Finishing Company in the Case Study

The company in study evaluated the supplies of the automotive industry in São Paulo, Brazil, and it produces nearly 120 tons of zinc-plated fasteners each month. The data collected refers to the company's production in 2005.

The energy system diagrams illustrated in Figures 4.2 and 4.3 were designed to combine information about the systems of interest from various sources and to organize efforts for data gathering. The diagrams show all material and energy flows circulating in both production systems as well as the systems' interactions with the environment. All driving energies from the external economic system (larger economy), the environment, and interactions are included (Odum, 1996). On the left side of the diagram, renewable resources (R) are represented, purchased or imported resources (F) are at the top, and the yield of the system (Y) is represented on the right side, which is the coated fasteners in this case. The diagrams were used to analyze tables of data required for emergy accounting.

As shown in Figure 4.2, the zinc-coating process has an effluent treatment unit (ETU), which feeds part of the water treated back into the production process. The sludge produced in the ETU is sold to the ceramic industry. The organo-metallic coating process also has an ETU, but the water is directly rel eased to the environment after treatment. The sludge is sold to the ceramic industry.

Tables 4.1 and 4.2 show all inputs needed for system implementation divided by plant lifetime, annual operating inputs (labor, electricity, machinery, human services), and direct and indirect environmental inputs (water). Suitable UEVs were assigned that resulted in the emergy values in sej after being multiplied by the energy inputs. During the implementation phase, steel was considered a resource from the economy (F) to be incorporated in the equipment purchased from third parties or in the facility structure. On the other hand, the steel used for the operation was considered a non-renewable resource (N). The water used in the system was taken from an artesian well and was considered a non-renewable resource (N) because the ground water in the city of São Paulo is used faster than its recovery time (Milaré, 1991).

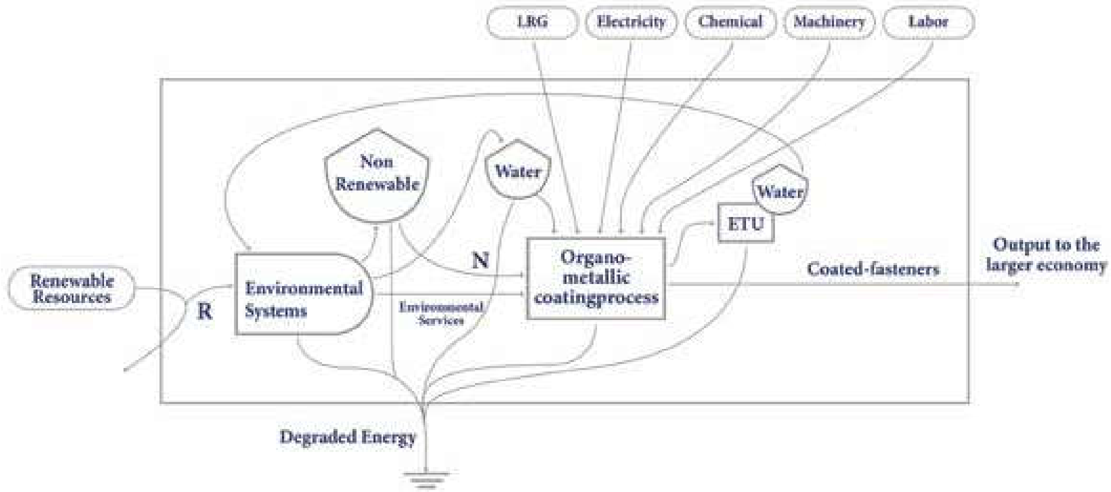

Figure 4.2 Energy System Diagram of the Zinc-Coating Process

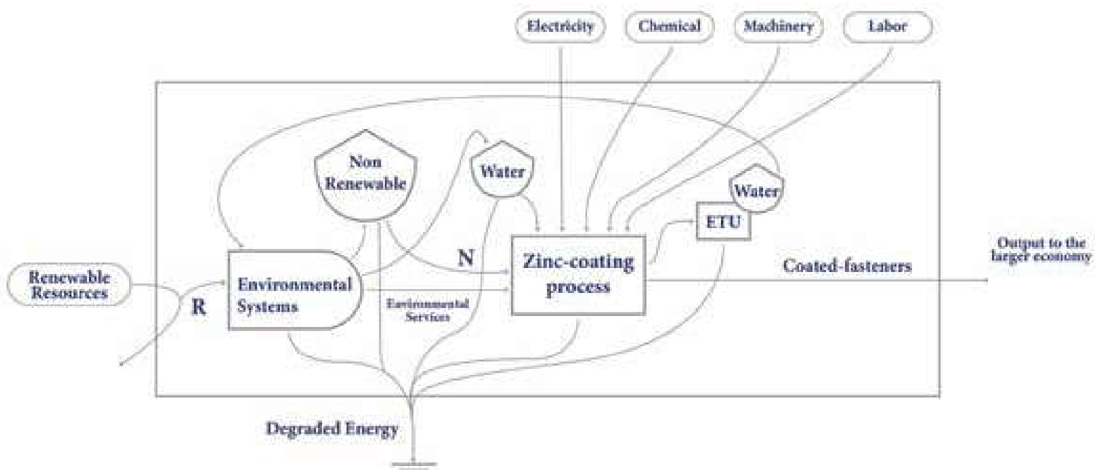

Figure 4.3 Energy Diagram of the Organo-Metallic Coating Process. LPG refers to Liquid Petroleum Gas.

Table 4.1 shows the flows of materials and energy required for the zinc-coating system. The emergy involved in the coating process as well as the emergy of the coated fasteners were calculated. Column (a) shows the percentage of each item in relation to the total coating process emergy (Y1), while column (b) shows the percentage values corresponding to the total emergy of the coated fasteners (Y2).

In the zinc-coating process, the highest values of emergy are associated with electricity (49%), labor (25%), and chemicals (15%) (column a). Column b of the table shows the steel used to make the fasteners, and the percentages drop to 4% for electricity, 2% for labor, and 1% for chemicals, while 92% of the total emergy corresponds to the steel used to make the fasteners.

The water fed back by the ETU corresponds to 31% of the weight of total water use. Thus, it would be reasonable to suppose that the savings related to its use would also correspond to environmental benefits. In fact, if there were no water reuse, a quantity of 8.4 x 108 g/year could be added to the water input, leading to an emergy contribution of 1.89 x 1014 sej/year to the total emergy of the zinc-plating process; however, as the contribution of water inflow represents only 0.5% sej/sej of the total emergy of the zinc-plating process, this value is not relevant enough to change the UEV of the process, that is, its efficiency.

Table 4.1 Material and energy flows for the zinc-coating process

Description		Unit	Class	Value	UEV (sej/un)	Emergy (sej/year)	% (sej/sej)	% (sej/sej)
							(a)	(b)
Implantation								
1	Concrete	g	F	5.94×10^6	1.54×10^9	9.15×10^{15}	5.55%	0.42%
2	Steel	g	F	1.60×10^6	2.77×10^9	4.43×10^{15}	2.68%	0.21%
3	Polypropylene	g	F	1.37×10^5	5.87×10^9	8.04×10^{14}	0.49%	<0.10%
4	Equipment	g	F	5.30×10^4	4.10×10^9	2.17×10^{14}	0.13%	<0.10%
5	Labor	J	F	5.02×10^7	4.30×10^6	2.16×10^{14}	0.13%	<0.10%
6	Machinery	g	F	2.22×10^4	4.10×10^9	9.10×10^{13}	<0.10%	<0.10%
7	PVC	g	F	1.15×10^4	5.87×10^9	6.75×10^{13}	<0.10%	<0.10%
8	Water	g	N	2.70×10^7	2.25×10^5	6.08×10^{12}	<0.10%	<0.10%
9	Rubber	g	F	1.00×10^3	4.30×10^9	4.30×10^{12}	<0.10%	<0.10%
Operation								
10	Electricity	J	F	4.95×10^{11}	1.65×10^5	8.17×10^{16}	49.52%	3.78%
11	Labor	J	F	9.80×10^9	4.30×10^6	4.21×10^{16}	25.52%	1.95%
12	Chemicals	g	F	2.55×10^7	1.00×10^9	2.55×10^{16}	15.45%	1.18%
13	Water	g	N	3.67×10^9	2.25×10^5	8.26×10^{14}	0.50%	<0.10%
	Emergy (process)	kg	Y1	7.2×10^3	2.29×10^{13}	1.65×10^{17}	100.00%	--
14	Steel	g	N	7.20×10^8	2.77×10^9	1.99×10^{18}	--	92.13%
	Emergy (fasteners)	kg	Y2	7.27×10^5	2.97×10^{12}	2.16×10^{18}	--	100.00%

(a) considering items from 1 to 13; (b) considering items from 1 to 14.

The influence of the water inflow on the total emergy of the zinc-plated fasteners is even lower at 0.10% sej/sej. Thus, despite an undeniable benefit of saving 840 m^3 of a non-renewable resource, this percentage is insufficient to improve the environmental efficiency of the process, and the use of the main inflows (electric energy, chemicals, and man labor) should preferentially be focused on other alternatives.

Table 4.2 shows the flows of materials and energy that contribute to the organo-metallic coating system. Data were provided by one of the largest Brazilian users of organo-metallic coatings, which has a unit capable of producing about 60 t/month of coated fasteners.

In Table 4.2, the emergy required by the organo-metallic coating process as well as the total emergy required by the coated fasteners are calculated. In the coating process, the highest values of emergy are related to electricity (44%), liquid petroleum gas LPG (33%), labor (17%), and chemicals (4%) (column a). Column (b) includes the number of produced fasteners, and the percentages are 10% for electricity, 7% for LPG, 4% for labor, and 1% for chemicals. The steel used to manufacture the fasteners corresponds to 78% of the total emergy.

Table 4.2 Material and energy flows for the organo-metallic coating process

Description		Unit	Class	Value	UEV (sej/un)	Emergy (sej/year)	% (sej/sej)	% (sej/sej)
							(a)	(b)
Implantation								
1	Concrete	g	F	3.50 x 10^{6}	1.54 x 10^{9}	5.39 x 10^{15}	0.96%	0.21%
2	Equipment	g	F	5.58 x 10^{5}	4.10 x 10^{9}	2.29 x 10^{15}	0,41%	<0.10%
3	Steel	g	F	2.00 x 10^{5}	2.77 x 10^{9}	5.54 x 10^{14}	0,10%	<0.10%
4	Machinery	g	F	1.10 x 10^{5}	4.10 x 10^{9}	4.51 x 10^{14}	<0.10%	<0.10%
5	Labor	J	F	5.02 x 10^{7}	4.30 x 10^{6}	2.16 x 10^{14}	<0.10%	<0.10%
6	Rubber	g	F	5.00 x 10^{4}	4.30 x 10^{9}	2.15 x 10^{14}	<0.10%	<0.10%
7	Polypropylene	g	F	2.00 x 10^{4}	5.87 x 10^{9}	1.17 x 10^{14}	<0.10%	<0.10%
8	Water	g	N	3.50 x 10^{6}	2.25 x 10^{5}	7.88 x 10^{11}	<0.10%	<0.10%
Operation								
9	Electricity	J	F	1.50 x 10^{12}	1.65 x 10^{5}	2.48 x 10^{17}	43.97%	9.69%
10	PLG	J	F	3.89 x 101^{2}	4.80 x 10^{4}	1.87 x 10^{17}	33.16%	7.30%
11	Labor	J	F	2.29 x 101^{0}	4.30 x 10^{6}	9.85 x 10^{16}	17.46%	3.85%
12	Chemicals	g	F	2.20 x 10^{7}	1.00 x 10^{9}	2.20 x 10^{16}	3.90%	0.86%
13	Water	g	N	2.64 x 10^{8}	2.25 x 10^{5}	5.94 x 10^{13}	<0.10%	<0.10%
	Emergy (process)	kg	Y1	3.00 x 10^{3}	1.88 x 10^{14}	5.64 x 10^{17}	100.00%	--
14	Steel	g	N	7.20 x 10^{8}	2.77 x 10^{9}	1.99 x 10^{18}	--	77.73%
	Emergy (fasteners)	kg	Y2	7.23 x 10^{5}	3.54 x 10^{12}	2.56 x 10^{18}	--	100.00%

Table 4.3 summarizes the results of both processes and shows that less emergy is required by the zinc-coating process. That is, fewer resources are used to obtain fasteners using this process. The organo-metallic coating has a total emergy of about eight times higher than the zinc-coating process in producing 1 kg of coated-fasteners, and the fasteners obtained through this process use about 19% more resources per year than zinc-coating.

Table 4.3 Total emergy used to produce zinc-coated and organo-metallic coated fasteners

	Zinc-coating	Organo-metallic coating
for the process		
Emergy / (x 10^{17} sej/year)	1.65	5.64
UEV (x 10^{13} sej/kg)	2.29	18.80
for the fasteners		
Emergy / (x 10^{17} sej/year)	21.60	25.60
UEV / (x 10^{13} sej/kg)	0.29	0.35

5. Evaluating the Implementation of the Organo-Metallic Process at the Company

The company aims to implement the organo-metallic process in combination with the zinc-coating process to comply with the needs of all customers. The aim of the initial project was to produce 45 tons of zinc-coated fasteners and 60 tons of organo-metallic fasteners monthly.

5.1. Emergy Efficiency (UEVs) Calculation

For the evaluation of each process, 727,200 kg/year of zinc-coated fasteners (Table 4.1) and 723,000kg/year of organo-metallic coated fasteners (Table 4.2) were considered in the emergy accounting. For project implementation, the quantity of zinc-coated fasteners equalled 545,400 kg/year, and the quantity of organo-metallic coated fasteners equalled 723,000 kg/year. Table 4.4 shows the UEVs for each process.

Table 4.4 Emergy and UEVs for the zinc-coated fasteners, the organo-metallic coated fasteners, and the combination of both processes (Project)

	Zinc-coated (Table 4.3)	Organo-metallic coated (Table 4.3)	Project
Emergy / (sej/year)	2.16×10^{18}	2.56×10^{18}	4.64×10^{18}
UEV / (sej/kg)	2.97×10^{12}	3.54×10^{12}	3.65×10^{12}

Table 4.4 shows that the zinc-coated fasteners' UEV is lower than that of the organo-metallic coatings, and it is also lower than that relative to the fasteners produced by the company if the processes were used simultaneously. The results obtained show that regarding the use of resources, it is more advantageous (i.e., higher global efficiency) to maintain the zinc-coating process technology.

5.2. Emergy Indices Calculation

Once the total number of input flows to the coating processes has been identified and the total emergy driving the processes has been calculated, a set of indices and ratios can be calculated. These indices have been shown to be particularly useful when studying processes under human control where a sustainable pattern is not guaranteed and choices must be supported by the careful consideration of several different parameters.

For systems that lack the use of renewable resources, the emergy yield ratio (EYR) and the emergy investment ratio (EIR) can be calculated, while the ESI and ELR cannot. These indices provide important information about a system's contribution to the economy (EYR) and its efficiency in the use of local resources (EIR). Table 4.5 shows the calculated indices for the coated fasteners for both processes separately and if the project were to be implemented by the company.

Table 4.5 Emergy indices for the coated fasteners produced by the zinc-coating process, organo-metallic coating process, and produced by the company, which includes with both processes (Project)

Emergy indices	Zinc-coated (Table 4.1)	Organo-metallic coated (Table 4.2)	Project
Emergy yield ratio (EYR*)	13.14	4.54	4.05
Emergy Investment ratio (EIR*)	0.08	0.28	0.33

* EYR = Y/F ; EIR = F/(R+N)

Table 4.5 shows that the EYR of the zinc-coated fasteners equals 13, meaning that the zinc-coating process returns 13 times the investment to the economy, while the process of organo-metallic coating aggregates 4.5 times more emergy to the local economy. The higher the value of this index, the greater the return obtained per unit of emergy invested. In the combined process planned by the company, there would be an emergy increase of four times the investment.

Regarding EIR, the less the ratio, the less the economic costs. It can be observed that the emergy investment of the zinc-coating process is the lowest among the three alternatives, indicating a higher usage of natural resources.

6. Extending the Evaluation beyond the Borders of the Company: The Emergy Invested by the Environment to Manage the Chromium Contained in the Effluent

It is worth noting that the organo-metallic coatings were suggested by the automotive industry as an environmentally friendlier solution to replace the zinc-coating processes. The major advantage is associated with the lack of chromium in the effluents of the production process.

Although the calculation of the UEVs is indicative of the efficiency of a process, it is insufficient in determining whether a case is more beneficial than another, especially when other factors influence the conclusion. Thus, the environmental benefit related to the application of organo-metallic coatings that was disregarded by the calculation of UEVs was evaluated.

Environment services that naturally treat effluents include the removal and immobilization (even bioaccumulation) of substances and the response of the environment to toxicity. Once emitted to the environment, all substances may be diluted by ecosystem services, such as wind and water flows, to a local concentration. Several factors, such as spatial and temporal dispersion, diffusion, and atmospheric chemistry, are crucial in the determination of the local concentration. If the concentration of the substance emitted is greater than the local concentration value, the emission will cause harm to humans and to the ecosystem. The damage itself is therefore dependent on the existence of pollutants in the ecosystem and on human exposure to the pollutants.

The amount of chromium present in the effluents generated by the zinc-coating process was used to calculate the response to the toxicity of the effluent and the energy used for its dilution. To assess the impacts to human health and to aggregate the effects of chromium emissions by the zinc-coating process, the DALY for hexavalent chromium emission to water (Disability Adjusted Life Years) was used (Goedkoop and Spriensma, 1999). The company's self-monitoring report indicated that the chromium concentration was below 0.01 mg/L (Review Report No. 6321 of 02.21.2006 issued by Centralsuper Commerce Chemicals Ltd.), which is the limit for disposal according to current Brazilian law.

The Effluent Treatment Unit (ETU) discards 4,000 liters of water per hour, and the zinc-coating process discards treated water for two hours daily for approximately 22 working days per month. The amount of chromium was calculated to be 0.02112 kg/year.

Equation 3 was used to calculate the emergy related to damage to human health. The calculated value (1.12×10^{14} sej / year) represents the emergy cost due to the chromium emission in its hexavalent form in the effluent (Genoni et al., 2003). This cost represents the response of the environment to the toxicity of the discharged effluent.

Taking both the dilution of substances in the physical environment and their processing by living organisms into account, Genoni et al. (2003) estimated the UEVs of several elements, including chromium. The chemical energy used to dilute the substances was considered to be at least equal to the Gibbs free energy associated with the gradient concentration between the effluent and the receiving environment (Equation 3).

$$E = N \times R \times T \times \ln C1/C2 \qquad (3)$$

Where:

N = number of moles of chromium discharged

R = universal gas constant (8.314 J / mol K)

Temperature T = 298K

C1 = concentration of the effluent discharged

C2 = the local concentration of the substance of interest

E = energy of the damage

The local concentration used (0.005 mg/L) refers to the concentration of chromium in urban areas because the company is located in Diadema, Brazil (Silva and Pedrozo, 2001). Thus, for 2.11 x 10^{-2} kg/year (0.41 mol/year), the chemical energy for the dilution of 0.01 mg/L is 704 J/year. To calculate the emergy invested from the environment in the dilution of chromium in the effluent, the energy value was multiplied by the UEV for the dilution (1.99 x10^{10} sej/J) of the hexavalent chromium that was calculated by Genoni et al. (2003). Table 4.6 shows the total emergy invested by the environment to manage the chromium discarded by the zinc-coating process.

Table 4.6 Emergy related to chromium discharge by the zinc-coating process

Description	**Class**	**Emergy / (sej/year)**	**% (sej/sej)**
Zinc-coating process	Y1	1.65 x 10^{17}	99.92%
Emergy to respond to toxicity	R	1.12 x 10^{14}	0.07%
Emergy for dilution	R	1.40 x 10^{13}	0.01%
Total	Y1	1.65 x 10^{17}	

Table 4.6 includes the emergy invested by the environment to respond to the toxicity of the chromium released and to dilute it in water bodies. The results show that the total emergy investment is basically unchanged. This indicates that the concentration of chromium present in the effluent

must be close to that of the local concentration and that the treatment of the liquid effluent, which complies with the law, is efficient for minimizing the work and the response of the biosphere. The calculation of emergy invested by the environment to manage the maximum amount discarded in wastewater showed that the value used by the environment to dilute the toxicity was lower than 0.1% of the emergy demanded in the coating process.

It should be noted that this evaluation does not consider some important aspects. First, the calculations proposed by Ukidwe and Bakshi (2004) and Genoni et al. (2003) do not consider the accumulation of chromium in the water bodies, which should increase the value of the energy for dilution and the damage to human health, as it reduces the processing capacity of living organisms as a function of time. Similarly, this calculation does not consider the limits of receiving these annual amounts of chromium for the environment. It is known that in water bodies in rural areas, for example, the chromium concentration is no more than 5.00 x 10-6 mg/L (Silva and Pedrozo, 2001); however, using this value as the local concentration base will increase the emergy for dilution to 1.54 x 1014 sej/year, and it still represents no more than 0.1% of the total emergy of the zinc-coating process.

7. Discussion

Emergy accounting was used to evaluate the environmental performance of the manufacturing process of coated fasteners.

Considering only the use of resources to obtain the same amount of product, the methodology indicated that it is best to maintain the zinc-coating process. The calculation of the UEVs showed that regarding the use of resources, the zinc-coating process technology is more efficient in converting global resources into products.

Fasteners coated by the zinc-coating process contribute more to the economy (EYR = 13) than the organo-metallic coating process (EYR = 4.5). For the combination process proposed by the company, there would be an increase of four times the emergy, from 2.56 x 10^{18} sej/year to 4.64 x 10^{18} sej/year.

The emergy investment is about 3.5 times higher for the organo-metallic coating process when compared to the zinc-coating process, which indicates a better use of resources supplied by the economy by the zinc-coating process.

The calculation of environmental services to assessthe toxicity of chromium in the effluent and its dilution in water bodies showed that the effluent treatment is efficient and that the emergy invested by the environment to manage the amount discarded is lower than 0.1% of the emergy used in the coating process.

8. Conclusion

This chapter has described the experiences of a medium-size company that adopted different CP concepts as an approach to environmental management in a joint action with the researchers of Paulista University. Due to pressure from its clientele, this company conducted an evaluation to determine whether a change in process technology would be beneficial. Emergy indicators in combination with a health loss indicator (DALY) were employed for the quantitative measurements.

The decision to implement either low-cost or high-cost interventions depends on the specific goals of the individual establishment; however, there are rewards that worth when the intervention has a low cost. While good management practices would focus on bringing the production process performance to the designed level, small investments in CP actions may considerably improve environmental performance. The evaluation presented in this chapter shows that a quantitative assessment is imperative to corroborate decision making. Despite the advantages that were offered by suppliers regarding the elimination of chromium, it was clear that the change in technology would lead to a decrease in global efficiency or to an increase in the use of resources. This increase in resources used would be higher than the environmental services saved with the avoidance of the toxic release.

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