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Developing eco-technologies: A possibility to minimize environmental impact in Southern Brazil

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Abstract

This article discusses the need to integrate scientific research with the concept of Industrial Ecology, acting as support for the development of Eco-technologies. In order to proceed with the discussion, an initial section presents the concepts. A new and more accurate position concerning the extension of Eco-technologies in the context of Industrial Ecology is proposed. Emphasis on the role of academic scientific research as a way to propose and support specific solutions for local problems. Thus, alternative solutions based on the application of non-conventional technologies, which explore the unique regional characteristics of a Brazilian region, are examined. The sharing of waste streams generated by two polluting industries, mining and leather tanning, can lead to lower environmental impact if compared with separate management of their wastes. A comprehensive bibliographic review of non-conventional technologies related to heavy metal attenuation is included.

Keywords: Industrial ecology; Eco-technologies

1. Introduction

The development of global markets and technologies is causing major challenges to industrial initiatives, especially in developing countries. Producers increasingly need to find a new role in an integrated form with product development, with supply and distribution networks and, especially, with the environment. As a consequence, there is a need for more effective use of resources and more efficient management of the residues produced by industries. This implies the fulfillment of Industrial Ecology principles[1,2] [3, 4].

In this article, Eco-technologies are proposed as tools for the achievement of the principles of Industrial Ecology. Thus, Eco-technologies will embrace the technological aspects contained in the Industrial Ecology in the same way as Cleaner Technologies[3] act within the Cle-

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[1] "Industrial Ecology is the means by which humanity can deliberately and rationally approach and maintain a desirable carrying capacity, given continued economic, cultural, and technological evolution. The concept requires that an industrial system be viewed not in isolation from its surrounding systems, but in concert with them. It is a systems view in which one seeks to optimize the total materials cycle from virgin material, to finished material, to component, to product, to obsolete product, and to ultimate disposal. Factors to be optimized include resources, energy and capital." [1].

[2] "The idea of an industrial ecology is based upon a straightforward analogy with natural ecological system. In nature an ecological system operates trough a web of connections, in which organisms live and consume each other and each other's waste. The system has evolved so that the characteristic of communities of living organisms seems to be nothing that contains available energy or useful material will be lost. There will evolve some organism that will manage its living by dealing with any waste product that provides available energy or usable material. Ecologists talk a food web: an interconnection of uses of both organisms and their wastes. In industrial context we may think of this as being use of products and waste products. The system structure of a natural ecology and the structure of an industrial system, or an economic system, are extremely similar." [2].

[3] "Cleaner Technology is a manufacturing process which by its nature or intrinsically: reduces effluent and other waste production; maximizes product quality; maximizes raw materials and energy and any other input use. Thus one technology is usually compared to some other technology or process. Cleaner Technology may be thought of a subset of Cleaner Production activities with a focus on the actual manufacturing process itself and considers the integration of better production systems to minimize environmental harm and maximize production efficiency from many or all inputs." [5].

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aner Production[4] context. The difference is based in the closed loop system vision of the first Eco-technology/Industrial Ecology couple compared with the point or sometimes linear vision of the Cleaner Technology/Cleaner Production. In this way, a more precise extension of the term Eco-technology is envisioned, differing from the ambiguous ones presented in the literature. Directly related to the subject, the importance of a scientific research program with the purpose of providing support, facilitating implementation and updating information, pertaining to new technologies involved in the Eco-technology practices, is explored.

This work was organized as follows

Revision of some fundamental concepts and discussion of the proposed objectives: a brief review of useful concepts is firstly presented as well as the discussion to support the proposed relations between Eco-technologies and Industrial Ecology is presented. Also, the importance of implementation of scientific research programs is examined emphasizing the lack of global solutions and the need for local proposals is examined.
The Present situation in Brazil: description of mining and tanning activities in the south of the country, and the environmental impacts as a consequence of these activities.
Laboratory studies: Possibilities towards Eco-technologies: reaffirming the need of the scientific research as a way to propose regional solutions, a complete bibliographic review of non-conventional technologies for heavy metal attenuation is presented.
Integrating mining and tanning: discussion of inter-sectoral use of wastes through use of management technologies under the Industrial Ecology point of view is presented.

The goal of this work is to position Eco-technologies as tools of Industrial Ecology, considering scientific research as a natural step for the implementation of these new technologies. A real example of a Brazilian problem serves as a concrete starting point in order to propose solutions within the frame of the presented discussion.

2. Revision of some fundamental concepts and discussion of the proposed objectives

Cleaner Production and Industrial Ecology have emerged separately, but divide the interest of practitioners, industry and academy. The two concepts share the goal to diminish environmental impacts of industrial production and their products, however differences such as system boundaries or driving forces are pertinent. Both, Cleaner Production and Industrial Ecology can work together to reduce waste and pollution.

Cleaner Production refers to the decrease in the waste generation and to the development of a product that causes a reduced environmental impact throughout its life cycle [7]. In this case, the manufacturer addresses all life cycle phases. This action may have a positive effect on pre-manufacture through its interactions with suppliers. Cleaner Production may result in improvements of the use of resources other than raw materials, as well as to consider the environmental consequences of using non-renewable materials. It also points to modernization of the manufacturing processes, determining the use of consumables and specifying by-product recyclability and/or reusability. Packaging and distribution have to be considered as well as their connection with the environment. Finally, the product itself may be taken into account as an intermediate that should be reused/recycled at the end of its life cycle.

Cleaner Production contributes to important industrial progress from an environmental point of view. Fig. 1 shows a conventional industrial unit where unlimited raw material and unlimited energy are consumed. Waste generation is high and, even after treatment, is totally discarded in the environment. The introduction of Cleaner Production practices results in a more efficient use of raw material and energy (Fig. 1) and in an enhanced flow of materials inside the industrial unit. A decrease in waste generation is achieved by Cleaner Technology [6] application, such as reusing/recycling practices. Despite economic and environmental benefits, the application of Cleaner Technologies within separate companies remains rather limited [8], as it is intrinsically

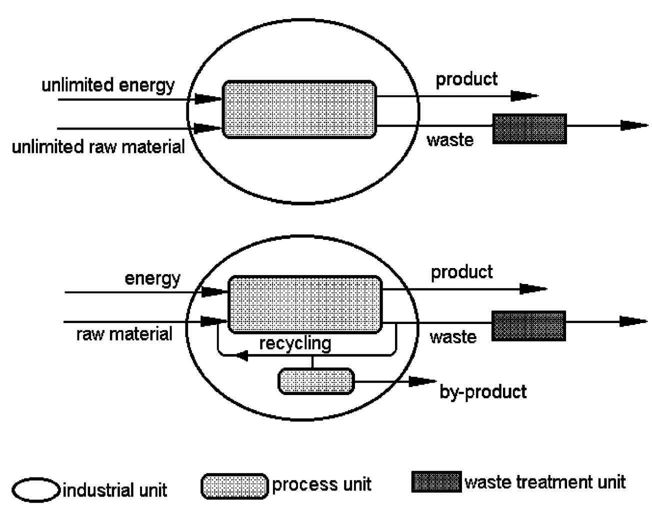

Fig. 1. Schematic representation of a conventional firm (top) and a firm where Cleaner Production practices were applied (bottom).

[4] "Cleaner Production is the continuous application of an integrated preventive environmental strategy to processes, products, and services to increase overall efficiency, and reduce risks to humans and the environment. Cleaner Production can be applied to the processes used in any industry, to products themselves and to various services provided in society." [6].

impossible to design an industrial process that has no environmental impacts.

To achieve Industrial Ecology, it is necessary to study all the flows of energy and materials of each industrial unit, that is, to study the Industrial Metabolism [9,10]. Under this approach, these flows are followed from their initial sources, through the industrial systems, to the consumer and to their ultimate disposal. This analysis shows how resources are used at each point of the system and helps to identify the areas where an immediate action is necessary.

Fig. 2 shows a diagrammatic representation of an aggregation of industrial units that grow up to form larger units such as industry parks and clusters. The complexity of the aggregation can increase, as the number and the variety of industrial units and the interactions between units also increase. A firm may dispose its waste for more than one company. Analogously, a firm may buy waste and by-products from more than one supplier. Despite the specific complexity of each unit, factors such as interactions between units with the enhanced exchange of materials and energy cause a mutual canceling effect, which would be responsible for reducing the system oscillations with respect to the environment. Thus, the global process, which results from several minor contributions, may cause a minor environmental impact compared to the impact caused by the sum of individual units.

Industrial Ecology designs the industry as a producer of both products and wastes and refers to an integrated assessment of the links between industry and environment [11]. The company boundaries enlarge passing through environment, utilities and product development between companies. Under this approach, the study of the aggregation may start at any point of the system, but the adjacent units must be considered. The essential object of Industrial Ecology has to be the total use/reuse of all resources, that is, zero-waste or zero-emission and the most critical aspect of Industrial Ecology, the achievement of inter-firms cooperation, sharing materials, energy and principally information.

Eco-technology was defined as the use of technological methods for environmental management in a way to minimize harm to the environment [12]. However, as technology itself is often associated to environmental impact, the term Eco-technology has also been related to remediation techniques [13,14], Cleaner Technologies [15,16] and, in some cases, is even used as a green slogan associated to products or processes which are supposedly environmentally friendly, for example by avoiding the use of specific toxic chemicals.

In our opinion, Eco-technologies should promote the link between firms, dealing with final products and waste recycling/reusing in a cooperative attempt to improve environmental efficiency. This kind of improvement cannot be achieved through direct transfer of advanced technology from one country to another. New technology must be created or adapted in accordance with the economic and geographical conditions of each individual country and each individual company within those countries. Thus, the implementation of these technologies will depend especially, on a scientific research program that targets the total use and reuse of all constituents of the system within a geographic region. In terms of the Industrial Ecology situation, it is useful to consider the industrial processes at regional levels, with boundaries large enough to deal with a number of industries with potential wastes that might be used by other industries, but small enough to permit transport and exchange of materials between/among industrial units. In this context, Eco-technologies regionally developed can enable conversion of wastes to resources and by-products based on the principles of Industrial Ecology.

3. The present situation in Brazil

The southern region of Brazil presents ideal conditions for the study of heavy metal attenuation between

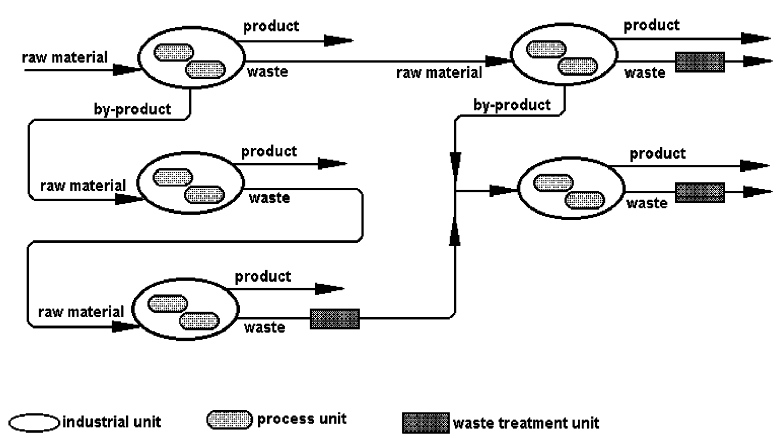

Fig. 2. Diagrammatic representation of an aggregation of industrial units.

two industrial sectors. The largest deposits of Brazilian coal are located in Rio Grande do Sul and Santa Catarina (Fig. 3, grey). Paraná has also minor deposits. Rio Grande do Sul is also responsible for the major production of the shoe industry and several tanneries are located in the region known as Sinos Valley (Fig. 3, black).

The coal reserves represent a significant fraction of the non-renewable energy resources of the country. They account for 28 billion tons or 89.3% of Brazilian total reserve [17]. As a result of both mining processes and waste characteristics, large amounts of waste are generated. The exposure of mining wastes, containing reduced sulfide minerals, to the environment results in release of acidic weathering products due to the oxidation and hydrolysis reactions in soil and geologic material. The impact of the mining industry is of increasing importance as the drainage of mine wastes can continue for hundreds of years, well past the economic life of a mine. The challenge is to establish a cost-effective way to control the oxidation rate of sulfides in mine wastes or to find a use for these wastes.

On the other hand, nearly 60% of the leather processed in Brazil comes from Sinos Valley [18]. According to the "Associação da Indústria de Curtumes do Rio Grande do Sul, AICSUL" (Rio Grande do Sul Tannery Industries Association), there are approximately 90 tanneries in the region that are responsible for 30% of the Brazilian leather exportation. Tanneries use chromium for the transformation of hides and skins into leather. Chromium tanned leather has been used for almost a century for the manufacture of consumer products such as clothing, gloves, footwear, furniture, automobile upholstery, as well as a variety of personal leather goods. The leather manufacturing process generates liquid and solid wastes containing chromium salts that are discharged as effluents to the environment, notably water and ground.

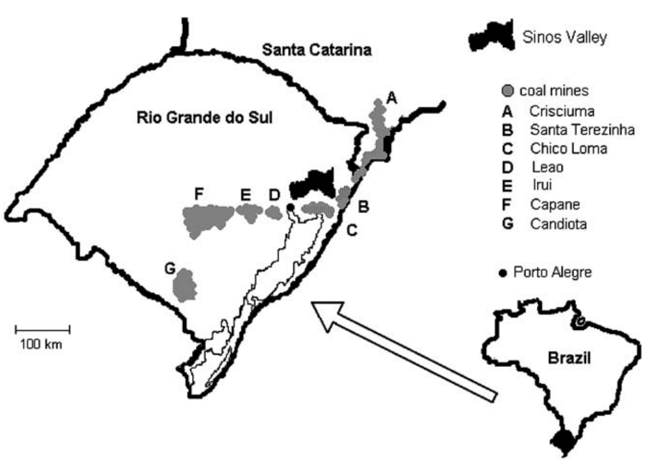

Fig. 3. Southern Brazil: location of the main coal reserves and tanneries region. The figure shows also the location of the state capital, Porto Alegre.

Both activities and the resulting by-products stimulate questions concerning their impact upon the environment and mankind. Cleaner Production assessments identified some solutions for tanneries that could bring significant environmental and economic benefits. For example, raising temperature and controlling pH of the tanning baths to increase chromium fixation on the hides [19] or recycling of chrome tanning liquors to reduce chromium discharge into waste water are well established as means of reducing effluent problems [20,21]. Actually, Cleaner Production solutions are widely utilized in tanneries and these practices reduce the quantity of toxic chemicals released and the amount of wastewater to be treated. The implementation of these solutions also results in improved productivity and increased quality of products. However, it is not possible to recover all of the chromium containing liquors in a tannery, including the tan bath liquor, any wash liquor and run-off liquor from hides after unloading. These wastes and the sludge formed from the chromium containing effluents are still major problems.

Industrial Ecology stimulates waste exchange among industries. For this purpose, it is necessary to find or develop a technology suitable to promote the union, that is, an Eco-technology.

3.1. Laboratory studies: Possibilities towards Eco-technologies

The scientific research offers a number of technologies to treat effluents containing heavy metals. These technologies first developed for remediation and attenuation can be divided in two different approaches: studies concerning soil remediation and studies regarding the metal removal from effluent to reduce heavy metals release to the environment.

Soil contamination is a major problem in industrialized countries, as the dissolved metal in the liquid phase is absorbed by the soil. Electro-remediation and extraction are methods that have been widely used, but these methods generate huge quantities of sludge containing heavy metal hydroxides. In other words, the metals are removed from the disturbed lands and concentrated in this sludge that has to be stored or treated/neutralized. Table 1 summarizes some treatments proposed for metal removal from soil.

The number of studies regarding soil remediation evidences that the great capacity of absorption of soil can be employed to attenuate the presence of heavy metals from aquatic systems. Several authors who investigated the use of soils to remove metals from liquid effluents (Table 2) explored this classical approach.

The removal of these metals at the source, that is, inside the company is now seriously considered, as it avoids traditional treatments. More recently, one can distinguish a number of studies concerning the

Table 1
Conventional methods for soil remediation

Metal	Method	Absorber	Treated medium	Ref.
various	Electroremediation		Soil	[22]
Cu	Electroremediation + cation selective membrane		Sand	[23]
Cu,Cr, Hg, Zn	Electroremediation		Sand	[24]
Cu, Zn	Electroremediation		Industrial sludge	[25]
Cr	Extraction	$Na_4P_2O_7$	Soil	[26]
Cr	Various	Various	Soil	[27]
Cr	Extraction, oxidation, separation and reduction	H_2SO_4, H_2O_2	Tannery sludge	[28]

Table 2
Classical methods for metal removal from liquid effluents

Metal	Method	Absorber	Treated medium	Ref.
Cu, Zn, Mn	Column flux	Mangrove	Municipal wastewater	[29]
Ba, Cd, Cr, Pb, Zn, Cu, Mo	Column flux	Sand	Municipal wastewater	[30]

Table 3
Methods employing natural materials

Metal	Method	Absorber	Treated medium	Ref.
Cr	Phytoremediation/absorption	Aquatic hyacinth	Tannery effluent	[31]
Cr	Phytoremediation/absorption	Mud	Tannery effluent	[32]
Cr, Cu, Zn	Fluidized bed	Sepiolite	Synthetic solution	[33]

Table 4
Methods employing materials developed to metal removal

Metal	Method	Absorber	Treated medium	Ref.
Hg^{2+}	absorption	Fluorohectorite heterocyclic	Hg^{2+} solution	[34,35]
Cr, Hg	batch	Activated carbon	Synthetic solution	[36,37]

development/utilization of new materials to the direct treatment of industrial effluents and the use of wastes from other processes. An excellent review describing low cost absorbents was published by Bayley et al [25]. Among the substances investigated there are natural materials: plants [31,32] and minerals [33] (Table 3), and several materials developed specially to remove metals from wastewater, as zeolites [34,35] and activated carbon [36,37] (Table 4).

At the moment, only a few studies make evidence of the importance of the use of wastes from other processes to attenuate heavy metals from effluents. With this purpose, the use of wood bark [38] and natural and gangue minerals [39–43] were evaluated (Table 5).

The aforementioned studies show that some damaging effects on species living in the ground and accumulation of heavy metals into the environment can be avoided.

4. Integrating mining and tanning

Considering the conditions found in Rio Grande do Sul, the proximity of mining industry and tanneries could encourage the use of an Eco-technology. Fig. 4

Table 5
Methods employing wastes from other processes

Metal	Method	Absorber	Treated medium	Ref.
Cr	Air bubbling	Pinus bark	Tannery effluent	[38]
Hg^{2+}	Adsorption	Pyrite	Hg^{2+} solution	[39]
Cr	Reduction	Fe(II)	Industrial water	[40]
Cr	Permeable wall	Iron and sand	Galvanic effluent	[41]
Cr	Permeable wall	Iron, pyrite, sand and quartz	Synthetic solution	[42]
Cr	Adsorption	Pyrite	Synthetic solution	[43]
Ag, Cr, Cu, Hg	Absorption	Oak, poplar, red spruce and pinus barks	Synthetic solution	[44]
Cu, Cd, Zn, Ni	Adsorption, reduction, precipitation	Iron	Mining water	[45]
Cu	Absorption	Straw of rice, chaff of rice	Synthetic solution	[46]

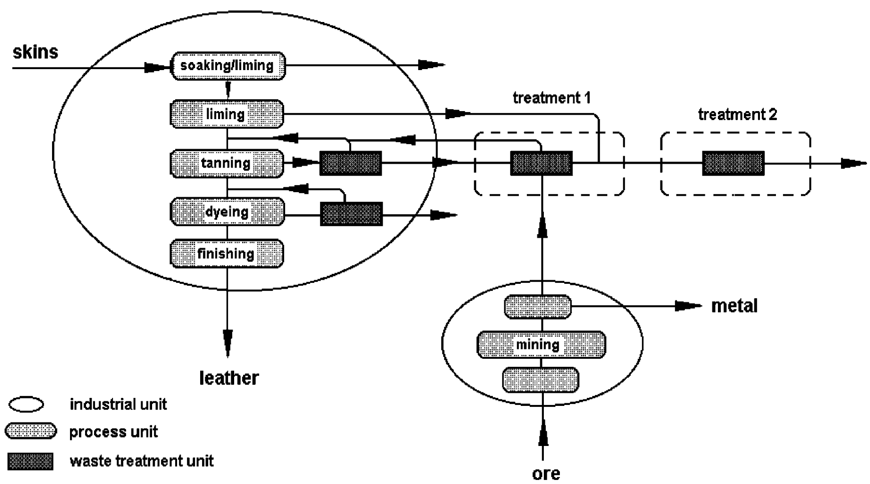

Fig. 4. Schematic representation of the aggregation of two industrial sectors, mining and tannery, joint by an Eco-technology (treatment 1).

shows a schematic representation of the possible union between two industrial sectors: mining and tannery, the first positioned within the primary extraction industries and the second within manufacturing industries, both associated with considerable environmental impact. These two industrial units, disconnected as they are today, lack the link that could be the first evolutionary step towards Industrial Ecology implementation in the region.

Information in Table 5 suggests that wastes from the mining industry (pyrite) could be employed to treat chromium containing tannery effluents. Thus, it is reasonable to propose that cooperation and future prospects of joint action concerning the use of mining wastes to treat tannery wastes could result in the implementation of an Eco-technology in the boundary between the two industrial sectors.

The extensive generation of mining wastes is sufficient to assist in the proper management of all tannery effluents, regardless of the seasonal production fluctuations. In such a case, both types of waste can be modified to allow the recycling of heavy metals and thus, to avoid contamination of the soil and water resources.

The utilization of mine wastes to treat tannery effluents (Fig. 4–treatment 1) could diminish the acid mine drainage due to the disposal of reduced sulfides while aiding the removal of chromium from tannery wastes. This approach would involve the waste transfer and transport from one company to another, thereby, promoting output–output relations between sectors. As an additional advantage, the prompt collaboration and the close relationship within a limited geographic region would be the basis for the formation of a first aggregation targeting a future sustainable condition.

The development of Eco-technologies calls for an integrated approach towards the environmental effects of the industrial network, rather than pointing to the reduction of the effects of separate industrial processes. The waste lime, from liming process (Fig. 4), could also be used to neutralize waste acid from treatment 1 or to precipitate metals from waste water, establishing another link outside the tannery boarder.

The example presented herein is to be seen as one of many alternatives. Rio Grande do Sul also produces more than 45% of the national rice [47] and about 130 millions m^3 per year of wood [48]. An example employing the link of tanneries with agriculture or the wood industry, using agricultural and/or forest wastes to treat the tannery effluent [36–38,44,46], could also have been proposed as viable in this geographical context.

Complementary technologies such as phyto-remediation [31,32] or the development of new materials [34,35] should also be used to refine the treatment and to guarantee the quality of water released into the river systems (Fig. 3–treatment 2). For example, after treatment 1, the amount of chromium is smaller and can supply nutrient cultures for aquatic hyacinth. Nontoxic Cr(III) accumulates in root and shoot tissues [32] and the reduction of Cr(VI) to Cr(III) that occurs in the fine lateral roots, being Cr(III) subsequently translocated to the leaf tissues.

It is important to emphasize the benefits that could arise from the implementation of Eco-technologies. Schematically, benefits directed to the industrial sector, to the environment and to society can be identified. For both industrial sectors the implementation of an Eco-technology offers opportunities to reduce costs. Mineral wastes transformed in raw material are removed from the mining neighborhood, avoiding remediation costs. Tanneries, in turn, will have a cheaper raw material to remove chromium from their effluents. The cost for remediation of degraded areas was evaluated as 10–50 times higher than that of prevention practices [49]. The link between mining/tannery besides avoiding remediation costs, permits the sharing of expenses related to waste treatment. The major environmental benefit is the reduction of waste and toxic substances released to the soil and the aquatic system, diminishing the size of water treatment plants, reducing health problems and, consequently, enhancing life quality. The link can also avoid the use of other materials and consumables to remove chromium and to diminish acid mine drainage, thereby reducing the negative environmental impacts of these two industrial sectors.

5. Conclusions

The Cleaner Production concepts have provided the knowledge that manufacturing needs to improve its performance for firms' profit. Evolution from a Cleaner Production from within the industry, to Industrial Ecology requires efforts, not only regarding the integration between enterprises but also regarding the decisive contribution of scientific research in order to develop and implement Eco-technologies. This work presents an extensive review of literature data. The studies related herein address non-conventional technologies for pollution control and present new strategies for environmental remediation or pollution attenuation. The solutions, developed in the laboratory, are directed to solve specific pollution problems. However, the combination of these laboratory studies with the concepts of Industrial Ecology may lead to the implementation of Eco-technologies among industrial processes. Thus, the studies developed in the academic context could represent the first step towards Eco-technologies, which may be implemented in industrial applications.

In our view, Eco-technologies are to be made compatible with Cleaner Production programs. The interdependence of industrial units must be considered as a consequence; that is, Cleaner Technologies are powerful instruments to correct some of the weaknesses present in separate production systems.

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